THE PRIMARY STRUCTURE OF COMMERCIAL TRANSPORT AIRCRAFT WINGS: RAPID GENERATION OF FINITE ELEMENT MODELS USING KNOWLEDGE-BASED METHODS

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ABSTRACT

Early decisions in the development of a new aircraft programme depend critically on the availability of high fidelity structural analysis to validate design principles and quantify the effect of design changes on structural performance.

This paper details British Aerospace's (BAe) progress in the development of a tool to produce MSC/NASTRAN data decks of commercial transport aircraft wings, in hours, rather than months. The tool is integrated into British Aerospace Airbus' Generic Transport Aircraft (GTA) knowledge-based design tool, created using the ICAD Design Language.

The GTA knowledge-based design tool enables a project team to design, analyse and optimise the primary structure of civil aircraft wings before creation and submission of MSC/NASTRAN decks. The tool rapidly produces consistent, high quality designs enabling several concepts to be considered during preliminary design[1]. It integrates surface geometry, structural layouts, 3D solid modelling, structural analysis, optimisation, manufacturability, weight and cost prediction to enable multi-disciplinary optimisation to be exploited. Recent developments have enabled the production of loads loop finite element (FE) models for a number of projects in a fraction of the time previously required.

The use of feature based modelling is also discussed, showing examples of where FE models of irregular assemblies, such as aircraft cockpit structure, can be rapidly generated. An example is shown using feature based methods to model the undercarriage attachment structure of a large civil transport aircraft.

The paper concludes that, using knowledge-based systems, it is now feasible to consider finite element modelling of wing primary structure to a level of detail previously considered impracticable during preliminary design. It also suggests that it is practical to use the same tools to establish mass/stiffness distributions throughout pre-production phases of the aircraft design cycle.

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BACKGROUND

The ever increasing demands on commercial aircraft performance (mission, payload, aircraft life, etc) have combined to increase the complexity of our design tasks to such an extent that, despite our modern technologies, it takes typically five to ten years to design a new aircraft from its inception. This protracted timescale and its associated cost conflicts with our desire to get the right product at the right price into the market place quickly to satisfy our customers.

As traditional design and stressing methods are labour intensive, several non-optimum design decisions may be 'locked' into a project simply because it would take too long to repeat the analysis. Tools that can radically reduce, or even eliminate, the labour intensive aspects of our design and analysis work would speed up the design process and enable several options to be considered in detail before making an informed decision as to the optimum design.

British Aerospace Airbus' progress in the development of such tools, in particular in the area of finite element modelling, is the subject of this paper.

INTRODUCTION

Commercial aircraft wings have structural items which are, essentially, repeated throughout the wing box. A rib, for example, is designed to the same design philosophy and sized using the same stressing methods as any other rib. The rib's individuality comes from its location geometry, the loads applied and the access required (for systems, inspection, etc) - not from the processes used in the rib's design.

These repetitive structures have been the focus for the introduction of knowledge-based systems (KBS) into the aircraft industry over the past ten years due to their high return on development time employed. It is now becoming evident that savings can also be made on applying design and stressing KBS methods to non repetitive structural items such as undercarriage attachment structure, fuselage nose structure, etc.

British Aerospace is creating a knowledge-based design and analysis tool called the Generic Transport Aircraft or GTA that can help design and analyse both generically repetitive and feature based components.
The crossing of skill boundaries by producing a truly multifunctional, concurrent engineering tool has enabled informed engineers to establish the implications of a design change - in terms of space allocation, cost, weight and, for high lift components, aerodynamic efficiency - in minutes. This speed of response, combined with its consistent level of accuracy enable optimum design decisions to be made at an early stage in the design process using levels of detailed information not usually available until much later in the project.

THE GENERIC TRANSPORT AIRCRAFT

The GTA has within it the combined knowledge of design, stress, aerodynamics, weight, cost, systems, and manufacturing engineers. The gathering of these methods and understanding the cross function interdependencies was, and continues to be, a major part of producing such a generic multi-disciplinary tool.

The GTA is written using the ICAD Design Language (IDL) which combines the functionality of a customised Computer Aided Design tool with the flexibility of a non procedural, object oriented, programming language. The ability of ICAD to link to and control the running of external programs makes it an ideal tool for all stages of design analysis.

