

Fast Tracking Rail Vehicle Design

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Abstract

Bombardier Transportation UK offers one of the most comprehensive and diverse rail vehicle portfolios in the world. The strategy is one of continuous development that provides the most effective and cost-efficient rail solutions for today and the future. A key ingredient is the use of Altair HyperWorks enterprise computer aided engineering (CAE) solution. Altair's technology is now present at every stage of the design process and has increased the efficiency of the product development process. The paper details how Altair tools have been used to generate Finite Element (FE) models of carbodies, bogies and secondary structures in reduced time scales. Significant weight and cost savings are achieved through structural optimisation of components such as large steel castings, aluminium extrusions and steel fabricated structures which are subjected to linear static, fatigue and abuse loading. Automated post processing facilitates the interpretation of results and the writing of detailed official reports.

Keywords: Rail, Bombardier, Carbody, Bogie, HyperWorks, FE, CAE

1.0 Introduction

In the recent years Bombardier's Derby site has maintained a close working relationship with Altair UK. A combination of on-site support and in-house project delivery has developed a successful partnership driving the use of the latest CAE technology. At every stage of the design process HyperWorks has provided a platform to produce efficient design solutions within shorter timescales. HyperMesh is used to create complex and detailed FE models of carbodies, bogies and secondary structures in reduced time scales. Railway structures are designed to satisfy a wide range of loading conditions defined in Railway Group Standard [1] and specific project Technical Requirement Document (TRD). Once interpreted into FE load cases, these are solved using the RADIOSS Bulk solver to calculate displacements, forces, stress levels and natural frequencies. HyperView enables the visualisation of the data interactively and is used as a basis to create comprehensive official reports. Cost and time has also been minimised with the use of structural optimisation. It is now often part of the design process, which allows FE analysis to drive the design forward from the concept stage to manufacturing.

Bombardier Transportation UK CAE deals with the Finite Element (FE) analysis of components such as:

- Cabs
- Extrusions
- Bolters
- Structural Partitions
- Secondary Structures (fitted equipment > 10Kg)

The bogie division deals with the analysis of components such as:

- Bogies
- Engines
- Brakes
- Suspensions

In order to model such a varied number of components, many FE modelling techniques are used. 1D, 2D and 3D elements are created trading off required accuracy and number of elements. **Figure 1** show a general carbody configuration.

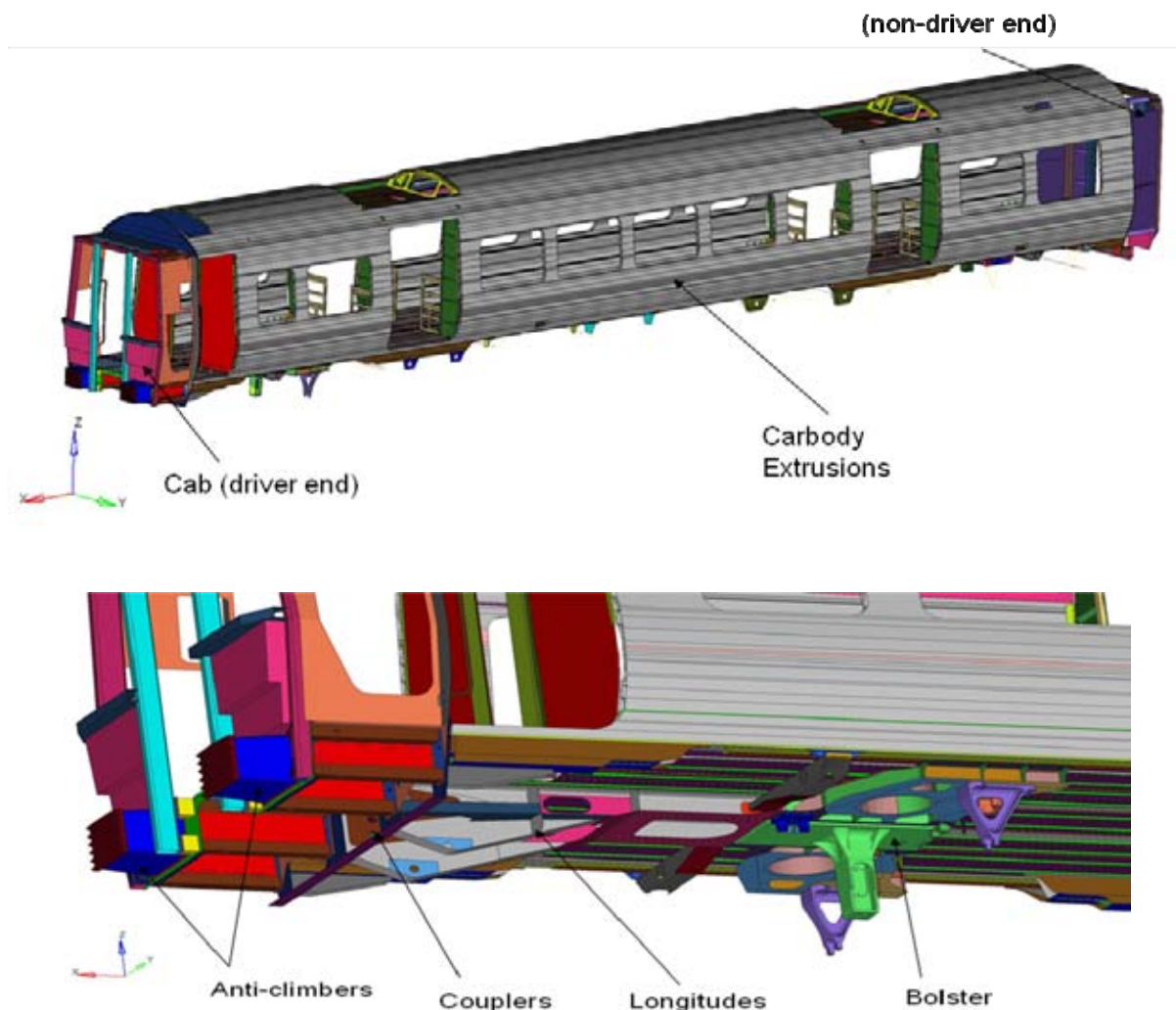


Figure 1: Carbody Configuration

Such carbodies are assembled using bolts, rivets and welding which are assessed during FE validation. Components are created using various manufacturing processes such as

casting, extrusion and welded plates assembly. Various materials are considered, mainly aluminium, steel and Glass-Reinforced Plastic (GRP).

