The Design and Prototyping of a Lightweight Crashworthy Rail Vehicle Driver's Cab

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Abstract

This paper describes the design, validation and prototyping of a lightweight crashworthy rail vehicle driver's cab using advanced composite sandwich materials. By exploiting the lightweighting, energy absorption and design integration benefits of composites, an innovative modular cab structure was developed that provides significant savings in mass, cost and part count compared to conventional cab designs.

1 Introduction

Within the rail industry, lightweighting is becoming an increasingly important topic. Recent studies (e.g. [1]) have indicated that trains have generally become heavier over the last thirty years. Whilst these increases in vehicle mass can often be attributed to enhanced passenger environments (e.g. the provision of air-conditioning, improved accessibility, crashworthiness, etc.), there are clearly undesirable side-effects of heavier trains. Everything else being equal, a heavier vehicle will consume more energy/fuel in operation than a lighter one, thereby making it more costly to run. Increased energy/fuel consumption also implies a likelihood of higher CO_2 emissions at some point in the energy supply chain. Furthermore, heavier trains are likely to cause more damage to the track, thereby resulting in higher costs for infrastructure maintenance and renewal. In some countries, heavier trains also attract higher track access charges for operators.

As part of the European Commission supported *DE-LIGHT Transport* project, NewRail, Bombardier Transportation and AP&M collaborated on the design, development and prototyping of an innovative modular rail vehicle cab based on lightweight composite sandwich material technology. This paper describes that activity.

2 Background

Conventional rail vehicle cab structures are typically based on welded steel assemblies, often with a thin non-structural fibreglass cover, and are therefore relatively heavy. Furthermore, current cab designs tend to be very complex, high part count assemblies with fragmented material usage. This is because they must meet a wide range of demands including proof loadings, crashworthiness, missile protection, aerodynamics and insulation. Assembly costs are high, and there is little in the way of functional integration.

By contrast, with the next generation cab described in this paper, the intention was to exploit the opportunities for design integration that are afforded by sandwich material technology in order to produce a lightweight construction in which the structural, crash, aerodynamic and insulative functionalities are realised in a single integrated package (Figure 1).

The basis for the lightweight cab design, named "D-CAB", was Bombardier's *SPACIUM* 3.O6 commuter train (Figure 2). This currently features a conventional cab assembly consisting of a steel primary structure, steel energy absorbers and a thin non-structural fibreglass shell. The objective for

D-CAB was to meet the existing requirements of the *SPACIUM* cab using composite sandwich materials so as to realise significant savings in mass, cost and part count.

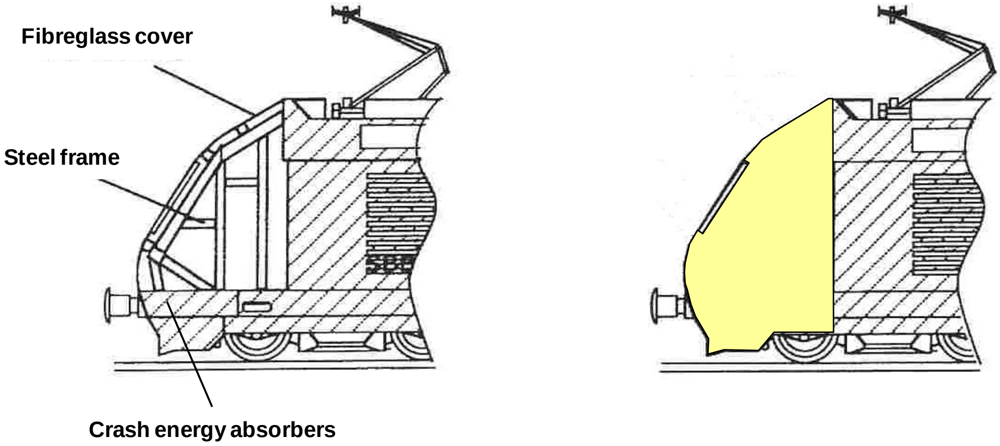


Figure 1 – the contrast between a conventional cab structure (left) with fragmented components and materials, and the highly integrated composite sandwich solution developed by the authors (right). The figure is a modified version of that presented by Cortesi et al. [2].