Since being adopted by British Aerospace Airbus, development of the GTA has concentrated primarily on wing design but also has within it functionality such as cabin layout, fuselage nose surface design combined with flightdeck systems configuration, undercarriage design, whole aircraft configuration and surface design.

The development of this capability has required the development and integration of several design and analysis tools. One such tool, the finite element model generator, has been developed in a similar manner to a number of others in that it was developed to cater only for repetitive structures (80% of a wing finite element model) but has recently been enhanced with the use of feature based methods to cater for the less generic structural areas.

FINITE ELEMENT MODEL GENERATOR

1 The overall process

The creation of finite element (FE) models is dependant on

- surface and component datum geometry
- component sizing and idealisation
- material properties
- load cases.

At the concept stage of an aircraft project the majority, if not all, of these dependencies are unavailable to the structural engineer. Traditionally it has not been worth his while creating a finite element model at this stage of a project because before he can complete it the structural datums, section properties or the loads will have changed. However, without a representative FE model the load paths within the structure may not be well represented and thus component sizing is a difficult exercise. Without component sizes the mass and stiffness distributions that are required to produce realistic load cases are not available. Thus 'first' loads loops have been produced on the basis of past experience and engineering judgement of what the structural sizes of components will be like. Unfortunately the creation of load loops is a lengthy process and a great majority of design and structural sizing work might have been be performed before the revised loads loop results are available to further optimise the design.

The inherent time delays in the traditional design process can now be prevented at BAe Airbus by use of the GTA to perform the initial couple of design loops automatically. This greatly increases confidence in initial weight and performance targets and significantly reduces the amount of re-work later in the project.

The process works as follows:

- The initial loads are produced based on historic parameters of wing mass and stiffness distribution.

- The structural datums are laid out - either using internal positioning rules or reading in datums produced using a CAD package

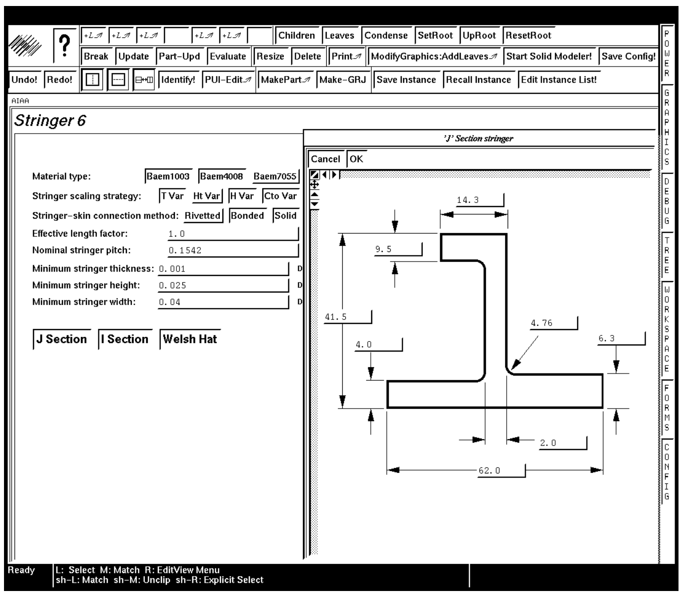


Figure 1. Specification of generic section shapes prior to idealisation.

- The preliminary loads are distributed to components using classical shear flow, bending and torque methods.

- Component sections shapes are chosen - eg I section or J section stringers (fig. 1).

- Initial sizing routines create properties which should not violate any of the stress or thickness optimisation constraints, the structure is idealised and a MSC/NASTRAN FE model is created (as explained in more detail below).

- The model is optimised - with weight as the objective function but including aeroelastic constraints to prevent flutter.

- The optimised properties are then de-idealised and read back into the GTA.

- A weight accounting module determines the mass and stiffness distributions along the wing and feeds them back into the loads module - where the loads are revised.

