Featured Articles

Development of Class 800/801 High-speed Rolling Stock for UK Intercity Express Programme

Andrew Rogers
Chris Robinson
Koji Agatsuma
Mitsuo Iwasaki
Satoru Inarida, Dr. Eng.
Takahisa Yamamoto
Kenta Konishi
Toshihiko Mochida

OVERVIEW: Hitachi was formally awarded a rolling stock manufacturing and maintenance contract for the UK IEP project in July 2012 through Agility Trains Ltd. Including additional orders, the contract covers the manufacture of a total of 866 cars and the provision of maintenance services for a period of 27.5 years. With a total value of 5.8 billion pounds, the IEP is the largest project in the history of British railways, and is intended to replace the aging rolling stock on the UK's East Coast Main Line and Great Western Main Line, which run between London and other major cities in the UK. The Class 800/801 rolling stock for the IEP was developed based on the A-train concepts of lightweight aluminum carbodies and self-supporting interior modules by taking technologies developed in Japan to provide lighter weight and higher speed and applying them to UK railway systems. It will contribute to the provision of high-quality and reliable railway services, with commercial operation scheduled to commence in 2017, following operation trials in the UK that will start in 2015.

INTRODUCTION

HITACHI developed the Class 800/801 rolling stock for the Intercity Express Programme (IEP) to run between London and other major cities in the UK (see Fig. 1). The IEP project is intended to replace all of the rolling stock on the UK's East Coast Main Line (ECML) and Great Western Main Line (GWML), that have been in service for more than 30 years[1]. The IEP is an initiative of the UK Department for Transport. It requires Hitachi to manufacture 866 high-speed cars and provide maintenance services for a period of 27.5 years. Hitachi also plans to build a factory in the UK and manufacture the rolling stock locally.

IEP: Intercity Express Programme ECML: East Coast Main Line GWML: Great Western Main Line

Fig. 1—Route Map for Class 800/801 High-speed Rolling Stock for UK IEP.
Based on the A-train concept developed in Japan, Hitachi has developed high-speed rolling stock for the UK IEP that runs services from London. The rolling stock will contribute to high-quality and reliable railway services, with operational testing in the UK to commence in 2015, and commercial operation on the ECML and GWML (two major railway lines) in 2017.

This article provides an overview of the Class 800/801 high-speed rolling stock for the UK IEP and describes the electrical system and the distinctive technologies it employs.

OVERVIEW OF CLASS 800/801

Concept

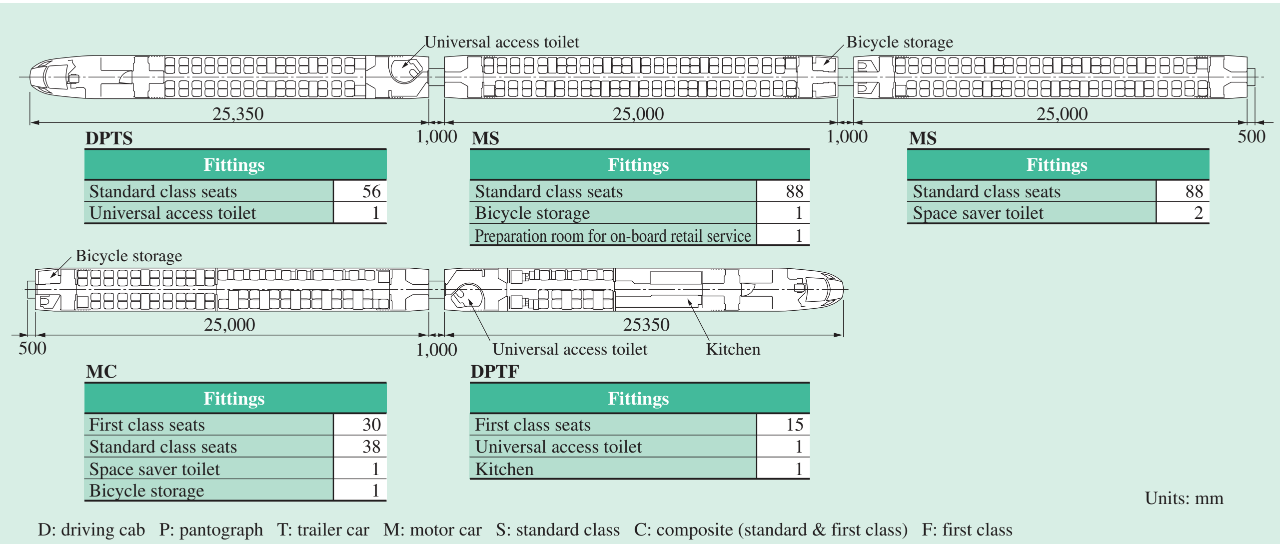
The Class 800/801 rolling stock needs to comply with the latest European standards, including the Technical Specifications for Interoperability (TSI), and the Railway Group Standard (RGS) UK railway standards, and to have the flexibility to run on a number of different lines with different infrastructure (including non-electrified sections as well as aging platforms, bridges, and other features), and to adapt to future plans for electrification and variable passenger demand. Trains have a unit configuration of up to 12 cars, including the ability to add or remove standardized intermediate cars and the generator units (GUs) (generators with diesel engines) needed to operate commercial services on non-electrified lines. Along with the A-train concept[(2), (3)] developed in Japan, the new rolling stock is also based on technology from the Class 395 rolling stock developed by Hitachi for the UK High Speed 1 that entered commercial operation in 2009[(4), (5)], providing compatibility with UK railway systems together with high reliability.

