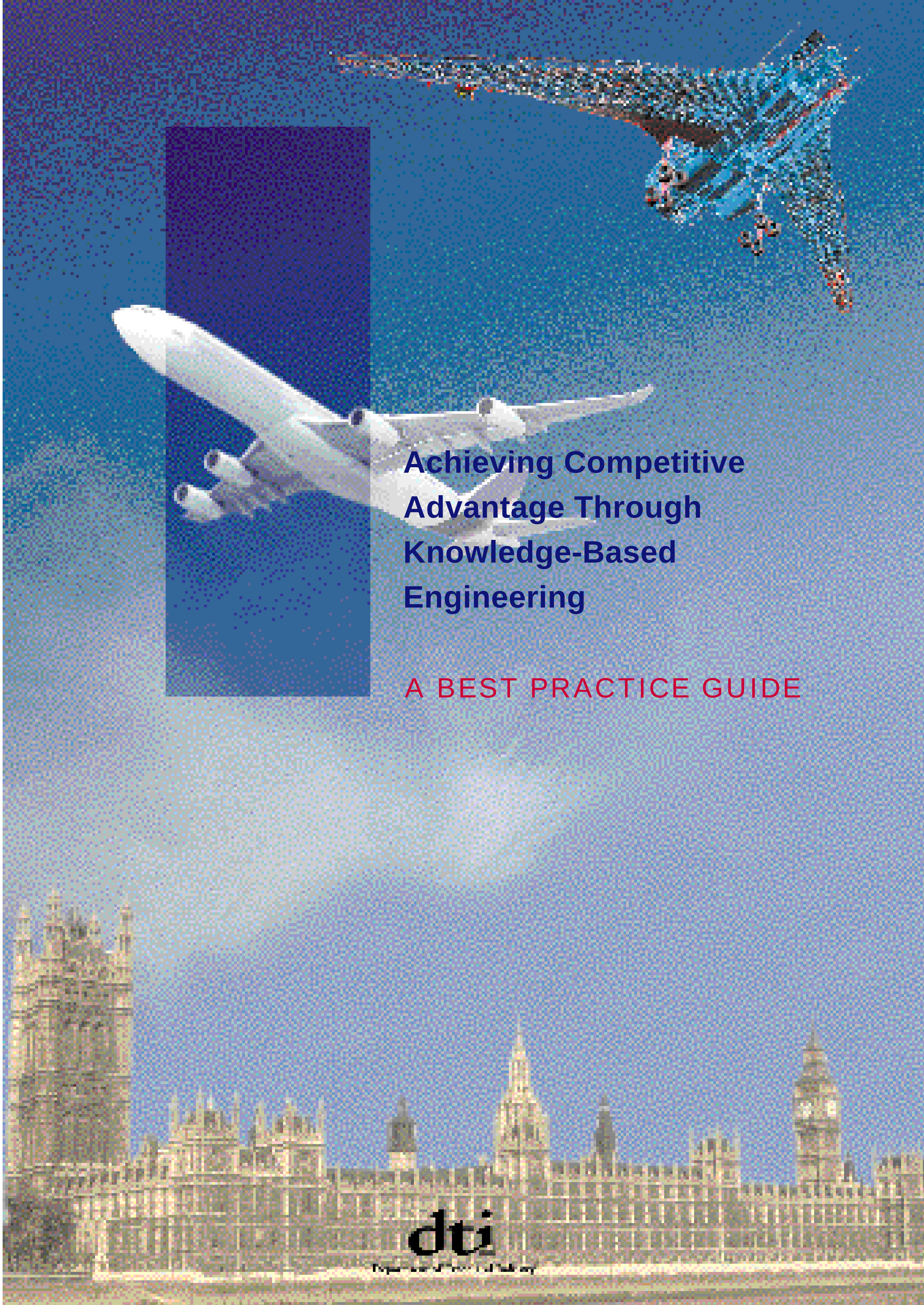

Achieving Competitive Advantage Through Knowledge-Based Engineering

A BEST PRACTICE GUIDE

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Achieving Competitive Advantage through Knowledge-Based Engineering

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Foreword by Jeff Jupp MA, FRAeS, FREng

The Industrial Revolution created a critical mass of factory-produced goods, a critical mass of possibility. Its impetus sustains our industries today but increasing product complexity threatens progress.

Once, small groups could hold the knowledge for a car or 'plane in their heads. They understood the how, what and why of each system and resolved problems daily. This is no longer possible. Today, if the specialists in one area of a design make a change, unresolved impacts elsewhere may easily increase delay and cost.

Current methods of resolution must improve. 'What ifs' need to be answered as they are asked. Expensive and time-wasting feasibility testing destroys creativity, the lifeblood of progress. Small groups cannot hold the knowledge required and large groups cannot control it.

The 'Intellectual Capital' of an enterprise must be trapped and deployed within a technology that understands the 'DNA of a design'. It has to behave intuitively, delivering knowledge not 'on demand' but 'as required', analysing the impacts of changes as they are made and allowing trade-offs to be made from a position of knowledge - optimisation not compromise. And it must be expandable to manage the process across an enterprise.

Tomorrow's engineers need to be free to innovate and to realise and assess their ideas 'virtually'. There can be no brake on creativity, no let up in the quest for better products faster, and with lower cost.

One of the answers to these ambitious needs exists. In Airbus we have used it on real projects and know its impact. Read on, as the astonishing potential of the Knowledge Revolution is revealed. Use it carefully, a little knowledge is a dangerous thing!

Jeff Jupp is Director Technical responsible for Engineering Process Development and IT at British Aerospace Airbus.

BEST PRACTICE GUIDE - ACHIEVING COMPETITIVE ADVANTAGE THROUGH KNOWLEDGE-BASED ENGINEERING

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Cover shows Airbus A340-600, reproduced with kind permission of British Aerospace Airbus Ltd

Contents

The aims of this booklet

In the knowledge age companies must harness their intellectual capital in order to compete and survive. This requires that companies make the development and maintenance of their knowledge, about the products that they manufacture and sell, a fundamental activity. A company that does so is termed a Knowledge-Based Organisation (KBO).

