*Fig. 4: NGT - train of the future.*

# Next Generation Train - The Revolution

**The DLR (Deutsches Zentrum für Luft- und Raumfahrt) is widely known as a governmental German aerospace research organisation with a workforce of about 7,000 - most of them scientists. Over the past ten years security, energy and transport research areas have been added to DLR's range of activities. From 2007 transport research for rail vehicles has engaged the capabilities of several DLR institutes in one theme - the Next Generation Train (NGT). 18 departments of nine institutes are involved in this DLR project until end of 2013. A prolongation until 2018 is being prepared, and depends upon the approval of the Helmholtz Society, which supervises the German research centres.**

As it is not possible to describe the full scope of the NGT project here we refer interested readers to [1]. This research contribution pays attention to the high speed train concept and the construction of lightweight carriages.

From 1911, when the first scheduled electrified railway services in Dessau (Germany) started, until today the railway has been the most environmental friendly means of mechanised transport that exists. In 2008 the mechanised transport sector contributed 25 % to the EU's **greenhouse gas** emissions. Road transport is responsible for 70.8 % of the overall emissions, civil aviation 12.7 %, sea transport 13.5 %, inland waterways vessels 1.7 % and rail just 0.6 % [2]. The electrified rail network, usually independent from the national grid, makes use of low-carbon electricity. On top of this the energy consumption, $CO_2$ and exhaust emissions of rail transport amount to 0.11 kWh/pkm and 0.06 kWh/tkm, much lower than road transport, which generates 0.47 kWh/pkm and 0.47 kWh/tkm [2].

In terms of land take, a double track railway will have the same traffic capacity as a motorway of up to 16 lanes [2]. Accident levels are approximately 200 times greater for road than for rail transport [2]. Several objectives of the NGT project are aiming to keep the leading position of the railway as a safe and „green" one and to make it more comfortable for users.

## Energy-Saving Potential For Rail Vehicles

### Basic Simulation Conditions

Simulation calculations help determine how much energy can be saved by reducing for example vehicle mass. We used a simple longitudinally dynamic vehicle model for simulation purposes, whereby mass is assumed to be punctiform. Since neither curve resistance nor climbing resistance is considered, assuming punctiform mass will not affect the calculated energy requirement [3]. **Three vehicle types** are considered, each of which represents one category of railway transport:

- high speed is represented by a Class 403 ICE3 EMU,
- electrified suburban and middle distance operations are represented by a Class 423 EMU,
- diesel-powered suburban and middle distance train services are represented by a Class 611 DMU.

Tractive power characteristic curves at the wheel describe the vehicles' drive systems; tractive power and drive power are independent of mass. Tractive and braking forces are limited by the frictional connection between the wheel and rail. Frictional connection specifications as laid down in TSI HGV [4] are used here, whereby the proportion of powered axles is considered. The speed-dependent operational deceleration of TSI HGV is used for all brakings. Constant efficiency is assumed for the drive systems. **Driving resistance** is described with the Davis formula:

$$F_{Resistance} = A + B \cdot v + C \cdot v^2$$

| | | BR403 | BR423 | BR611 |
|---|---|---|---|---|
| Empty mass | tons | 409 | 105 | 92.9 |
| Occupied mass | tons | 442.2 | 119.4 | 115.7 |
| Mass for v-t profile | tons | 458 | 124 | 120 |
| Minimum mass | tons | 309.54 | 83.58 | 80.99 |
| Dyn. mass (fix) | tons | 28 | 7.5 | 6 |
| Davis A | N/t | 8.1 | 23 | 17 |
| Davis B | N/(m/s) | 81.2 | 48.2 | 37.1 |
| Davis C | N/(m/s)² | 7.154 | 6.480 | 3.758 |
| Max. speed | km/h | 330 | 140 | 160 |
| Starting tractive effort | kN | 300 | 120 | 120 |
| Max. drive power at wheel | kW | 8000 | 2350 | 900 |
| Recovery power at wheel | kW | 8000 | 2350 | 0 |
| Max. accel. | m/s² | 1.2 | 1.2 | 1.2 |
| Braking decel. | m/s² | TSI operational | TSI operational | TSI operational |
| Efficiency of drive/recoveries | % | 80 / 75 | 80 / 75 | 30 / 0 |
| UIC service profiles | | Intercity, HST | Suburban, Regional, Intercity | Suburban, Regional, Intercity |
| Data sources | | [7 ] [8 ] | [9] [8 ] | [5] [10 ] |

*Table 1: Vehicle data used in simulations of driving resistance.*

This is divided into mass-dependent and mass-independent components. According to Wende [5], in the Davis resistance formula coefficient A is in the first approximation directly dependent on mass, while coefficients B and C are independent of mass. Table 1 compiles vehicle data used in the simulations. The traction energy requirement is determined using service profiles published by the UIC in Technical Recommendation 100-001 [6]. These standardised profiles describe typical **operational scenarios** for rail vehicles in suburban, middle distance, inter-city, and high speed service. Table 2 compiles the most important data of the service profiles.

Separate travel times are defined for each vehicle and each service profile. Additionally, a simulation with a vehicle whose mass exceeds the occupied mass was conducted at the highest feasible speed in order to determine the standard travel times between the individual stations. In order to determine the influence of vehicle mass, mass was reduced in the simulations in steps of 2.5 % until 70 % of the occupied mass was reached.

### Results Of Simulation Calculations

The simulations have shown that the potential for savings through reduction of vehicle mass is dominated by the characteristics of the service profile. There is a particularly high potential for savings with service profiles that have short inter-station distances and low maximum speeds. As the maximum speed increases, the proportion of energy needed to overcome aerodynamic resistance also increases and the potential for savings diminishes.

The potential for savings with **DMUs** is up to four times greater than with electrically-powered vehicles because the latter can recover a portion of the kinetic energy during braking. However, if the electric braking power is not adequate to achieve the required deceleration, then the potential for savings also increases with electrically-powered vehicles. Table 3 summarises the achievable energy savings, expressed per metric tonne of reduced vehicle mass as well as in terms of a weight reduction of 10 % of the occupied mass.

