THE DEVELOPMENT OF A KNOWLEDGE BASED SYSTEM TO AID HELICOPTER ROTOR BLADE DESIGN

J R Hamilton, P J Clarkson, S C Burgess, D E Newland
Engineering Design Centre, University of Cambridge
Cambridge, UK

Abstract

Established aerospace companies have a valuable asset in the skills and experience of their workforce. In the light of ever increasing competition there is a motivation to be able to fully exploit this knowledge throughout the company. The application of Knowledge Based Systems tools to support the engineer in the design process is one way in which to enhance the skills and knowledge of the workforce.

This paper discusses the extent of current theory and application of Knowledge Based Systems in the field of aerospace engineering. Based on case studies carried out at GKN Westland Helicopters, modelling techniques are proposed for the representation of information within a Knowledge Based System. The methods developed include the clustering of information around specific actions and the use of rules to create a dynamic framework connecting the information. The implementation of the methods is discussed and an example given.

Introduction

Aerospace companies are increasingly striving for greater efficiency and standards of quality in the design process. Failure to do so can result in the failure of the companies themselves. There are a number of reasons for this:

1. Increased competition; caused by demographic, economic and political changes, exasperated by the reduction in military spending following the end of the cold war.
2. Increased complexity of technology. It is no longer possible for an individual to fully understand all the disciplines relevant to aeronautical design. Engineers are becoming increasingly specialised in individual disciplines, not fully understanding the impact of design changes on the overall design.
3. Infrequent design projects; this, coupled with increasing design lead times due to the complexity of the product, makes it increasingly difficult for individuals to gain and apply knowledge on the job.

However, established aerospace companies have a valuable asset in the form of their well qualified and experienced workforce. Consequently, one of the ways in which companies may keep or improve their position in the world market is by developing tools to amplify and enhance the skills and knowledge of this workforce.

Due to the nature of experience it is very unlikely that all knowledge resident in the company in stored in an easily retrievable fashion. Consequently it is highly likely that useful knowledge is effectively lost to the company whenever key personnel leave their area of expertise.

To enable aerospace companies to become more efficient and effective in the design process there is a need for a medium in which knowledge and information may be collated and made available to the engineer at the required time in the required format.

GKN Westland Helicopters have recognised that this is important in maintaining their market position. Consequently they have embarked on a collaborative project with Cambridge EDC to develop a Knowledge Based System to support the engineer through the design process.

This paper discusses the limitations in current Knowledge Based Systems in aerospace engineering and proposes the use of a Knowledge Based System as a support tool to aid the engineer in adaptive design. The paper firstly discusses the application of Knowledge Based System in aerospace engineering. The need to model all information pertinent to the application area is then highlighted and a modelling technique suggested. The technique is then applied to a specific design task. The implementation of the techniques presented in a computer prototype Knowledge Based System will be discussed in a future paper.

Review of Knowledge Based Systems in Aerospace Design

What are Knowledge Based Systems?

In defining Knowledge Based Systems, it is useful to consider the role of the expert in the design process. An expert may be thought of as being able to draw upon a vast amount of knowledge, and select and apply specific information relevant to the solving of a particular problem. Knowledge, in this sense, may be in a number of forms, including text references, mathematical formulae, common sense, knowledge of previous tasks amongst others.

An expert however, is more than an efficient problem solver. For example, a given solution will often be insufficient without the relevant line of reasoning as to how the conclusion was reached. The expert may also be regarded as a source of information with whom evaluation and decision techniques may be debated, and hypothetical cases deliberated. In each case, the expert will impart the information in terms understandable to the questioner.

A Knowledge Based System aims to computerise some, or all (depending on the actual system) of the activities given above. The term Knowledge Based Systems (KBS) refers to computer systems in which an attempt is made to capture, represent and intelligently apply knowledge to a given problem. To date, the application of Knowledge Based Systems in Industry has largely been limited to the application of Expert Systems (ES) for diagnostic purposes or in routine repeatable design tasks. There have been some notable successes in the application of Expert Systems to perform these tasks. Sacon,[1] is an example of an Expert System that interrogates the engineer and then makes informed decisions given this information. The system asks the user questions about a given mechanical structure and it's design requirements and then recommends a series of analysis using a Finite Element package. R1,[9] is perhaps the most successful example of a systems developed to perform configuration tasks. Given a set of components selected by the customer, R1, developed by DEC, specifies the location of each component relative to the others and specifies the cabling required to connect pairs of components.

Dixon et al[4] define an expert system as a computer program that has captured the *experience, knowledge and judgement* of an expert practitioner in a field and has organised that expertise for use by other practioners. In a later paper Dixon,[3] then differentiates between knowledge based and expert systems by saying that a KBS must contain and use explicit knowledge. Furthermore, the system must have explicit knowledge of the knowledge represented and used by the system. Consequently, Dixon argues that a Knowledge Based System must have one or more methods that may be removed or replaced without having to alter the basic problem solving algorithm.

KBS systems therefore differ from conventional programs and Expert Systems in that knowledge exists as an interchangeable discrete entity that may be used intelligently in a variety of ways.

A KBS comprises a number of distinct parts: a facts base concerning the current state of the design, a knowledge base and some kind of inference engine. To be of significant use, a KBS must also have some kind of knowledge acquisition facility and explanation facility. Coyne et al[2] propose the schema depicted in figure 1.