In order to reduce weight, the carbody structure is made with an assembly of aluminium extrusions up to 21m long, with machined apertures for windows and doors. The various extrusions can be welded or bolted to one another. **Figure 2** shows a typical carbody extrusion assembly.

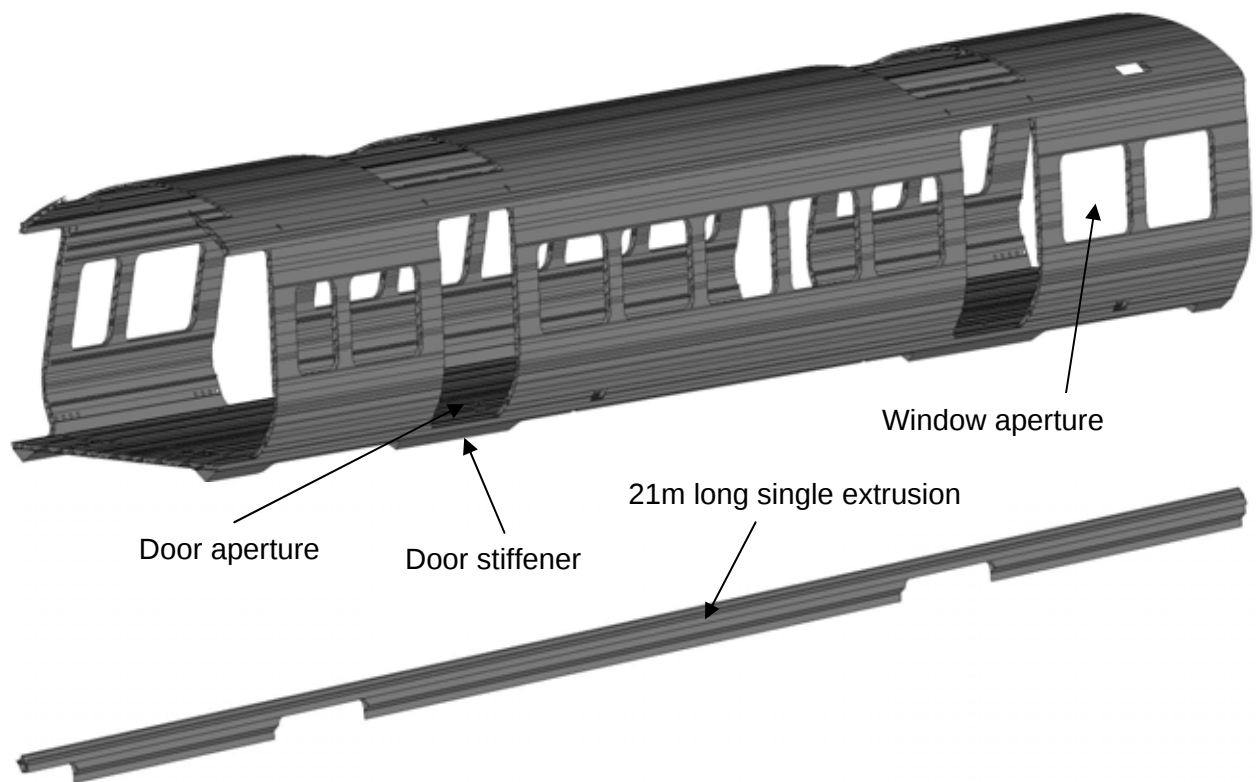


Figure 2: Carbody Extrusion

Large steel castings are often used in the design of bolsters. **Figure 3** shows general dimensions of a casting weighing approximately 200Kg. The use of structural optimisation technology is used to keep size and weight to a minimum.

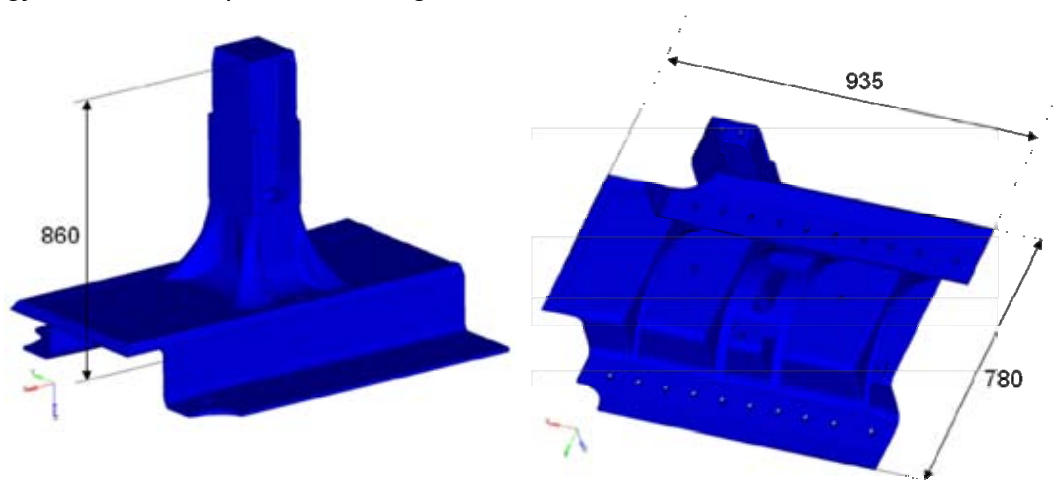


Figure 3: Large Steel Castings

2.0 Finite Element Model Creation

The wide range of components used in the design of railway bogies and carriages result in a large variety of modelling methods and element types being employed in the creation of the FE model. HyperMesh is used to rapidly generate complex FE models with a combination of 1D, 2D and 3D elements.

