The Application of CES to the Lightweighting of Rail Vehicles

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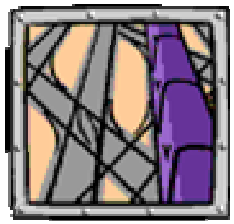
NewRail – Newcastle University's Centre for Railway Research

1994 2004

Vehicles



Infrastructure

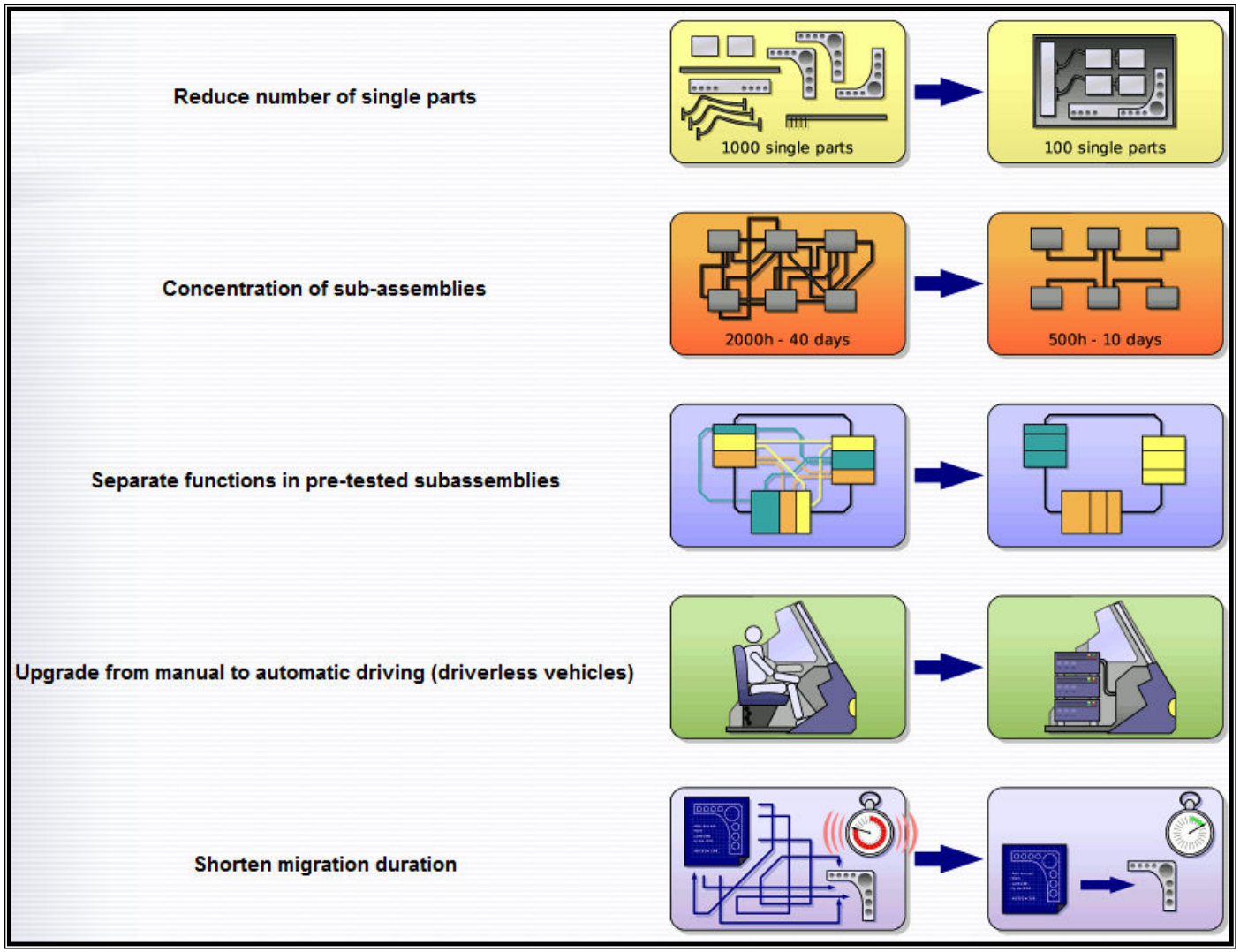
Systems

Freight & Logistics

CES EduPack at Newcastle University

- Part of the teaching syllabus in at least three Schools:
  - Chemical Engineering & Advanced Materials.
  - Marine Science & Technology.
  - Mechanical & Systems Engineering.
- In all three Schools, the students are formally introduced to CES EduPack in their first year.
- Students in later years often use it to support project work.

