An Application of Artificial Intelligence for Computer-Aided Design and Manufacturing

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1. ABSTRACT

The knowledge required to integrate aircraft manufacturing characteristics and constraints into the structural design process is beyond the proficiency of a single engineer. Concurrent Engineering (CE) enables the integration of design with manufacturing to permit trades based not only on product performance, but also on other criteria not easily evaluated, such as producibility and support. A decision support system, or Knowledge-Based System, that can direct manufacturing issues during the preliminary design process would be an invaluable tool for system designers. The objective of this technical paper is to clearly describe the development of a Knowledge-Based System (KBS) for the determination of manufacturing processes for selected airframe structural components for the wing of the High Speed Civil Transport (HSCT). The KBS evolving with this research will be utilized within an integrated design environment along with existing tools to demonstrate its functionality as a design tool. The system will empower engineers to design the strongest, lightest possible wing structure at the least cost that meets the load-carrying requirements for a specified aircraft range. The paper outlines the knowledge- and rule-base development required to build the KBS. The interfaces and relations to CAD packages, external synthesis and analysis codes, as well as links to cost estimating software and methods are discussed.

2. INTRODUCTION

Much of the recent research and development in the fields of computer science and information technology is leading to the automation of many elements of aerospace systems design. Computer-aided design and manufacturing (CAD/CAM), advanced aircraft synthesis methods, finite element analyses, manufacturing process modeling, and cost estimation/prediction are just a few areas that are benefiting from the latest technological advancements. In addition to the tool development and improvement, new design environments are being postulated and implemented which will permit the simultaneous design of both products and processes. The emerging field of Multidisciplinary Design Optimization (MDO) is providing technologies that are changing the way in which designers design.

The aerospace design community is showing much interest in the modeling of many components of manufacturing engineering. The design and manufacturing cycle itself is an iterative one. While the integration of manufacturing characteristics into the design process would not eliminate the iterations required, it may reduce the number, thus preventing many expensive redesigns. Manufacturing process modeling and its inclusion in an efficient manner in the systems design process is the first step towards the integration. Hence, this establishes some of the motivation for the research efforts described by this paper. In the most general sense, the research addresses the integration of design and manufacturing for the HSCT, specifically the wing structural design.

The significance and relevance of this integration dates back to the 1970s. The Lockheed-California Company was involved in the design of a supersonic transport (SST) aircraft concept [1]. They discovered that a significant mass penalty was incurred in the wing tip to meet flutter speed requirements. Two of the most logical solutions were providing additional stiffening in the wing tip or increasing the depth of the wing tip structural box. Both solutions, however, showed no significant advantages in reference to the flutter speed constraint if the baseline use of titanium was retained, since the wave drag penalties offset the savings resulting from the reduced surface panel thickness. Another option was to select a new structural material. It was found that the application of boron-aluminum composites on the baseline wing tip provided a relatively significant improvement in performance. However, the state-of-the-art at the time was not mature enough to reliably design and predict the manufacturing consequences of selecting such an advanced material. Hence, the wing tip flutter problem remained unsolved for the SST studies and is still one of the key technical considerations in the design of today's HSCT.

Since then, there have been many disjunctive advances in the areas of aerospace design and manufacturing. New initiatives, such as NASA's Affordable Design And Manufacturing (ADAM) program are addressing the need for integration theories and tools for the two disciplines [2]. Many of the hopes for the integration of design and manufacturing are dependent upon a particular subset of Artificial Intelligence (AI) called Expert Systems, or Knowledge-Based Systems (KBS). Knowledge-Based Systems are complex AI programs; they are designed to solve problems that are typically solved only by human "experts." In order to be able to solve such problems, a system needs access to large domain knowledge bases. These knowledge bases must be developed and built, or encoded, as efficiently as possible. In addition, a KBS will need to use some type of reasoning system or "inference engine" to apply its knowledge to a given problem.

3. KNOWLEDGE-BASED SYSTEM DEVELOPMENT

3.1 Problem Domain

The domain of this research is the integration of design and manufacturing, with the HSCT as the specific test case. In order to keep the task and data manageable, a major component of the airframe will be the concentration of this research; precisely the same one that gave designers the most problems in the 1970s. Hence, the wing structural design is the focus of this investigation. The components that are designed and optimized during a first-level finite element analysis, namely the spars, ribs, spar caps, and skin panels, will be the airframe members for which manufacturing processes are selected by the KBS. Many tools are available for the wing product design stages; comparatively, they are relatively well-defined. On the other hand, the process design tools that are available have demonstrated only limited capabilities.

Specifically, the task of the KBS is to select the manufacturing processes for the wing structural components. It is not possible, in this large domain, to preenumerate all of the possibilities and then select the optimum solution based on the information that is typically available after a first-level structural analysis. Rather, a set of feasible processes will be determined that satisfies external constraints imposed by material specifications, fabrication and assembly considerations, and cost factors. Once the manufacturing processes are selected, it will be possible, with the development of new process-adjusted cost models, to show the cost implications of the design decisions earlier in the design process.