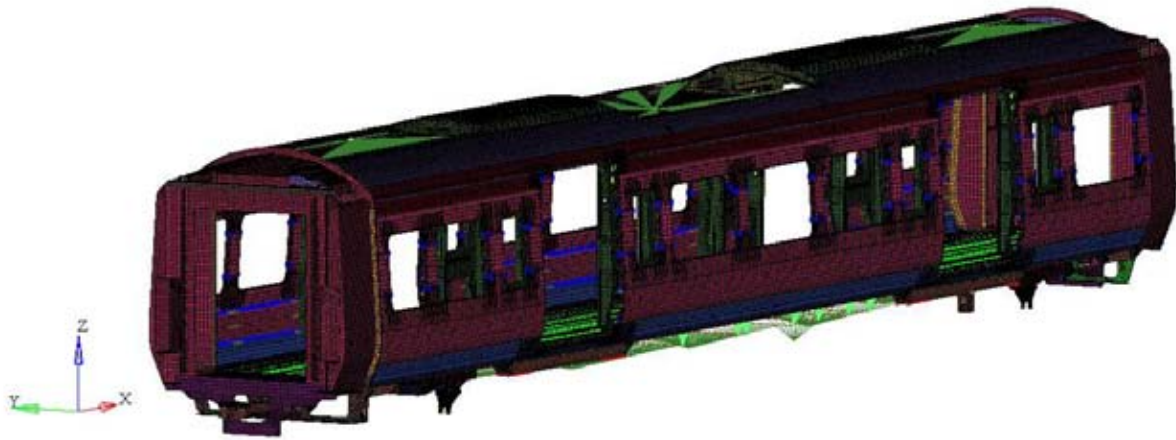


Figure 4: FE Model of a Carbody

Most models start with the import of 3D Catia V5 geometry that is then processed in order to clean up unnecessary details or components. Mid-surfaces are often created as a basis for the FE 2D element generation. At this stage, the nature of railway components (i.e. large extrusions and thick fabricated assemblies) requires HyperMesh to perform geometry alteration and creation. This significantly reduces the time required to generate the FE mesh. In some instances HyperMesh is used to create the geometry without importing any 3D CAD geometry. This is particularly essential when FE is used to validate the concept at the beginning of a vehicle project or for the bidding on new programs where there is no existing 3D CAD geometry. Once FE components have been created HyperMesh has the flexibility to create the fixings manually or automatically using connectors technology.

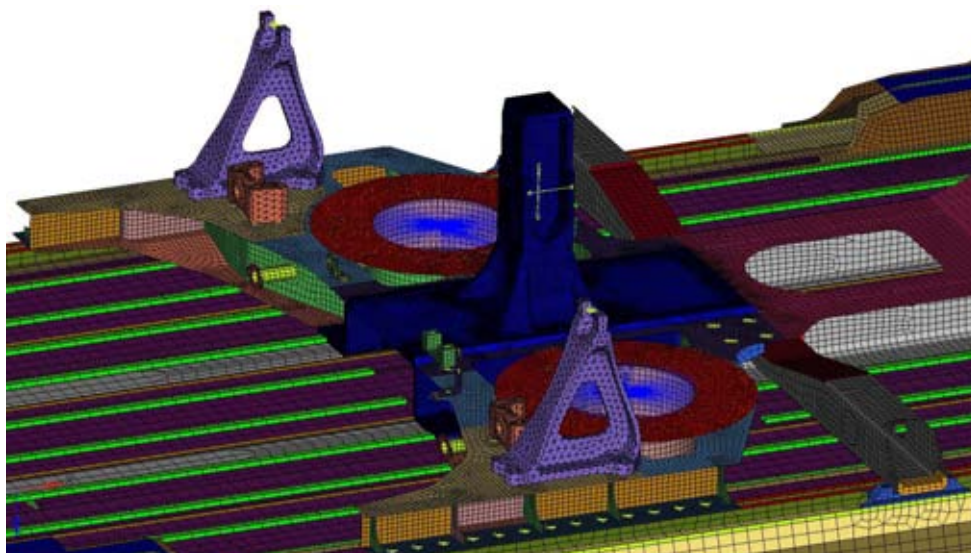


Figure 5: FE Model of a Bolster

Railway vehicle projects are spread over several years and FE pre-processors need the ability to rapidly modify and up-date FE models without any 3D CAD geometry. This is also true when projects are based on an existing design and mainly requires dimension changes. FE morphing technology or even simple transformation tools are essential in order to reduce modelling times by making the most of existing FE models.

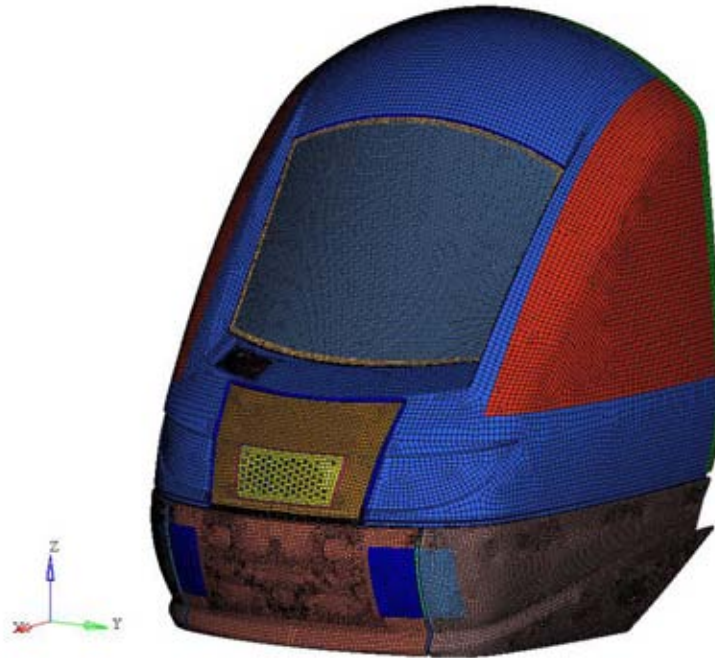


Figure 6: FE Model of a Cab GRP Structure

Railway vehicles are assessed for a large number of loads. Inertia loading, forces, pressures and moments are all used in combination to create a multitude of load cases. The HyperMesh loadsteps browser gives a clear and organised solution to generate load cases that uses various load types and factors. For each load case, boundary conditions are defined and sometimes symmetry constraints are used to reduce the number of modelled elements. This is commonly used through the carbody length as the vehicle is usually assumed symmetrical along its width.