- The revised loads are fed into the optimised FE model and the process repeats once or twice until there is no significant change to the weight and

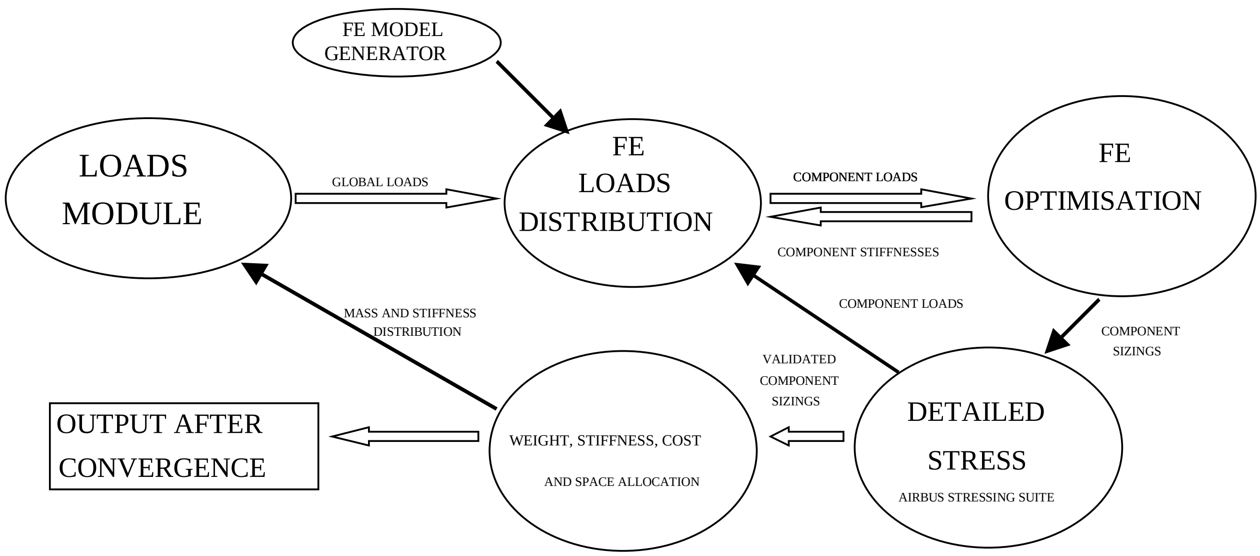


Figure 2. Sizing and optimisation process

stiffness distributions (fig. 2).

2 Benefits to an Integrated Approach

The main benefits from this integrated approach to finite element modelling are speed and consistency. These result from the following:

- Automated sizing routines.

- Automated idealisation routine

- Ability to read properties from external data sources; spread sheets, data-bases, previous FE models, etc.

- Material properties associated with component and automatically allocated to property cards. Direct link to in-house materials data-base (being converted to link with MSC/M-VISION this year).

- Direct association between component and finite element mesh - allowing automatic allocation of property cards to elements.

- Standard meshing routines giving consistent element normals.

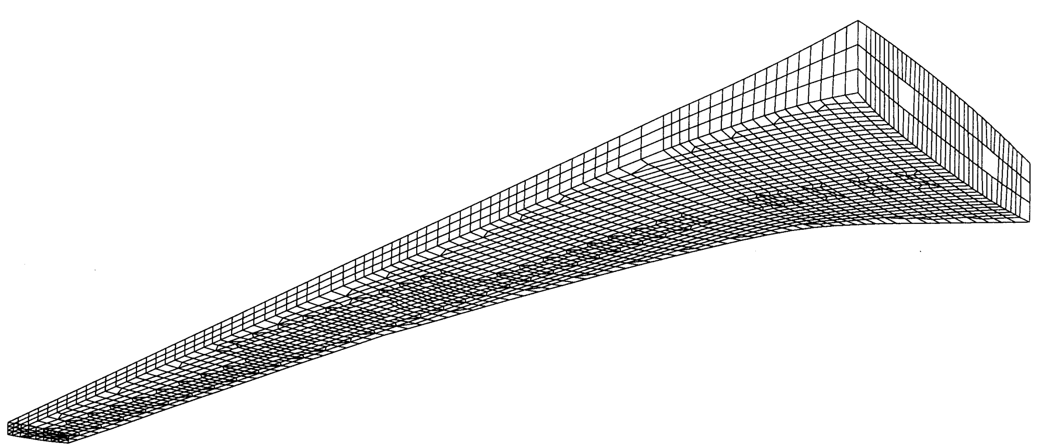


Figure 3. Completed generic finite element mesh

- Interactive control of placement and meshing of features (such as access holes, undercarriage mounting structure, pylon attachments, etc), with an automatic meshing default (fig 3).

