Pedestrian Hood Generation & Optimization Using Knowledge-Based Engineering

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Abstract

Knowledge-based Engineering (KBE) has been used in industry in for some time. Companies such as Jaguar initially used KBE to automate well-understood, but repetitive, man-intensive engineering issues at the early phases of a programme. These were / are mainly based around geometrical problems (e.g. ergonomic design). Airbus (UK) in particular over the last few years has taken this to a new level by using ICAD as a method of not only generating geometry, but interacting with other existing programmes and creating a method of 'glueware' that takes initial input data, and runs through a design and analysis sequence that would normally take human processing much longer to achieve.

The next logical step is to control the overall process using a piece of optimization software

Introduction

Knowledge Based Engineering has been used with great effect in both Automotive and Aerospace to automate design tasks, greatly reducing design lead times whilst at the same time improving design quality. An excellent example of the benefits to be gained by the use of this technology was reported by Airbus UK Ltd [1] in a press release in January 2000:

"The use of KBE is revolutionising the design of Airbus wing components at British Aerospace Airbus. It vastly reduced the time taken to complete some of the lengthy repetitive design and development processes on the A340-500/600 wings.(…)For example, design of a set of wing ribs for this aircraft took two people just six weeks, previously such a task would have taken twenty people six months."

Jaguar is an established user of KBE technology[2], with a number of specific applications providing support to its vehicle design and packaging teams. One of the most successful applications has been the hood designer, taking in a style surface and, by applying the basic structural and manufacturing rules, delivers a fully surfaced hood inner panel design together with the necessary attachment flanges for the style surfaces. By providing the capability to suppress features such as small fillet, the resulting hood assembly can be passed to the CAE teams to assess structural and durability performance prior to passing to the design teams for final detailing.

The introduction of Pedestrian Safety legislation (e.g. EC Agreement Phase 1 in Oct 2005)[3] places significant demands on the design and engineering of hood structures, needing to balance the needs of pedestrian safety with structural and durability requirements. Various methods have been studied as to how an impactor can be decelerated in the shortest amount of space without exceeding the HIC values given as criteria for the test procedures[4,5,6]. The Mazda RX-8 hood and the new Jaguar XK hood (Figure 1) are examples of creating a homogeneous hood – i.e. a regularized structure that will exhibit a uniform energy response no matter where impacted.

Figure 1 a) – Mazda RX-8 Pedestrian Hood

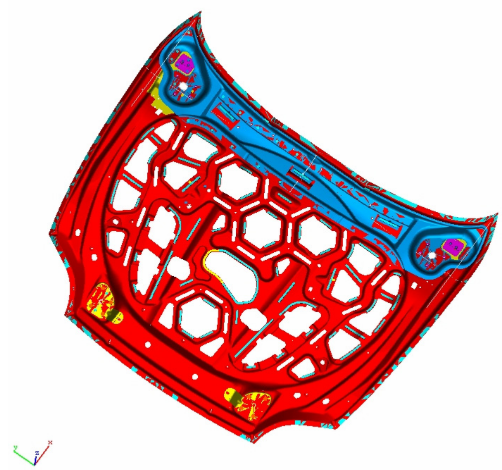

Figure 1 b) – The new Jaguar XK 'Hexageneous' Hood

A significant issue, however, is in determining the geometry parameters for the inner structure. Changing parameters, such as the size of the repeating pattern or the depth of the structure will clearly require the whole structure to be redesigned prior to any analysis being performed.

The prospect of optimizing a structure (which needs to be redesigned at each iteration) led Jaguar to consider coupling a KBE design module to an automated analysis back end with the whole of the process driven by an optimizer. Jaguar contracted Corus Automotive, due to their expertise in the delivery of innovative KBE solutions and located a few miles from their Engineering Centre in Coventry, to develop the KBE application and assist with integration.

The point to be made about this method is that it is the first time that an automotive company has used ICAD beyond purely geometric generation and may allow any future standards to be taken into account. For instance, should the head impactor standard be changed, this method should ensure a fast method to develop a hood that will provide a passive safety benefit within the already existing constraints.