For every project there are a number of carbody mass conditions. Point masses are usually the preferred method of spreading non-structural mass to produce an accurate model mass and a correct centre of gravity location. Point masses are connected in such a way as to be switched on and off depending on load case requirement. This means that all the different mass conditions can be assessed within one FE model and all design responses can be defined in one single OptiStruct input deck.

The following shows an example of the main mass conditions:

- TARE: Service ready, including fuel, full water & one driver, no passengers and no other consumables
- LADEN: Tare condition + all seats occupied + 20 standees, 80kg per person
- CRUSH: Tare condition + all seats occupied + 4 passengers per m², 80kg per person

3.0 Solving using Radioss Bulk and OptiStruct

3.1 Proof and Abuse Load Cases

Railway structures are subject to a multitude of proof and abuse load cases. To comply with a proof load case, the structure must be able to endure applied loads without showing any significant visible permanent deformation. An abuse load case is satisfied by proving that the design is able to endure loading without dramatic failure of the design. These loads are usually factored by a safety factor, the factor can be integrated in the load case or added at the post-processing stage with HyperView. The FE Von Mises stress results are assessed against material yield using a linear static solution.

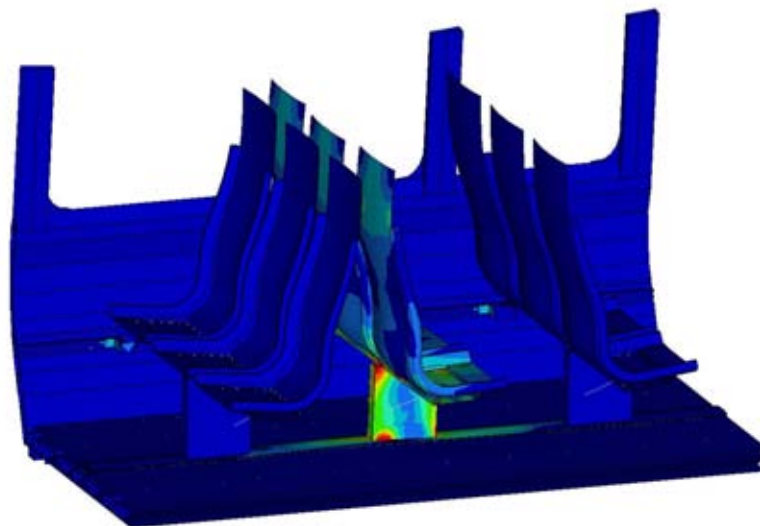


Figure 7: Von Mises Stress Contour on a Seat Structure

Due to the nature of railway structures symmetry boundary conditions are often created. This allows a reduction of the solving time by limiting the number of elements. If loading should only be applied on one side of the structure, the symmetrical side of the loading can be cancelled using linear superposition. It is achieved by running two load cases which are then superposed in order to remove the unwanted side of the loading at the post-processing stage of the analysis with HyperView.

Some structures rely on the appropriate contact condition between components. Contacts are represented using non-linear gap elements. The solver will iteratively assess which gaps are closing or opening in order to represent correct load transfer accordingly.

3.2 Fatigue Load Cases

Fatigue load case are assessed against the BS7608 for steel [1] and BS8118 for aluminium [2] in order to satisfy the required design life. The design life is the period in which the structure or component is required to perform safely, with an acceptable probability that it will not require repair or withdrawal from service. For railway vehicles, if it is not specified by the client, the typical minimum design life is 35 years. Fatigue is the damage, by gradual cracking, to a structural member caused by repeated applications of a stress that is insufficient to cause failure by a single application. British Standards describe and classify local detail of the structure into different classes. The detail class is the rating given to a design detail which indicates its level of fatigue resistance.

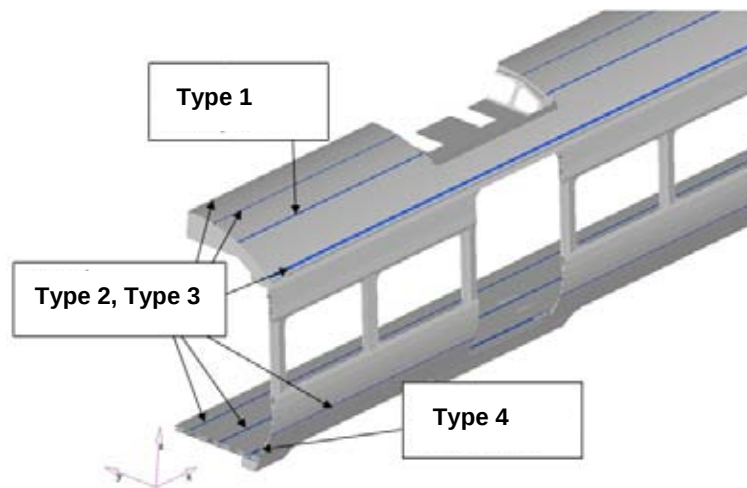


Figure 8: Fatigue Detail Classification of an Aluminium Carbody Structure

The fatigue strength of a detail is always dependent on the following factors:

- (a) the direction of the fluctuating stress relative to the detail;
- (b) the location of the initiating crack in the detail;
- (c) the geometrical arrangement and relative proportion of the detail.

it may also depend on the following:

- (1) product form;
- (2) material (unless welded);
- (3) method of fabrication;
- (4) process quality control.

Once the fatigue loading event is created with its own number of occurrences, it is interpreted and created as an FE fatigue load case in HyperMesh. Principal stresses are calculated and magnitude of stress with vector direction is displayed with HyperView. Each stressed location is assessed against the allowable of the corresponding class of the design detail. Damage is calculated for each fatigue load case and Miner's summation is used to determine the cumulative fatigue damage.