- Automatic element and node numbering allowing association with component type, element type and component location (fig 4).

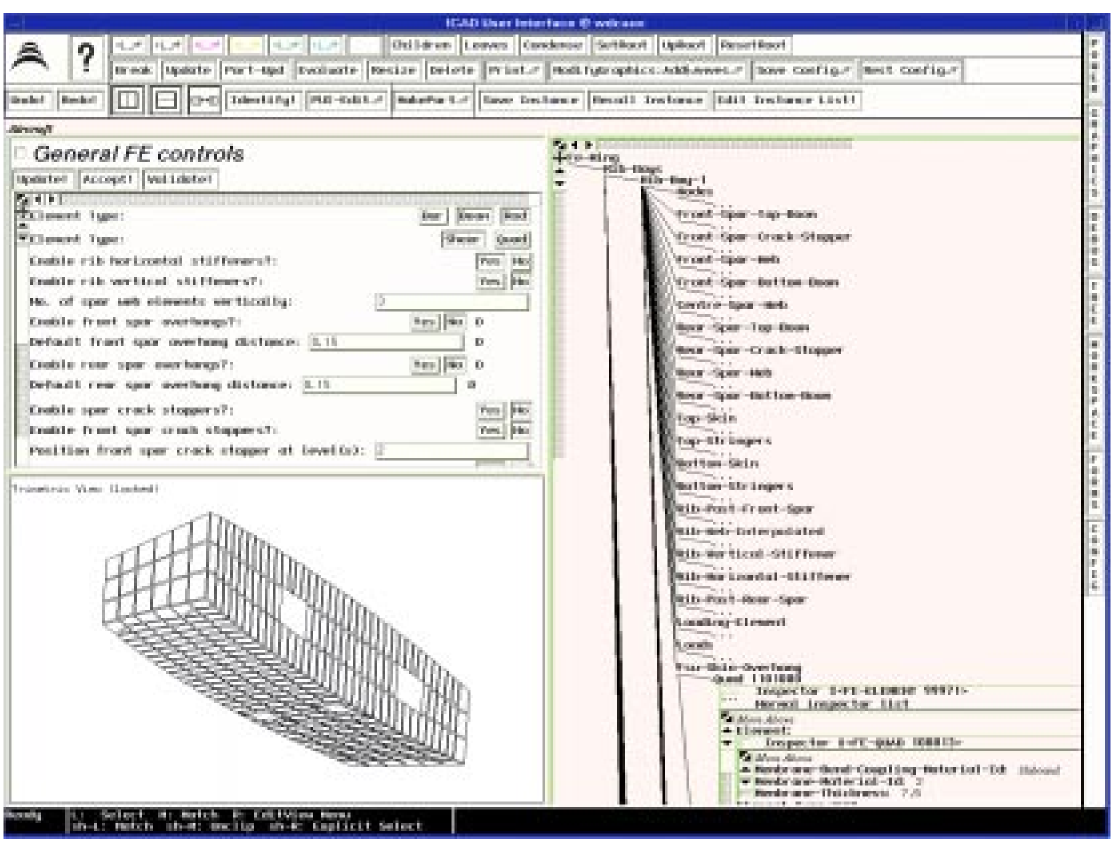


Figure 4. General meshing controls and component associativity.

- Interactive association of design variable regions calling on a database of previously defined regions, variables and constraints.
- In-house stressing programs called during optimisation cycle to ensure non-linear buckling effects are accounted for.

3 Finite Element Modelling Automation

Whilst the structural wing box of a commercial airliner, with its repetitive structural layout is a natural candidate for FE modelling automation using a traditional rule based approach there are several structural assemblies within the wing which are less generic. These items, such as undercarriage support structure, pylon attachments, leading and trailing edge assemblies including attachments for high lift devices, can all benefit from using a feature based modelling approach.

Features - objects with specific characteristics or properties that can be assembled to form components - have been used extensively in the CAD environment for several years. Adding 'knowledge' to these features so that they can position, size and associate themselves with the features they are connected to, greatly enhances their functionality. We can, for example, change the FE meshing on one feature and the meshing on associated features will alter to preserve element connectivity.

Reducing the time to create finite element models of the structural wing box from months to days puts the modelling of these 'features' into the critical path.