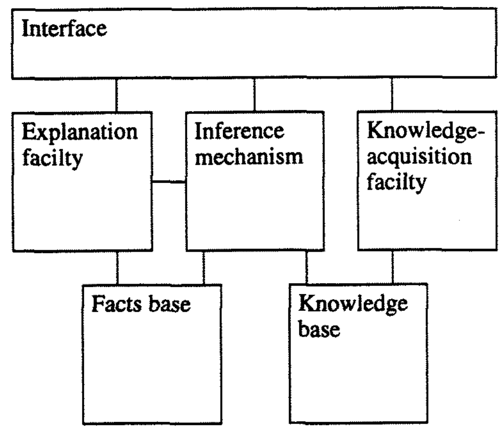

Figure 1: The components of an expert system[2]

Coyne et al then go on to say that part of the art of formulating useful and effective knowledge-based design systems is in providing computational structures and systems of organisation so that design knowledge of different kinds can be represented and made operable. This paper attempts to structure and organise knowledge involved in helicopter rotor blade design to support the efficiency and innovation of the engineer.

There are a number of references that provide introductory texts to Knowledge Based Systems. In particular Turner[14] presents possible areas in which KBS may be applied. Hayes-Roth & Waterman[7] and Coyne et al[2] introduce and discuss the underlying assumptions, approaches, techniques and implementations of KBS.

Current Uses of KBS in Aeronautical Design

Perhaps the most widely known Knowledge Based (or Expert) System used in Aerospace is Concentra's ICAD system.[15] In repeatable, routine design, Concentra have reported considerable success in the application of ICAD. In the system, a product model is developed that contains all the engineering intent behind the geometric design. Having created the product model, engineers may then generate and evaluate new designs by changing input specifications, or modify designs by extending or changing the product model. Boeing have successively used the system in the design of the wing structure parts for the new 737-600,-700 and -800 transports.[12] The system is applied successfully in a similar fashion in The BAe subsidiary AVRO.[8]

In both of the applications described, the systems have been developed to explicitly represent a set of design rules and criteria to create a digitised version of the design process. Varying the input requirements then allows the same design process to be used for a number of projects. This is a successful strategy if the design process is repeatable, outside routine design however, the method would depend upon prescribing a rigid framework upon an ill defined problem.

How then, can Knowledge Based Systems aid the engineer tackle ill defined design problems. To do this it is necessary to briefly discuss the different types of design. Pahl and Beitz,[11] distinguish between three types of design:

- Original design; which involves elaborating an *original* solution principle for a system with the same, a similar, or a new task;
- Adaptive design; which involves *adapting* a known system to a changes task;
- Variant design; which involves *varying* the size and/or arrangement of certain aspects of the chosen system, the function and solution principle remaining unchanged.

A survey of mechanical engineering companies showed that in engineering design, 55 % of products were based on adaptive design, 25 % on original designs and 20 % on variant designs.[11] More than half the products were therefore based on the adaption of previous designs, whilst less than a quarter were based on varying the parameters of known designs. Current KBS and ES aerospace applications deal only with variant design.

Creative design involves either original or adaptive design. Oxman[10] states that creative design involves being able to recognise analogies with previous design cases whilst being able break with previous convention and call upon other resources, either from within the established field of knowledge or external to it.

Following this line of argument it is then difficult for a Knowledge Base System to support creativity by representing the design process in an automated computer form. However, by allowing the engineer to perform parametric analyses, a number of different design configurations may be assessed, thereby improving the final product.

This paper argues however that the innovation of the engineer may be further aided by supplying the engineer with the appropriate information at the right time and in the correct form, *without* imposing a prescribed design process.

Development of Knowledge Based Systems

One of the main limitations in the development of KBS systems lay in the creation of such a system. A phenomena known as the knowledge elicitation bottleneck[13] is often cited as the major difficulty in the development of a KBS application. The problem lies in trying to represent the requisite information in an explicit fashion that may then be implemented in a KBS. This task usually involves two specific groups of people, the domain expert and the knowledge engineer. Ideally the two should be the same although it is rare that the expert will fully understand the issues involved in developing a system or will have the time to learn. Gregory[6] suggests that the problems would be minimised by the introduction of an expert helper that may negotiate between the knowledge engineer and the engineering domain expert.

The development of a KB application consequently takes longer time than that of the actual task being implemented[15].[8] As a result, the implementation of KBS in industry has been restricted to small definable routine repetitive tasks.

Development of a Knowledge Based Support Tool in Helicopter Rotor Blade Design

Rotor Design at GKN Westland Helicopters

The performance of the main rotor blade determines the performance of the whole aircraft, from the all up weight to the maximum forward speed. Through the implementation of advances in blade aerodynamics, dynamics and composite manufacturing techniques Westland Helicopters have established themselves as world leaders in helicopter rotor blade design. The composite composition of the Lynx Composite Main Rotor Blade (CMRB) is shown in figure 2

As a consequence of implementing the technological advances, the design of a new composite rotor system is a highly complex, multiple objective design process. There is no unique design attribute that is optimised within the design process. Rather there are a series of design aims which must be considered as the design progresses. The various design objectives span the whole spectrum of disciplines associated with the rotor blade. Table 1 lists a number of the design objectives and the relevant disciplines.

The table is not complete, but serves to highlight the complexity of the design problem. It is highly unlikely

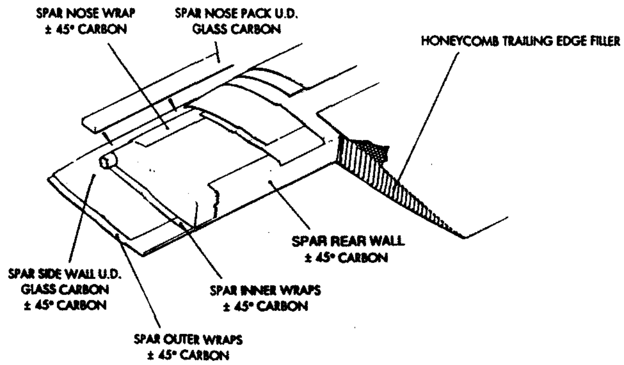

Figure 2: Lynx CMRB construction

Objective	Discipline
Lift	Aerodynamics
Drag	Aerodynamics
Acoustic performance	Aerodynamics, Acoustics
Vibration	Aeroelastics, Dynamics
Total mass	Weights, Dynamics
Aeroelastic Stability	Aeroelatics, Dynamics
Blade strength	Dynamics, Stress, Materials
Auto-rotative index	Dynamics, Weights
Ballistic tolerance	Stress, Materials
Manufacturability	Manufacturing
Unit Cost	Manufacturing
Cost of ownership	Manufacturing, Stress
Commonality	All Disciplines

Table 1: Design objectives and constraints and their discipline areas

that a design change will impact solely on one particular performance attribute. Consequently trade-offs must be made at all stages of the design. There is no rigid design path that may be followed as the decisions made in the design process are dependent upon the actual design itself. Accordingly, the progress of the design is governed by the application of engineering knowledge and experience.