Knowledge-Based Engineering (KBE) is a key technology to retain competitiveness in the knowledge age. It allows companies to capture and deploy the knowledge and experience of their engineers, together with manufacturing best practice, legislation, costings, and other rules. KBE is now being used by a wide variety of companies to massively reduce design time and cost, whilst simultaneously improving the cost, performance and quality of the end product. For example, using KBE:

- British Aerospace was able to evaluate 60 new design concepts in the same time-scale as it took a partner company, using modern CAD technology, to generate one.

- Jaguar was able to transform a 4-week design feasibility study, requiring specialist supplier input, into an interactive procedure that can be completed by their own engineers within minutes.

- Caradon Everest was able to convert the procedure for releasing manufacturing data for customer specific product requirements, from a four-week process to a same-day activity.

The primary aim of this booklet is to demystify the terminology surrounding KBE and explain how it may be deployed in order to gain competitive advantage. To this end, the next section introduces the fundamental concepts of the technology. Subsequent sections then describe the impact that KBE can have on the business and provide guidelines for its implementation and use. The content of this booklet draws on the experiences of companies that are currently using KBE and a number of case studies illustrate the variety of products to which the technology has been applied.

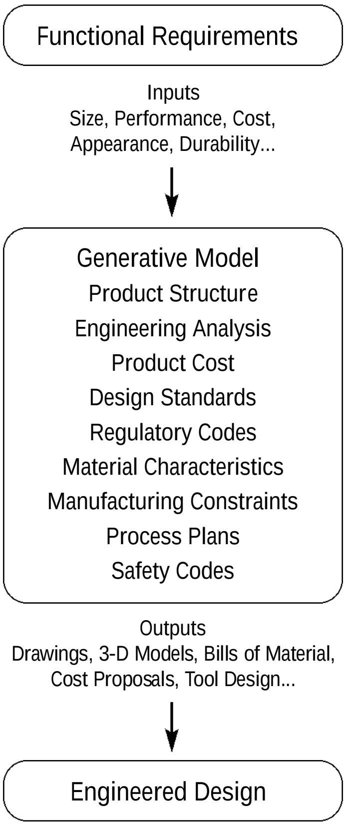


Figure 1
The generative model of a KBE application takes input specifications, applies relevant procedures, and generates a product design automatically .

(source: Knowledge Technologies International)

Knowledge-Based Engineering

Technically, Knowledge-Based Engineering (KBE) is used in this booklet to describe a particular type of knowledge-based system that is based upon an object-oriented programming language and is tightly integrated with a geometric modelling tool. Practically, a KBE system provides a software environment in which a skilled KBE development engineer can create KBE applications, which are then used by designers, engineers and other company staff, as appropriate. To these end users, a KBE application provides a structured approach to design. Geometry generation is automated, being controlled by rules encoded by the KBE development engineer. This allows the user to focus on delivering an end product to the customer's functional requirements. This is different to CAD, where the user has to simply 'get on with it' and generate geometry. KBE generated geometry is also far smarter and richer, which allows better reaction to changes later on. These differences are due to KBE's 'generative'and 'integrated' modelling capabilities.

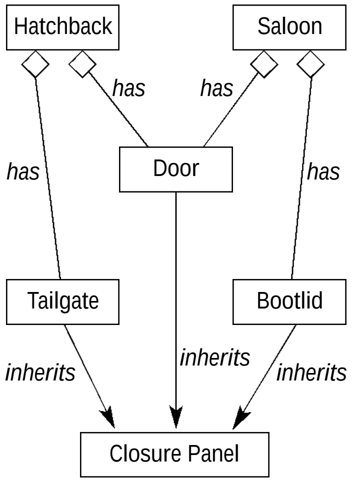


Figure 2
The object-oriented pr ogramming used in KBE systems enables product models to be constr ucted in a modular fashion. For example, hatchback and saloon car bodies can be divided into their consitutent parts, such as doors, tailgate and boot lid. Each of these may then inherit pr operties from other objects, such as a defi nition of a closure panel.

Generative Modelling

The generative model is at the heart of a KBE application (Figure 1). It is a generic representation of the product type for which the application has been created. Hence, it is not made up of fixed geometric entities, with fixed dimensions, in a fixed configuration. Instead, it contains the engineering rules that determine the design of the product. The model is normally built using an object-oriented programming language. The object-oriented architecture of the language allows the application to be built in a modular fashion (Figure 2). This enables complex applications to be produced and eases the maintenance, further development, and reuse of the code.

When the user inputs the functional requirements for a new version of the product, the specific data is generated almost instantaneously. This data may include product geometry, manufacturing instructions, costs, etc. depending upon the construction of the generative model.

Caradon Everest are leaders in the custom design and manufacture of home improvement products, particularly windows, doors and conservatories The company has used KTI's ICAD KBE software to produce applications to support the generation of manufacturing data, based upon the customer 's individual, functional requirements. This has improved quality by removing er rors from the process and reduced a four-week procedure into a same day activity .

Integrated Modelling

The designs created by a KBE application have a predictable structure, which contains individually identifiable objects. This means that it is possible to include additional rules, in the generative model, to create alternative views to support a wide spectrum of product development activities. For example finite element meshes, process plans or cost models may be automatically created. Furthermore, because it is a single model that is used to generate the data, consistency can be assured. This integrated modelling capability may also be referred to as virtual product modelling or total product modelling.

SUMMARY
KBE systems are characterised by their combination of object-oriented programming with geometric modelling. These enable 'generative modelling' that allows the near instantaneous generation of new design data and 'integrated modelling' that provides the means to automatically create views to support a wide range of product development activities.

Impact of Knowledge-Based Engineering

KBE provides major benefits to the business by improving the speed and effectiveness of the product development process (see Figure 3). KBE's generative modelling capability gives direct benefits by reducing the time taken to create new designs. Massive savings in design cost can be achieved on each pass of the design cycle. By automating the tedious and time-consuming parts of design, KBE frees up engineers for other projects. The integrated modelling capability ensures consistency, with each new design created subject to specified constraints, such as cost, legislation or manufacturing. Together, the generative and integrated modelling allow rapid feedback to the various members of the design team of the impact of their decisions. Used like this, KBE is a powerful concurrent engineering tool, helping to massively reduce rework and so cut the costs of both product development and the end product itself.