### Costs Of Lightweight Construction

In conclusion, we derive from the calculated energy savings the costs that may arise for eliminating 1 kg of vehicle mass so these costs can be amortised through energy savings over the lifetime of the vehicle. We make the following **assumptions** for calculating cost savings:

- yearly mileage according to data in the service profile in Table 2,
- vehicle service life of 30 years,
- price for electrical energy from the pantograph 12.44 Ct/kWh (in euros),
- cost of diesel fuel 1.15 euros/litre corresponding to 11.533 Ct/kWh (in euros).

Interest payments on employed capital and increasing energy costs are not taken into consideration. Table 4 contains the calculated values for each vehicle and service profile. The listing clearly shows that the expense of reducing weight is amortised faster with DMUs than with electric vehicles.

The identified potential energy savings of high speed trains is significantly larger in the event of the annual service performance being taken into account. Nevertheless for high speed trains the **axle-weight** of less than 17 tonnes [4] is the most challenging issue. Both objectives can be achieved through lightweight construction of rail vehicles. Lightweight construction of the bodyshell plays a major role. Thus, within the NGT project we have developed a method that provides a good foundation for creating a lightweight structure. This method is described in the following section.

| Type | Suburban | Regional | Intercity | High-Speed |
|---|---|---|---|---|
| Total distance km | 40 | 70 | 250 | 300 |
| Number of stations | 12 | 15 | 10 | 3 |
| Maximum speed km/h | 120 | 140 | 200 | 300 |
| Min. station distance km | 2 | 2 | 15 | 90 |
| Max. station distance km | 7 | 10 | 60 | 210 |
| Mileage km/year | 100000 | 130000 | 275000 | 550000 |

*Table 2: Service profile by type of train.*

| Energy savings in kWh/100km | | | Vehicle | | |
|---|---|---|---|---|---|
| | | | DMU BR611 | EMU BR423 | HST BR403 |
| Service Profile | Suburban | per metric ton | 22.0 | 4.0 | --- |
| | | 10% mass red. | 255 | 48 | --- |
| | Regional | per metric ton | 20.6 | 3.8 | --- |
| | | 10% mass red. | 238 | 46 | --- |
| | Intercity | per metric ton | 5.2 | 1.3 | 1.2 |
| | | 10% mass red. | 60 | 15 | 54 |
| | High-Speed | per metric ton | --- | --- | 0.7 |
| | | 10% mass red. | --- | --- | 32 |

*Table 3: Calculated savings potential through mass reduction, in kWh/100 km, by service profile.*

| | | Service Profile | | | |
|---|---|---|---|---|---|
| | | Suburban | Regional | Intercity | High-Speed |
| Vehicle | BR611 - DMU | 76 | 96 | 50 | --- |
| | BR423 - EMU | 15 | 19 | 13 | --- |
| | BR403 - HST | --- | --- | 12 | 15 |
| | | | | | |

*Table 4: Energy savings from a 10 % reduction in mass, in euros/kg.*

## Train Concept

### Derivation And Evaluation Of Rail Vehicle Concepts

To define an optimum solution for a rail vehicle, different train configurations (an individual railcar, an articulated trainset, and running gear construction and layout), car structures (single deck, double deck and maximum width) and propulsion possibilities (type, layout and power supply) were systematically combined, analysed and evaluated using selected comparison criteria and compared with vehicles already in use [11].

## Development In High Speed Traffic

In rail traffic terms, an operating speed of 200 km/h or more is designated as high speed [12]. As many multiple-unit train sets are running faster than 200 km/h today we are talking about high speed defined as between 200 and 300 km/h, very high speed defined as between 300 and 400 km/h and ultra high speed between 400 and 500(+) km/h.

In **recent decades** the development of the TGV, the ICE and the Shinkansen trains played a prominent role in evolving high speed international services. These and other types of rail vehicle are predominantly employed and have been further developed in various countries in Europe and Asia. They differ considerably in design characteristics and show that speeds of up to 400 km/h can be achieved in regular operation in different ways. The Chinese railways ran their CRH 380 trains for some months in late 2010 and early 2011 at scheduled speeds of 420 km/h and achieved a record for non-modified passenger trains at 486 km/h. They then had to reduce scheduled speeds to 250 km/h and 300 km/h afterwards, to allow the simultaneous operation of trains of various maximum speeds on