The following section presents a key task carried out as part of the rotor blade design process. The task is addressed at a number of different stages of the design process at increasing levels of complexity, although the example given focusses on the conceptual/embodiment stage of the design. The conceptual stage of the design process has been chosen as it is a good example of an area in which a great deal of engineering experience and judgement is applied, supported by complex computational packages.

The task involves the derivation of the mass and stiffness distribution of the rotor blade given the external geometric profile of the blade.

<u>Derivation of the blade mass and stiffness distributions</u>

The derivation of the mass and stiffness distribution is concerned with achieving a satisfactory dynamic response of the blade whilst satisfying constraints such as stress considerations and ensuring that the blade is manufacturable.

The dynamic performance of the blade is extremely important in rotor blade design since the main rotor system represents the chief source of low frequency vibration. High levels of which may lead to fatigue stresses of over riding importance in the design of the rotor system and significant problems in the airframe itself.

The rotor blade natural frequencies and shapes are of paramount importance to the dynamic performance of the rotor blade. The proximity of the modes to the harmonics of rotor speed can significantly effect the response, hence the magnitude of the vibratory loads at the rotor head. Additionally, the mode shape itself, compared to the loading distribution at a given harmonic is significant. Modal couplings must also be considered.

By applying the experience of previous designs, the engineer will know roughly the preferred frequency placements and shapes. By adjusting the mass and stiffness distributions the frequencies and couplings of the modes may be chosen to minimise the response at the frequencies which provide air-frame vibration.

<u>Method</u>

In the initial stages of the design the preliminary mass and stiffness distributions are estimated from previous similar design cases using empirical scaling formulae.

The idealised mass and stiffness distributions are then used to predict the rotating natural frequencies of the rotor blade. An in-house program, "J134", is used to calculate the natural frequencies and shapes of the rotating blade. The use of modal data drastically reduces the necessary degrees of freedom whilst still allowing physical insight.

The mass and stiffness distributions are varied to give acceptable modal characteristics. The process will be iterated until acceptable modal frequencies and shapes are achieved.

In addition to modal considerations, thought must be given to the actual mass and stiffness distributions themselves. The mass distribution must be viable and satisfy auto-rotation and flyaway considerations. The stiffness distribution must also be realizable and must also consider blade sailing and droop issues.

The task may be broken down into a number of distinct sub-tasks:

1. Select appropriate design cases
2. Obtain and scale mass and stiffness distributions to required dimensions using empirical scaling formulae
3. Predict the dynamic performance of the mass and stiffness distributions
4. Using previous examples and rules of thumb, assess the performance of the distributions
5. Modify distributions to improve dynamic performance whilst satisfying constraints

This process is illustrated in figure 3.

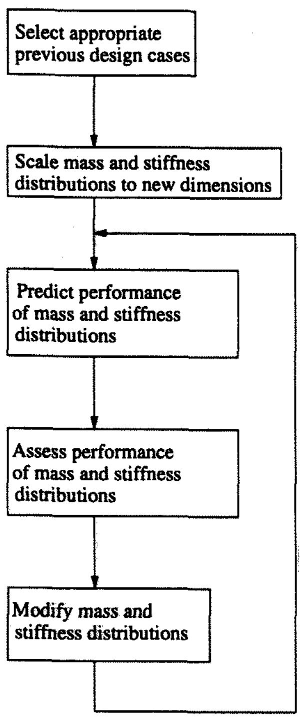

Figure 3: Simplified flow chart of the initial derivation of mass and stiffness

The task is repeated using calculation methods with increasing levels of complexity as the design progresses. For example, initially the mass and stiffness distributions may assumed to be constant to establish a ball park figure. Ultimately however, the distributions will be calculated directly from the internal blade definition in PATRAN.

The use of a KBS support tool in the derivation of the mass and stiffness distributions

Each stage of the task depicted in figure 3 involves the application of engineering experience and judgement in some form. For instance, various issues must be considered in selecting previous cases to be used as a starting point for the process. Ideally the past cases should be as similar as possible to the design specification of the new rotor blade. However, what constitutes a similar case, dimensions, mass, disk loading? The engineer must consider all of these attributes in selecting previous cases.

In modifying the mass and stiffness distributions, knowledge and experience is applied in the form of incrementally modifying particular sections of the distributions so as to improve the dynamic performance of the blade.

A KBS support tool could aid the engineer by supplying the user with the appropriate information given the particular design configuration and state of the design. The tool may also provide the user with a list of available options given the information at that instant. The engineer may then determine the most advantageous next step. Additionally, the engineer is in a position to consider all the implications of changes on all aspects of the design performance.

A KBS support tool could achieve this by capturing experience applied in the design task and supplying the appropriate information throughout the task. By using the tool in the task an electronic log of the process may be kept, so increasing the experience captured.