Certain assumptions have been made in reference to product design modeling. The first is that the materials from which the wing structural components will be fabricated are preselected, from a database of possible candidates, *before* structural modeling and optimization. This assumption is made since it is not possible to obtain accurate weight estimates of the structural components without modeling the specific material properties for each component. Second, the calculated dimensions and weights of the structural members will change significantly with different materials depending on performance requirements and load conditions; this fact becomes consequential when using weight-complexity based parametric cost models. This consideration is typically not accounted for when using commercially available parametric cost models. Third, a portion of the process selection knowledge will be abstracted to the functional level. In the aerospace manufacturing industry, the manufacturing processes are not selected until detailed models of the parts are built in the CAD systems. In this case, however, the process selection will be made with just the information that is obtained after a first-level finite element analysis and the relevant selection heuristics. Only in this way will the KBS be a usable tool for a designer who wants to reduce the design cycle time during the conceptual and preliminary design stages, when there is still some flexibility in the design parameters. Table 1 shows the information that will be known about the components before the modeling, after the structural analysis and optimization, and before the processes are selected by the KBS.

Product & process parameters	Skin panel	Rib	Spar	Spar cap
before modeling and structural analysis/optimization:				
material & associated properties, constraints, & max. service temp.	√	√	√	√
grid coordinates	√	√	√	√
modeled as membrane element	√			
modeled as shear panel		√	√	
modeled as rod element				√
after structural analysis and optimization:				
thickness	√	√	√	
cross-sectional area				√
part weight (mass)	√	√	√	√
production considerations and decisions:				
manufacturing process	√	√	√	√
fasteners	√		√	√
stiffener type	√			
stiffener material	√			
solid or honeycomb construction	√			

Table 1: Wing Component Modeling

The knowledge about the material selection, the manufacturing processes, stiffener types and materials, fasteners, and basic part configuration must be represented in such a way that the KBS can function properly. The most common way of representing domain knowledge in a KBS is as a set of rules. The rules, in turn, are often coupled with a frame system for defining the objects that occur within the rules.

3.2 Knowledge Base Development

There are several important issues related to the development of the knowledge and rule bases. Much of the data needed for the assembly of the knowledge bases is not collocated. An extensive knowledge acquisition process is required to gather the necessary data. Both historical data regarding material usage and process selection parameters and current design guidelines and rules must be compiled and coded in the most appropriate format.

The data that represents the technical knowledge, i.e., that which concerns the candidate materials and processes for the wing structural components, can be classified through the use of frames. An efficient manner for assembling such information would be the compilation of tabular data. The development of the relevant data tables for the wing component modeling is currently in progress. Knowledge or data bases are being constructed for the candidate materials for the HSCT wing structure (both alloys and composites) as well as suitable manufacturing processes that can be used to produce spars, spar caps, ribs, and skin panels. Due to length limitations on this paper, these data bases were not included.

3.3 Rule Base Development

Many of the older expert systems that were built were created from scratch, usually being coded in LISP [3]. However, after many systems had been separately built in this manner, it became apparent that these systems had much in common. Specifically, the systems were usually constructed as sets of declarative representations combined with an interpreter. Because of the distinction, it was possible to disconnect the interpreter from the domain-specific knowledge, thereby separating the control from the knowledge. Hence, new expert systems could be created simply by adding new knowledge applicable to another domain. The resulting domain-independent interpreters were called shells. The C Language Integrated Production System (CLIPS) [4] has been selected as the expert system shell for the development of the KBS described by this paper. CLIPS was developed at NASA Johnson Space Center and is a publicly available code.

Because expert systems are usually written primarily as rule-based systems, a forward-chaining or backward-chaining (or a possible combination) inferencing strategy is used to proceed from the known data to the desired solution. Such a data-driven solution strategy is appropriate given the types of data that are produced during preliminary structural design analyses. Rules are being developed for selecting processes for manufacturing the wing structural components based on the material type, part shape and dimensions, the member type, and function. The rules are being built with "if-then" formatted logical constructs. Using the forward-chaining method of inference, the applicable manufacturing processes can be selected for a given structural member. The task of the KBS is *not to select the optimum process* for the structural members; it *is to provide sets of feasible alternatives* for performance and cost worthiness or effectiveness trade studies.

4. SYSTEM INTEGRATION WITH EXISTING TOOLS

Knowledge-Based Engineering (KBE) can be considered a subset of KBS and AI technologies which focuses on automation of the creation of the CAD geometry, the engineering analysis, and generation of the support information [5]. In order to have a useful system, and demonstrate its functionality, the system will have to operate within an integrated design environment. The system integration will be one of the most important factors in gaining system acceptance and credibility. Without the appropriate interface automation procedures, the designed functionality of the system will not be apparent. Figure 1 shows the proposed integrated design environment in which the KBS will function. Several existing tools and codes will be utilized within the environment to perform the necessary product and process modeling and design trades. Without an integrated design environment, the success of the KBS would be restricted.