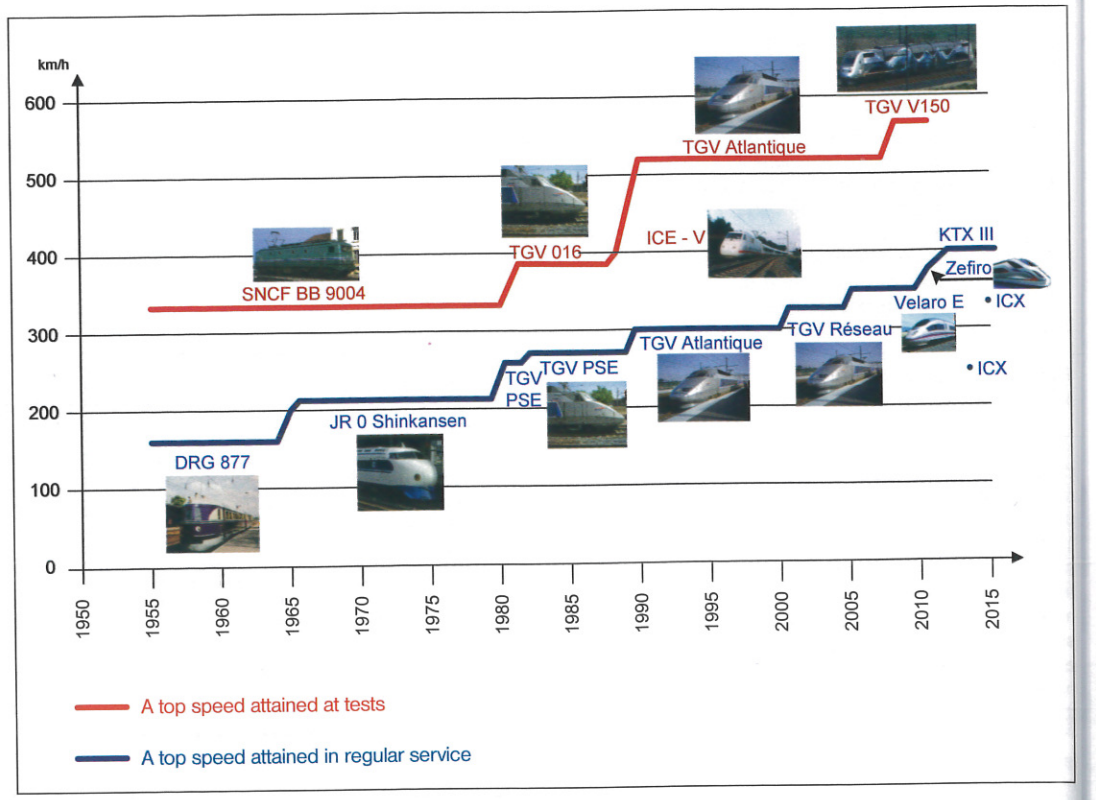

*Fig. 1:* ***Evolution of top speeds for rail vehicles [13].***

*Table 5:* ***Comparison of high-speed trains, data compiled from the following references: [12, 16, 17, 18, 19, 14, 20, 21, 22, 23, 24, 25].***

| Vehicle / Class | Year Of Building / Start Of Operation | Maximum Speed [km/h] | Train Length [m] | Empty Weight [kg] | Number Of Seats [-] | Traction Power at 25 kV 50 Hz [kW] | Traction Power at 25 kV 60 Hz [kW] | Traction Power at 20 kV 50 Hz [kW] | Traction Power at 1.5 kV DC | Traction Power at 3 kV DC | Traction Power at 15 kV 16.7 Hz | Traction Power at 750 V DC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ICE 1, 401, Einsys., 12 Wagen | 1989 | 280 | 358 | 798000 | 685 | | | | | | 9600 | |
| ICE 2, 402, Eisys. | 1995 | 280 | 205 | 418000 | 391 | | | | | | 4800 | |
| ICE 3, 403, Einsys. | 1997 | 330 | 200 | 409000 | 441 | | | | | | 8000 | |
| ICE 3, 406, Mehrsys. | 1997 | 330 (AC) | 200 | 435000 | 431 | 8000 | | | 3600 | 4300 | 8000 | |
| Velaro D / ICE 3, 407 | 2011 | 320 | 200 | 454000 | 360 | 8000 | | | 4200 | 4200 | 8000 | |
| Velaro E / AVE S-103 | 2001 | 350 | 200 | 425000 | 404 | 8800 | | | | | | |
| TGV Sud-Est | 1981 | 270 | 200,2 | 384000 | 386 | 6400 | | | 3100 | | 2800 | |
| TGV Atlantique | 1988 | 300 | 237,6 | 450000 | 485 | 8800 | | | 3600 | | | |
| TGV Réseau | 1993 | 300 | 200,2 | 385000 | 377 | 8800 | | | 3680 | 3680 | | |
| Eurostar | 1994 | 300 | 393,7 | 723000 | 794 | 12240 | | | 4000 | 5700 | | 3400 |
| Eurostar | 1997 | 300 | 318,9 | 620000 | 578 | 12240 | | | | 5700 | | 3400 |
| Thalys PBA | 1996 | 300 | 200,2 | 385000 | 377 | 8800 | | | 3680 | 3680 | | |
| TGV Duplex | 1995 | 300 | 200,2 | 380000 | 516 | 8800 | | | 3680 | | | |
| Thalys PBKA | 1997 | 300 | 200,2 | 385000 | 377 | 8800 | | | 3680 | 3680 | 3680 | |
| Shinkansen 100 | 1985 | 220 | 395 | | 1321 | | 11000 | | | | | |
| Shinkansen 200 | 1980 | 210 | 300,3 | 702000 | 885 | 11040 | | | | | | |
| Shinkansen 300 | 1992 | 270 | 395 | | 1323 | | 12000 | | | | | |
| Shinkansen 400 | 1991 | 240 | 128,2 | 278000 | 335 | 5040 | | 5040 | | | | |
| Shinkansen 500 | 1996 | 300 | 404 | 688000 | 1324 | | 17600 | | | | | |
| Shinkansen 700 | 1999 | 270 | 404,7 | 708000 | 1323 | | 13200 | | | | | |
| Shinkansen JR E1 | 1994 | 240 | 302 | 692000 | 1235 | 9840 | | | | | | |
| Shinkansen JR E2 | 1997 | 275 | 201,4 | 366000 | 630 | 7200 | 7200 | | | | | |
| Shinkansen JR E3 | 1997 | 275 | 107,65 | 220000 | 270 | 4800 | | 4800 | | | | |
| Shinkansen JR E4 | 1997 | 240 | 204,7 | 428000 | 817 | 6720 | | | | | | |
| AGV11 | 2008 | 360 | 200 | 375000 | 446 | 9400 | | | | | | |
| CRH3 / Velaro | 2005 | 300 | 200 | 447000 | 556 | 8800 | | | | | | |
| CRH3 350 / Velaro | 2005 | 350 | 400 | 1000000 | 1025 | 9200 | | | | | | |
| AVE S-130, Talgo 250 | 2008 | 250 | 180 | 312000 | 299 | 2400 | | | | 2000 | | |
| AVE S-102, Talgo 350 | 1998 | 330 | 200 | | 318 | 8000 | | | | | | |
| ETR 470 Cisalpino | 1993 | 200 | 236,6 | 798000 | 475 | | | | | 6000 | 6000 | |
| ETR 500, 1. Gen. (nach Umbau) | 1990 | 250 | 327,6 | 642000 | 662 | | | | | 8800 | | |
| KTX | 1995 | 300 | 388,1 | 701000 | 965 | | 13200 | | | | | |
| KTX-II | 2008 | 305 | 201 | 403000 | 358 | | 8800 | | | | | |

the line and to save energy costs (see Fig. 1 and Table 5).