Structuring of Information in KBS Support Tool

It has been stated previously that knowledge and information must be made explicit before it can be implemented in a Knowledge Based System. Before this can be done it is necessary to to understand the myriad of links between the various pieces of information. It is of considerable benefit therefore to model that information diagrammatically. There are a number of reasons for modelling the information in this manner before implementing:

- Information represented in this fashion may easily be translated into the necessary computer language;
- The formal and systematic nature of the model exposes inconsistencies and gaps in the information acquired;
- An understandable model of the information may be presented to and subsequently reviewed by the domain experts so that the accuracy of the information can be confirmed or the information corrected;
- The model may be used as an instrument of communication between different disciplines;
- The model presents a format in which the information may be stored without inundating the analyst.

The following section details how such information may be acquired and modelled schematically.

Information acquisition

The acquisition of information for use in a KBS tool is one of the major issues on the development of such a system. There are a number of distinct difficulties in the information acquisition process:

- There is no single source from which the information may be acquired. Sources include human experts, textbooks, documentation, working practices, work files etc;
- Individual experience may be incomplete, irrelevant or even incorrect if applied in the wrong context;
- As proficiency increases, the knowledge becomes more instinctive and harder to verbalise and thus harder to elicit;
- It is not immediately possible to represent all knowledge in mathematical or simple rule form.

There is as of yet no standard knowledge based system methodology, although KADS[13] is being developed as part of an ESPRIT programme with the ultimate aim of becoming the commercial standard in Europe.

The knowledge elicitation was undertaken within the project as a series of interviews of the engineering experts. Throughout the interview process, the benefits of the interviewer being familiar with the background to the design problem were clearly evident. This enabled the interview to be conducted using terminology understood by both sides. In addition, the interviewer was able to change the line of questioning whenever appropriate. However, care was taken throughout the interview process to ensure that the structuring of the questions did not influence the information acquired and subsequently modelled and implemented in a KBS.

Information Structuring

In order to support the engineer in the design task, it is necessary to provide the correct information in the correct form at the correct time. The information required is likely to change as the design task progresses. Consequently, links connecting relevant pieces of information are dependent upon the level of information at that instant.

For example, given an estimate of the total mass of the current blade design it is possible to derive scaling formulae between a previous design and the current based on the total mass. Alternatively, given the blade geometry, this may provide a different means of scaling the previous design distributions to the required dimensions.

A system is required therefore that provides the engineer with information that is appropriate to the problem state. In the above example, different information would be provided to the engineer given the exact geometry as opposed to an estimate of the total blade mass.

In supplying the correct information, the engineer is placed in a position to make informed decisions and be aware of the implications of design changes on a number of performance requirements.

In order to achieve this, it is first necessary to structure the information in such a manner that facilitates the use of a dynamic framework. This provides the key challenge of the project. This paper explains why it is not possible to break down the model hierarchically into a series of sequential tasks. The paper then goes on to suggest a method of clustering the information around generic tasks and using **If - Then** rules to establish dynamic links between the information.

Hierarchical Breakdown

Typically in design, a general strategy for tackling complex problems is to break the problem down into smaller more manageable problems and solve each problem in turn.[16] This was taken as the first approach to creating a model of the process.

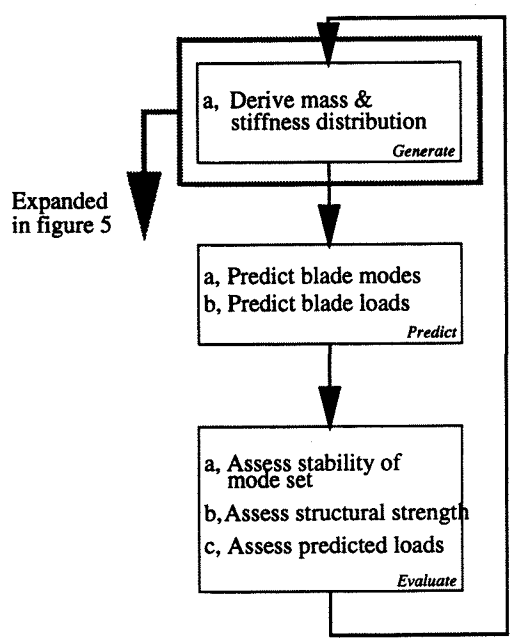

Figure 4: Breakdown of the design task into sub-tasks

Figure 4 shows the problem broken down into three subsections. *Generate* in which various design configurations are developed, *Predict* in which the respective performance of the configuration is predicted and *Evaluate* in which the performances are tested against acceptability criteria. The *Generate - Predict - Evaluate* process is then repeated, guided by the insight gained from the previous iteration. This is similar to the method employed in the Dominic KBS program[3] developed to solve parametric design problems.

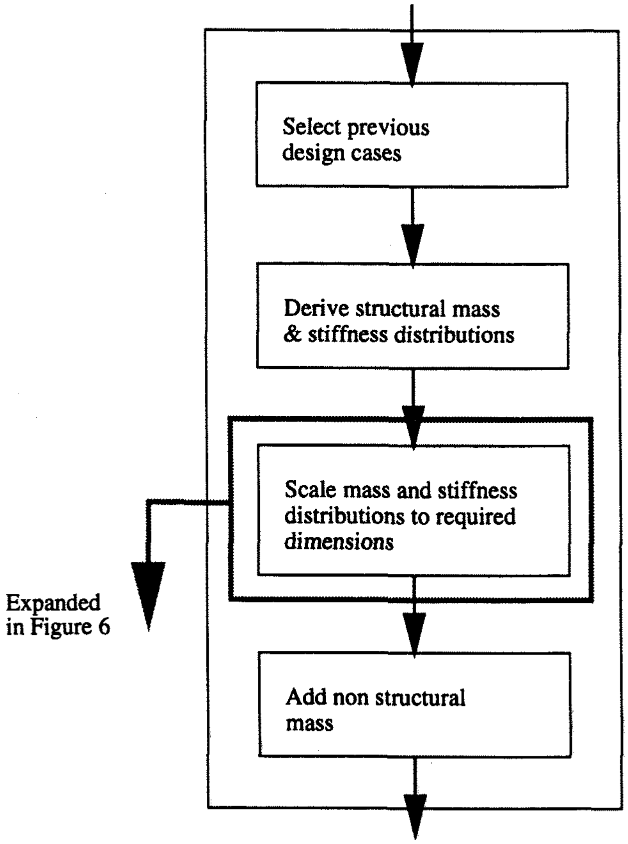

Figure 5: *Derive mass and stiffness* hierarchical breakdown

The process of breaking the design task down into sub-tasks may be continued until a level is reached in which each sub-task may be tackled more or less independently. This process is illustrated in figures 5 and 6.