4 A Feature Based Approach

The non-repetitive structural examples mentioned above, when decomposed consist of generic components like webs, holes, skins, flanges etc. These are features of the structure which, when assembled, form an assembly of structural components. If we have a library of such features extensive enough, then by assembling particular ones, we can create complex structural assemblies.

There are two issues evolving out of this:

- What features do we create?
- How do we assemble them?

Definition of which features to create is simply an exercise of breaking down the structural assembly and checking for generic forms or patterns, ie. holes, flanges, webs etc.

Features must contain 'knowledge' of how they adapt in any particular environment, which defines an instance of them. They also need to understand how to represent themselves based on the discipline concerned. This means that a feature can offer its solid representation to designers, FE representation to structural engineers, manufacturing representation to manufacturing engineers etc.

The assembly aspects are of particular importance as the interactions between features define how they are formed at their boundaries. From a design point of view, two features need to understand their connecting face in order to join themselves in such a manner to avoid clash. Additionally they need to know how many FE elements they have on their common boundary to ensure continuity of the mesh.

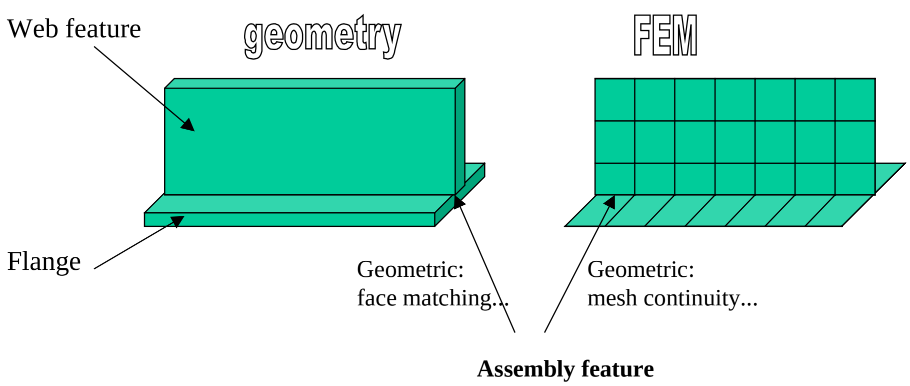


Figure 5. Feature assembly and associations

A feature is almost always an assembly of others. For example, a frame feature is an assembly of web and flange features. These in turn are assemblies of other features like holes etc.

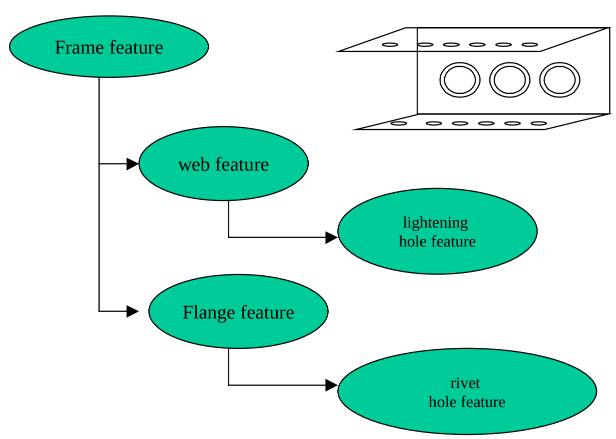


Figure 6. Cascaded feature assembly

The feature definitions mentioned above can be expressed in an object oriented manner, where each feature is an object which can exist on its own, but also join with other objects to form assemblies. The inheritance aspect of an object-oriented approach allows behavioural characteristics from one feature to be passed into another or superseded by manual inputs if required.

5 Test Case - Undercarriage Support Structure

A feature based approach has been adopted to deal with automation of the FE modelling of certain complex non-repetitive structural assemblies such as the undercarriage support structure of a commercial aircraft wing. These tools have been developed using the ICAD Knowledge-Based System, and incorporated in the Generic Transport Aircraft (GTA).

A typical example of a wing undercarriage support structure consists of several components, which on their own may be treated as features. These features can be assembled in such a fashion, to facilitate the creation of a complex assembly (fig 7).