MODURBAN: Modular Urban Guided Rail Systems

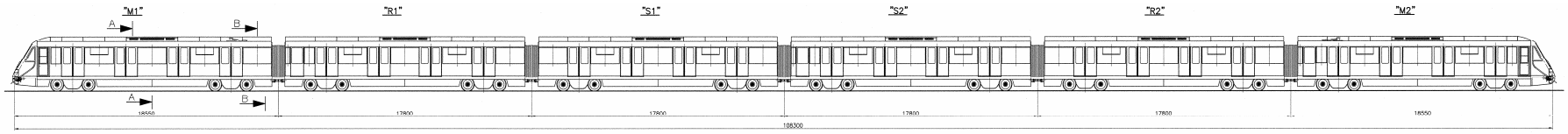


MODURBAN: “Removing Constraints on the Use of Lightweight Materials”

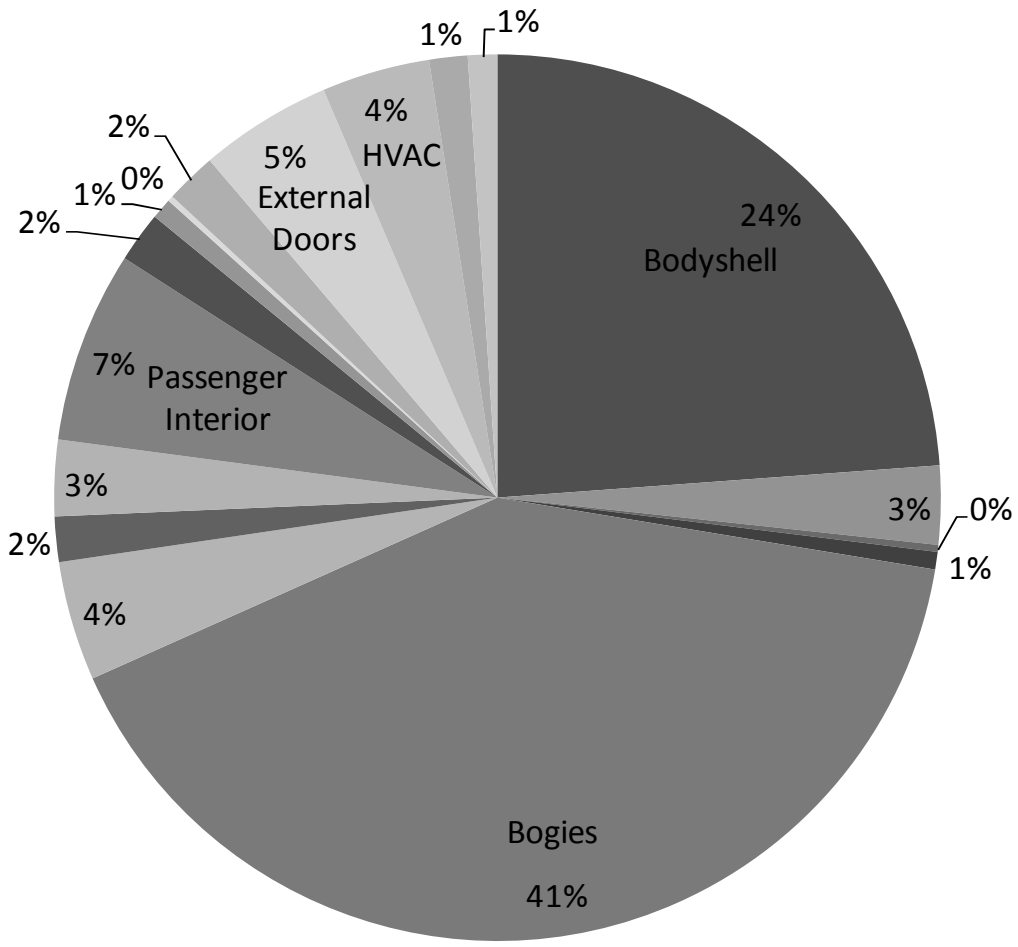
“ … to provide engineers in urban vehicle production with lightweight materials, concepts and designs in order to provide affordable vehicles with reduced weight” (and reduced energy consumption)

The benchmark vehicle

- Six car metro vehicle.
- Tare mass approximately 190 tonnes.
- Aluminium bodyshell.