Figure 2 – Bombardier's SPACIUM 3.O6 commuter train that provided the basis for the development of the lightweight crashworthy cab.

3 Lightweight Cab Design Concept

3.1 Materials

An important feature of D-CAB's novel design is the advanced sandwich material construction employed. Sandwich materials typically consist of two relatively thin, stiff facings bonded either side of a thicker, lower density core material or structure. Such assemblies have a number of characteristics that make them attractive for applications in transport. Their high mass specific stiffness and strength make them a good enabling technology for lightweighting, leading to improved performance and/or lower life cycle costs. Sandwich materials also provide opportunities for design integration, i.e. the ability to combine different functionalities within a single material construction. For example, mechanical properties such as stiffness, strength and energy absorption can often be combined with other properties such as thermal insulation.

The lightweighting and crashworthiness benefits of high performance composite materials have been well demonstrated in other sectors. However, the relatively high cost of structural composites has precluded their widespread use in rail vehicle applications. By focussing on affordable raw materials (glass fibres, thermosetting resins, aluminium honeycombs and polymer foams), and by combining them in a novel, highly integrated fashion that significantly reduces part count, D-CAB is able to simultaneously exploit the lightweighting and energy absorption benefits of these materials whilst providing savings in assembly, outfitting and operational costs.

3.2 Modular Construction

Another key aspect of D-CAB's design is the three-stage modular construction that has been employed to facilitate assembly, inspection, maintenance and repair (Figure 3). The frontal nose section, which is the area most likely to suffer incidental in-service damage, has been designed to be easily removable for repair or replacement. Removing the nose also provides easy access to the primary energy absorbing devices for inspection or replacement purposes. Behind the nose is the main crush zone that houses the primary energy absorbing devices for compliance with EN 15227 [3]. Again, this is a self-contained module that can be removed and replaced if necessary. The driver sits within the third "survival" zone, a strong module that is designed to resist proof and crash loadings without suffering permanent deformation or damage.