At the end of the project, the company also benefits through having effectively captured the knowledge behind the product's design, which may then be reused on other projects. The end customer sees a company

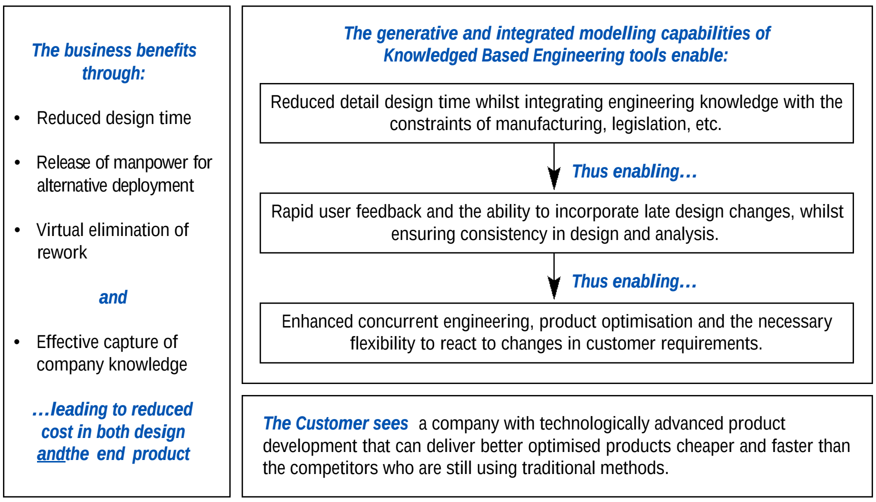


Figure 3
The impact of KBE is transmitted throughout the design process, providing measurable benefits to both the business and its customers.

CASE STUDY 1 - BAe Airbus

Airbus Industrie, an undisputed world leader in the civil air transport marketplace, is a partnership between four European aerospace manufacturers; British Aerospace (UK), Aerospatiale (France); DaimlerChrysler Aerospace (Germany); and CASA (Spain). Each partner is responsible for the design, manufacture and assembly of one part of the aircraft. British Aerospace, through BAe Airbus, leads on the Wing and Undercarriage, Aerospatiale on the Cockpit, Wing Centre Box and Systems, DaimlerChrysler on the Fuselage and CASA on the Empennage (Fin and Tail). However, each partner company also maintains a whole aircraft concept design team to ensure that they understand the impact of any potential new aircraft on their business.

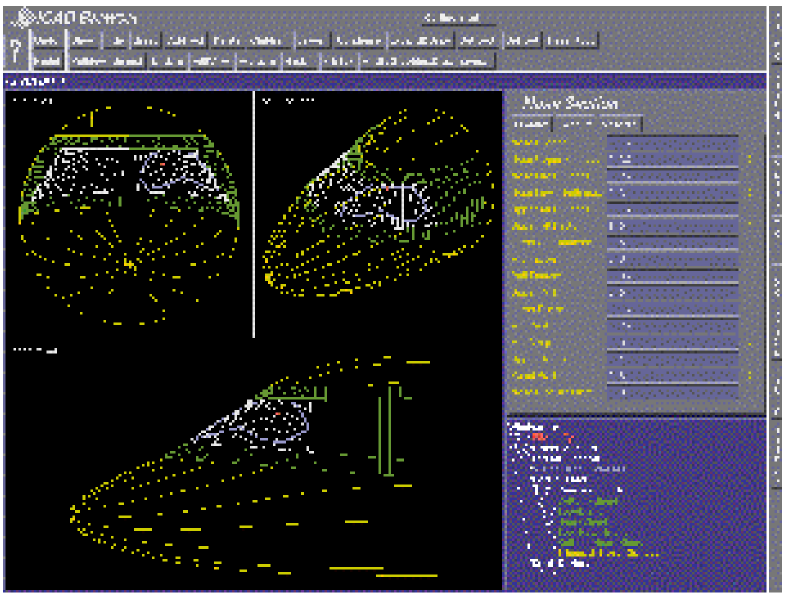
BAe Airbus has extensive KBE experience. An example of KBE's effective use is a concept evaluation for a 100-seat short to medium range passenger aircraft, completed by Airbus Industrie in conjunction with China. It should be noted that this 100-seat aircraft concept is not considered the optimum for current market conditions. This is often the case in concept work. Two main concepts for the nose and cockpit emerged in initial discussions. The first integrated the existing cockpit from the A320 aircraft family into the narrower fuselage being considered. The second required a new cockpit, which repackaged many of the A320 systems.

The Aerospatiale design team generated the first concept. This involved grafting the flat plate glass panels of the A320 windscreen onto the narrower fuselage and nose. The result, a 'classical' passenger jet cockpit, consisted of a mix of complex double curvature surfaces and flat plates. Their approach used a CAD focused process. This involved high level analysis, before draughting the concept in the CAD system, which then drove their more detailed analysis.

The design team at BAe Airbus took their existing KBE applications, developed on a previous RJX feederliner project, for Nose, Fuselage, Cockpit, Seating Layout and Undercarriage and developed the second concept. This included a "Business Jet"style windscreen consisting of curved glass panels, something Airbus had never produced before. KBE provided BAe Airbus with the ability to:

- Evaluate of over 60 concepts to a consistent level of detail.
- Import the concept generated by Aerospatiale in order to do comparison work to the same standard.
- Evaluate the two concepts to a far higher level of detail than previously thought possible within the resource and time-scales available.
- Use consistent data for Aerodynamics, Structural Design, Operational and Manufacturing analyses.

This case study has shown the value of KBE in conceptual design, enabling engineers to deal with increased levels of detail, topology change and design iteration. It has also shown KBE's role in concurrent engineering, providing a consistent model that all disciplines can work around, and its ability for delivering benefits on one-off items.



BAe Airbus is the largest European user of the ICAD KBE system, from Knowledge Technologies International (KTI).

that is employing leading edge technology to support their product development. The customer gets products that are better optimised to their requirements, and which can be delivered faster and cheaper than those from competitors using traditional, CAD based, design techniques.

This example taken from the Prescient Technologies web site, at: http://www.prescienttech.com/

Rohr, Inc. of Chula Vista, California, a leading supplier of aircraft engine nacelle and structural subsystems, have used Prescient Technologies' STONErule software to develop several KBE applications. One such application supports the design of nacelle pressure relief doors. This provides significant benefits by allowing direct feedback of analysis results to the design engineer for early design trade-offs. The rules in the knowledge base also make 'on the fly' cost information available, taking the design decision criteria to a new level.