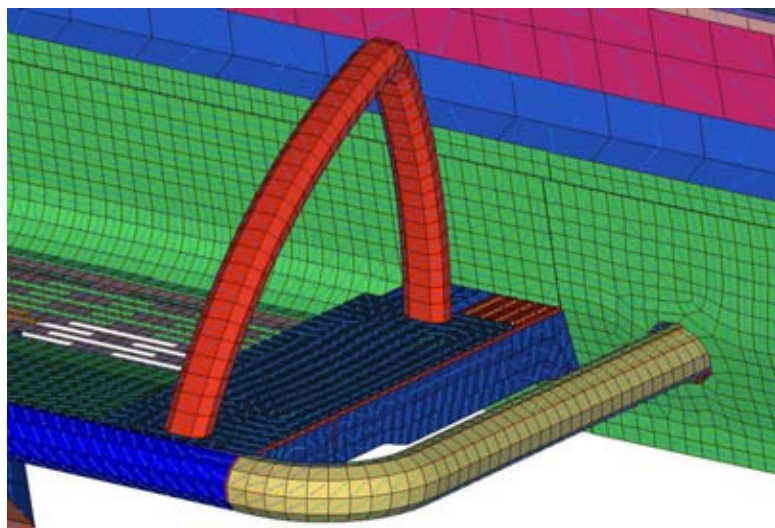


Figure 9: Principal Stress Vectors of Overhead Luggage Rack

3.3 Modal Analysis

Modal analysis is performed on FE models and can be added in the same run to all the other load cases. All fitted structures are designed with sufficient modal separation to avoid coupling. **Figure 10-11** show the vertical bending and the torsion mode shape of a carbody. Since the modal analysis can be part of the same run as the linear static analysis, structural optimisation can be performed while using design variables from the linear static solution in combination with the normal mode solution.

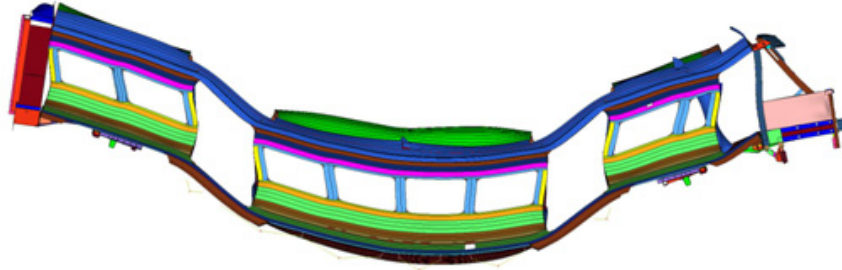


Figure 10: Vertical Bending Mode Shape of a Carbody Structure

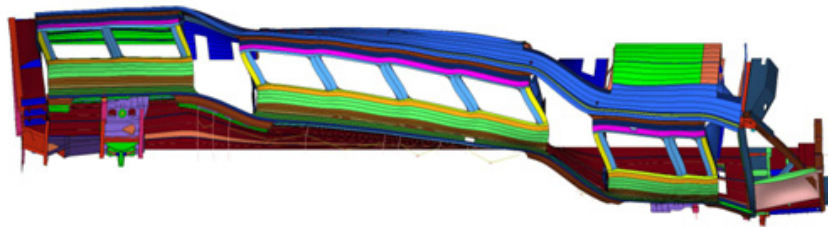


Figure 11: Torsion Mode Shape of a Carbody Structure

3.4 Fasteners

Railway structures are assembled with a wide variety of fasteners. **Figure 12** shows examples of nuts and bolts, rivets, monobolts and huckbolts. Each fastener is assessed according to the calculated endured loads, some using the manufacturer's performance specification (manufacturers such as AVK, ADVEL, POP, HUCK and BÖLLHOFF).

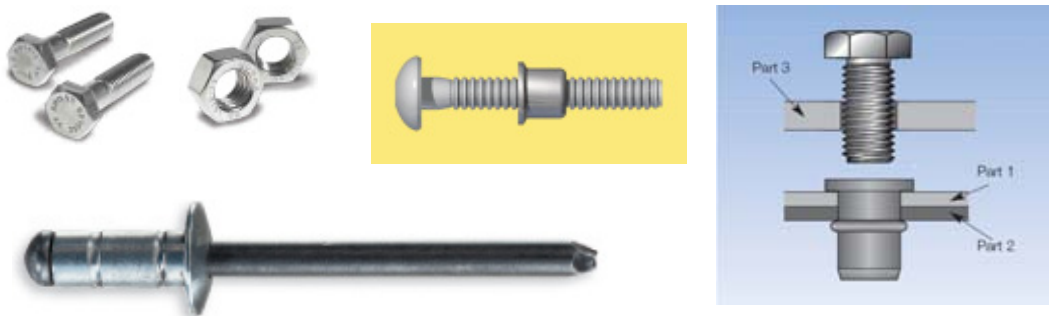


Figure 12: Example of Fasteners

The FE analysis is used to calculate the axial and shear forces carried by each fastener. The fastener assessment includes joint separation check, slip check and bolt stresses. Size and grade can be defined using linear static analysis, numbers and location can be optimised using structural optimisation methods.

3.5 Structural Optimisation

The use of Altair's structural optimisation is now part of the design process for a large number of railway components. Structural optimisation methods such as thickness optimisation and topology optimisation are the most commonly used. It is applied to the design of castings, extrusions and fabricated structures. The following shows structural optimisation examples that were carried out at Bombardier's Derby site using Altair HyperWorks.

3.5.1 Topology optimisation of a coupler casting

Figure 13 shows the initial design of a coupler bracket casting. The design needed modification to be able to fit into a more compact design envelope. An FE model of the newly required design space, including areas of material required for bolted interfaces, was created [**Figure 14**]. The optimum material distribution within the design space was calculated using the topology optimisation feature of the OptiStruct. This included fabrication constraints, such as member size and casting draw direction, in order to improve ease of manufacturability. The results were interpreted into an optimised design satisfying the required design space and various load cases. Also a weight saving of 23.5% was achieved.

