DESIGN AND ANALYSIS OF A COMPOSITE ENERGY ABSORBING RAIL CAB NOSE CONE

Conor O'Neill, Joe J. Carruthers, Steve Ingleton and A. Mark Robinson[1]

NewRail
School of Mechanical & Systems Engineering, Newcastle University, NE1 7RU, UK
conor.oneill@ncl.ac.uk

ABSTRACT

The use of composite materials for rail cab applications has traditionally been driven by the need to produce a lightweight aerodynamic cab structure of complex geometry. This composite shell provides some protection to the cab and its occupant from very low energy projectile impacts. However, such structures provide little in the way of energy absorption in the event of higher energy impacts, such as vehicle-to-vehicle or vehicle-to-obstacle collisions. To produce a complete composite rail cab that meets crashworthiness requirements, there is a need to convert the cab structure into a structural energy absorbing component. To contribute to this, an energy absorbing primary crush zone (nose cone) has been designed.

1. INTRODUCTION

The use of composite materials in energy absorbing structures is well proven with a number of industries designing and implementing composite crush structures to improve the safety and crashworthiness of their products.

The Formula One industry not only uses composites for lightweight and aerodynamic purposes, they also employ these materials to absorb impact energy through controlled crushing. To ensure the safety of the driver, the Formula One governing body, the FIA (Fédération Internationale de l'Automobile), enforce strict safety guidelines concerning the crashworthiness of Formula One racing cars. Each car is designed with four impact structures: front, rear, side and steering column. Current FIA test procedures require the energy absorbed by each of the four impactor segments to be between 15% and 35% of the total energy absorption. To achieve this, composite energy absorbers are employed to control the crush sequence, reducing the forces transmitted to the driver whilst containing the damage within the impact absorbing structure [1].

The aerospace industry utilises the energy absorption properties of composites in a different manner to Formula One. Although not specifically designed to absorb aircraft-to-aircraft or aircraft-to-ground impacts, a number of components on modern aircraft are optimised to absorb high energy (large mass) projectile impacts, e.g. composite sandwich panelling on the underside of the wings is optimised to absorb and deflect bird impacts during take-off and landing. Manufactured from Nomex honeycomb core and faced with carbon fibre reinforced epoxy, these secondary structures provide significant birdstrike and FOD (Foreign Object Damage/Debris) energy absorption which protect the primary load bearing structure (spars, ribs, etc.) and assist in preventing fuel tank puncture.

The crush characteristics of composite tubes and flat sandwich panels are relatively well understood [2-5]. However, the crush characteristics of non-tubular structures, i.e. where the crush volume is restricted by an external surface geometry, requires further research.

2. CURRENT DESIGN PHILOSOPHY

The driver's cabs of current trains are primarily comprised of a steel substructure, off which are attached by means of brackets a series of thin aluminium or composite panels and valances. The main function of these secondary structures is to provide improved aerodynamic performance and improved vehicle aesthetics, although they have been shown to provide some protection to the cab and its occupant from very low energy projectile impacts [6]. However, from a crashworthiness perspective these panels do not offer any significant energy absorbing qualities, being largely destroyed during impact. In instances where minor collisions take place, this may mean that the primary energy absorbers are required to dissipate the loads. Repairing these units is a costly and time-consuming activity, leading to longer train downtime and lost revenue. By converting the existing panels and valances into primary load-bearing structures which can manage larger impact energies, the main energy absorbers will not need to be replaced or repaired as often in the event of minor collisions.

3. DESIGN CONCEPT

According to the Office of Rail Regulation's Annual Reports [7,8] there have been 1506 incidents in the UK of trains running into obstructions between 2004 and 2006. In addition to this, they report 48 buffer-stop collisions between 2000 and 2006. A nose cone design that absorbs higher energy levels than current designs will help decrease the downtime of trains caused by such incidents, through quick removal and replacement of the nose cone unit after collision.

The nose cone design concept is being developed as part of DE-LIGHT, a European Framework 6 project, with the aim of producing a composite energy absorbing driver's cab for a suburban rail network. Based on the crashworthiness requirements for these vehicles, it was agreed that a stepwise approach to energy absorption should be adopted. This divided the cab into three distinct crush zones: Primary Crush Zone, Secondary Crush Zone and Reaction Zone.