KBE and CAD

"Unlike traditional CAD, KBE technology focuses on capturing the design and manufacturing intent, not just the geometric end result" Steve Murphy, The Boeing Company. Taken from the International ICAD Users Group web site, at: http://www.iiug.com/

A misunderstanding that often arises with KBE is that it is an alternative to CAD. This can sometimes be propagated by CAD vendors, who may see KBE systems as competitors. The truth is that KBE does not remove the need for CAD. However, KBE will reduce the number of CAD stations that are needed for a particular task, in the same way that it frees up engineers for other programmes. The facts are:

- For the foreseeable future, CAD will be required as the detailing mechanism for the product data model.
- There are some design tasks for which KBE is not suitable (see page 15). CAD will be required to support these and provide appropriate geometry to related KBE applications.
- For the foreseeable future, KBE systems will continue to offer generative and integrated modelling capabilities that are far beyond those available from a CAD vendor.

This example taken from the Design Power web site, at: http://www.dp.com/

YIT Corporation is the largest construction company in Finland. They found the traditional CAD-centric focus too limiting, as only the design result could be retained, with neither the design intent nor methodology being documented or incorporated. Using Design Power's Design++ software, YIT have now developed a KBE-based approach. This allows the functional requirements to be explicitly provided, with the methods to fulfil these requirements being incorporated the KBE system.

KBE in the Supply Chain

Another misunderstanding that often arises with KBE is that it can only be used by large prime contractors. The truth is that suppliers may be able to achieve even greater benefits than the prime contractors. This is

CASE STUDY 2 - New Design Paradigm

Electrical Systems Design (ESD) is a KBE application developed by New Design Paradigm Ltd. that allows vehicle and aircraft companies to design a complete electrical system in just a few days, instead of several months with the traditional approach. Unlike traditional systems and processes that require large engineering teams to work with low-level detail, ESD allows a small number of engineers to generate the design direct from high-level specification libraries, minimising the possibility of errors and offering the capability of truly-optimised electrical systems.

ESD, developed using KTI's ICAD system, is an example of KBE technology being used to re-engineer large-scale dysfunctional engineering processes, a common problem in many engineering organisations. In the past 20 years companies have introduced CAD/CAE tools that have accelerated and enhanced many aspects of the design process but, at the same time, introduced new bottlenecks.

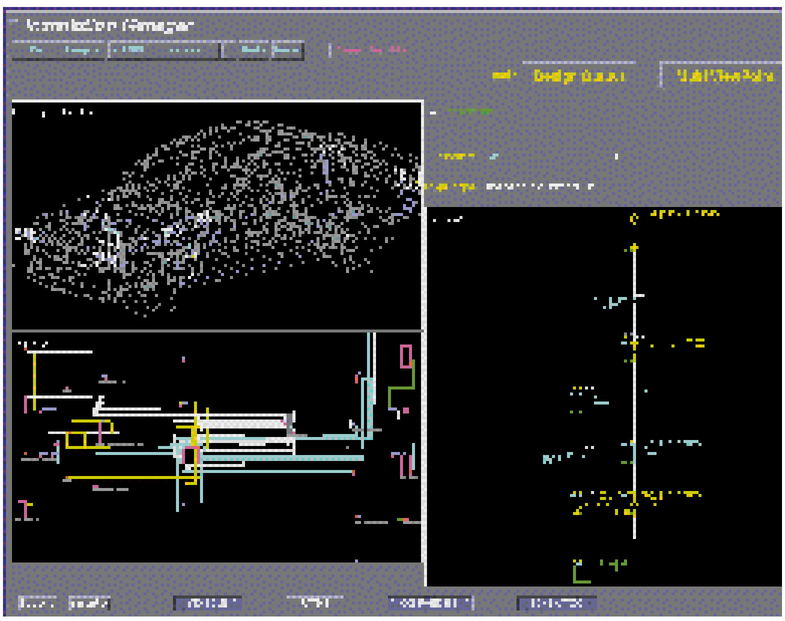
The bottleneck in electrical design is caused by the requirement to model the system in two separate CAD systems, in parallel - electrical topology with 2D electrical-CAD, and physical design with 3D mechanical-CAD. Both systems demand accurate specification of design details. A catch-22 situation is created in which each activity depends on the other. Making changes is difficult, so the engineers are reluctant to start the design until design parameters are frozen - late in the programme. Validation of the design, and discovery of errors, can only be performed when the design is complete, so there is little time, or inclination, to optimise the design.

The architecture of ESD is based on a number of insights to this problem and the special way that KBE can help:

- A KBE-based Virtual-Product-Model (VPM) can be used to create a single entity that integrates all aspects of design. Electrical-CAD, mechanical-CAD, analysis-program inputs, reports, and so on, can be output directly from the VPM, with integrity guaranteed.
- KBE tools allow the creation of a connected series of data-structures, each representing the design at a particular level of maturity, from initial outline to full-detail; yet the VPM can complete the design starting with any level of the data. So engineers can generate the design with broad-brush data initially, test and optimise it through many iterations, then refine the data later as more information becomes available.
- Discontinuous process improvements can be achieved without major disruption. KBE applications can be designed and built to use the existing computer systems, applications and data-structures allowing them to be installed in a modular, plug&play fashion with minimum disruption.

This case study particularly illustrates the integrated modelling capabilities of KBE, providing a common model that engineers from different disciplines can work around.

By integrating the electrical, mechanical and analysis aspects of electrical systems design, the KBE based ESD application can provide massive savings in both design and final product cost.



because, whilst prime contractors only design parts for use on their own products, suppliers provide essentially similar components (e.g. body panels, headlamps, windscreen wipers) to several customers. This means that the same KBE application can be used more often, to support the design and manufacture of parts for each customer and, as already noted, KBE provides a direct payback each time the process is repeated.

This example taken from PCAI, vol. 12, no. 6, Nov/Dec 1998.

Trico supplies windscreen wiper parts and systems to many of the worlds best known car manufacturers. Using KTI's ICAD KBE system, Trico has been able to automate the thousands of calculations involved in designing a windscreen wiper system. As a result, a system can be optimised for a particular vehicle in minutes, rather than weeks. KBE has helped Trico to become a full service supplier without adding further engineers.

SUMMARY

KBE benefits the business by automating the time consuming, repetitive data generating and data consistency management tasks that make up 80% of the typical design process. This provides benefits by reducing design costs and enabling the definition of a better optimised, more competitive product.