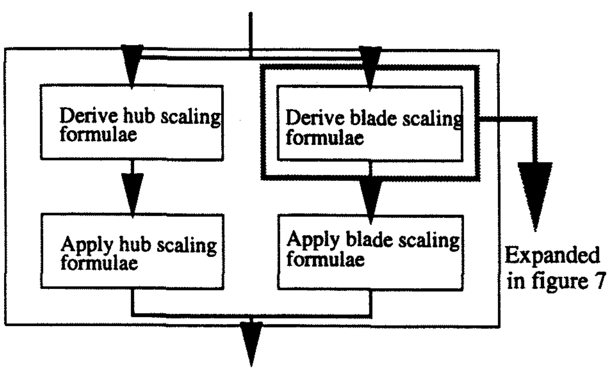

Figure 6: *Scale mass and stiffness* hierarchical breakdown

The recursive hierarchical breakdown of the design task is relatively straightforward to the level illustrated in Figure 6. Each task and sub-task is ordered and subsequently executed in a sequential manner.

The breakdown of the *Scale mass and stiffness* task illustrates that a number of tasks may be considered in parallel. In the task, the derivation of the scaling formulae of the hub and blade may be considered separately. Once applied, the mass and stiffness distributions are then combined for predictive and evaluation purposes at higher levels of the hierarchy.

At this level, it is not necessary to prescribe an order in which the tasks must be performed as the information made available on completion of scaling the blade say, is not directly applicable to the scaling of the hub.

However, it is not possible to further breakdown the *Derive blade scaling formulae* task in this fashion. Figure 7 depicts the breakdown of the *Derive blade scaling formulae* task into subtasks.

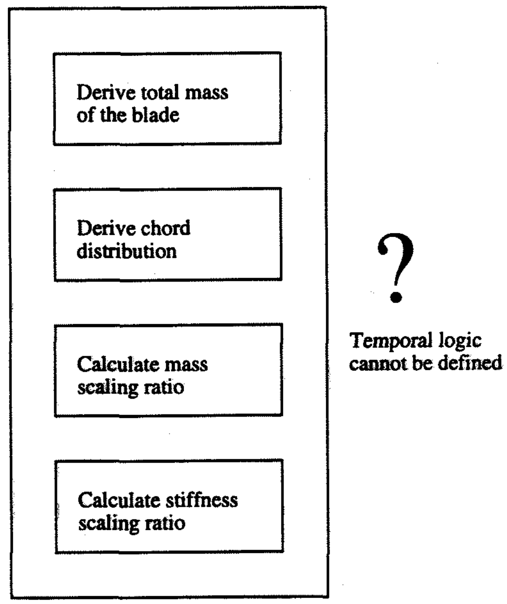

Figure 7: *Derive blade scaling formulae* hierarchical breakdown

Figure 7 illustrates that, due to the nature of the task, it is not possible to place the subtasks into a pre-prescribed sequential order. This is a direct consequence of the manner in which the actual engineer performs the task. In practice, there is no prescribed way in which the scaling formula is derived, the engineer, through the application of experience, selects the next action dependent upon the information available at that particular instant. Consequently it is not possible to represent the *Derive blade scaling formulae* task as a series of sequential subtasks without imposing an artificial framework on the design process.

Therefore there exists a need for a method in which the problem may be broken down into subtasks without imposing a prescribed sequential order.

Relational Breakdown

An alternative approach to the hierarchical breakdown into sequential tasks would be to cluster specific actions around generic actions. These actions may then in turn be clustered around other generic actions at a higher level of abstraction. This method is illustrated in figure 8.

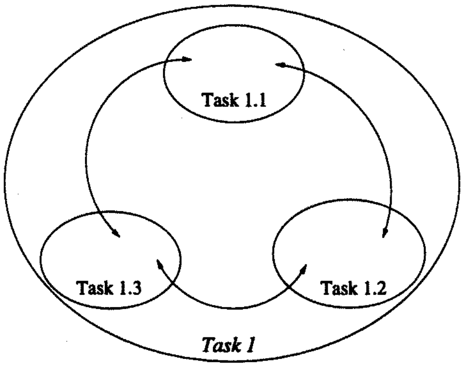

Figure 8: Clustering of design tasks around generic task

In clustering specific actions around generic actions in this fashion, it is not necessary to impose a particular ordering scheme.

Figure 9 depicts the clustering approach applied to the sub-structuring of the *derive blade scaling formulae* sub task.

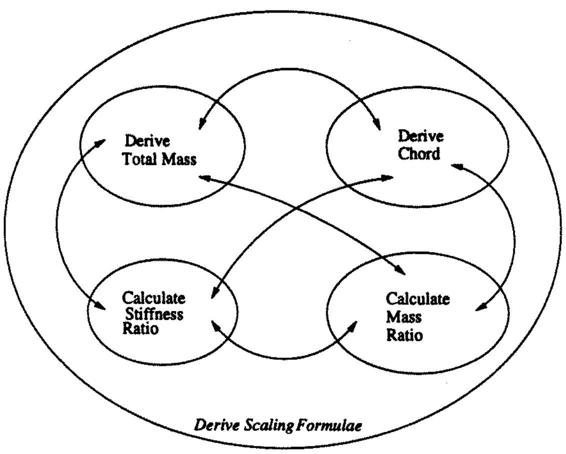

Figure 9: *Derive blade scaling formulae* relational breakdown

Using the approach, different levels in the breakdown of the design task may also be represented. Figure 10 depicts the breakdown of the *Derive mass and stiffness distribution* task into different levels.