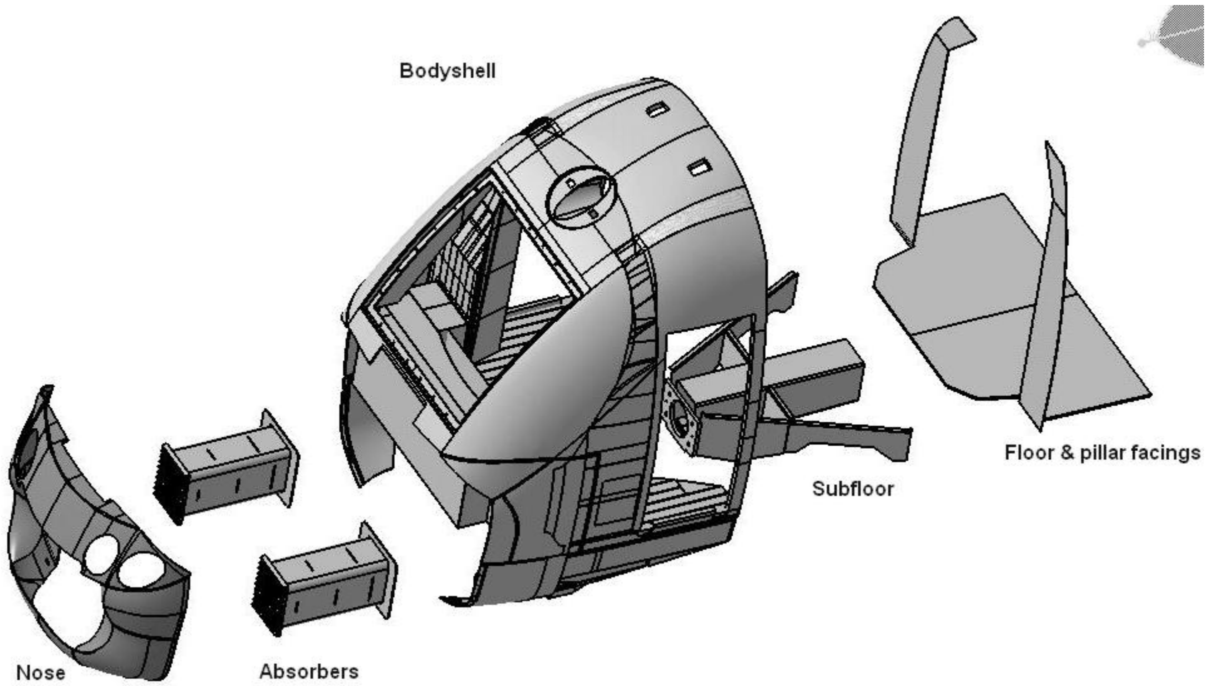


Figure 3 – an exploded view of the overall D-CAB design concept.

4 Cab Detailed Design and Validation

4.1 Static Loads

The major structural components of the existing *SPACIUM* cab are two substantial welded steel pillars. These provide much of the cab's overall static stiffness and strength. They also resist the collapse loads of the energy absorption devices.

In place of these steel pillars, D-CAB employs a structural composite sandwich design. However, it was found that it was necessary to significantly reinforce the sandwich in the buffer regions and pillar areas in order to ensure that it was sufficiently strong to resist the energy absorber collapse loads.

Figure 4 shows a CAD image of the reinforced sandwich sections. The “reactors” in the lower buffer regions consist of an array of bonded square-section foam cores wrapped in glass fibre reinforced polymer (GFRP) to produce a macro-cellular structure. The “pillars”, above the reactors, also consist of an assembly of GFRP and foam cores. Each vertical column of foam in the pillars is sandwiched between continuous vertical layers of GFRP to produce a multi-layer sandwich construction.

In order to validate the strength of the reactor elements, prototype samples were manufactured and tested (Figure 5). These specimens had an overall cross section of 215 mm x 215 mm, and were 300 mm long. Each of the four foam cores in each specimen had a cross-section of 100 mm x 100 mm and the GFRP wall sections were 5 mm thick. The average overall density of the samples was 264 kg/m^3.

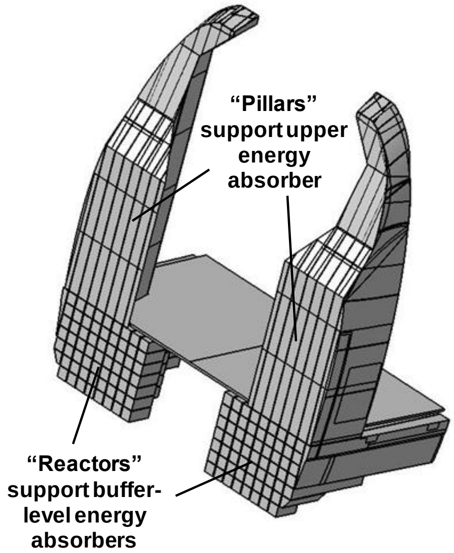


Figure 4 – D-CAB’s reinforced sandwich sections.

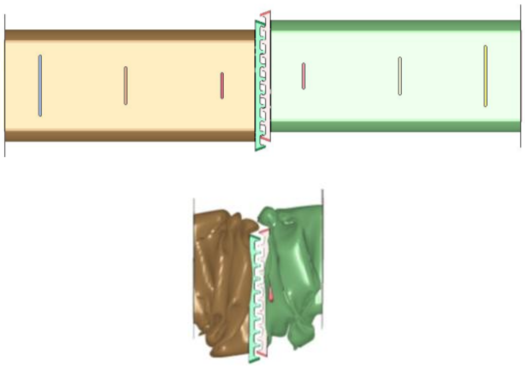
Figure 5 – the reactor test specimens.