**Propulsion concepts** offer different possibilities with regard to propulsion type, layout and energy supply. The first high speed trains were designed as trainsets with electric (or diesel in the case of the British HST) power cars/locomotives. The HST and TGV are in fact multiple units, but do not have distributed traction. Only with the development of the Shinkansen trains and (starting around three decades later) the ICE3 trains was it possible to move from this design to multiple unit trainsets with distributed traction under all or some of the cars. This concept has the particular advantage that the end cars can be used for passenger accommodation. Moreover, acceleration (and deceleration) can be improved because of the distribution of the power to different wheelsets [15].

In addition to steam, diesel or gas turbine traction, electric drivelines are most widely used. In high speed operations, for example, conventional electric AC or DC propulsion systems and running gears or linear motors and magnetic fields are used, such as on the Transrapid [11, 14, 15].

In the analysis of these different concepts it became particularly clear that **specific requirements** have led to very different vehicle configurations. For example, because of the wider loading gauge in Japan, compared with Europe, an additional row of seats is possible in both single and double deck vehicles. This is reflected not only in the specific number of seats per running metre but also in the seat weight, which then influences the propulsion equipment and the furnishing (Fig. 2). Based on these considerations alone, it becomes apparent that any new rail vehicle concept has to be optimised with respect to specific local requirements.

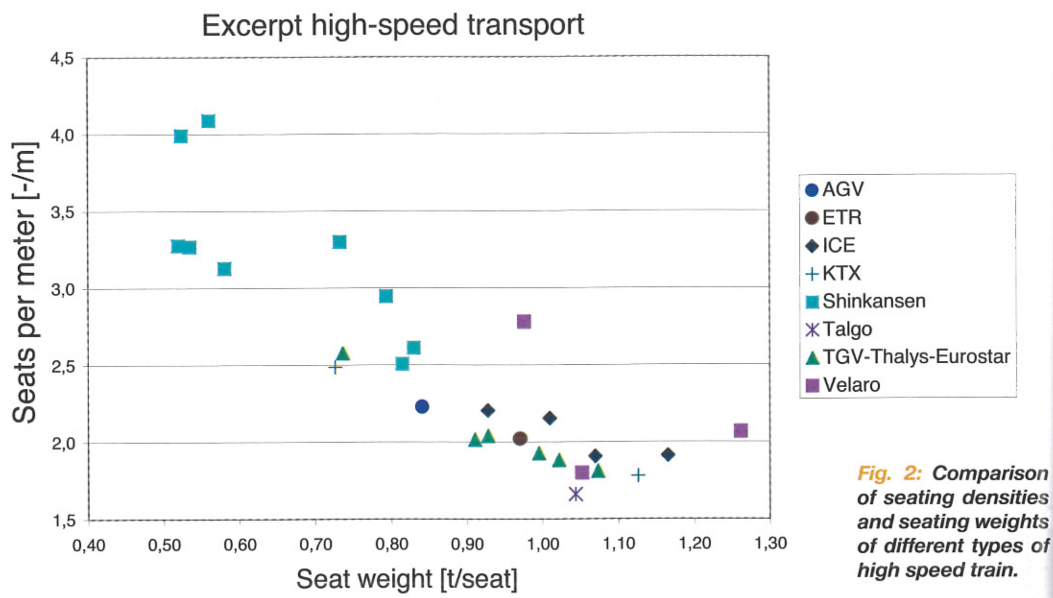

*Fig. 2: Comparison of seating densities and seating weights of different types of high speed train.*

## Vehicle Concept Of The Next Generation Train

There are eight higher level objectives to be specially singled out in the foreground for the design of the Next Generation Train, in addition to other important requirements [13]:

- increase in the permitted speed to 400 km/h,
- halving the specific energy demand compared with that of the ICE3 operating at 300 km/h,
- reduction of running and aerodynamic noise,
- increase in passenger comfort,
- improvement in vehicle safety,
- reduction of wear and life cycle costs,
- use of modularisation and system integration for cost-efficient construction,
- improvement of the efficiency of development and approval processes.

Based on this initial situation all technical possibilities for the vehicle concept must be taken into consideration. The analyses regarding maximum construction volume passenger capacity, energy reducing measures, such as improved aerodynamics and innovative energy transfer, vehicle dynamics or lightweight construction, and various other advantages and disadvantages of the concepts lead to the choice of the **individual car principle** [26]. Here, because of the greater car width, individual cars with a length of only 20 m (and with a distance of 17 m between running gear pivots) run on low-wear mechatronic two-wheel sets of running gear, rather than four-wheel bogies.

The optimisation of the rail vehicle concept with regard to energy demand per seat also results in a double deck vehicle with continuous decks without stairs offering space for around 800 passengers, of whom about 40 % are in 1st class on the upper deck, where accommodation includes a restaurant, „mother and child" compartments and compartments for persons with limited mobility. As much technical functionality as possible is integrated into the bodyshell structure here in order to make the best possible use of the G2 loading gauge. This conforms with the standards laid down by the EBO (Eisenbahn-Bau- und Betriebsordnung). In comparison with the international G1 European loading gauge, which permits a maximum height above rail top of 4,280 mm, the G2 is a more generous German clearance, permitting a maximum vehicle height of 4,650 mm.

