KNOWLEDGE-BASED MANUFACTURING AND STRUCTURAL DESIGN FOR A HIGH SPEED CIVIL TRANSPORT

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ABSTRACT

The aerospace industry is currently addressing the problem of integrating manufacturing and design. To address the difficulties associated with using many conventional procedural techniques and algorithms, one feasible way to integrate the two concepts is with the development of an appropriate Knowledge-Based System (KBS). The authors present their reasons for selecting a KBS to integrate design and manufacturing. A methodology for an aircraft producibility assessment is proposed, utilizing a KBS for manufacturing process selection, that addresses both procedural and heuristic aspects of designing and manufacturing of a High Speed Civil Transport (HSCT) wing. A cost model is discussed that would allow system level trades utilizing information describing the material characteristics as well as the manufacturing process selections. Statements of future work conclude the paper.

KEYWORDS: Producibility, Knowledge-Based Systems, High Speed Civil Transport, Manufacturing

INTRODUCTION

The extent of knowledge required to perform the task of integrating aircraft manufacturing into the structural design process is beyond the expertise of a single engineer. This defines the need for a decision support system, or Knowledge-Based System (KBS), to aid the engineer in considering manufacturing issues during the preliminary design process. Integrated Product and Process Development (IPPD) techniques for assessing producibility can help designers perform the necessary trade-offs to design the strongest, lightest possible structure at the least cost that meets the load-carrying requirement for a specified aircraft range. This concurrent or simultaneous design requires an integration of design with manufacturing and a decision / selection process that will permit design trades based on product performance, producibility, and support. This approach involves encoding the knowledge of human experts concerning aircraft manufacturing and design into an

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appropriate representation. The seamless integration of a manufacturing KBS with aircraft preliminary design and analysis tools will yield a concurrent engineering method that will assist aerospace systems designers in performing parallel product and process trade studies.

Requirements for product performance at the product design stage and those for the product manufacturing cost at the process design stage often have conflicting relationships. Hence, sequential decision making at both stages may not yield the global optimum design solution even if individual optimizations are performed at both stages. The number of design variables related to product design and process design is excessive. The feasible regions of decision variables, such as manufacturing method and material selection, are discretely distributed on the decision variable space [1]. Therefore, optimization of all pertinent design variables at once is incredibly difficult, if not practically impossible.

As all system designers know, there are certain information-processing problems that do not yield well to traditional computing methods. The concept of integrating design and manufacturing is a prime example of such a problem. To evaluate the potential of possible application domains for Knowledge-Based Systems, a set of desired attributes for good KBS domains have been developed as part of a major expert system development project at GTE Laboratories [2]. These attributes are related to basic system requirements, the type of problem, the "experts", problem bounds, and domain personnel. Many of these attributes are general enough to be applicable to all expert systems; several are easily inferred to be appropriate to the domain of the integration of design and manufacturing.

For example, some of the attributes associated with the system basic requirements are:

- *Conventional programming (algorithmic) approaches to the task are not satisfactory.* The tasks are governed by a complex reasoning process that is partially judgmental and subjective.
- *The completed system is expected to have a significant payoff for the corporation.* A reduction in design cycle time would constitute a very significant payoff for any aerospace corporation that utilized such a KBS.

An attribute related to the problem type is:

- *The task requires the use of heuristics (rules-of-thumb, strategies, etc.). It may require consideration of an extremely large number of possibilities.* Many of the complexities associated with the selection of structural concepts and the manufacturing of an aircraft wing are best addressed by heuristics.

Another general feature is:

- *The need for the task is projected to continue for several years. The need must exist enough beyond the period of system development to generate the payoff.* NASA's High Speed Research (HSR) program is currently in its fifth year (Phase II) and is projected to last through the year 2001.

The aforementioned attributes substantiate the use of a KBS within an integrated design environment.

INTEGRATION METHOD

As related to the overall concept of product affordability, cost can be viewed as a key element of producibility. Therefore, the utilization of a cost model as a procedural module within a synthesis model is a valid method to assess producibility in design [3]. NASA Langley's aircraft synthesis code, FLOPS, has an economics model developed by Johnson [4], that is capable of performing LCC analyses for aircraft conceptual designs. This integration of an LCC model into the synthesis model FLOPS is an example of the utilization of procedural knowledge to determine the producibility of an aircraft concept at the earliest design levels.