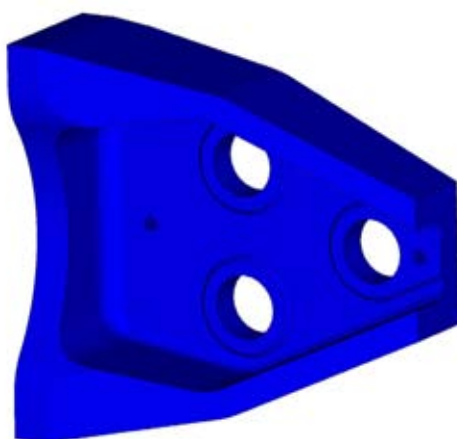


Figure 13: Initial Design

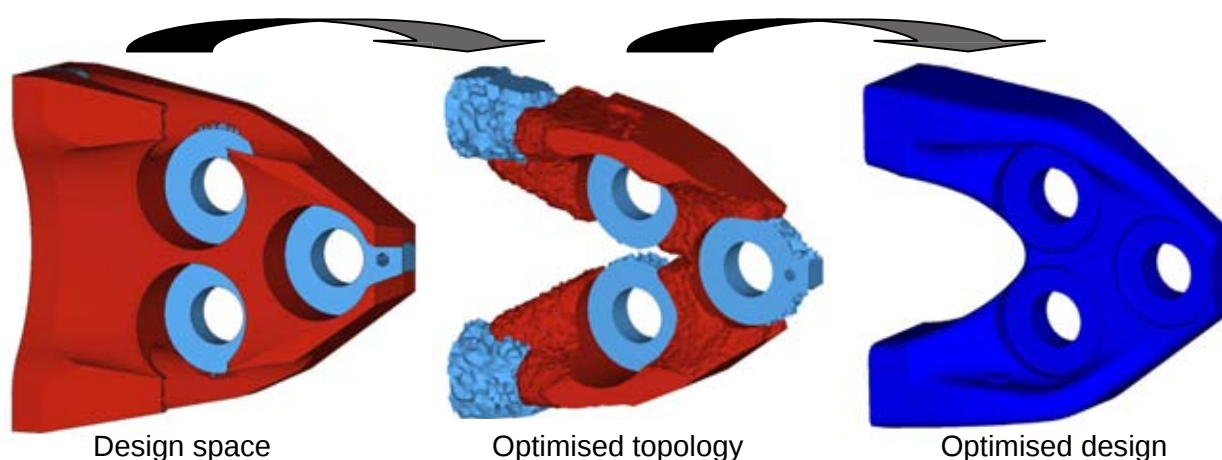


Figure 14: Topology Optimisation Process

3.5.2 Topology optimisation of an extruded window corner

Figure 15 shows the initial design space and resulting topology of an extruded window corner. It is possible to impose an extrusion constraint on the resulting topology. This study was carried out to investigate whether the extruded profile could be optimised in order to reduce local stresses in the window corners of an aluminium extruded carbody.

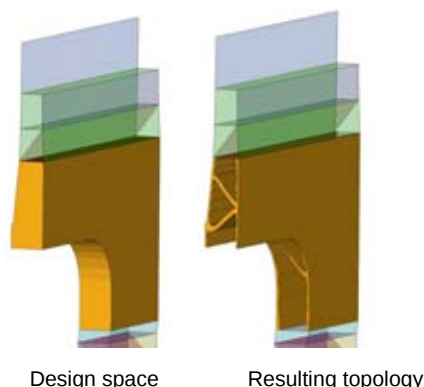


Figure 15: Extruded Topology

3.5.3 Topology Optimisation of a bogie yaw damper casting

This example shows the topology optimisation study carried out on a yaw damper casting. The yaw damper casting is fitted onto the bolster via 4 bolts, and loads are applied by the yaw damper to the casting via a pin. **Figure 16** shows the model setup with designable and non-designable material.

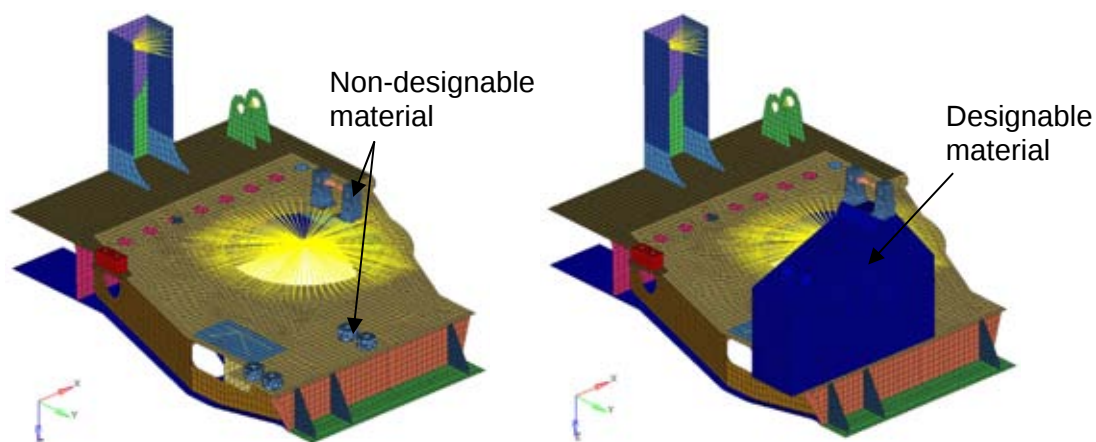


Figure 16: Topology Optimisation Setup

The objective of the optimisation was to improve the initial design performance. Both topology for improved stiffness and improved stress distribution was considered. **Figure 17** shows how minimum member size, casting draw direction and symmetry constraint help in the definition of a non-handed optimised casting. The weight of the initial design was reduced by 36.5% while stiffness was increased by 9.3% and the peak Von Mises stress was reduced by 9.6%.