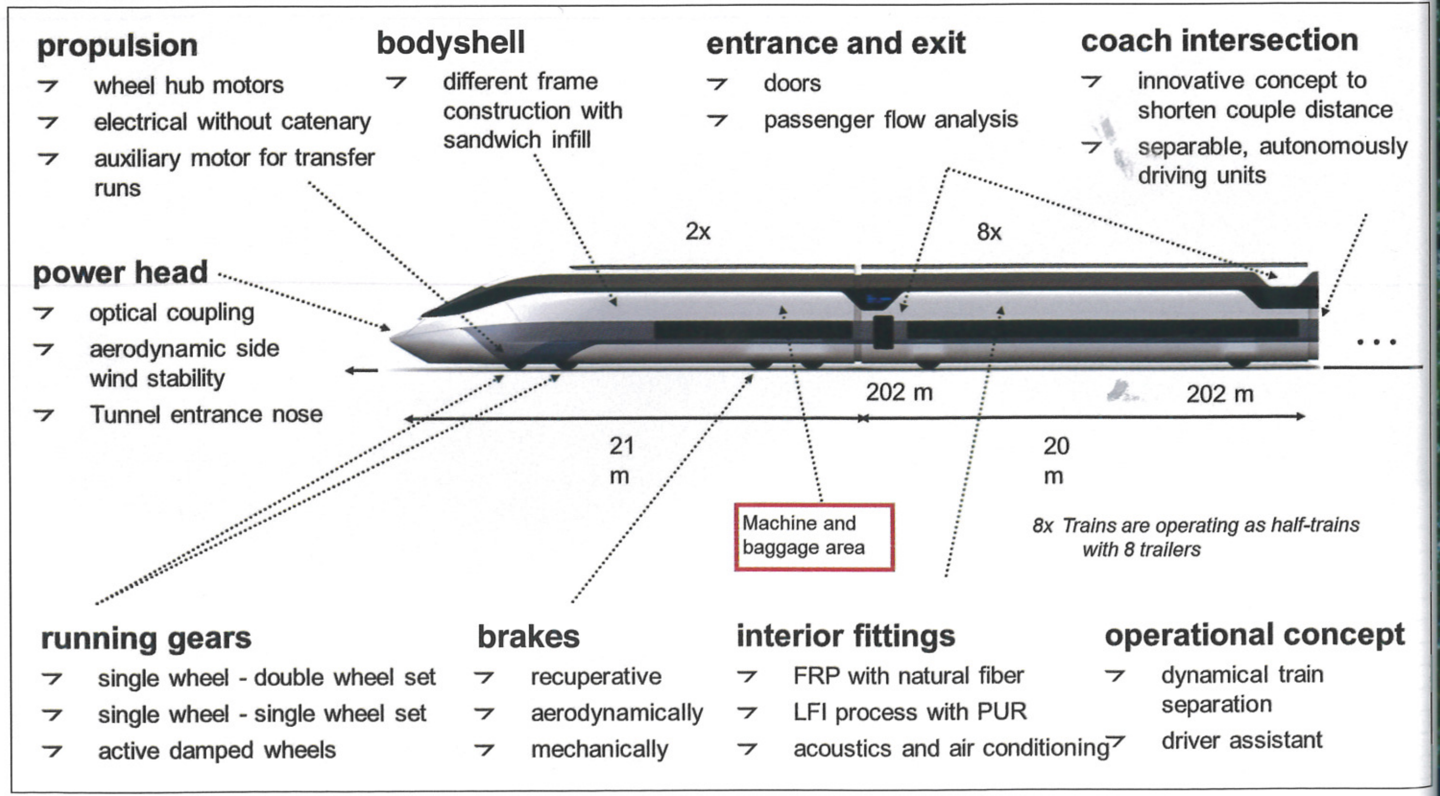

*Fig. 3: Diagram showing the proposed NGT EMU concept.*

Thus the NGT **double deck cars** allow for an aisle headroom of around 2,000 mm on each deck, throughout the vehicle. Passengers can board and disembark from the deck where they have their seat reservation, so this means that flights of stairs are not needed in all cars. Passengers visiting the restaurant, persons with limited mobility and train crews can use the lift in the centre car between decks. Passenger luggage is stowed in a separate area in the end cars of the train, using a baggage handling unit. To achieve faster boarding and alighting, door design and the configuration of interior fittings are determined by a passenger flow analysis [27].

From eight intermediate carriages and two end cars, a completely double deck EMU is created, 202 m in length (Fig. 3). A full train consists of two such EMUs, 410 m long (including the telecontrolled clutch). The aerodynamic head wave of such a train can be reduced by a substantial **thickness ratio** of the end car nose. A medium thickness ratio is used for the NGT because on very high and ultra-high speed routes it is usually planned to build single tube tunnels, with a form of feed hoppers at the portals to manage the continuous air displacement as trains pass through. The side wind susceptibility of the light front sections of the EMU will possibly be reduced by active control surfaces, aerodynamic pressure balance [28], or inductive means on the train's end car nose and/or on the first intermediate car. Fig. 4 shows an artists impression of the train.

## Propulsion And Braking Concept

The propulsion and braking concept makes a key contribution to achieving the desired technical performance parameters and to determining the energy requirements and therefore the environmental compatibility of each rail vehicle.

The **energy supply** of the NGT EMU is future-oriented and envisaged to be situated in the track. This means that high maintenance overhead catenary is no longer required. The propulsion concept is envisaged to incorporate a contact-free current collection from the track distributed along the whole length of the train. This means that there is no longer a requirement for noisy pantographs, which have a rapid wear rate. Each end car of the train provides about 25 % of the traction power of about 18 MW, the remaining drive power is produced by the traction motors of the 32 single wheel running gears. These motors are located near the wheels. Instead of two-axle bogies the single wheels are preferred, since they allow to pass through on the lower deck, and the number of wheelsets is reduced when compared to bogies. Thus the weight is significantly reduced.

The acceleration of this EMU is therefore above average. The double decker high speed version will be built for a service speed of 400 km/h, which means that it will be approved for 440 km/h [29].

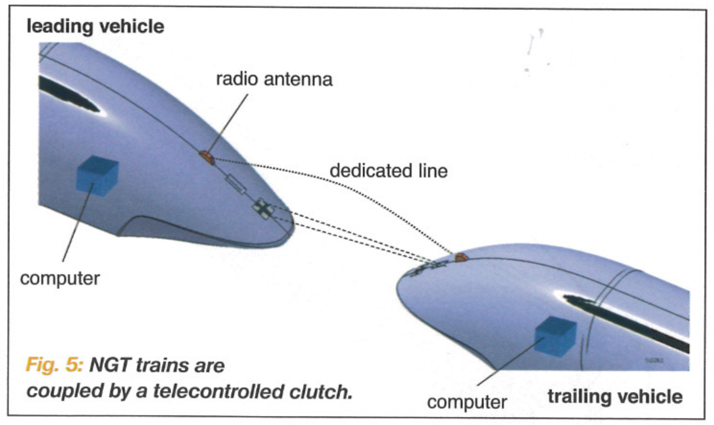

*Fig. 5: NGT trains are coupled by a telecontrolled clutch.*

The **braking** concept provides for the use of different brakes depending on the speed. The train is driven in an advanced, eco-friendly manner, with a driver assistant, aimed at coasting rather than braking to reduce speed. Should this prove insufficient, at high speeds, additional aerodynamic and regenerative braking is applied. Linear eddy-current brakes will be used at lower speeds. The stopping distance for applied service brakes in this way can be reduced to 10 km from 440 km/h on a gradient of 40 ‰ and with a tailwind of 15 km/h compared to the TSI requirement of 21 km from 440 km/h (no gradient, no tailwind).