The target strength for each of the four-cell reactor test specimens was 200 kN. This was equivalent to the strength required to resist the peak buffer-level energy absorber collapse load of 1,500 kN in the full cab. The samples were tested in quasi-static axial compression. In each case the failure load was recorded. The mean measured compressive failure load across the specimens was 542 kN (i.e. a safety factor of 2.7). This was deemed satisfactory.

4.2 Crash Loads

D-CAB’s buffer-level energy absorbers are based on an aluminium honeycomb construction. The absorbers feature a novel material configuration that has proved to be particularly effective at accommodating the problematic 40 mm offset overriding condition associated with Collision Scenario 1 of EN 15227 [3]. The estimated mass of a single lightweight buffer-level energy absorber is 113 kg. This represents a mass saving of more than 50% compared to the existing *SPACIUM* device.

Figure 6 shows the predicted “before” and “after” conditions of two D-CAB buffer-level energy absorbers involved in a face-to-face collision. Note the initial 40 mm vertical offset between the two devices. The prediction was produced using an LS-DYNA non-linear finite element analysis. Figure 7 shows the associated load-displacement profile for a single absorber. It can be seen that the absorber’s characteristic behaviour is reasonably close to the target response, although the mean crushing load is slightly too low, and the useful stroke is slightly too short. However, with further tuning of the energy absorber’s performance, these deficiencies could be addressed.



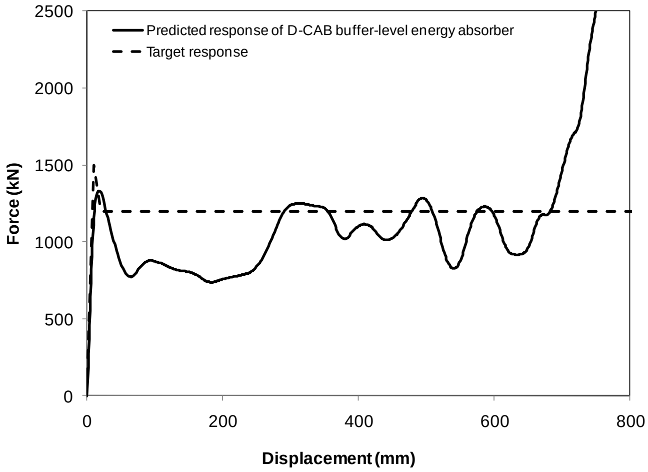
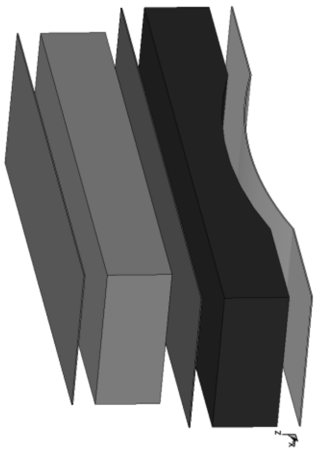


Figure 6 – the predicted collapse behaviour of two D-CAB buffer-level energy absorbers in a face-to-face collision.

Figure 7 – a comparison between the predicted (solid line) and target (dotted line) load-displacement characteristics for a D-CAB buffer-level energy absorber.