Mass breakdown



- Bodyshell
- Windows
- Exterior Attachments
- Gangway
- Bogies
- Power / Propulsion
- Auxiliary Power Supply
- Brake System & Pneumatics
- Passenger Interior
- Seats
- Drivers Cab Interior & Cabinets
- Communication & Surveillance Systems
- Harnessing, Cables & Connectors
- External Doors
- HVAC
- Couplers
- Others

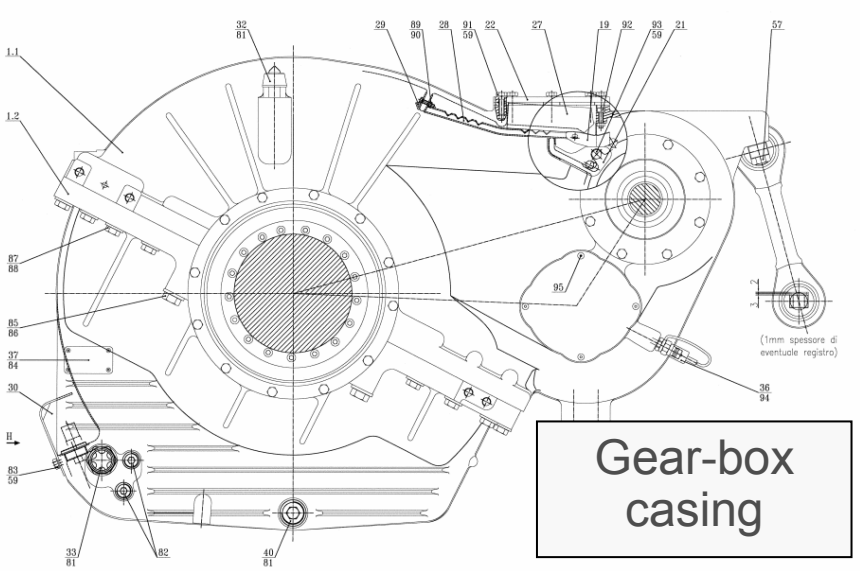
Material selection for lightweighting

- The rail vehicle designers within the project team identified the ***lack of reliable, comparable material property data*** as one of the current constraints to the use of lightweight materials.
- What they requested was:
  - A large (customisable) database that provides a global population of possible material options.
  - A means of sorting through that database in a systematic and rational manner in order to identify and compare only those materials that fulfil the requirements and constraints of the application considered.