Yet that is still quite a long distance compared with the ICE3, which has a stopping distance for applied emergency brakes of 3.3 km from 330 km/h. It is technically possible to shorten the stopping distance even more, but that would probably require taking additional measures to ensure passenger safety. As long as the block distance separation applies the braking distance is limiting the line throughput.

Because the braking system is controlled electrically, the NGT will not have compressed air ducts. The disc brake is to be used as a parking brake only. In the event that the train has to be towed, electro-hydraulically operated brakes are to be used.

## Telecontrolled Coupling

Several EMUs can be coupled together by a telecontrolled clutch. Through a geometric target point, optical sensors observe the state of the train in front. Simultaneously, the trainset driver control commands, via **radio communication,** of the propulsion and braking system control the whole train,

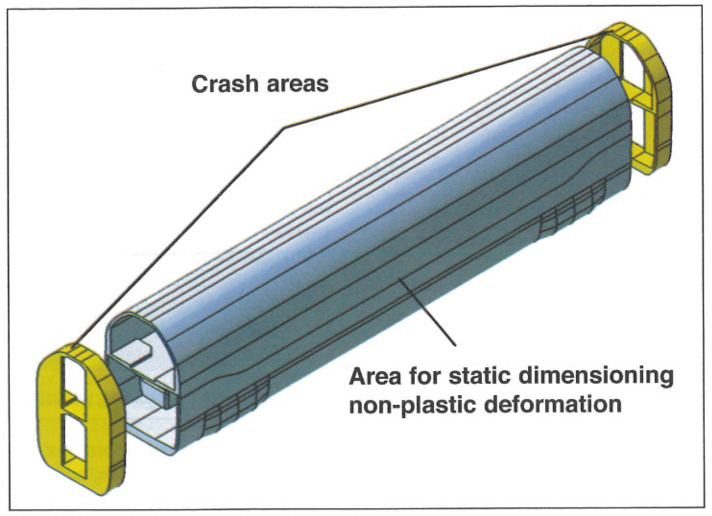

*Fig. 6:* ***Subdivision of the bodyshell into crash absorbing and centre zones.***

so that the weakest link of the train determines the longitudinal dynamics. The operating flexibility is further increased by the possibility to split and couple trainsets en route to serve different destinations (Fig. 5). Following the introduction of flexible train spacing as a principle of train protection it would be possible to further increase line capacity.

### Methodology For Creating Force Flow Optimised Bodyshell Structures

Creation of a force flow optimised bodyshell structure is offered by topology optimisation methods. In topology optimisation the relevant main load paths are identified using numerical calculations. The programmes for topology optimisation currently available on the open market only take account of static loads. This means that the bodyshells have to be divided into areas which predominantly satisfy either static or dynamic crash loads.

According to the methodology used here the bodyshell is divided into **three segments**. The two outer crash segments absorb the crash energies, as specified by EN 15227. The crash segments further limit the maximum loads on the link points with the centre segment, meaning that the latter must be designed expressly to correspond to the static loads. Based on the results of the topology optimisation, conclusions can be drawn on a favourable bodyshell structure from a lightweight construction point of view (Fig. 6) [1, 30].

To obtain generally valid findings relating to lightweight bodyshell structure, it is desirable to use this methodical procedure for different bodyshell dimensions and train concepts. Furthermore, it makes sense to examine the effects and the relevance of the individual and combined load cases relating to the bodyshell structure. Research and investigation are being realised in line with the NGT project [1].

Taking into consideration the limiting factors and conceptual requirements (such as bodyshell length and width, double deck, axle load, and optimum space utilisation) the optimum dimensions are defined for the **inside and outside** bodyshell structure. The resulting bodyshells are put under static loads, as defined in EN 12663, for the simulation. The non-load bearing components of the operating mass (such as the interior, inner lining and equipment) together with the payload are applied to the appropriate areas of the bodyshell. These loads depend on, among other things, the vehicle dimensions and are individually determined for each bodyshell model. The mass of the structure resulting from the topological optimisation is also taken into consideration at each iteration step.

Sufficiently realistic basic conditions for the topological optimisation can be created. It should be noted that initially no window or door openings are taken into consideration, since these influence and limit the configuration possibilities of the topological optimisation. Suitable door locations can be derived from the framework resulting from the topological optimisation and taken into consideration in designing the bodyshell structure (see also Railvolution 5/10, p. 29).