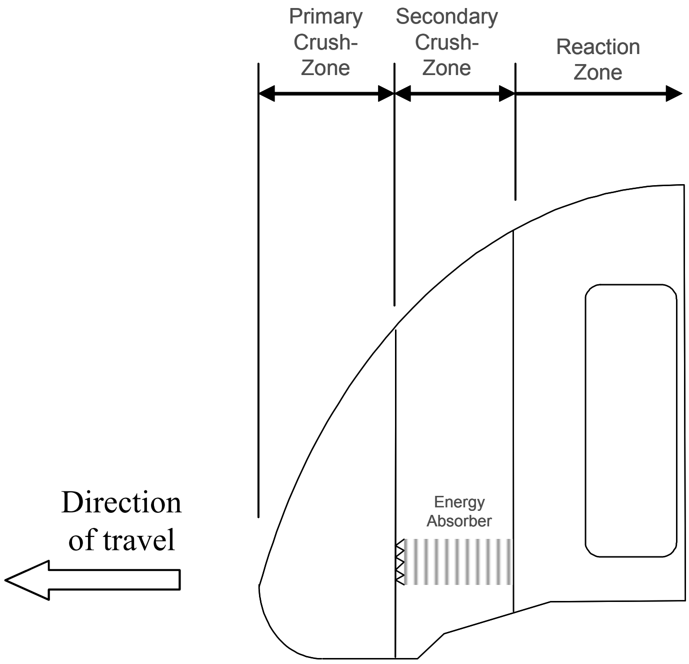

Figure 1: Stepwise division of cab to react impact energies.

Figure 1 approximates the crush zone divisions of the composite cab. The Primary Crush Zone is described as that section of the rail cab structure from the front of the rail cab (ignoring the coupler) to approximately the front of the primary energy absorber (Figure 1). The Secondary Crush Zone is that part of the cab which shall house the main energy absorbers (Figure 1). The Reaction Zone is the non-deformable section of the vehicle designed to transfer and create load paths into the main vehicle body.

This Primary Crush Zone shall be manufactured as a composite structure which functions as an interchangeable and replaceable nose cone for the front of the rail cab to react to low energy collisions, whilst providing load transfer and additional energy absorption in high energy collisions. Designed specifically for the DE-LIGHT composite cab, the nose cone shall act both independently as an energy absorber, and in unison with the secondary crush zone to react and transfer crush loads in a controlled manner.

4. DESIGN PERFORMANCE

Low energy impacts can be described as collision events where there would be expected to be minimal crushing of the main energy absorbers. Such incidents could include slow speed vehicle-to-vehicle contact, vehicle-to-buffer-stop impacts or minor obstacle collisions. Typically these would be up to 0.2MJ. The composite nose cone shall be designed to absorb energy impacts of this magnitude with its performance being analysed by finite element models and quasi-static testing. Subsequently, the modular design approach allows for the rapid replacement of damaged nose cones, providing the operator with reduced out of service times for vehicles sustaining minor damage.

Figure 2 shows the typical reaction of a rail cab in a low energy buffer-stop impact. In this scenario the cab skirt, valances and shell provide little energy absorption and as such the main energy absorbers get partially utilised or damaged as they absorb the loads from the impact. In Figure 3 however, the cab's composite nose cone begins absorbing energy on impact, crushing in a controlled manner and thus dissipating the impact energy and reducing the forward momentum of the train, leaving the main energy absorbers undamaged.