CES Selector / Constructor

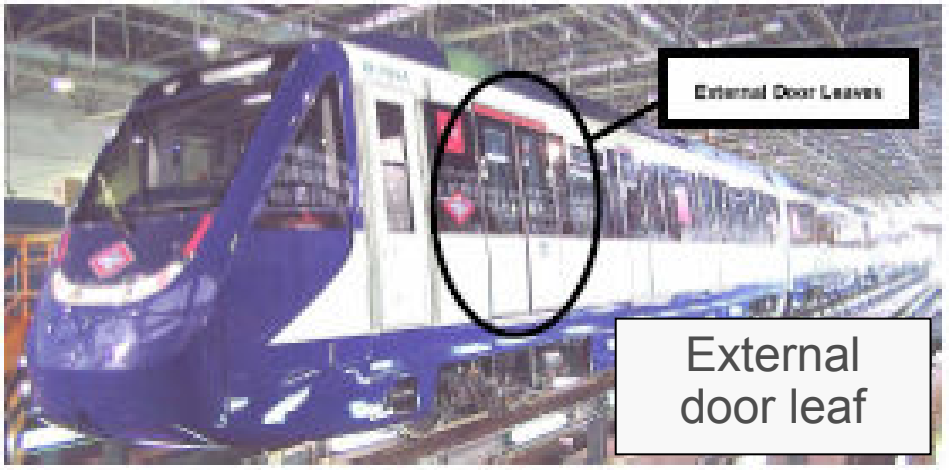
Four case studies

Grab rail



Gear-box casing

Floor panel



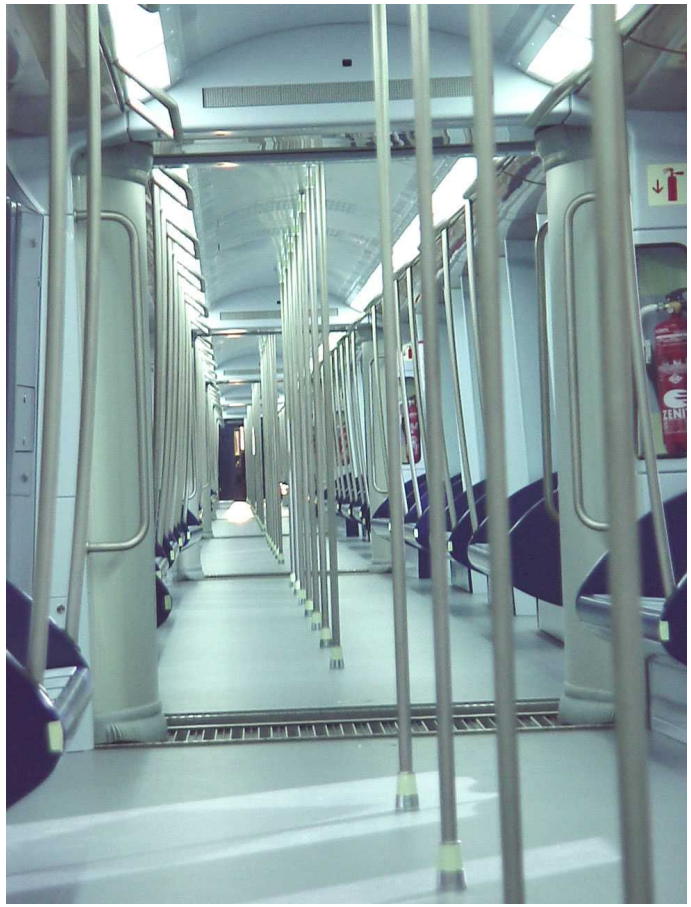
External door leaf

Case studies

Component	Individual Mass	Number per Six Car Metro Set	Overall Mass per Six Car Metro Set
Grab Rail	3.9 kg	180	0.7 tonnes
Gear-Box Casing	345 kg	16	5.5 tonnes
External Door Leaf	36.2 kg	96	3.5 tonnes
Floor Panel	10 kg/m^2	250 m^2	2.5 tonnes
		Total:	**12.2 tonnes**

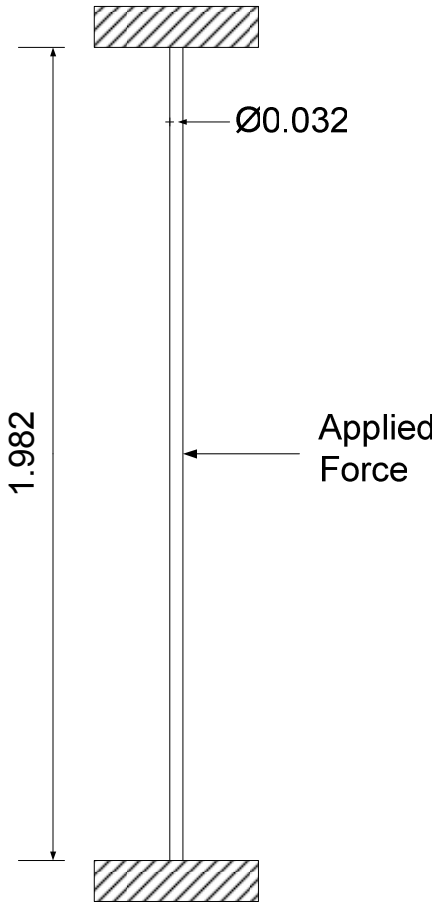
Example – grab rails

- Consider metro vehicle interior grab rails.
- Currently, these are typically made from stainless steel, steel or aluminium.
- Grab rails typically add more than half a tonne to the mass of a metro vehicle.
- ***Is there a material that could provide a lighter solution at similar cost and performance levels?***