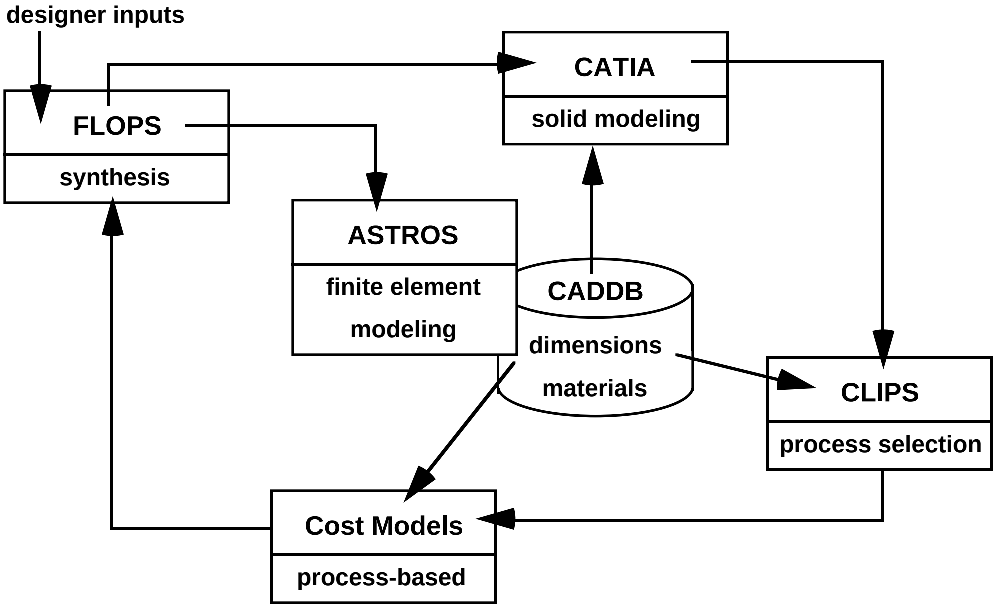

Figure 1: Integrated Design Environment

The system executive scripts will be coded using the interpretive shell system called Tk/tcl (toolkit / tool command language) [6]. Tk/tcl combines an interpretive language core with windowing applications to provide the capability to develop full-featured, fully-functional graphical user interfaces. A particular goal of many aerospace industries is to develop and use parametric, intelligent CAD systems. While the use of a KBS in conjunction with a CAD package does not constitute a next-generation system in itself, it is a step in the right direction. As Figure 1 shows, the system will have direct links provided to CATIA for accessing or storing information about the structural components of the wing. To access the CATIA resources with Tk/tcl, a single function will be used that dynamically accesses all of the internal CATGEO routines [7]. Figure 1 also shows the other tools that are currently being used for the product design analyses, including NASA Langley's FLight OPtimization System (FLOPS) and the USAF's Automated STRuctural Optimization System (ASTROS).

5. COST MODELING

The wing product design stages in this research are following a traditional decomposition process from the system to sub-system to part level. Many metrics exist for evaluating product performance at all three levels. Typical system level examples include take-off gross weight (TOGW), range, payload, cruise speed, and number of passengers. Component weights are a sub-system product metric and the number of parts, the part weights, and their dimensions are part level product metrics.

Process metrics are more difficult to quantify and calculate. In the same fashion that the product design stages are being decomposed, the process design stages for the wing will be recomposed, with quantitative evaluations at each level using process metrics. If process metrics are not used to evaluate the decisions made during the design stages, then redesigns are often required. The Life Cycle Cost (LCC) of the designed system, including all production costs (both recurring and nonrecurring), will govern any decisions made about funding a particular program. Accordingly, a three-tier hierarchical LCC model is being developed in parallel with the product and process design tools described by this paper. Development of the hierarchical LCC model will permit the difficult, but required, recomposition process that has not been a part of past systems design processes. It will enable the evaluation of both the product and process parameters that characterize the system, thereby facilitating Integrated Product and Process Development (IPPD).

6. CONCLUDING REMARKS

An application of Artificial Intelligence technology is being developed for use in the area of computer-aided design and manufacturing. A Knowledge-Based system has been described that will be used for selecting manufacturing processes for structural components of the wing of the High Speed Civil Transport. The integrated design environment in which the KBS will function with existing analysis and structural optimization codes has also been proposed and outlined. The success of the KBS is dependent upon its functionality within the design environment. The seamless integration of the manufacturing-oriented KBS and the process-dependent cost models with aircraft preliminary design and analysis methods will yield an invaluable new tool for aircraft systems designers.

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