Both the *SPACIUM* cab and D-CAB also feature upper energy absorption devices that are designed to mitigate against Collision Scenario 3 of EN 15227 [3] (the 15 tonnes deformable obstacle). The *SPACIUM* cab has two upper energy absorbers that are of a similar design to its buffer-level ones, i.e. welded steel fabrications. However, D-CAB's upper energy absorption provision consists of a single multi-layer sandwich construction comprising two thicker (290 mm) core layers of 29 kg/m^3 aluminium honeycomb, together with three metallic facing layers (Figure 8). The two flat forward and intermediate facings are 5 mm thick aluminium sheet. The rear curved plate is 5 mm thick steel. The curve in the back plate limits the extent to which the absorber is pushed between the supporting pillars during crushing, thereby preventing encroachment upon the driver's survival space. The predicted load-displacement response of the D-CAB upper energy absorber is shown in Figure 9. In terms of lightweighting, the estimated mass of the D-CAB upper energy absorber is 128 kg, which is a saving of more than 60% compared to the existing IDF upper absorbers.



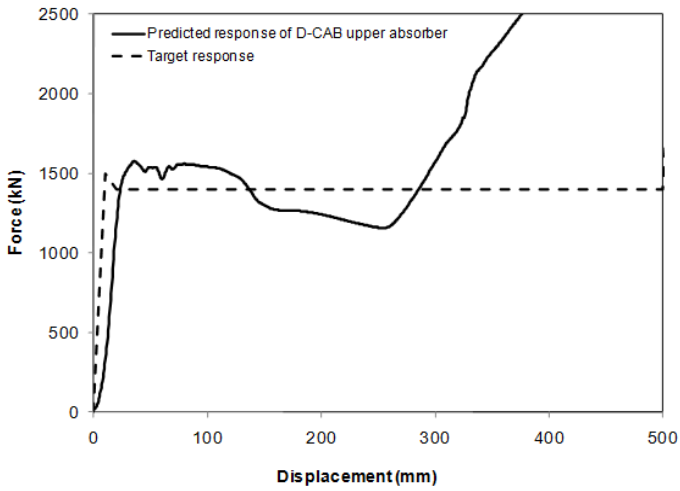


Figure 8 – the multi-layer aluminium honeycomb sandwich construction employed for D-CAB's upper energy absorber.

Figure 9 – a comparison between the predicted (solid line) and target (dotted line) load-displacement characteristics for the upper energy absorber.

D-CAB's estimated overall energy absorption capacity, including the combined effects of the buffer-level and upper energy absorbers, the controlled brittle fracture of the composite sandwich materials in the primary and secondary modules, and the collapse of the coupler, is 2.8 MJ.

5 Prototyping of the Lightweight Cab

A full-scale prototype of the cab was produced using representative materials and manufacturing techniques. First of all, an impression of an existing *SPACIUM* cab was taken to provide a female mould for the production of D-CAB. The glass fibres, polystyrene resin and polyurethane foam were then laid-up inside this mould and allowed to cure before demoulding. The nose module was separated from the main moulding to allow for easy detachment and reattachment. The buffer-level and upper energy absorbers, as well as the floor of the cab, were produced separately and then assembled within the main moulding. Figure 10 shows some photos of the completed prototype.

Figure 10 – the full-scale prototype of the lightweight crashworthy D-CAB concept.

6 Evaluation of the Lightweight Design

The next generation train cab that has been developed provides structural, crash, aerodynamic and insulative functionality within a single integrated package. In comparison to existing cab designs it is up to 40% lighter, has up to 60% fewer parts, and is up to 20% less costly due to greatly reduced assembly and outfitting times. In-service, the lightweight design will also reduce life cycle costs through improved energy/fuel efficiency.

7 Acknowledgements

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8 References

[1] Ford, R., “Transport mass”, *Institution of Mechanical Engineers Seminar: Weight Saving and Structural Integrity of Rail Vehicles*, Derby, UK, (25 September 2007).
[2] Cortesi, A., Issenmann, T. & Kalbermatten, T., “Light nose for fast locomotives”, *Schweizer Eisenbahn Review*, No. 12, pp. 435-442, (1991).
[3] CEN, *Railway Applications – Crashworthiness Requirements for Railway Vehicle Bodies*, EN 15227, (2008).