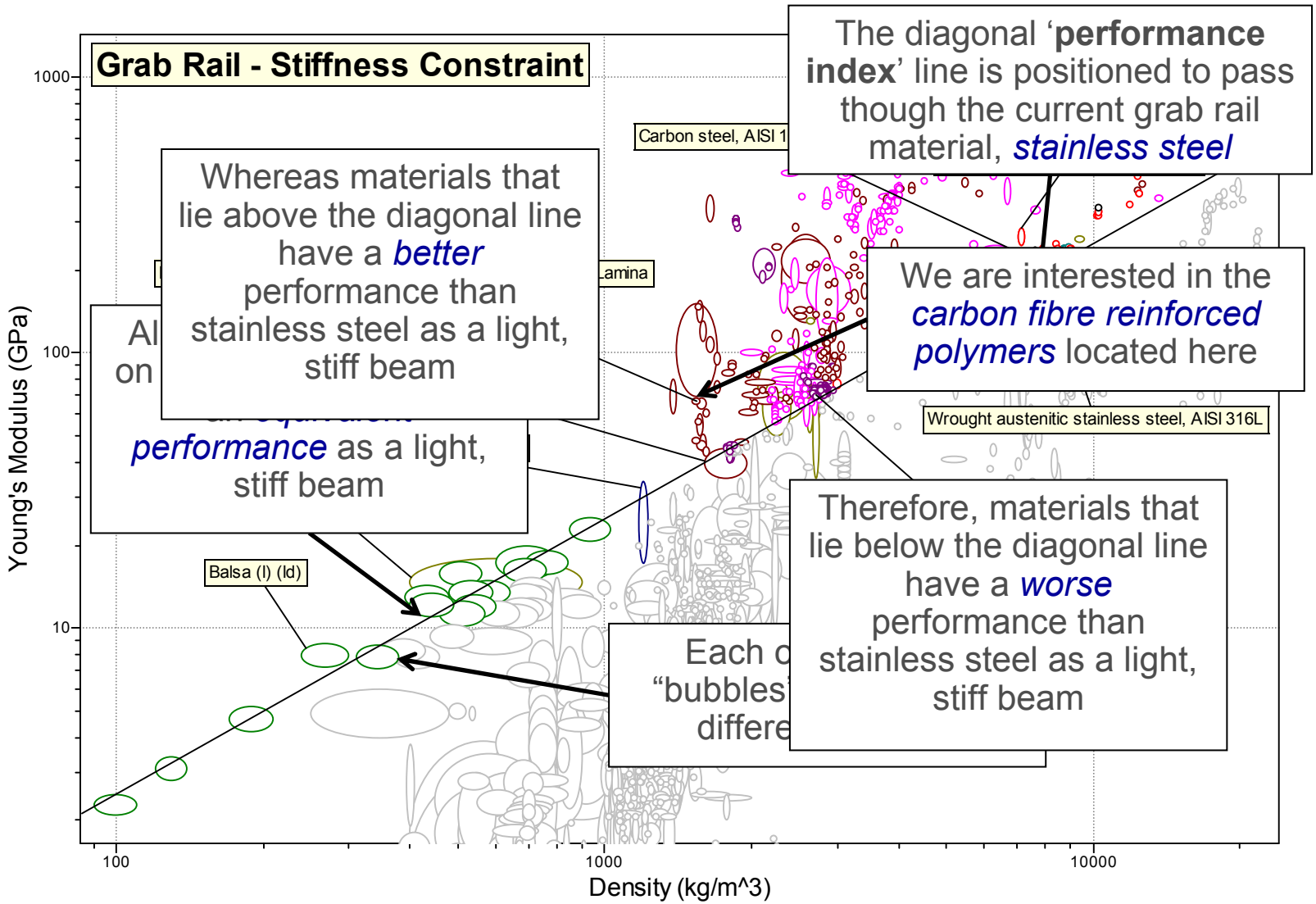
Problem definition

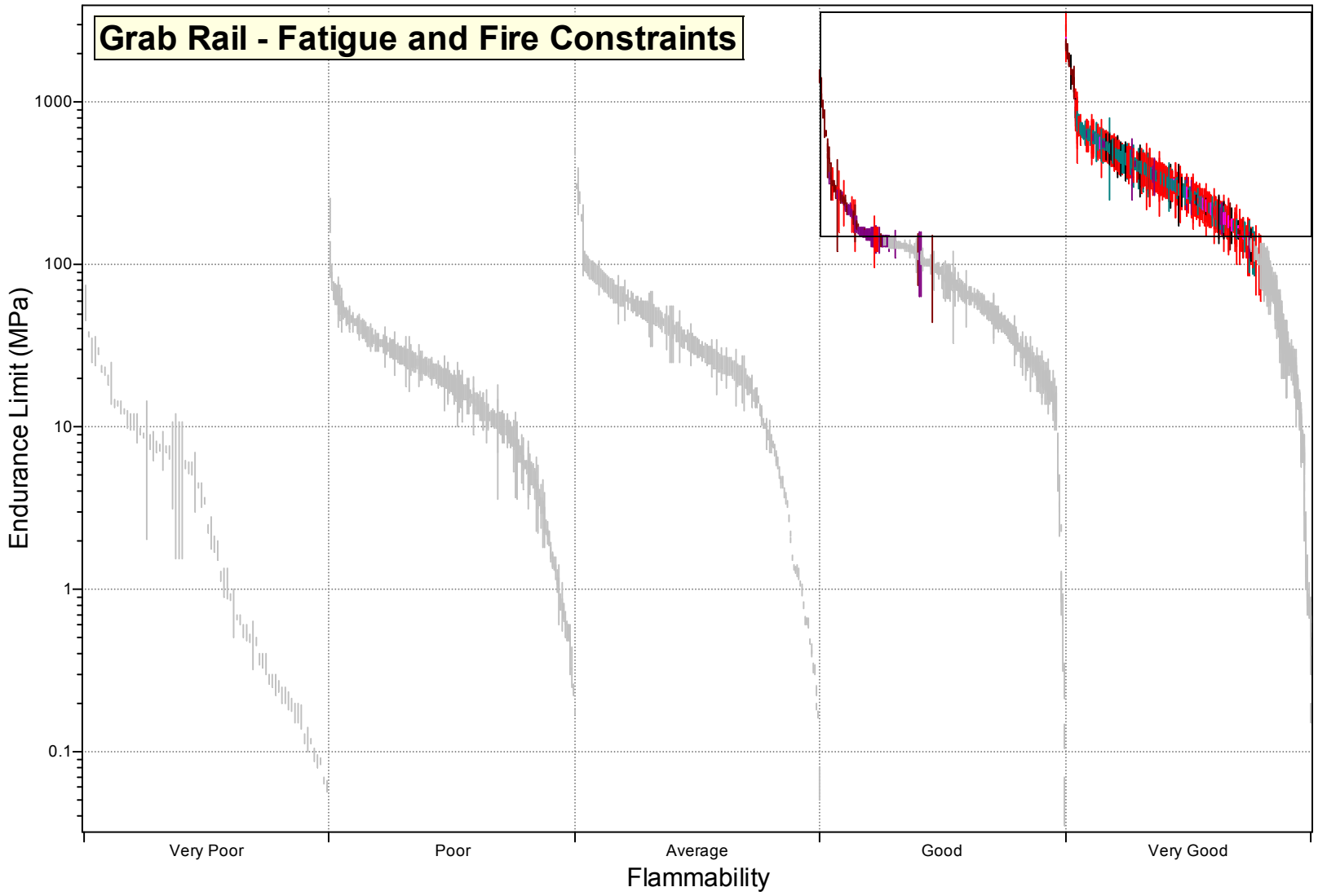
- Function:
  - Stiff beam to add the stability of standing passengers.
- Objective:
  - Minimise mass.