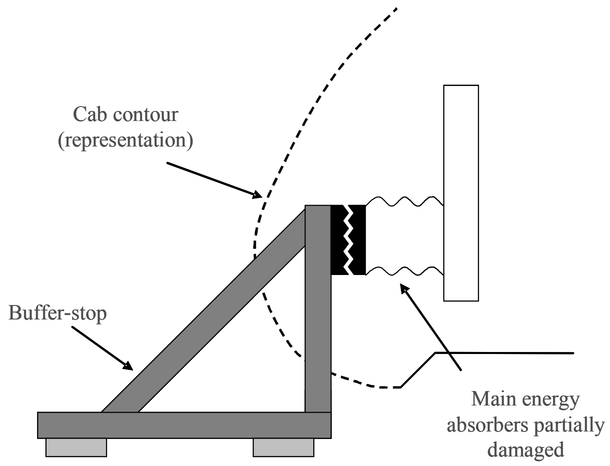

Figure 2: Typical result of low energy buffer-stop collision

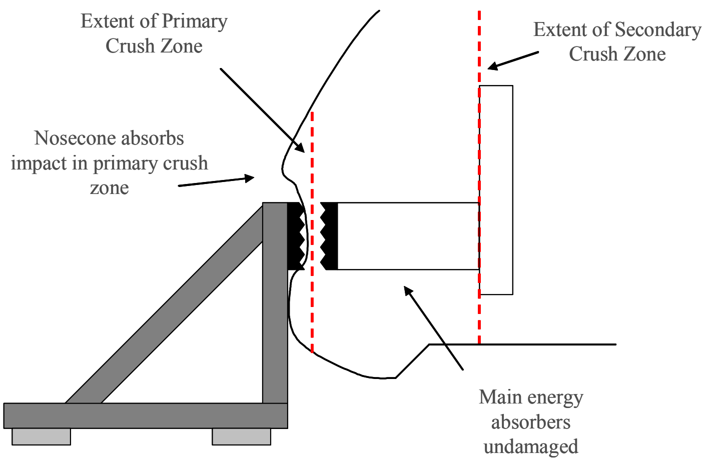

Figure 3: Low energy buffer-stop collision absorbed by nose cone

For high energy impacts (collisions where the main energy absorbers would be expected to be fully utilised) the nose cone serves a secondary purpose: to react and transfer a proportion of the crash loads, as well as initiating a staged and controlled crush sequence from the primary crush zone through to the secondary crush zone. This extension of its primary functionality means that the rail cab as a whole can absorb collision energy more efficiently than it can through using the main energy absorbers alone. Through finite element modelling it is anticipated that load paths can be optimised to ensure the maximum performance in the event of a collision, providing additional controlled energy absorption in high energy impact scenarios.

5. WEIGHT & ENVIRONMENTAL IMPACT

In a recent report the Office of Rail Regulation stated that the railway industry “cannot afford to become complacent about its current environmental advantage”, adding that “…in some respects, for instance the weight of trains…, the industry’s performance is deteriorating.”[9]. To achieve the goal of reducing vehicle weight the industry has made some progress in removing mass from rail vehicles through redesign and developments in bogie technology[10]. The use of composite materials can offer further weight reduction opportunities; typical steel tubular energy-absorbers can weigh up to 1000 kg, but it is envisaged that significant weight can be removed through the use of volumetrically optimised, lightweight, energy absorbing composite structures. The proposed composite nose cone design, in conjunction with a composite rail cab, could represent a viable alternative to traditional rail cab materials and design philosophies, achieving significant weight and part count reductions.

6. ONGOING AND FUTURE ACTIVITIES

The design of the composite nose cone will be driven by the train’s aerodynamic requirements, material properties under crush loading and load transfer requirements. A sequence of testing is proposed for a variety of material types, where specimens of a hemispherical or semi-ellipsoid shape (Figure 4) shall be placed under continuous loading to assess their ability to absorb crush energies.