KBE is complementary to CAD and provides capabilities that no current CAD system can match. KBE can provide a competitive advantage to suppliers as well as prime contractors.

Implementation of KBE

The implementation of KBE is a major task, requiring high-level and ongoing support to promote its use and clear obstacles that may hinder its deployment. This section draws from the experience of current users of KBE, discussing the major issues associated with implementation.

Options for initial deployment

BEST PRACTICE TIP

Sell KBE to task engineers with deadlines to meet. Once they have bought into the technology, it is in their interest to ensure its success.

A key decision in the initial implementation of KBE within a company concerns whether to use the technology first to support an offline activity or to deploy it straightaway online, on a product development programme. Each approach has its own strengths and weaknesses. An offline deployment mitigates risk by preventing any KBE application development difficulties from impacting on the launch of the company's next revenue earning product. However, such an approach will require additional effort in raising awareness of the technology in the company and will lengthen the payback period. Often such experimentation, without immediate return on investment, will not be justifiable.

The alternative, online deployment approach has higher risk and will require a higher initial investment in a trained KBE resource but it has a number of benefits, as it:

- Requires early consensus on the use of the technology.
- Gives high visibility of the technology within the company.
- Provides definite deadlines for delivering applications.
- Provides immediate and quantifiable benefits to the business.

It is because of these benefits that established KBE users tend to take the online deployment approach in order to expand the use of the technology. The implementation approach that is appropriate in any given situation will be dependent upon a number of factors, including:

- If the technology is to cover a shortfall in engineering resource.
- Whether there is sufficient commonality in the company's products to allow offline development of an application that can then provide immediate payback when deployed in a live project.
- The amount of dedicated KBE resource immediately available.

Retaining a KBE resource

BEST PRACTICE TIP

Exploit KBE vendors and explore co-operation with major prime contractors in order to acquire sufficient dedicated KBE resource.

There are basically two approaches to gaining access to a group of KBE developers with the necessary skills to construct applications: evolve an in-house KBE resource; or use some kind of external development. The main advantage of the first option is that, over time, a group can be built up that is not only KBE proficient but also familiar with the particular application area. The disadvantage is the large, long-term investment that it requires. This is due to the time required to become proficient with the technology and the need to continually invest in training, as skilled developers move on within the organisation. However, if a large KBE resource can be developed then the time taken for new developers to gain proficiency is often reduced.

There is a critical mass above which an internal KBE resource becomes to some extent self-sustaining but below which it is difficult to retain the necessary expertise.

If KBE development is to be completed externally then there are at least three options that should be considered:

- Contract for a consultancy package when acquiring the software.
- Negotiate not only for the software but also for ongoing development and maintenance of particular KBE applications.
- Invest in concert with a major customer, also using the technology.

BEST PRACTICE TIP

Combine internal and external developers to accelerate the KBE implementation and develop the expertise of the in-house KBE team.

The use of external developers will require additional effort, during application development, in order to ensure user confidence in the end application. Additional effort will also be required to ensure that completed applications are kept up to date and not left to fall into disuse.

CASE STUDY 3 - BAe Airbus

BAe Airbus deploys KBE not only in concept design (page 4) but also on live projects. The 400-seat A340-600 is the latest addition to Airbus Industrie's line up of modern, efficient transport aircraft. BAe Airbus assumed their usual role in the development of this aircraft, leading the design of the wing. The company completed this task using several applications developed by their KBE team. The wing rib tool is a good illustration of the capability of the technology.

The ribs were obvious candidates for a KBE application. They are important and expensive major structural items and a civil aircraft wing contains a considerable number of them. At a cursory glance they are all broadly similar but each one has a different shape and may have very different combinations of function and critical structural load.

As with any KBE development, the key to the success of the rib application was to understand the design process associated with the parts. Ribs must be as light as possible (weight is critical in aircraft performance and ribs contribute significantly) whilst resisting the loads imposed on them. They are critically dependent upon the other components that surround them and with which they interface, such as the skin and the spars. Even a small change in the skin will have a large effect on the shape and required thickness of the rib. The position and orientation of each rib in the wing also determines the number and types of its features.

Conventional rib design entails modelling each one by hand in a parametric CAD system. The KBE team developed one application that could generate the parametric CAD model of a rib in any location on the wing, in minutes. The associated analysis was also integrated, enabling rapid iteration of the design and analysis loop.

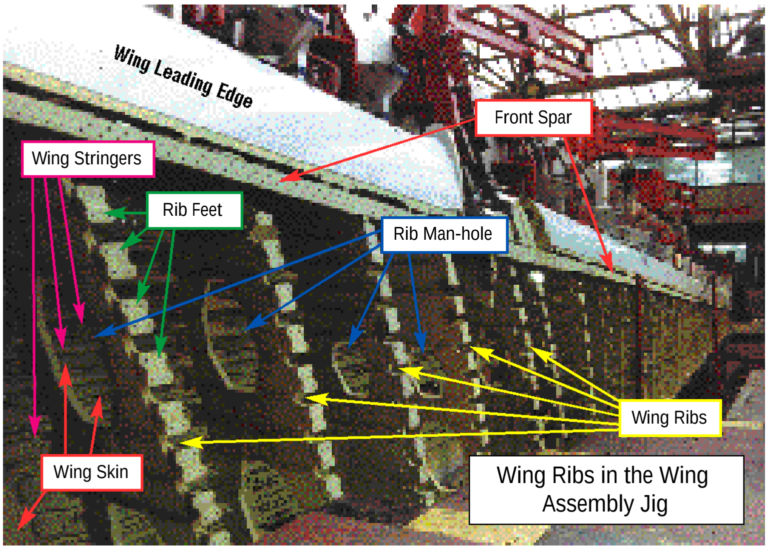
Further knowledge was also included to support engineering processes not well supported by the company's standard CAD system.

Numerous benefits were provided by the application:

- The cost of developing the application was far less than developing the parametric CAD models manually.
- True concurrent engineering was enabled, with different engineering disciplines working at the same time from one model. In this way the team achieved 'Analysis Driven Design' instead of design driven analysis.
- Engineers could focus on the intuitive and taxing design problems, rather than on the act of data generation.
- The parametric CAD models output by the KBE tool were consistently constructed, which cannot be proven in a manual approach. This is important in the rigorous certification procedure applied to aircraft components.
- Models were iterated far more often in the life of the project and late design changes were easily handled. This enabled enhanced quality and greater maturity prior to entry of the product into service.
- The application is now available to other projects, enabling conceptual work to be carried out to far higher levels of detail, for little increase in effort.