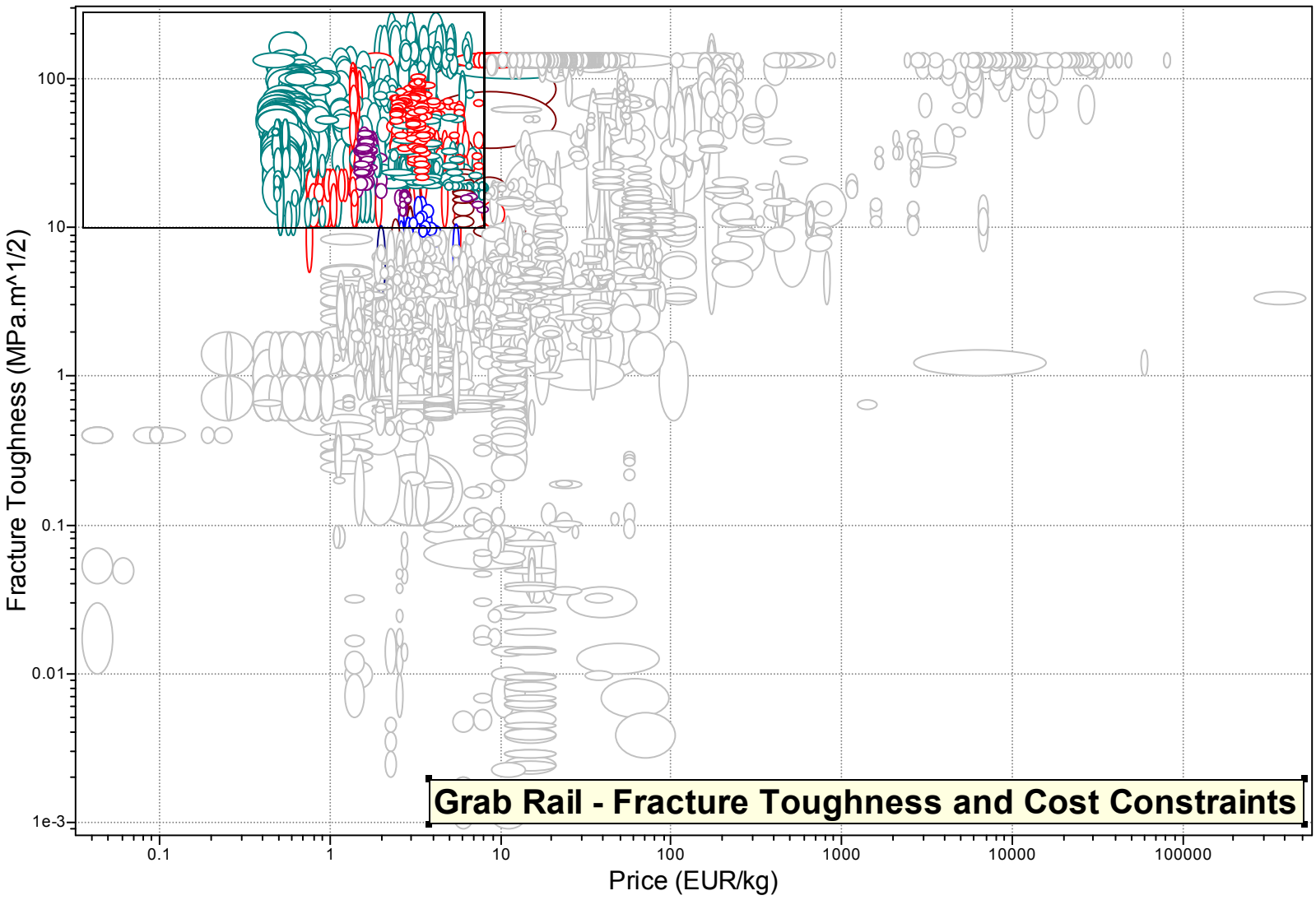


Problem definition (continued)

- Constraints:
  - Length and radius fixed.
  - Must be sufficiently stiff to support passengers.
  - Must not fail by fatigue in bending.
  - Must have a natural frequency above 30 Hz to avoid vibration issues.
  - Must have adequate fire performance.
  - Must be cost comparable to existing solutions.

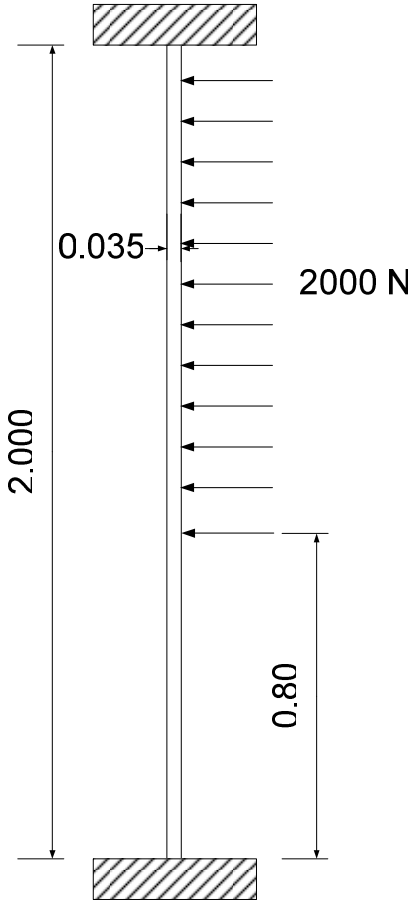

Grab Rail - Stiffness Constraint
The diagonal '**performance index**' line is positioned to pass though the current grab rail material, *stainless steel*
Whereas materials that lie above the diagonal line have a *better* performance than stainless steel as a light, stiff beam
We are interested in the *carbon fibre reinforced polymers* located here
performance as a light, stiff beam
Therefore, materials that lie below the diagonal line have a *worse* performance than stainless steel as a light, stiff beam
Carbon steel, AISI 1
Lamina
Wrought austenitic stainless steel, AISI 316L
Balsa (l) (ld)
Young's Modulus (GPa)
1000
100
10
100
1000
10000
Density (kg/m^3)