The figure highlights the similarities between the relational and sequential hierarchical breakdowns of the task at higher levels of the models. The relational approach has the advantage however in the fact that it does not necessitate a particular ordering scheme to be imposed on the model.

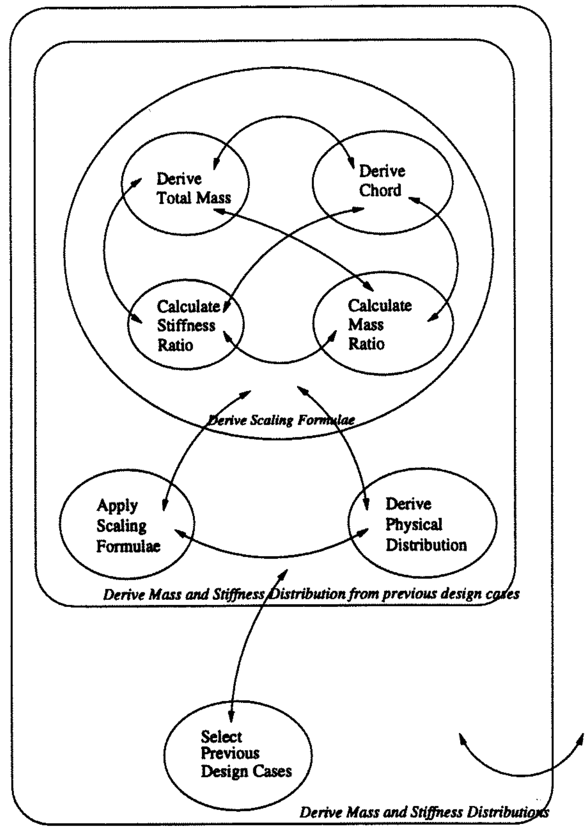

Figure 10: *Derive mass and stiffness* relational breakdown

Temporal structuring of information

The previous section suggested structuring the information in the form of relational clusters. However, it is not sufficient to just cluster actions. There must be some means of controlling the information represented. This logic, itself a form of information, must represent various forms of knowledge, such as:

- The current state of the design task;
- Knowledge of analysis methods, when they are suitable, their capabilities and limitations, their fundamental basis, how to perform them and the data required to perform them;
- Guidance as to the next action to be performed;
- Impact of the change in information on all aspects of the problem;
- Level of confidence in the information;
- The point at which an acceptable solution has been achieved.

In a sequential design process, such information may be represented as

Having done task i do task $i+1$

However, in a non-sequential design task, the control logic is dependent upon the state of the information available at that instant. Additional information must therefore be applied to the problem, either in the form of user input or computer logic. This is illustrated in figures 11 and 12

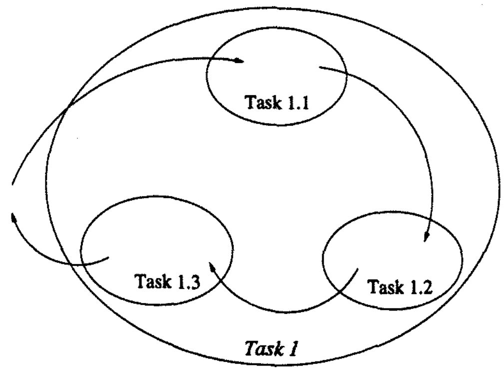

Figure 11: Control logic in sequential design task

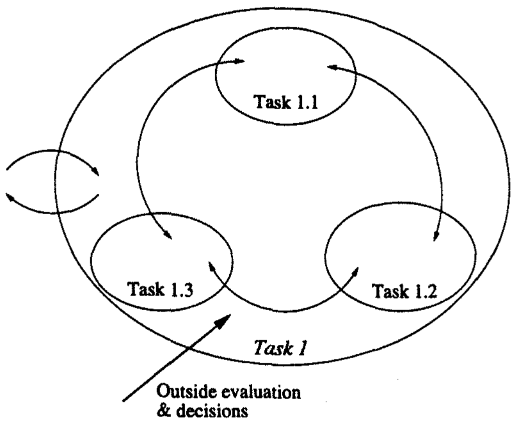

Figure 12: Control logic in non-sequential design task

By using rules, the KBS may model the consequences of a change in information in the form of deleting or creating connections where appropriate. Subsequently, a dynamic framework, dependent on the information available at that instant, will be created.

By establishing mappings between relevant clusters of information, (dependent on the information available) the KBS is in a position to derive and present all feasible options to the user. Another benefit of establishing mappings of this nature is that the consequences of a change in the information may be considered.

To achieve this, the relevant information available at a particular instant in time must be recorded and considered. However, to be of significant use the history of the methods employed in the derivation of the information must be considered in addition to the actual information itself. Consequently, it is necessary to transfer the appropriate information, and the history of information between relevant clusters.

The passage of information between clusters may be represented by using nodes to record the relevant information in the cluster. The node also records the most recent methods used, thereby recording the recent history of the cluster. The information flow using nodes is illustrated in figure 13

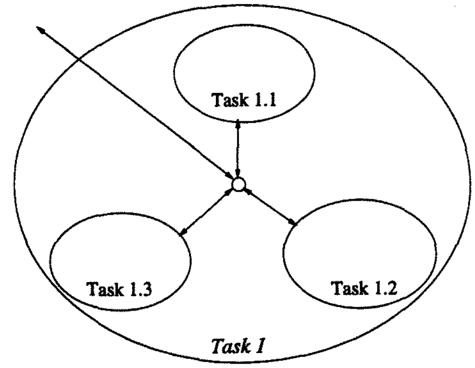

Figure 13: Information flow in relational clusters

By using nodes in this way, figure 13 may represent both the sequential and non-sequential clusters presented in figure 11 and 12.