The combination of FLOPS and ASTROS, a structural optimization package, with heuristic components of producibility constitutes the authors' attempt for an integration of design and manufacturing for aerospace systems designers. Aircraft development at the conceptual level will be addressed by the procedural model, while the heuristic module would apply a suitable cost module during the preliminary design. Figure 1 shows the relationships within the procedural and heuristic components for an HSCT producibility assessment. Heuristic producibility issues are those that require the knowledge of experts to resolve. Design and manufacturing experts from academia, industry, and government are used in conjunction with design and manufacturing oriented textbooks to develop checklists, lists of guidelines, and design rules. These checklists and rules pertain to constraints associated with materials, fabrication, assembly, and processes. These issues will be developed as a KBS for manufacturing process selection.

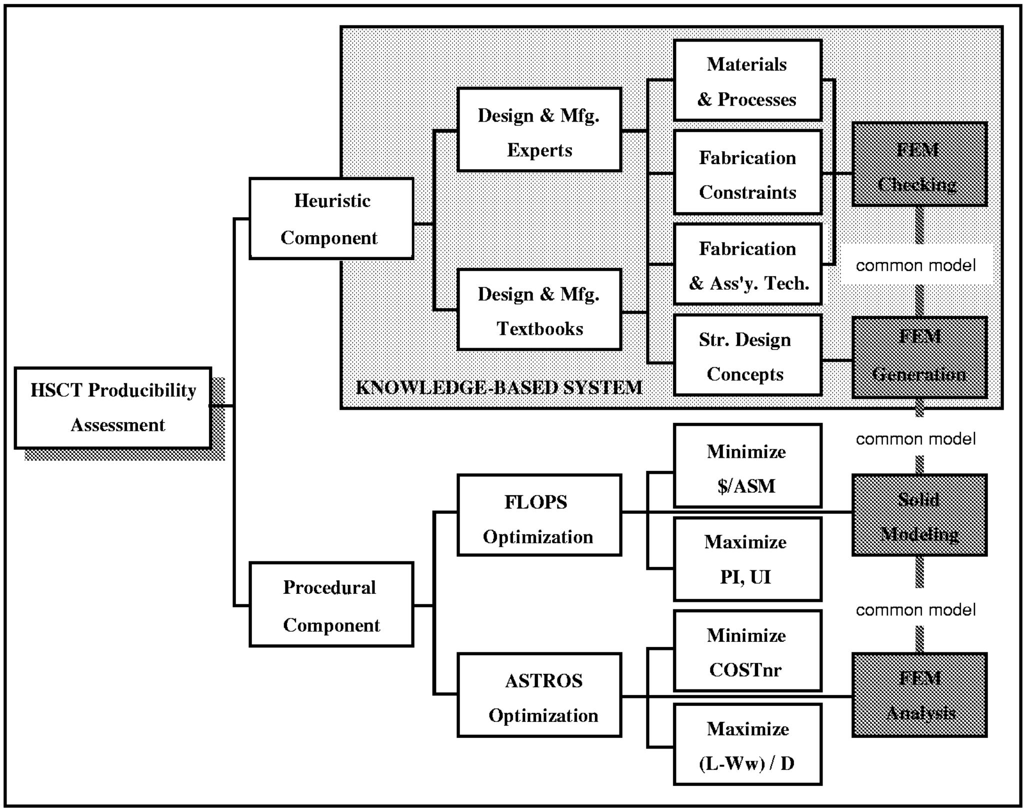

FIGURE 1. Producibility Assessment

Several examples of heuristic issues related to manufacturing processes that are suitable for incorporation into a KBS are discussed here. All manufacturing processes are subject to limitations in terms of shape complexity, minimum and maximum dimensions, tolerances, and surface finishes [5]. These limitations are highly dependent upon workpiece material. The maximum size of a part or component that can be produced by any one technique is often limited by the availability of large equipment. There are also limitations due to process conditions themselves. More often, the limitation is on the minimum size that can be produced or on wall thickness. There are both practical and fundamental thickness limitations. Unnecessarily tight tolerances and surface finish specifications are a major cause of excessive manufacturing costs. Each manufacturing process is capable or producing a part to a certain surface finish and tolerance range without extra expenditure. The specified tolerances should, if possible, be within the range obtainable by the intended manufacturing processes to avoid separate finishing operations.