This case study illustrates KBE development being completed on a live project, with application capability being continually refined as the programme progressed.

The complex structure of an Airbus A340 wing is shown during assembly at BAe Airbus. The company has applied ICAD KBE in the design of the new -600 variant of this aircraft, reaping major benefits.



However, the best practice is to use a combination of internal developers and external consultants. This enables both the rapid and efficient completion of the KBE project and facilitates the accumulation of expertise in the in-house KBE team.

Selecting the pilot application

BEST PRACTICE TIP

Hit the soft targets first. Use the experience and results gained on well-defined applications to justify more difficult developments.

The design task to be automated in the pilot KBE application should be:

- Highly rule driven, not stylised or subject to constraints that are difficult to define.
- Have stable rules, so the application is not out of date once complete.
- Subject to repetition, either through optimisation or multiple versions of similar products.
- Driven by rules that are known and accessible to the KBE developer.

The last two criteria usually mean that the design task is repetitive due to multiple product versions (giving immediate savings in design cost) and that the engineering expertise to be captured is available in-house.

After gaining experience on the pilot project, it is then possible to consider more challenging applications, which may not meet all of the above criteria. An example is the BAe Airbus 100-seater nose (page 4), in which the optimum rules were not known up front, and KBE allowed the company to handle the consequences of changing the design rules.

Building internal suppor t

BEST PRACTICE TIP

Make a major effort to effectively communicate the capability of KBE throughout the organisation. People must understand what the technology can do before they can suggest further applications.

The human aspects of deploying KBE must not be underestimated. The two main points that must be addressed are: mental pigeonholing of the technology; and understanding the organisational impact. The first point concerns the tendency of people to mentally pigeonhole KBE as being suitable only for applications in areas where it has been demonstrated - e.g. “it’s a mechanical design tool,” or, “it’s for system configuration.” It can take time, and several different demonstrations, to communicate the true flexibility of the technology. In understanding the organisational impact of the technology, it is important to realise that some people may view KBE as a tool that will ultimately lead to their redundancy. In reality, the following benefits can be gained from KBE application: a) faster completion of creative, value added activities; b) removal of mundane, repetitive activities and c) improved job satisfaction.

CASE STUDY 4 - British Steel

British Steel's Automotive Engineering Group (AEG) is a centre of excellence that works with vehicle manufacturers, early in the design development phase, helping them to use steel in the most cost and mass efficient ways. AEG acquired KTI's ICAD system in 1998 and is now developing a number of KBE applications that will enable the company to provide an added value and quality enhanced service for its customers whilst also improving internal productivity.

Tailor Welded Blanks (TWBs) are the focus of one such application. Traditionally, automotive body panels are made from single piece steel blanks. In contrast, a TWB consists of multiple blanks, of variable grade and thickness, which are laser welded together. TWB's enable the appropriate grade and gauge of steel to be positioned only where it is structurally needed. This obviates the need for additional structural reinforcement, leading to reductions in the number of parts and tooling, weight and ultimately cost.

ICAD has been used to build a KBE application that automates the routine parts of the process associated with assessing the manufacturability of a TWB. This application inputs the geometry of the required blanks, as assembled, from a CAD file. The engineer then specifies the required material and thickness for each blank - material properties are accessed from an associated database. The application then feeds back advice on any material incompatibilities, and where changes to blank geometry would enable the use of a cheaper manufacturing process. Subsequent steps lead to the definition of the welding sequence and the blank nesting pattern. The end result consists of a high-level process plan, facilities requirements and cost estimates.

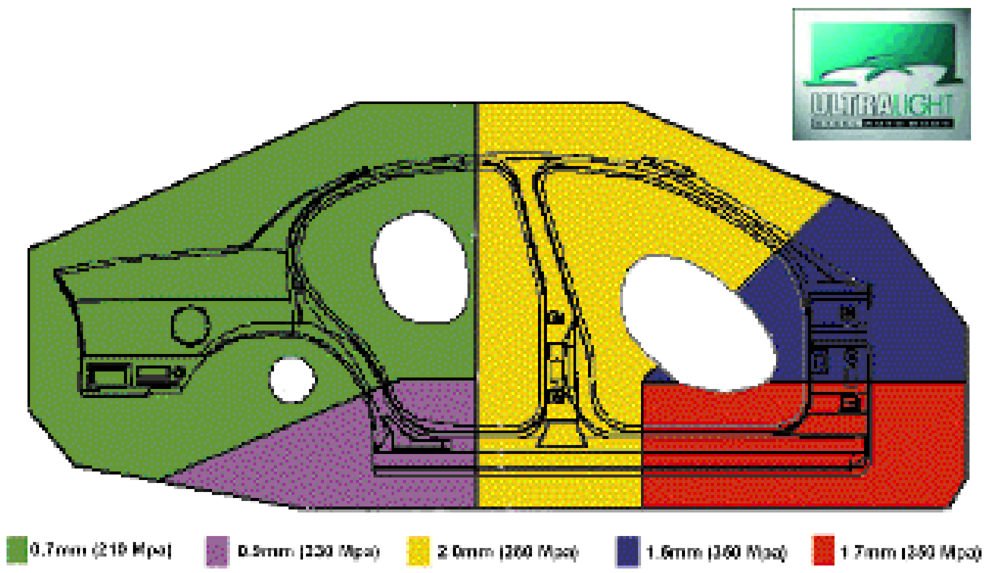
In order to hasten the return on the investment in the technology, AEG contracted with KTI both for software and ongoing consultancy support. This is being used to aid the development of general application frameworks. The in-house KBE team is hence able to focus on coding the detail domain knowledge, which both fosters closer links with the prospective end users and enables more confidence to be placed in the end results produced by the applications. The TWB KBE application was developed using such external support and provides AEG with many benefits:

- It enables a higher volume of work to be completed to a consistently high standard by the current engineering team, thus removing the need to recruit additional staff with the necessary expertise in a near reach technology.
- It enables customer requirements to be dealt with more quickly (a three-fold productivity increase is expected).
- It provides positive publicity, demonstrating to potential customers that AEG is using the latest technology to support their product development.