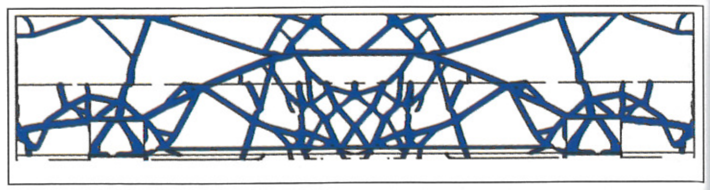

*Fig. 7:* ***Topological optimisation of a 20 m long double deck bodyshell.***

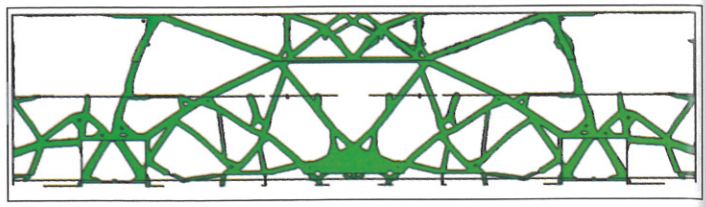

*Fig. 8:* ***Topological optimisation of a 17 m long double deck bodyshell.***

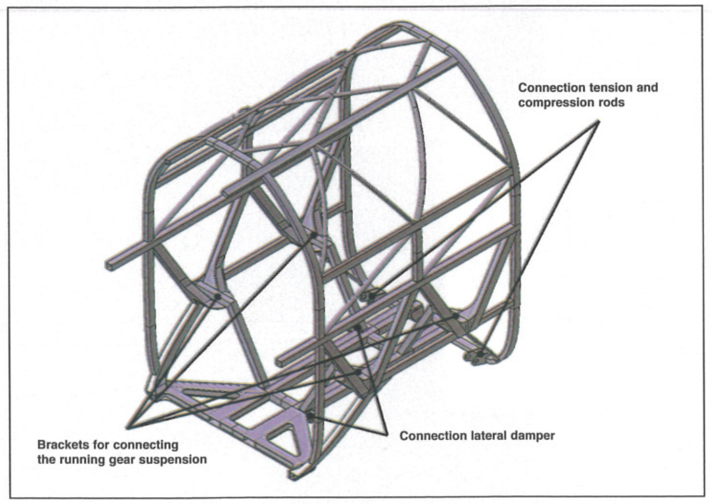

*Fig. 9:* ***Construction design of a section of running gear based on a methodological approach.***

### Principle Findings Regarding Force Flow Optimised Bodyshell Structures

Significantly relevant for the concept is the load which results from the compressive force at buffer height combined with payload. The impact of the payload, at a maximum permissible deflection of 1 ‰ of the distance between supports, is within the considered car lengths for the NGT (a maximum of 20 m) less relevant for dimensioning of a bodyshell. Despite the relatively **low compressive force** (300 kN) at the height of the cantrail, this load case noticeably affects the framework resulting from the topological optimisation. Separate load paths are formed because of the position of the force application at the height of the cantrail. From this it follows that connection paths of these load paths to the rest of the framework are necessary. Also, the main load paths are influenced (Fig. 7).

A comparison of the frameworks of the bodyshells of different lengths shows a largely similar structure. This makes a force flow optimised style design possible, which can then be applied to various other bodyshell dimensions. As the length of the bodyshell increases a requirement for additional **stiffening elements** is identified, but the main load paths principally remain the same. This means that when the design is being used for various bodyshell lengths, the same structural elements can be included. Only in localised areas are additional supports needed to match the results of the topological optimisation. As a result of the high number of common parts and segments of the bodyshell structure both the engineering and the production costs can be minimised (Fig. 7, Fig. 8).

### Concept Of Force Flow Optimised Bodyshell Segment

The concept of a force flow optimised bodyshell structure includes the support structure. A suitable process for optimum selection of the panelling elements according to set basic conditions is also necessary.

### Concept For Force Flow Optimised Support Structure

Based on the findings of the topological optimisation, a structure concept for the segment over the running gear can be derived. This can be adapted to various bodyshell lengths with only minor changes. On account of the high complexity of the bodyshell segment over the running gear, the potential of the methodology can be well demonstrated.

Taking into consideration the load path and force directions which result from the topology optimised models, three dimensional shaped **bulkheads** are used for the support structure. The specific sequence of the individual bulkheads produces ideally a curved shape and a torsion stiff honeycomb tube. The loads and forces acting on the running gear result primarily from the running gear mountings, the coupling forces, the static loads according to static layout load cases specified in EN 12663, the mass of the rest of the bodyshell and the payload.

All vertically directed forces are absorbed by the bodyshell through the secondary suspension of the running gear. For this reason brackets are included within the aluminium structure for suspension support. Multiple supports assure a minimum of bending moments. The supports are integrated into the load bearing structure and designed to be continuous as well as force flow optimised. The transmission of the **traction forces** of the running gear is realised through the tension and compression rods, which engage through eye connections and further distribute the loads into the floor area. The connection of the running gear with the two lateral dampers is provided at the inner cross beams.

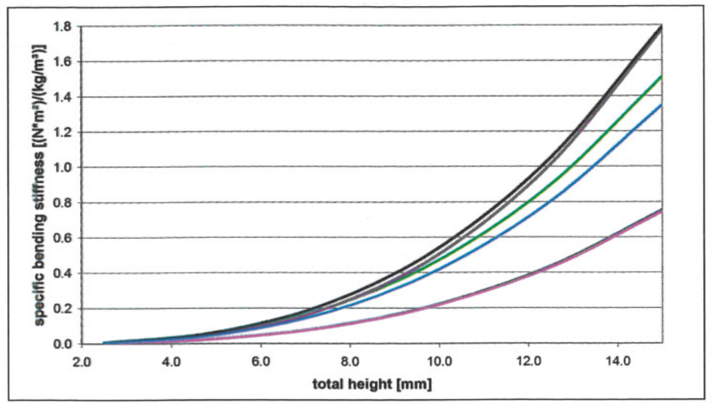

*Fig. 10:* ***Comparison of specific bending stiffness of a 100 mm wide bending beam.***

A force flow optimised design is realised between the spring brackets and the load bearing floor structure. The connection points for the coupling forming part of the running gear segments is dimensioned in line with EN 12663, and optimised with regard to force flow and stiffness. The forces, acting in a longitudinal direction, according to the EN 12663 standard, distribute themselves over the structure in the subfloor. Similarly these are introduced into the diagonal running members in the honeycomb structure, which thus form a link to the spring connection (Fig. 9).

As a result of **aerodynamic** optimisation, a complex external contour of the car is predefined. This requires the diagonally running beams with a square cross-section to follow a three dimensional curve, and in addition, they have to be twisted. This can be avoided by using circular cross-section beams in moderately loaded areas. These beams then only have to be curved in one direction. In heavily loaded areas suitable beams are welded together from individually shaped or from one-dimensionally curved sheets.

## Systematic Process For Construction Of Panelling Elements

Consistent lightweight construction is contingent on the structural support of as many parts as possible. Depending on the intended panelling, construction using independent beams can be dispensed with, in local areas. The required stiffness can be integrated in the panelling. Given sufficiently high stiffness and panel strength, stiffeners can possibly be completely dispensed with at appropriate locations. This can, for example, be achieved with sandwich structures, which have a high bending stiffness, by increasing the area moment of inertia.