The aircraft designers and manufacturers must know the production rate and the total quantity to be produced to select the appropriate method of production. The part or item can be produced in any of three general ways. It can be produced manually, with a flexible manufacturing system (FMS), or with fixed automation [5]. All three methods can be used on individual workstations or throughout the factory. The method of manufacturing is ultimately determined economically; the approach that yields the highest return on investment (ROI) and the lowest unit production cost (UPC) is used [6].

Because of its availability at Georgia Tech, CLIPS will be used as the expert system language. CLIPS is a multiparadigm programming language that provides support for rule-based, object-oriented, and procedural programming [7]. The procedural programming language provided by CLIPS has features similar to languages such as C, Ada, and Pascal and is syntactically similar to LISP. CLIPS was developed at NASA Johnson Space Center with the specific purpose of providing high portability, low cost, and easy integration with external systems. CLIPS is written using the C programming language to facilitate these objectives. CLIPS is an acronym for C Language Integrated Production System.

COST MODELS

The integration method will provide a design technique in which cost is embedded in the design [and producibility] analysis. Previous cost modeling has mainly been based on physical product parameters such as weight and number of parts. Estimates of manufacturing complexities had to be made. There is a growing recognition that new design processes must have an *integrated* cost and engineering model. The main use of cost models should not be to predict costs based on historical examples; it should be to provide cost *reductions* for future aerospace systems as well as the capability for cost optimizations. Most optimum systems of the past have been optimized for mission performance, or gross weight, not cost [8]. Future design methods must include the use of LCC models that are functional within the entire concurrent engineering design process.

Resetar [9] presents a RAND Corporation study of the cost effects of structural materials that may be used for fabricating aircraft in the 1990s (including aluminum, aluminum-lithium, steel, titanium, graphite/epoxy, graphite/bismaleimide, and graphite/thermoplastic). Cost data and a cost estimating methodology are given for several cost elements: non-recurring engineering, non-recurring tooling, recurring engineering, recurring tooling, manufacturing labor, manufacturing material, and quality assurance. The data are representative of current estimating factors used by the aerospace companies that participated in the study. The list of companies includes: Boeing Aircraft Company, General Dynamics Corporation, Grumman Aerospace Corporation, Lockheed Aerospace Systems Corporation--California Division and Georgia Division, LTV Aerospace and Defense Aircraft Group, McDonnell Douglas Corporation, Northrop Aircraft Division, and Rockwell International Group. Though the cost estimating method is not provided in a commercial package, the cost estimating relationships (CERs) are published in a format that may be coded and used as a callable application. The method provides for cost calculations of the airframe structure, the airframe subsystems, and the final assembly/integration. This RAND method may prove to be most suitable for use as a callable routine in connection with the proposed KBS. The RAND method, in a generic format, with an additional modification for manufacturing process consideration, is shown in Figure 2. The opportunity to encode the RAND CERs may be more appropriate than trying to use a "black box" type approach with one of the commercial packages within the aircraft design environment.

A newer type of cost model, described by Lee [10], is called a process-oriented parametric cost model. This model has been used to determine the recurring production costs of rocket engine hardware in the Rocketdyne Division of Rockwell International Corporation. As opposed to weight and manufacturing complexity based parametric models, this model uses process oriented CERs. Due to the proprietary nature of the Rocketdyne method, and the fact that it has so far been applied only to rocket engine hardware, it will not be used for the research described by this paper. The opportunity to use a manufacturing process based cost model, if a non-proprietary model is available, may be an alternate approach to the weight-complexity based models. However, the weight-complexity based model may indeed be the best approach since its cost drivers are representative of the designer's technical parameters [11].