The information flow between nodes and hence clusters may also be easily modelled in this way. Figure 14 illustrates the introduction of nodes and information flow into the *Derive mass and stiffness distributions* breakdown.

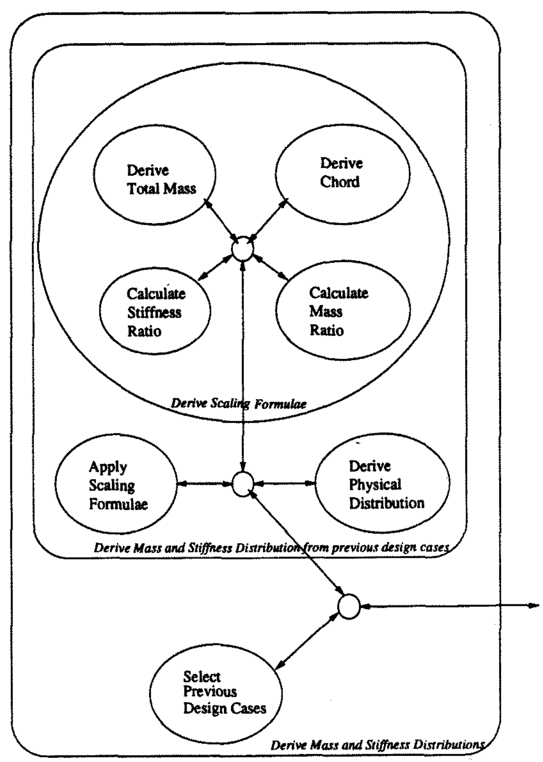

Figure 14: Information flow in *Derive mass and stiffness* relational breakdown

Using this modelling technique it is possible to represent *all* the information required in order to implement a knowledge based system to support adaptive design. The technique models:

- Explicit information;
- Relationships between information;
- Temporal logic;
- Data flow.

Implementation

One of the main objectives of the collaborative project is to develop a prototype Knowledge Based Support Tool. The development of a prototype tool supports a number of project objectives:

1. Evaluation of the clustering and dynamic framework concepts derived in the project
2. Assessment of the impact of the Knowledge Based System as a support tool in an industrial setting
3. Development of a prototype demonstrator tool

The development of the the tool will focus upon the implementation of two cases studies used throughout the project. The system will be modular in nature in order to facilitate future expansion when appropriate, and integration with other computational packages.

The derivation and evaluation of the required methodologies will also make the creation of a more robust system a feasible option.

There are a number of ways in which information may be represented in a KBS. These include fuzzy logic, semantic nets, frames and rule based systems.[4] Of these, frames and rule based systems will be used in the implementation stage of the project.

Computer representation of relational clustering using frames

A frame is a generic data structure, containing any desired number of categories of information attached to the subject of the frame. In a frame the different properties of an object are each represented as slots with associated values. A slot may even be another frame.

Rather than containing actual data, the slot may contain information on how to derive the required data. This may be in the form of formulae, procedures or calls to external computational packages. Consequently, it is possible to integrate existing packages within the KBS environment.

By utilising a property of frames, inheritance, it is possible to cluster the data around generic actions as described in the previous sections.

The use of rules in creating a dynamic framework

Dixon,[4] states that rule based systems comprise a number of parts:

1. A knowledge base of rules in the form **If** X **Then** Y
2. A working memory
3. An inference engine which decides which rule to apply next based on information from the short term memory.

The inference engine searches the short term memory to decide which X is true and then by applying the appropriate rules, determines the next actions to be performed. The actions consequently change the problem state which is updated in the working memory. The process iterates until a specified final state is achieved or no more rules may be applied.

By using rule based systems therefore, it is possible to modify the framework dynamically dependent upon the problem state The derivation of the necessary rules in the **If - Then** format to create a dynamic framework is currently being undertaken.

Computing Environment

In developing a computer prototype it is possible minimise the amount of computing effort by using an expert system shell. Expert system shells are effectively knowledge based systems with empty facts bases and empty knowledge bases, figure 15.

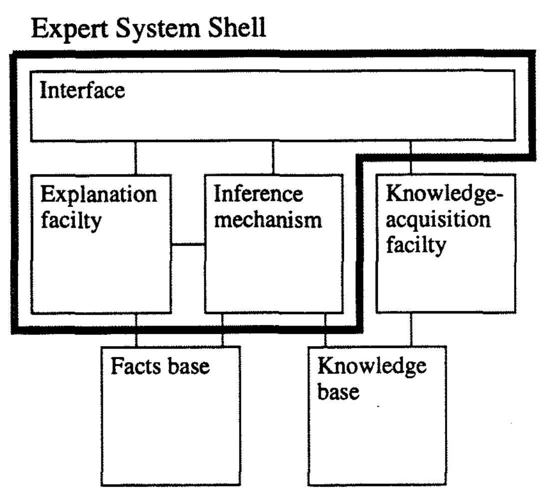

Figure 15: The components of an expert system shell[2]

By taking care of the support of information, an expert system shell serves as a domain independent tool enabling the analyst to concentrate solely on providing and organising the information itself.

The development of a prototype demonstrator is being undertaken using the GoldWorks III expert development system.[5] The expert shell provides the necessary support facilitate frame representation and cause and effect relationships (rules) in the form of **If - Then** relationships. The inference mechanism provides several different techniques for selecting and implementing the appropriate rules.

The development of the graphics interface is being undertaken using an interface design tool within the expert system development system.