The principle of **sandwich construction** here corresponds to the behaviour of an I-beam. Under a bending load the sandwich core is stressed on shear, and the cover layers absorb the tensile and compressive forces, like the I-beam chords. Thus the area moment of inertia and the bending stiffness of the whole structure can be greatly increased (Fig. 10). By this analysis it can be shown that, even with a total thickness of 10 mm, the specific bending stiffness, in comparison with solid steel sheet or aluminium sheet, can be increased by over 50 % [31].

A systematic process must be used for the optimum selection of possible **panelling** for structure designs which are easy to bend (Fig. 11). The large number of different material and production combinations of core and cover layers means that the space, the loading, and any other requirements first have to be defined. Here, in addition to the mechanical loads, other selection criteria such as thermal properties, chemical resistance, fire protection, acoustic properties, and possible functional integrations have to be taken into consideration. Based on these specified requirements, with the aid of an analytical preliminary layout and a database of sandwich materials, the combinations are selected which can be used for the specific application. The analytical preliminary layout involves only a small amount of work, in comparison, for example, with an FEM analysis, since most requirements can, at this early stage, be simplified or abstracted.

The detailing and the optimisation of the component then follows, and here other influences from the production process to the transfer of forces and installation concepts with the **honeycomb** support structure have to be taken into consideration. A possible concept for connecting the floor plates to the honeycomb structure is shown in Fig. 12. A combination of gluing and the local introduction of force by an insert or by bolting ensures symmetrical force transmission, the necessary seal, quick installation and compensation for possible production tolerances. Furthermore, with such a structure and the necessary joining technology, additional functional integrations such as acoustic properties, heat insulation using foam cores, and the integration of heating/air conditioning with appropriate material combinations can be achieved.

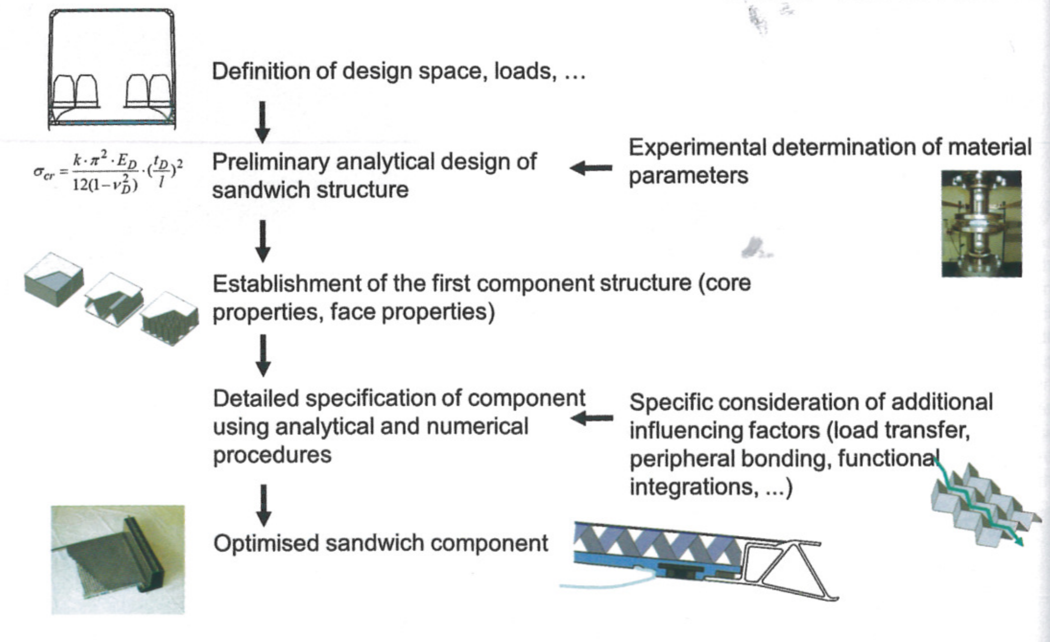

*Fig. 11:* ***Procedure to follow when selecting sandwich components for panelling (based on [31]).***

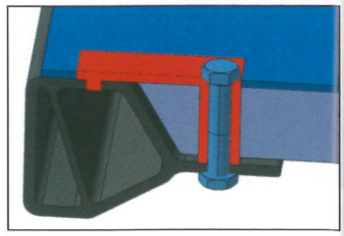

*Fig. 12:* ***Cross-section of a possible connection of the sandwich with the honeycomb structure profiles in the floor area.***

## Summary

The German Aerospace Centre is focusing railway vehicle-related research activities into the NGT - Next Generation Train project. Several objectivies are aimed at improving the technical performance of railways to make the best use out of the most environmentally friendly means of transport. A design process and a construction method for a lightweight high speed EMU is explained in this contribution. Lightweight cars are necessary because of the permitted axle-weight a of under 17 tonnes. To make best use of the traction energy, the number of passengers should be as high as possible, so long as we can provide excellent passenger comfort.

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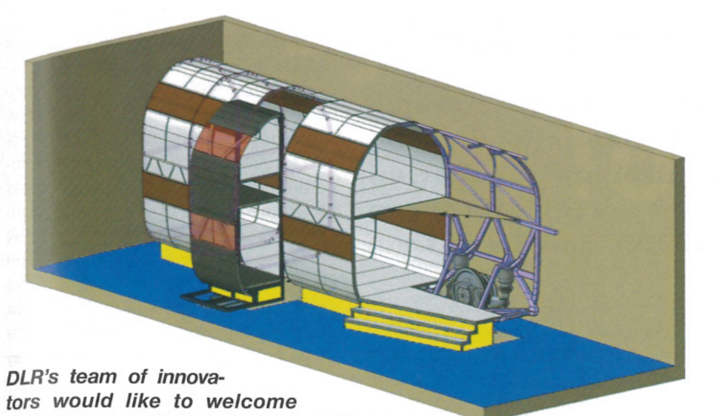
***Pictures: DLR***



***DLR's team of innovators would like to welcome Railvolution readers to experience the 1 : 1 DLR Generic Laboratory at InnoTrans 2012 in Hall 4.2, Stand 215. The exhibit represents a roughly 12 m long section of a intermediate powered NGT car with Standard class accommodation, to be used for future research into rail vehicle air conditioning and lightweight construction principles, as described in this article.***

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