Grab Rail - Fatigue and Fire Constraints
1000
100
10
1
0.1
Endurance Limit (MPa)
Very Poor
Poor
Average
Good
Very Good
Flammability


Fracture Toughness (MPa.m^1/2)
100
10
1
0.1
0.01
1e-3
0.1
1
10
100
1000
10000
100000
Price (EUR/kg)
Grab Rail - Fracture Toughness and Cost Constraints

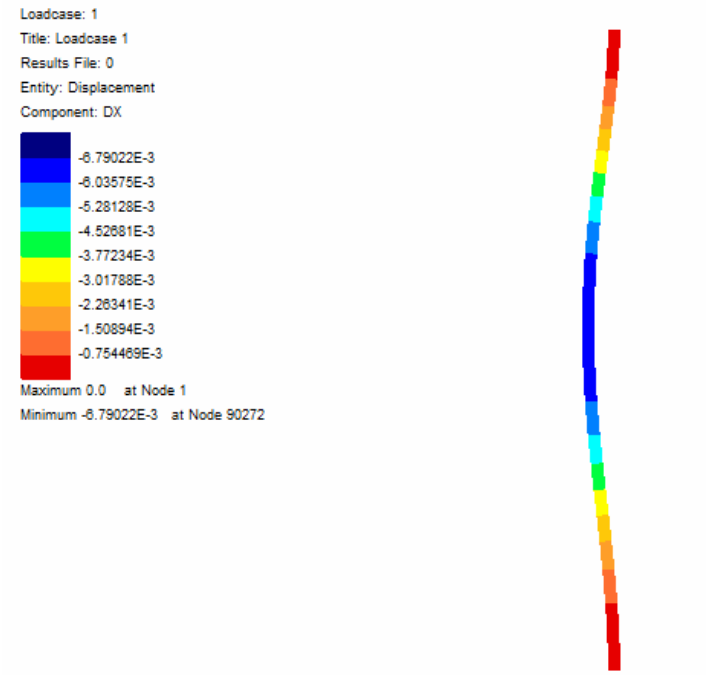
Lightweight grab rail: detailed design

- The CES material selection software suggested that a grab rail manufactured from a ***carbon fibre reinforced polymer*** would provide a significant weight saving.
- For the load case shown, a typical stainless steel grab rail would have a predicted maximum deflection of 6.3 mm.
- Can a **carbon fibre reinforced polymer** grab rail really provide similar performance with reduced mass?



Lightweight grab rail: predicted weight saving

- Material = carbon fibre reinforced modified acrylic.
- Outside diameter = 38.1mm.
- Wall thickness = 6.35mm.
- Maximum deflection for previous load case = 6.8 mm (i.e. similar to stainless steel).
- Weight saving compared to stainless steel = 57%.



Lightweight grab rail: wider design aspects

- The modified acrylic matrix resin and paint system employed have been specified to provide the required levels of ***fire performance***.
- The paint system has also been specified to provide the required resistance to ***scratching***, ***impact***, ***chipping***, ***abrasion*** and ***graffiti***.

Lightweight grab rail: prototyping

- The lightweight carbon fibre reinforced polymer grab rail was prototyped in collaboration with ***Exel Composites UK***.
- ***Real (measured) mass saving = 57%***.
- The prototypes were produced using a continuous manufacturing process known as ***pullwinding***.
- In sufficient volumes, the resulting tubes are ***less costly*** than the equivalent stainless steel.

Lightweight grab rail: demonstration

Summary of mass saving benefits

- Using the MODURBAN energy model it has been estimated that a 10% saving in metro vehicle mass would provide:
  - A 7% saving in energy consumption.
  - A 100,000€ annual cost saving per vehicle due to reduced energy consumption.

With thanks to the European Commission ...

- ... for supporting MODURBAN under contract number TIP4-CT-2005-516380 ...

And Exel Composites UK ...

- ... who kindly prototyped the lightweight grab rails.

For more information ...

- ... please contact Joe Carruthers,
  - joe.carruthers@ncl.ac.uk
  - www.newrail.org
- ... and see:
  - Carruthers, J.J., Calomfirescu, M., Ghys, P, Prockat, J., "The application of a systematic approach to material selection for the lightweighting of metro vehicles", *Proceedings of the Institution of Mechanical Engineers Part F: Journal of Rail and Rapid Transit,* 223(5), 427-437, (2009).
  - Available at http://eprint.ncl.ac.uk/.