Solution Concept

The base concept was to develop a fully automated geometric optimizer delivering a hood structure conforming to pedestrian safety requirements, subject to manufacturing constraints, and respecting design best practice. This concept is shown schematically in Figure 2.

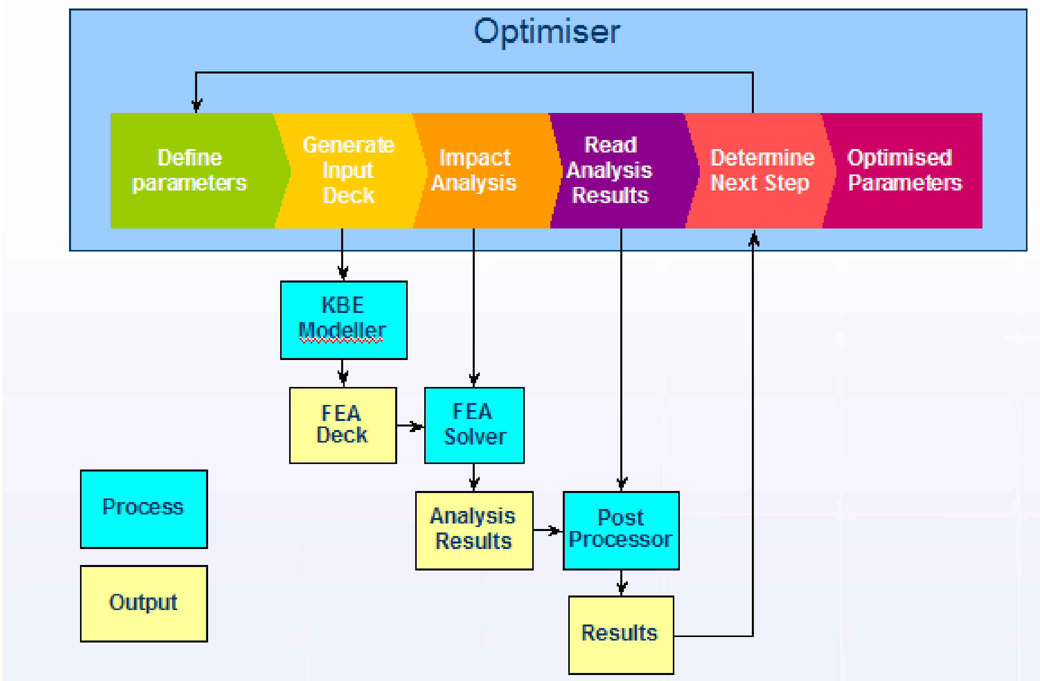

Figure 2 – Overview of Pedestrian hood process

A number of fundamental decisions were taken at an early stage relating to the tools and techniques to be used for the different stages in the process, although the overall architecture was designed such that each tool could be replaced with another one with minimum development effort.

When considering the optimization technique, a non-linear optimizer was felt to give the best chance of success since the design envelope for hood performance was expected to be highly non-linear. In particular, it was felt that there was a significant risk of bi-Modal behaviour and that outliers may be possible with potential for best solution to be next to worst.

It was also recognized that an optimum solution was not necessarily required, but simply a solution, or a number of alternative solutions, which conformed to pedestrian safety requirements. It was also felt that tools which would provide a greater insight into the dynamic response of the system would be invaluable in gaining a greater understanding of the options available and recognized that there could potentially be a large number of input variables. With these objectives in mind, the stochastic design improvement methodology was considered to be most appropriate. SDI is a variant of the general optimisation process that establishes relationships between input variables and output results leading to a clearer understanding of the problem. Using Monte-Carlo algorithms, SDI is largely insensitive to the number of design variables and the random nature of variable selection handles non-linear behaviour.