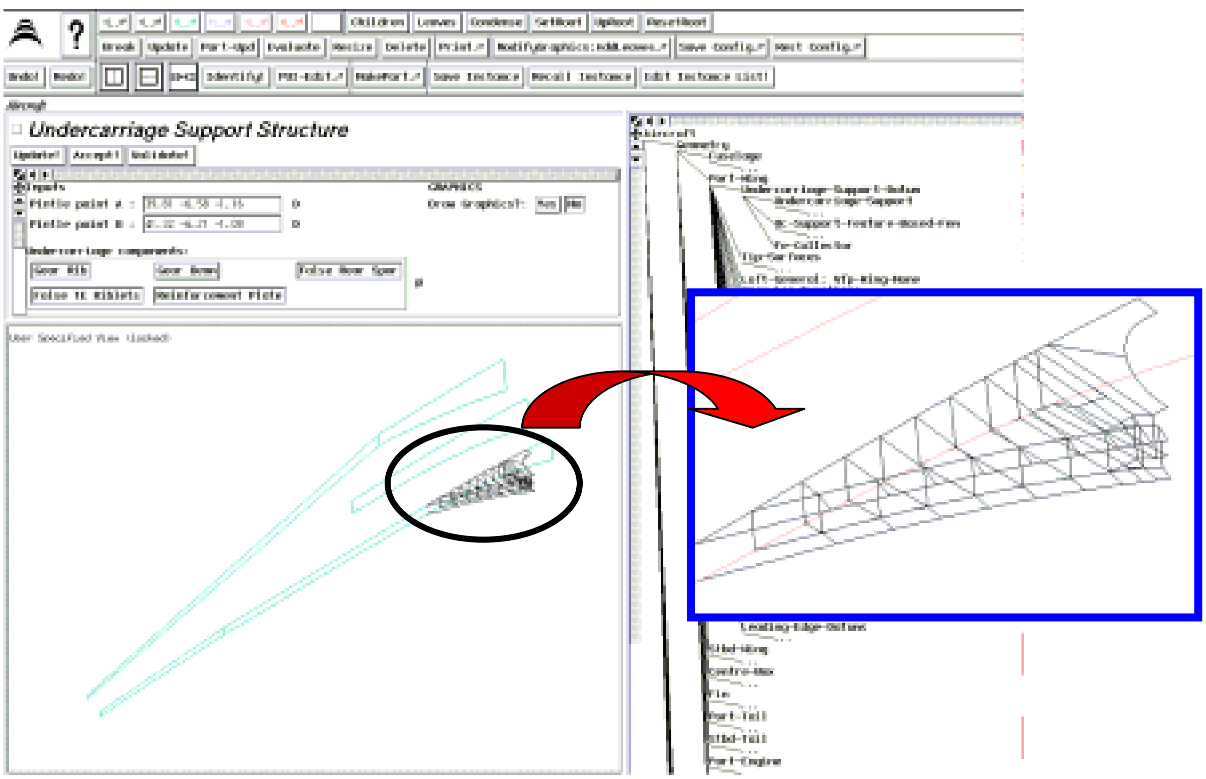


Figure 7. Structural datums in GTA - undercarriage attachment structure

This package is split in three sections: Geometry Definition, Mesh Creation and Property Association

5.1 Geometry Definition

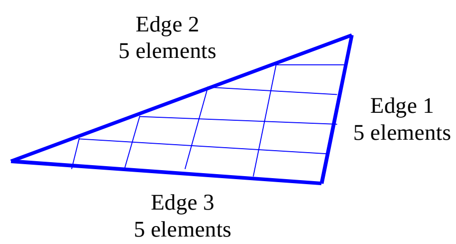
The geometric aspects of the undercarriage support structure have been incorporated in the geometry definition section of the GTA. This enhances the current functionality beyond the wing box, leading edge and trailing edge datum definition to include undercarriage support structure datum definition. A feature-based approach has been used where the engineer has the freedom and flexibility to select the types of features required and place them in an assembly relative to the wing box. As an example a typical assembly may or may not have the following features: gear rib, gear beam, false rear spar, trailing edge riblets and others. This allows definition of many structural assembly concepts for this problem.

5.2 Mesh Creation

Once the geometry of the structural assembly has been defined, the corresponding datums are then passed into the **Feature Based Mesh Generator**. This is integrated into the Mesh Generation package of the GTA.