In the future, AEG is hoping to link the TWB application with other KBE tools, now being developed, to provide wider ranging benefits to both the business and its customers.

This case study demonstrates several points, including the use of KBE in the supply chain to provide a customer service, the use of external developers, and the ongoing review that is required to identify new KBE opportunities.

Tailor Welded Blanks are gaining ground in the Automotive industry as vehicle manufactur ers strive to improve str uctural performance and r educe vehicle mass. British Steel is using KBE to support its customers' product development, providing a faster response service at less cost to itself. (Image courtesy of ULSAB)



Impact upon the product development process

KBE must be integrated into the product development process. In traditional engineering design, the product geometry is gradually refined in a series of steps. With KBE, it is the generative model, not the geometry, which is developed. In fact, the geometry does not exist unless the functional requirements are fed into the generative model. The impact that this will have on the other areas of product development must be anticipated. Those involved in analysis activities, particularly if not involved with the KBE implementation, need to understand the status of the data that they received. KBE generated data will be more up to date and, often, more detailed than that previously received. The ability of other CAE systems to cope with KBE data, which is generated very quickly, in large quantities also needs to be verified.

SUMMARY

A successful implementation of KBE will require ongoing, high-level support. Early on, it is necessary to decide if a relatively high risk, but potentially highly profitable, online deployment can be supported, or whether a lower risk approach, but with a longer payback period, is appropriate. Much of this decision will depend upon how a KBE resource is to be acquired, there being several options. The selection of the pilot application is also very important, as the results achieved with this will largely affect the ongoing viability of the implementation. The success of the pilot will also depend upon factors that are external to its immediate development, it being important to build internal support for the technology and consider its impact upon other product development activities.

Development of KBE Applications

The end users of KBE applications are typically company employees, usually engineers, who will use the software according to a defined process. It is therefore not always necessary to use commercial software development methods, which must account for how an application will perform in the variety of situations that arise in general use. In fact, many KBE applications are likely to evolve over time, as new functions are added to meet new user requirements. Too rigid a development process may stem such improvement. However there will also be some applications, such as stressing tools, that are performance critical. Their development needs to follow a defined procedure in order to ensure confidence in the results that they produce. This variety of situations in which KBE may be applied means that there is no one ‘correct’ method of application development. The choice of approach depends upon the individual requirement. This section outlines the basic process.

The Structured Development Process

The core members of the development team are the domain expert and the KBE development engineer. The domain expert is the person within the company who through their training and experience has a detailed understanding of how the task, which the KBE system must complete, is undertaken. The role of the development engineer, by working with the domain expert, is to elicit the necessary knowledge, structure it into engineering rules and then code the KBE application. Other tasks, which depending upon the size of the implementation, may or may not be done by the development engineer, include integration with existing CAD/ CAE tools and programme management. The basic steps that may be followed by the team are described below.

Problem Definition
The first step is to agree the design task to which KBE is to be applied. The required interfaces with other systems must be identified. This will involve agreeing the basic concept and assumptions with potential users of the application and those who will provide/receive information to/from it. An outline implementation plan will also be agreed.

BEST PRACTICE TIP

Be very rigorous in defining the boundary of the application, in line with KBE's capabilities and actual user requirements. Mistakes here are the major cause of failure in application development.

Analysis and Design
The analysis and design of the application is concerned with turning the 'what' into 'how'. It involves analysing the process to be completed by the application in detail, leading to the design of its architecture. This phase is completed by the KBE development engineer, working closely with the domain expert, and various knowledge elicitation techniques* may be employed. The structure of some KBE systems is such that the application architecture can be made to reflect the screens that are seen by the user. Therefore, users of such systems will sometimes base the application analysis and design around the user interface. This involves creating a paper-based application, including the screens and the user manual, and subjecting it to scenarios of how the tool may be used. An alternative approach is to use an object oriented analysis and design method, such as is discussed in a subsequent section.

* J.C. Miles & C.J. Moore, Practical Knowledge Based Systems for Conceptual Design, Springer-Verlag, 1994.

Realisation
Once the design is complete, work can begin on coding the application. The key point here is to hold regular review meetings to ensure that the development is following the desired direction. Further requirements may arise at these meetings, as the full functionality of the application becomes apparent. These should be assessed for feasibility, resulting in iteration between the analysis and design, and realisation phases.

Deployment
The completed application is rolled-out, ensuring that the necessary user documentation is complete and that any required training has been done.

Refinement
Once the application is in use, mechanisms must be defined for the handling of further enhancements and bugs.

CASE STUDY 5 - Jaguar Cars

In 1988 Jaguar Cars became the first European customer for KTI's ICAD system. The company has now developed a range of KBE applications to aid the design of such varied parts as, inner body panel structures, suspension systems, brakes and windscreen wipers. Jaguar's use of KBE has focused on two areas: generation of new designs; and automatic verification of design conformance to legislative requirements. One KBE tool, which addresses both of these using supplier data, is the Headlamp Designer application.

Headlamps are an integral part of the styling of modern cars, but are produced by dedicated lighting manufacturers. Jaguar found that this caused a bottleneck in the, time critical, styling phase of vehicle development. Every time the styling was revised there could be a delay of up to four weeks whilst the selected supplier assessed the feasibility of producing a headlamp to fit in the required space.

The KBE Headlamp Designer solves this problem. Using the tool, first the external surface of the lamp, including its peripheral curve, are imported from Jaguar's CAD system. The engineer then selects the intended headlamp supplier, the market where the car will be sold, and the required functions (e.g. high beam, fog lamp, etc.). The system then interrogates the glass surface for its properties and queries the supplier rulebase for feasible solutions. These are then presented to the engineer, grouped by technology type and comparative performance. The specific location of each function can then be selected, from the presented options, subject to the known packaging requirements.