Simple mathematics, however, demonstrated the magnitude of the problem to be solved. SDI needs, as a minimum 4 runs of 16 shots to converge to a reasonable certainty. To satisfy pedestrian safety requirements, a minimum of 50 separate impacts would be required for each design iteration. The size of the problem was therefore

- 64 unique, fully surfaced, inner panel designs
- 64 fully meshed unique models
- 50 impactor models at desired position and orientation
- 64x50=3200 non-linear analyses plus 3200 master control include files

Clearly without full automation the use of SDI does not present a feasible engineering solution.

Using Knowledge Based Engineering to generate the hood inner structure geometry only represents a small element of the full automation required. The KBE application, based on the ICAD system, was therefore extended to deliver a full 'ready-to-run' LS-DYNA keyword deck, including all outer panel clinch flanges, inner structure, hinge and latch reinforcements and gutters.

The KBE application (shown in figure 3) contains a number of unique features.

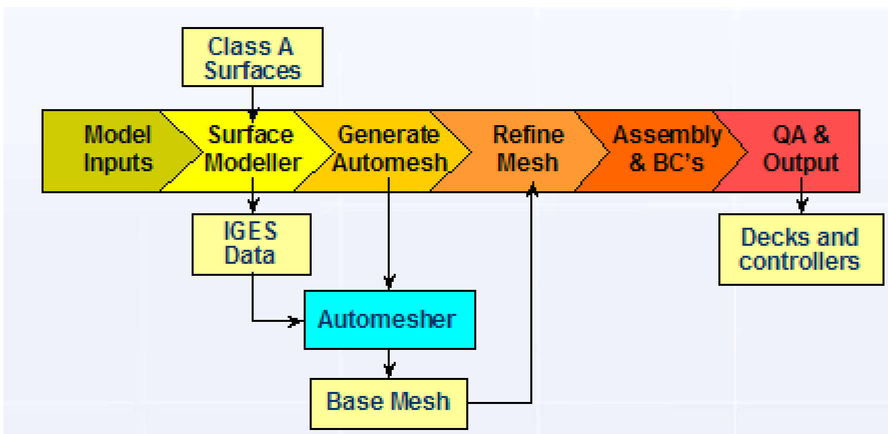

Figure 3 KBE Application schematic

The inner structure geometry, based off the class A surface, is generated completely automatically. Whilst speed was considered to be important, the need for a successful completion was paramount. To achieve this, speed was sacrificed for to use of more rigorous surfacing techniques, capable of coping with some of the extreme geometry conditions seen during testing. Following generation of the inner structure, hinge and latch reinforcers, gutters and clinch flanges are also generated and exported as separate models for automeshing. The KBE application invokes an external automesher and on completion of this process reads back in the individual meshes.

These meshes are then refined (for example 2 elements deep along all flanges) and assembled into a single model, applying connections to the Jaguar modeling standards. Finally QA is run on the mesh and corrections made to elements of poor quality.

Table 1 shows a comparison of the results from automeshing alone, KBE generated mesh and a professionally prepared manual mesh. It can be seen that the KBE approach offers a number of enhancements over normal automeshing and can approach the quality of a manually prepared mesh. Bear in mind, however, that the KBE mesh takes just 12 minutes to prepare, compared to typically several days required for the same manual processs.

Criteria	Automeshing	KBE	Manual Deck *
No. of elements	35460	35737	-
Minimum Angle	97 non-conform	28 non-conform	7 non-conform
Maximum Angle	303 non-conform	18 non-conform	6 non-conform
Warp	160 non-conform	140 non-conform	174 non-conform
Skew	2 non-conform	2 non-conform	1 non-conform

Table 1 Comparison of mesh quality from automeshing and manual deck preparation with deck prepared automatically using KBE
* Values normalised to KBE Mesh size

As part of the initial preparation, an input deck is created from a library which includes material details, standard head impactors, a rigid engine under-hood reaction surface etc.

The head impactor is called from this library and its location and orientation modified to enable it to be used at a specific location, and the impact is run with the generated LS-DYNA hood encompassing the other library details (e.g. materials etc).