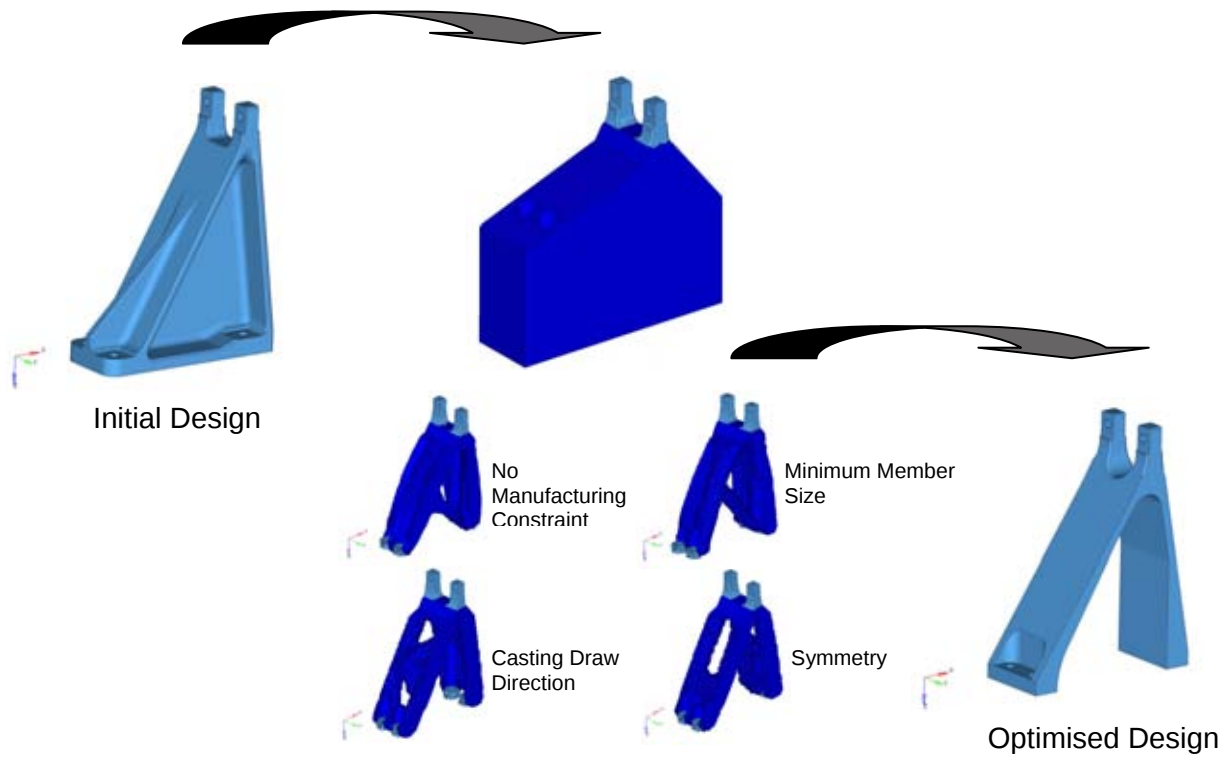


Figure 17: Topology Optimisation of a Yaw Damper Casting

3.5.4 Topology optimisation of a steel fabricated an obstacle deflector

Topology optimisation is also used on steel fabricated structures. The design of the obstacle deflector shown with **Figure 18** was driven all through its design process by structural optimisation. **Figure 19** shows the various loads considered by the analysis.

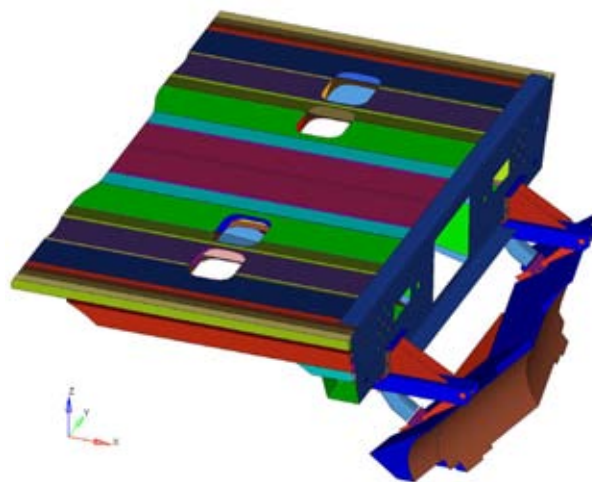


Figure 18: Obstacle Deflector

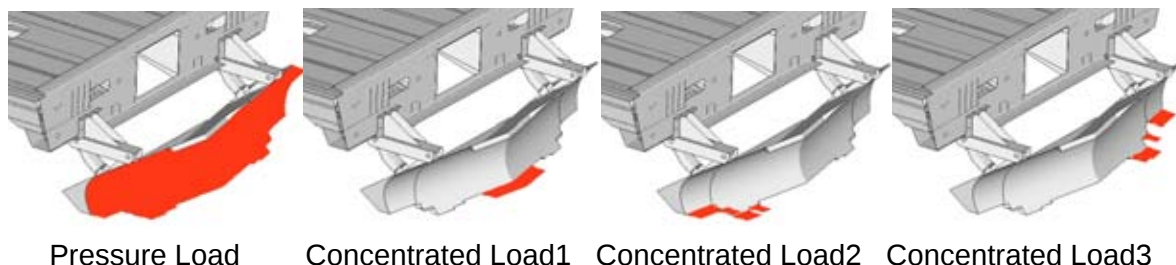


Figure 19: Deflector Load Cases

Every topology optimisation starts with the definition of the design space, in this instance it was created using 3D tetra elements. Its definition is crucial as unnecessary limitations can prevent the analysis from evolving into an optimum design. **Figure 20** shows the volume of material considered for the optimisation of the obstacle deflector. It is also very important to carefully choose the manufacturing constraints as it will significantly change the resulting design. A resulting design that was constrained to produce internal webs, whereas a resulting design without any constraint on the manufacturability can also be seen in **Figure 20**.

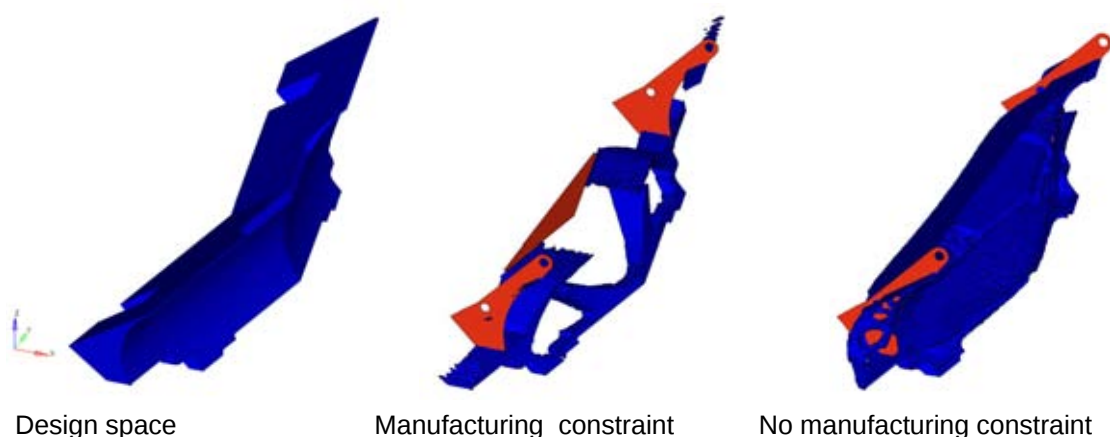


Figure 20: Design Space, Manufacturing Constraint and No Manufacturing Constraint

Once the resulting topology has been selected, it is interpreted into a steel fabrication. This time the FE model is made of 2D shells, as shown with **Figure 21**. The topology optimisation process can be repeated on the 2D shell model in order to create lightening holes, as shown with **Figure 22**.