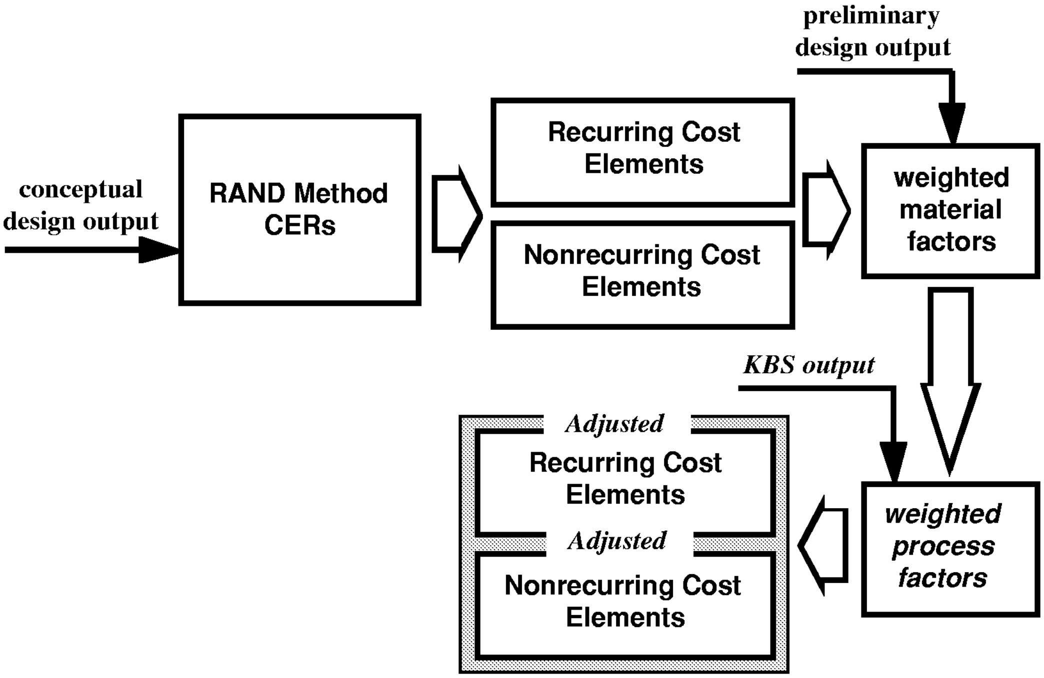

FIGURE 2. Cost Estimation Process

It is essential to capture and encode the undocumented expertise of manufacturing engineers in a Knowledge Base (KB) to give design engineers access to the information. It is necessary to obtain the structural design characteristics governed by manufacturing heuristics and formulate them as an intelligent (rule-based) reasoning / inferencing system. A model will be researched, formulated, and encoded that can accurately predict airframe structural costs based on such characteristics as part weight, manufacturing process, tolerances, material selection, tooling requirements, manufacturing complexities, etc. It is anticipated that the method developed through this research will provide a framework that permits cost optimization(s) for design-to-cost (DTC) applications. The research will require extensive knowledge acquisition and engineering to capture the expertise of experienced designers and manufacturing engineers. A generic architecture will be provided for a design technique in which cost is embedded in the design analysis. Also, links will be available to commercial cost estimating software for demonstration and validation. The research will yield an integrated architecture of engineering and cost models in such a way that cost truly becomes a design parameter.

Recently, the government and the aerospace industry have defined and accepted the need and challenges to incorporate manufacturing considerations into the preliminary design phase in order to easily identify a cost-effective design satisfying the given design objective functions and achieving minimum production costs. Such a challenge provides an incentive for research and development of methods that can ultimately demonstrate communications and closure between the procedural and heuristic components of design and manufacturing. If costs are to be reduced, it is necessary to incorporate manufacturing considerations into the design process in order to generate designs which need fewer re-designs and have lower production costs. One anticipated result / benefit of this research will be a method that will enable aerospace systems designers to perform *parallel* product and process design trades. The method will permit simultaneous product and process design by including *both* procedural and heuristic components of design and manufacturing.

For the cost estimation process, the weights of the spars, spar caps, ribs, and skin panels will be available after the structural analyses and optimizations are performed. The complexities may be estimated relatively accurately based on the output of the structural analysis, and information stored in the CAD solid model data files. The cost estimates will be made using data available during the preliminary design process. While current conceptual estimating methods provide early answers with a limited amount of information, their utility decreases as the concept is defined because the details of design begin to exceed the fidelity of the estimating methods [12].

CONCLUSIONS AND FUTURE WORK

The integration of design and manufacturing is a monumental task that is only beginning to be addressed by the aerospace industry, government, and academia. While much research and formulation has been done, the overall goal of the integration of design and manufacturing is a long way from completion. The KBS will be integrated into an aircraft design environment. Information from the conceptual design and analysis of the system will be used to generate the finite element model(s) of the wing airframe structure. It will be possible to make solid models of the aircraft itself in CATIA to aid in wing structural concept generation. Some of the information used by the KBS describing the structural members will be retrieved automatically from the finite element analysis database. There will also be the capability to display the finite element model in CATIA. There will be direct links to the external cost models. The development and growth of suitable Knowledge-Based Systems may present an opportunity for the aerospace industry to replace the trend of increasing manpower with increasing computational power.

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