Finally all controls, material properties and master include files are output, and the simulation is run. The post-processing of results is controlled by ST-ORM, and are mainly based on the HIC (head impact criterion) calculated from the acceleration output of the head impactor. These results are used in the optimisation process, and fed into the SDI method. This continues until a solution converges for an acceptable hood, or if no solution is possible, the process stops after a number of cycles.

Implementation

The details of creating a batch method, within the constraints of a large OEM's CAE suite was a challenge, however after some dedicated work, it was possible to show the KBE/ST-ORM routine running as an entire continuous process. The CAE hardware at Jaguar forms part of a dedicated grid of computing power on different platforms, and in addition ST-ORM also had to interact with a JLR queueing and submission architecture. As substantial amounts of data were being transferred around the JLR network, data routing was crucial to the success of this project and had to be optimized. As with all 'bespoke' architectures, this set-up had to be maintained within the changing demands of the mainstream CAE community.

Outputs

Using Stochastic Design Improvement, there is potential for a number of design solutions to be delivered which conform to the goals. Given that all of these solutions meet the requirements, it is necessary to determine which is the ‘best’ solution. At the outset it was decided that this would be based on other performance requirements (such as stiffness, normal modes etc) and mass. By evaluating each option against these criteria and applying engineering judgment a ‘best fit’ solution (one which meets legislative performance and best satisfies product requirements) can be delivered.

To carry out this assessment, the KBE application is re-run, but this time in standalone, rather than optimizer, mode to generate the decks suitable for the performance analysis.
This is an important feature of the whole process; automation has been used to significantly reduce lead times and indeed make a process feasible to use, but the end results require skilled interpretation and engineering judgment applied to locate that design which best fulfills all requirements.

Benefits

The adoption of KBE techniques is the key element in being able to use SDI to determine a design solution that meets challenging requirements. Tables 3 and 4 show process and model dimensions and total estimated runtime for a SDI scheme based on 4 runs and 16 shots

Number of configurable inputs	280
Number of potentially variable geometric inputs	21
Geometric model size (IGES)	25-35Mb
Analysis model size	~40000 elements
Outer panel, flanges & BIW surface generation run-time	3 minutes
Outer panel mesh & Impactor translation run-time	4 minutes
Inner structure surface generation run-time	7 minutes
Inner structure deck generation run-time	13 minutes

Table 2. Process and Model dimensions

Model	Time (mins)	Runs	Total time (mins)
Outer deck generation	7	1	7
Inner deck generation	20	64	1280
Total for optimization			1287

Table 3. Solution time based on and SDI scheme of 4 shots x 16 runs

As can be seen, a total time of just under 22 hours for all model preparation required for an SDI project can be delivered using automation, compared to 3-4 days for geometry generation and 4-5 days for deck preparation (3360-4320 minutes) for one manual iteration. In summary, 64 iterations can be carried out in less than 40% the time for a single manual iteration. Obviously this does not take into account the solver time, which for an SDI run of this magnitude will be extensive.

Summary

This paper has shown how a complex (yet contained) repeatable CAE task can be broken down and addressed using a high-level language KBE routine, coupled to existing off-the-shelf analysis software. The same approach could be used for other applications, and further research is on-going.
Care must be taken at all times to ensure that any automation empowers the user. By this we mean that a repetitive task can be undertaken by a KBE routine, allowing the analyst more time

to examine the wider problem than spend time carrying out on laborious tasks. Additionally it is important to maintain the balance of providing the analyst with enough information on how a solution is developing, but not over-burden him/her with redundant data.

Knowledge Based Engineering has already been shown to be the key enabler in achieving large-scale geometric optimization, however when analysis is included in the routine, a significant reduction in time, plus a consistent and repeatable improvement in quality can be derived.

This paper has shown how a number of other standard tools have been used within their basic functionality, and combined into something that is much more powerful than the sum of its parts. It is hoped that this approach can be further developed by the analysis vendors and in future a 'modular' approach to analysis and pre-processing tools may be developed to allow easy implementation.

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