The Feature Based Mesh Generator breaks down the datums into smaller components such that each sub-component can be expressed in FEM terms as one of the following mesh features:-

- Tri-Edge Mesher



- Tetra-Edge Mesher

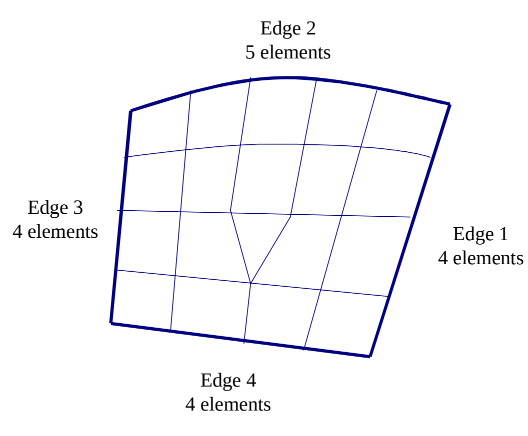


Figure 8. Meshing routines

Each of the above FE features has the ability to create a mesh consisting of QUADS, BARS and BEAMS. The inputs to each of these features is a list of edges (3 for the tri, 4 for the tetra), a list defining the number of elements at each edge, geometric and material properties, and hole data on this feature (centre, radius,…). Each meshing feature can accommodate holes, so for a skin feature with a hole in it, the tetra-edge mesher will mesh the hole and the required stiffening elements to model hole reinforcements (fig 9).

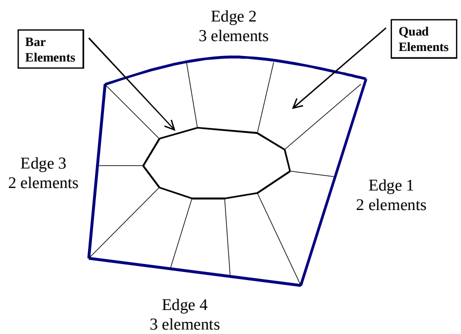


Figure 9. Meshing around holes

When two features are created which are adjacent to each other, they automatically have knowledge of which boundary they have in common so they both receive the corresponding number of elements from that boundary (fig. 10). Each boundary curve is a feature that contains information like number of elements and its name. The user can alter the number of elements along any edge, which automatically updates the meshing elements of the corresponding meshing features.

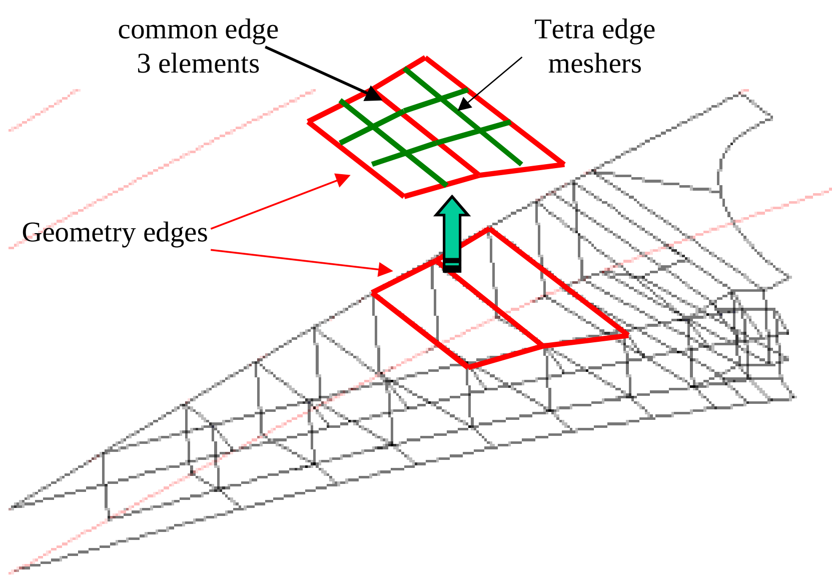


Figure 10. Meshing philosophy of undercarriage attachment structure

Each feature can create its own Bulk data file if necessary, but at the very least all the relevant information is collected in a FE-plist* which contains the element id’s, and the grid points associated with each element in the mesh (fig. 11).

At a high level, the Feature Based FE Generator has a facility called the FE-Collector, which assembles all the mesh feature FE-plists, compares them for duplicate grid points, and writes an overall FE-plist for the whole assembly. This is then used to feed into the Bulk Data File writer which creates the output of this process, a Bulk data file.