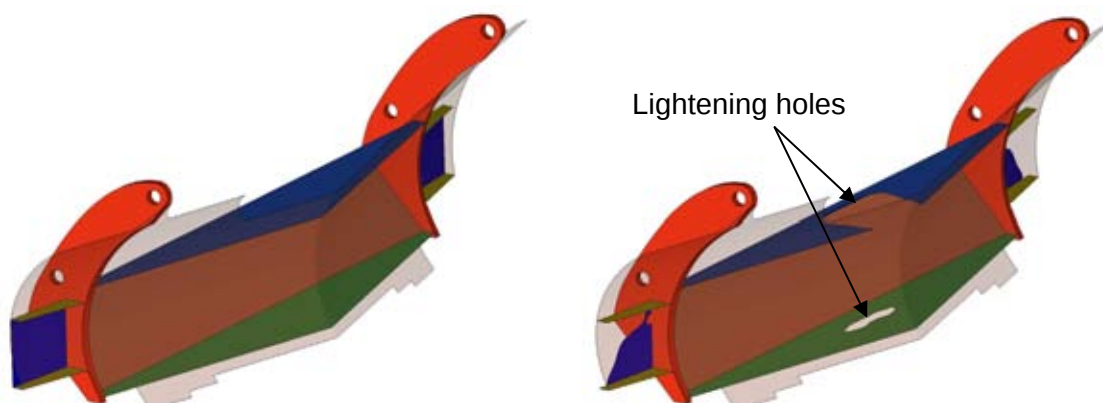


Figure 21: Interpreted Fabricated Design Figure 22: Resulting Topology on 2D Shells

At this stage the overall topology of the design has been established and the FE model is ready to go through gauge optimisation. Each panel gauge is setup as a discrete design variable that is then defined by the optimiser while taking into account all load cases and satisfying stress constraints.

3.5.5 Topology Optimisation of a bolster

In this example, topology optimisation was used to create the optimum design of a bolster within a very compact design envelope. Bolsters are subject to a wide range of load cases applied through both carbody and bogie, and the design envelope is always reduced to a minimum. The whole FE model of the carbody needed to be part of the analysis in order to accurately simulate carbody load cases. **Figure 23** shows how the design space was divided into two areas allowing different manufacturing constraints.

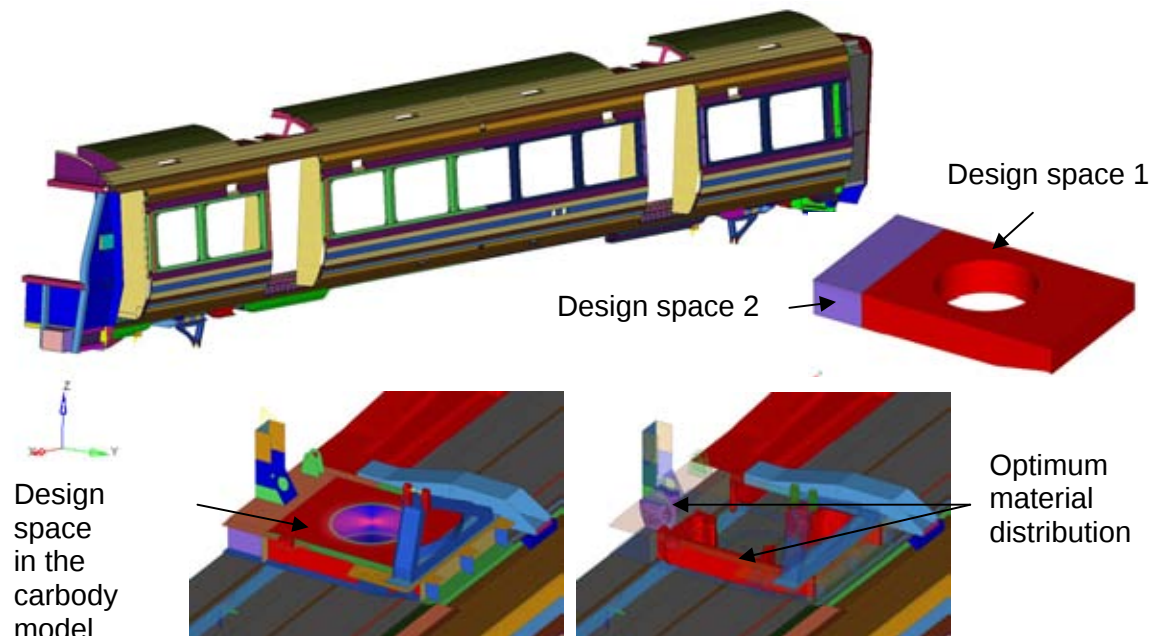


Figure 23: Topology Optimisation of a Bolster

4.0 Conclusion

Altair HyperWorks has provided the complete platform for the use of FE analysis in the railway industry at Bombardier Transportation UK. The HyperWorks suite of products are now successfully used at every stage of the design process and has reduced product development times, allowing for weight saving and increased performance. More advanced CAE techniques have been facilitated with the use of structural optimisation. The collaboration between Bombardier's Derby site and Altair UK has successfully delivered a cost effective CAE driven design solution. New features are continually being introduced with every HyperWorks version which will enhance software functionality, increase speed and further facilitate interactivity between user and software. PBS Professional, a computing resource manager, has the potential to increase productivity even further by turning local desktops into a CAE dedicated computer farm. It will improve job submission by maximising existing hardware capabilities.

[Click here to contact Altair](#)

5.0 References

- [1] Railway Group Standard GM/RT2100 Issue 03
- [2] BS7608: 1993 Fatigue design and assessment of steel structures
- [3] BS8118 : Part 1 : 1991 "Structural use of aluminium; Code of practice for design"