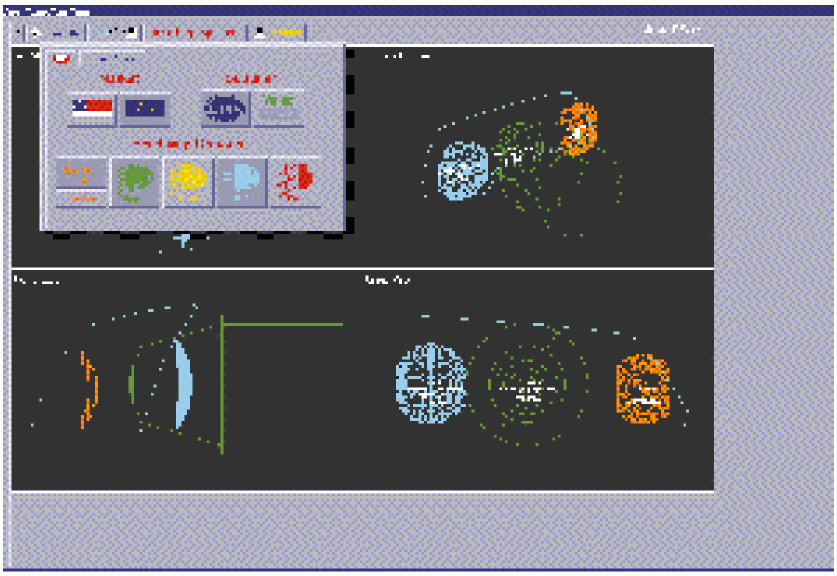
When using the Headlamp Designer it is clear that much effort has been put into developing the user interface. Like most engineering problems, headlamp feasibility requires a large number of inputs. A series of specially developed, screen displays containing appropriate illustrations ensure that engineers find the tool quick and easy to use.

In creating the Headlamp Designer, Jaguar had to work closely with their suppliers to develop algorithms that relate headlamp styling and performance to capabilities of their suppliers. In doing so, the company also had to address suppliers' concerns about their capabilities becoming accessible to competitors. However, by overcoming these issues Jaguar has been able to develop a KBE application that provides the company with considerable benefits.

- Feasibility evaluation has been transformed from a potential four week delay into an interactive activity that can be completed by a Jaguar engineer within minutes.
- Styling changes can be introduced without concern for the delays that would previously have occurred due to feasibility assessment.
- The feasibility of producing headlights of the required style to meet the various legislative requirements of different markets can be rapidly assessed.

This case study illustrates several interesting points, such as the potential for using supplier data and legislative requirements in KBE tools, the importance of constructing the application and its interface to suit the particular task, and the benefits that KBE can provide to styling activities.

KTI's ICAD - KBE system has helped Jaguar to reduce its product development times whilst advancing the distinctive styling and class leading performance of its cars.



KBE project management - visual modelling

One tool that can assist in the implementation of a KBE development project is visual modelling. It helps in establishing a common vision, enabling those involved in a project to communicate how an application can achieve its specification, at a level above the code itself. It is also useful after the application has been deployed, when people not involved in its original development need to understand its operation in order to create enhancements. At the heart of a visual modelling method is its notation, which defines a number of different types of diagrams that support the analysis and design process. A number of different notations were developed in the late 1980's to early 1990's but these have now been condensed into a recognised standard in the Unified Modelling Language (UML)†#.

† R. Pooley & P. Stevens, Using UML: software engineering with objects and components, Addison-Wesley, 1998.

T. Quatrani, Visual Modelling with Rational Rose and UML, Addison-Wesley, 1998.

UML consists of a number of linked diagrams, which support different phases of the analysis and design process. Use case diagrams illustrate the people and systems that will interact with an application together with their high level requirements. Sequence and collaboration diagrams are then used to represent the interaction between objects that takes place during scenarios that are derived from the use cases. Class diagrams represent the architecture of the application and are created based upon the objects and operations defined in the sequence and collaboration diagrams. State diagrams may then be used to analyse individual classes in more detail. It should be noted that, by itself, UML is just a notation and not a process. However, by using it within a defined process, it can promote the iterative and incremental development of an application in line with its user requirements.

SUMMARY
The identification of the appropriate approach to application development depends upon the particular application requirement. However, a structured method of development in which user requirements are carefully identified and used to drive the construction of the application architecture will help to ensure success. Visual modelling is a useful tool to support this activity.

The long term outlook for KBE

Following current trends, there will come a time in many industries when the use of KBE will be necessary, simply in order to compete.

KBE is not suitable for all design tasks but this does not mean that it is not applicable to a wide variety of products. For example, if a product's design is heavily influenced by its style, then traditional methods may be more appropriate for completing the exterior styling. However, it is still likely to be advantageous to use KBE to automate the design of the production tooling and to support the design of the engineered 'interior' of the product. This booklet alone has discussed example applications in the aerospace, automotive and construction industries in order to gain competitive advantage. A Coventry University survey of the scope of current KBE application found it being used for such tasks as one-of-a-kind design, product configuration, customer-driven design, generative tooling, and generative process planning in the aerospace, automotive, consumer and industrial equipment industries[‡].

‡ S. Kneebone & K. Oldham, 'The Integration of Supply Chain Engineering Using Knowledge Based Engineering', Proceedings of the Time Compression Technologies Conference, pp 42-49, Gaydon, UK, 29-30 September 1997.

Knowledge ownership in the supply chain

There is an increasing trend in many industries for prime contractors to subcontract the design and manufacture of parts and subsystems. As KBE use in the supply chain increases, one question that arises is, "who should own the knowledge in KBE tools?" The British Steel case study (page 11) illustrates the competitive advantage that suppliers can gain from developing their own KBE applications. In contrast, the Jaguar case study (page 14) illustrates how the downward pressure on product development time can make it advantageous for prime contractors to develop their own KBE applications using supplier knowledge.

In the future, non-KBE suppliers may not be used if their manual procedures constrain their customers' KBE processes.

In order to secure a competitive edge, it is important for suppliers to retain the ownership of their product development knowledge. Hence, the preferred approach is for suppliers to take responsibility for KBE application development that supports their own product design. This can be achieved by an independent KBE implementation. However, given the scale of investment required and the advantage that the prime contractor customer would gain from the end application, a joint implementation may be more appropriate, provided that agreement can be reached in advance on intellectual property rights and how the benefits will be shared.

Knowledge management in the Knowledge-Based Organisation

In progressing towards becoming Knowledge-Based Organisations, current KBE users are now investigating how the engineering rules encoded in their applications can be effectively managed to ease future use and maintenance. Software to support this is now being developed. In the meantime, these companies are making use of the KBE tools that already exist to develop their new product ranges cheaper, better and faster than those competitors that are still using traditional, CAD based approaches to product development.

Sources of help and advice

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