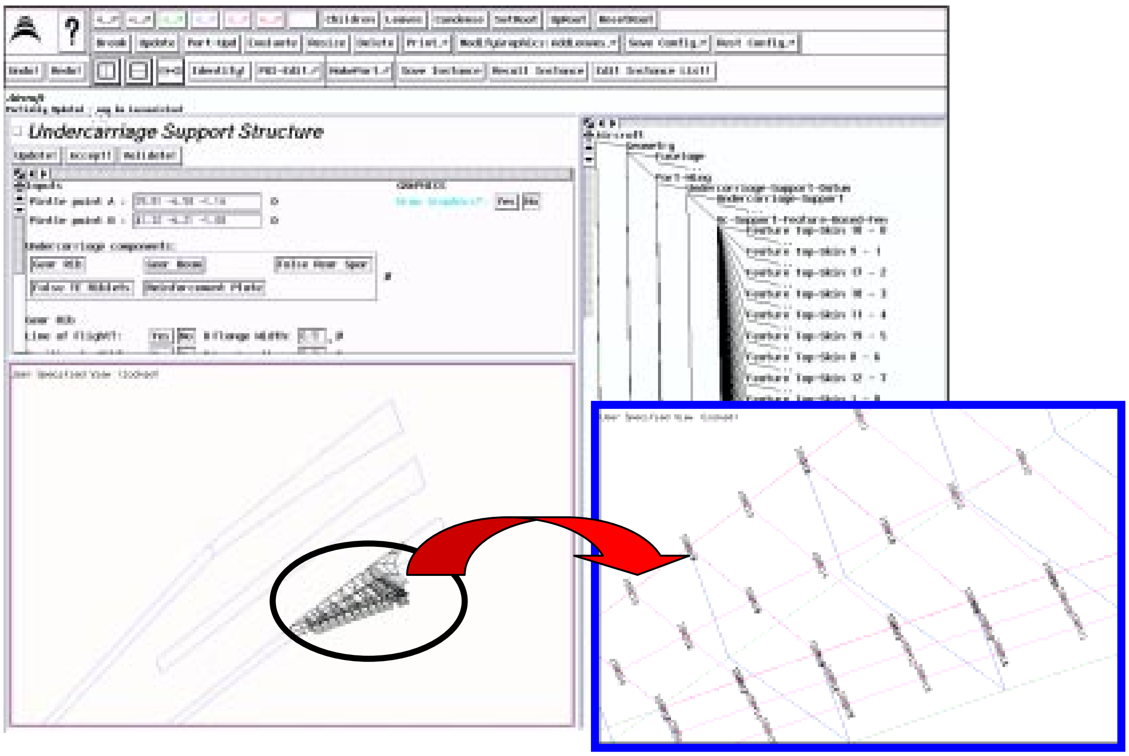


Figure 11. Meshing of undercarriage attachment structure

5.3 Property Association

The feature-based approach uses the same component association as the generic FE module. The mesh is integrally linked with the structural component. The FE element has positional knowledge and can therefore enquire of its associated component what its properties (thickness, area, moments of inertia, neutral axis offset, material, etc.) are for that position on the component. These properties are linked to the element and output along with the rest of the bulk data.

* “plist” is an ICAD Design Language term for a property list. This is a list of keywords and associated values.

CONCLUSION

Using integrated, multidisciplinary, knowledge-based systems, it is now feasible to consider finite element modelling of wing primary structure to a level of detail previously considered impracticable during preliminary design. These generic models can be enhanced using feature-based methods to produce a complete wing structural finite element model. It is practical to use the same tools throughout pre-production phases of the aircraft design cycle and in doing so improve the speed and fidelity of the design process.

ABBREVIATIONS

BAe	British Aerospace PLC
CAD	Computer Aided Design
FE	Finite Element
GTA	Generic Transport Aircraft – a KBS developed by British Aerospace Airbus
IDL	The ICAD Design Language
KBS	Knowledge Based System

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The ICAD System™ based on the ICAD Design Language™ is marketed by Knowledge Technologies International, 21 North Avenue, Burlington, Massachusetts.

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Dave Rondeau, et al. British Aerospace, Commercial Aircraft Ltd, Woodford, Cheshire, England.