Evaluation of the Knowledge Based Support Tool

Assessing the usefulness of any design support tool is not a trivial task. There are a number of issues that contribute to this:

- It is difficult to quantify "an improvement" in either the design process or the finished product;
- The benefits of such a tool may not be realised until the tool has been fully implemented in the design process;
- Imposing artificial constraints on the process, so as to establish a clinical experiment, may lead to a completely artificial environment;
- In establishing results, engineers of differing ability will be involved. Some account of this must be made.

In order to collect data from a number of sources, it is inevitable that any clinical evaluation of the tool will necessitate the use of an artificial environment. It is important therefore to be aware of the imposition of all artificial constraints and make allowances for these in the interpretation of data gathered in the experiment.

The experiment task

The experiment will involve the use of the KBS prototype tool to support the engineer in the derivation of the initial mass and stiffness distribution. Initially the task will be performed without the use of the system by an engineer highly experienced in the task. The problem will then be repeated by engineers of differing levels of experience and knowledge.

Each engineer involved in the experiment will be set the same design task. A detailed log of the computer session will be kept enabling the use of the tool to be monitored. The use of other information sources ie, questions asked, books/documents consulted will also be recorded.

Assessment criteria

In determining the performance of the support tool, a number of criteria will be considered:

1. Does the tool provide all the required information?
2. Time taken to complete the task
3. Performance of the mass and stiffness distribution
4. Experience gained in the task
5. Ease in which the tool was used

Comparing the distributions derived using the support tool with those of the datum removes the need to establish a single figure of merit by which the performance of the design may be assessed. Rather the overall performance may be assessed diagrammatically, figure 16. However, whilst the depiction of the blade mass in this manner is trivial, thought must be given to the measurement of other disciplines such as dynamic performance and manufacturability.

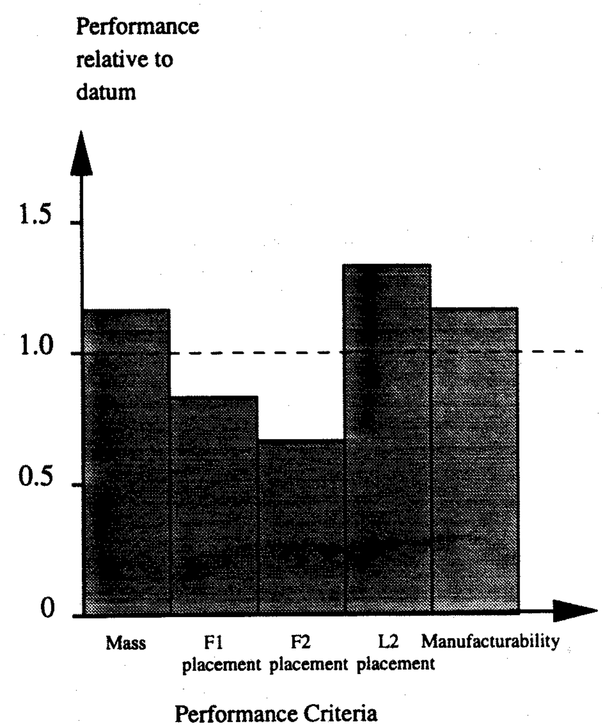

Figure 16: Histogram approach to assessing the performance of the design

Conclusions

1. Aerospace design has special needs which make the use of an "off the shelf" Knowledge Based System difficult.
2. The application of Knowledge Based Systems in aerospace design has largely been restricted to variant design.
3. The key issue in the development of a Knowledge Based System to support adaptive design is identifying and modelling the requisite information. The model generates understanding of the requirements and acts as a basis for implementation.

4. It is important to model all information, including:
    - Explicit information;
    - Relationships between information;
    - Temporal logic;
    - Data flow.
5. This paper has suggested a modelling technique in which all the information required may be represented.

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References

[1] J. S. Bennet and R. S. Engelmore. SACON: A Knowledge-Based Consultant for Structural Analysis. *Proceedings, 6th International Joint Conference on AI, Stanford University, Palo Alto*, pages 47–49.

[2] R. D. Coyne, M. A. Rosenman, A. D. Radford, M. Balanchandran, and J. S. Gero. *Knowledge-Based Design Systems*. Addison-Wesley, 1990.

[3] J. R. Dixon. Knowledge-Based Systems for Design. *Transactions of the ASME, Special 50th Anniversary Design Issue*, 117:11–16, June 1995.

[4] J. R. Dixon and M. K. Simmons. Computers That Design: Expert Systems for Mechanical Engineers. *Computers in Mechanical Engineering*, pages 10–18, November 1983.

[5] Gold Hill Computers, Inc. *Goldworks III*.

[6] S. A. Gregory. Design support environment: expert systems. *Design Studies*, 8(2):88 – 95, April 1987.

[7] F. Hayes-Roth, D. A. Waterman, and D. B. Lenat. *Building Expert Systems*. Addison-Wesley, 1984.

[8] A. Kochan. Drawing on Knowledge. *CIM focus - The Engineer*, March 1996.

[9] J. McDermott. R1: A Rule-based Cconfigurer of Computer Systems. *Artificial Intelligence*, 19:39–48, 1982.

[10] R. Oxman. Prior knowledge in design: a dynamic knowledge-based model of design and creativity. *Design Studies*, 11(1):17–28, January 1990.

[11] G. Pahl and W. Beitz. *Engineering Design*. The Design Council, 1984.

[12] P. Proctor. Boeing Adopts "Expert" Design System. *Aviation Week & Space Technology*, April 1995.

[13] G. Schreiber, B. Wielinga, and J. Breuker. *KADS A Principled Approach to Knowledge - Based System Development*. Academic Press, 1993.

[14] M. Turner. Expert Systems: A Management Guide. PA Computers and Telecommunications, 1985.

[15] M. R. Wagner. *Understanding the ICAD System*. ICAD, Inc, 1990.

[16] K. Wallace. An Introduction to the Design Process. Technical report, Cambridge Engineering Design Centre, March 1993.