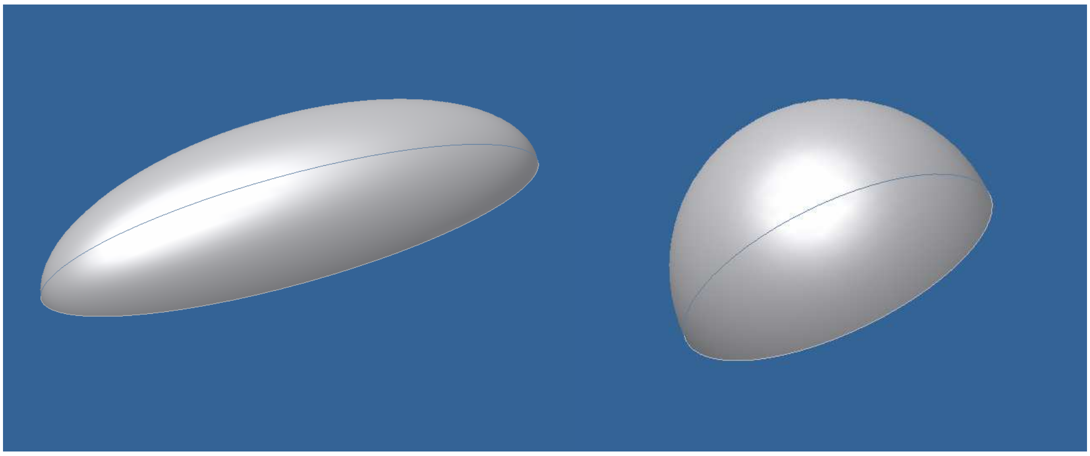

Figure 4: Typical volumetrically filled crush specimens

Each specimen shall comprise of an outer skin with a volumetrically filled inner core. The crush response of the specimens shall be predicted and optimised using finite element analysis and subsequently verified by physical testing. The effects of various cores (foam, honeycomb, etc.) and design concepts (layering, stepwise density changes, etc.) shall be investigated to produce an optimised structure. The optimised construction method shall then be applied to the nose cone of the DE-LIGHT composite cab, with the production and testing of full-scale prototypes.

7. CONCLUSIONS

Optimised for use on suburban rail vehicles, an aerodynamic composite nose cone has been designed to improve the crashworthiness performance of the rail cab whilst reducing weight. For high energy impacts, the nose cone has been designed to have a secondary purpose: to react loads directly into the secondary crush zone.

A composite nose cone for suburban rail applications has the potential to:

- Provide viable low energy crash absorption up to 0.2MJ.
- Improve high energy collision performance.
- React and transmit a proportion of the crash loads to the secondary crush zone.
- Increase fuel efficiency and reduce environmental impact through lightweight structures.
- Reduce costs and out of service time through ease of repair or replacement.

ACKNOWLEDGEMENTS

The authors would like to thank the European Commission for supporting DE-LIGHT Transport as project number TST5-CT-2006-031483.

REFERENCES

1- Bisagni, C., et al., "Progressive crushing of fiber-reinforced composite structural components of a Formula One racing car." *Composite Structures*, 2005:68(4):491-503.
2- Carruthers, J.J., Kettle, A.P. & Robinson A.M., "Energy Absorption Capability and Crashworthiness of Composite Material Structures: A Review", *Applied Mechanics Reviews*, 1998:51(10):635-649.
3- Pitarresi, G., Carruthers, J.J., Robinson, A.M., Torre, L., Kenny, J.M., Ingleton, S, Velecela, O., & Found, M.S., "A Comparative Evaluation of Crashworthy Composite Sandwich Structures", *Composite Structures*, 2007:78:34-44.
4- Ochelski, S. and P. Gotowicki, "Experimental assessment of energy absorption capability of carbon-epoxy and glass-epoxy composites." *Composite Structures*. In Press, Corrected Proof.
5- Velecela, O., Found, M.S. and Soutis, C., "Crushing energy absorption of GFRP sandwich panels and corresponding monolithic laminates." *Composites Part A: Applied Science and Manufacturing*, 2007:38(4):1149-1158.
6- Kim, J.-S. and S.-K. Chung, "A study on the low-velocity impact response of laminates for composite railway bodyshells." *Composite Structures*, 2007:77(4):484-492.

7- Office of Rail Regulation, *"Railway Safety Statistical Report 2006"*, retrieved February 2008 from http://www.rail-reg.gov.uk/upload/pdf/rss_report_06.pdf
8- Office of Rail Regulation, *"Annual Report on Railway Safety 2005"*, retrieved February 2008 from http://www.rail-reg.gov.uk/upload/pdf/296.pdf
9- Office of Rail Regulation, "ORR's Sustainable Development & Environmental Duties - A Consultation Document." 2006
10- Heath Reidy, "Lighten the load", *Professional Engineering*, 2007:20(17):24-25.