The shape of the front-end cars features a "One Motion Form" (a Japanese expression meaning streamlined) design suitable for high-speed rolling stock. And, in addition to environmental measures for reducing air resistance and noise, it features a collision safety structure that complies with the latest European standards. It also incorporates an automatic coupling system that shortens the time taken to couple or uncouple trains while stopped at a station.

The interior of the rolling stock needs to comply with the Persons with Reduced Mobility-TSI (PRM-TSI) standard, maximize the seating capacity, and also be able to satisfy the requirements of different railway operating companies and future internal refurbishment. Accordingly, the basic layout and carbody structure are standardized in accordance with the A-train concept of having a self-supporting interior module, and the specifications were determined at the design stage, which included review by UK railway operators, associated organizations, and third-party institutions.

Basic Specifications

Fig. 2 shows the trainset layout and Table 1 lists the main specifications. Each trainset consists of either five or nine cars, with an automatic coupling device and cover (incorporating an opening and closing mechanism) fitted on the leading car. The 12-car maximum configuration for commercial operation is formed by linking two trainsets together and adding or removing standardized intermediate cars. Because the coupling or uncoupling of cars in a trainset occurs



DPTS

Fittings	
Standard class seats	56
Universal access toilet	1

MS

Fittings	
Standard class seats	88
Bicycle storage	1
Preparation room for on-board retail service	1

MS

Fittings	
Standard class seats	88
Space saver toilet	2

MC

Fittings	
First class seats	30
Standard class seats	38
Space saver toilet	1
Bicycle storage	1

DPTF

Fittings	
First class seats	15
Universal access toilet	1
Kitchen	1

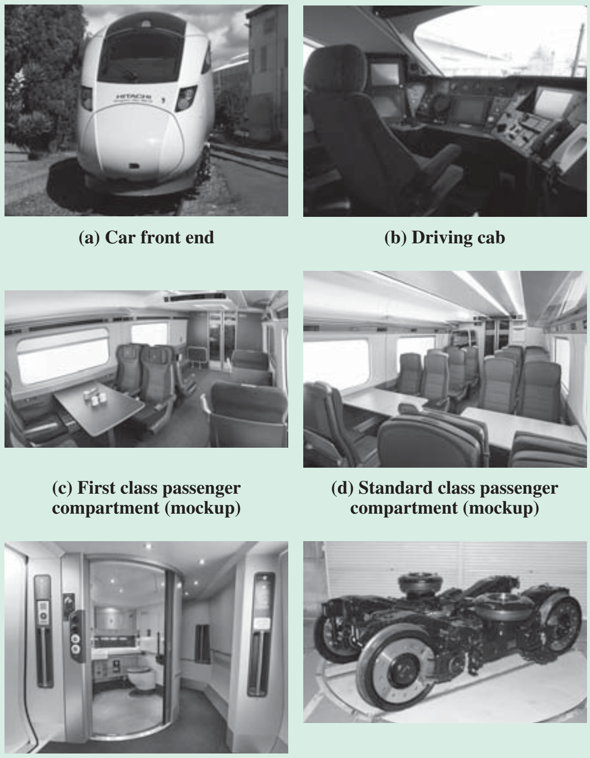
Fig. 2—Train Configuration (Five-car Trainset).

Each trainset consists of five or nine cars, with an automatic coupling device with a cover (incorporating an opening and closing mechanism) fitted on the leading car and a 12-car maximum configuration for commercial operation formed by linking two trainsets together and adding or removing standardized intermediate cars.

Table 1. Main Rolling Stock Specifications
These are the main specifications of the Class 800/801 rolling stock.

Parameter	Specification
Car type	UK Class 800 (dual-mode train), Class 801 (electric train)
Trainset	5 cars (DPTS + MS + MS + MC + DPTF) 9 cars (DPTS + MS + MS + TS + MS + TS + MC + MF + DPTF)
No. of seats	5-car configuration: 45 first class, 270 standard class 9-car configuration: 101 first class, 526 standard class
Electrical system	AC 25 kV, diesel engine-generator
Gauge	1,435 mm
Max. operating speed	201 km/h (max. design speed: 225 km/h)
Acceleration	0.70 m/s^2
Deceleration	Standard: 1.0 m/s^2, Emergency: 1.20 m/s^2
Gradient	1/37 = 27‰
Brake control	Electrically actuated pneumatic brake
Main converter	IGBT converter/inverter + brake chopper
Main motors	226 kW continuous
Auxiliary power supply	240 kVA
Carbody	Aluminum double-skin
Bogies	Bolster-less
Air conditioning	Heater/cooler (internal ventilation fan)

AC: alternating current DC: direct current
IGBT: insulated-gate bipolar transistor



(a) Car front end (b) Driving cab
(c) First class passenger compartment (mockup) (d) Standard class passenger compartment (mockup)
(e) Universal access toilet (mockup) (f) Inner frame bogie

Fig. 3—Car Front End, Driving Cab, Passenger Compartments, Universal Access Toilet, and Bogie.
A "One Motion Form" design suitable for high-speed rolling stock is used for the front-end shape (a), and the driving cab was designed with input from drivers and "human-factor" experts regarding its ease-of-use and visibility (b). Full-size mockups were built of the passenger compartments and toilets so that they could be inspected by stakeholders to confirm the specifications and to identify and incorporate any design suggestions (c), (d), (e). The weight of the trailer bogies used by intermediate cars in the nine-car configuration was significantly reduced by using an inner frame design (f).

during commercial service at an intermediate station, the automatic coupling device is able to perform this operation in less than 2 minutes.

Fig. 3 shows photographs of the front end of a car, the driving cab, passenger compartments, a universal access toilet, and a bogie. The carbodies are made of aluminum alloy with the sides, ceiling, and floor having a double-skin structure of hollow extrusions with a truss cross-section. The welding is performed using friction stir welding (FSW) to create light and strong carbodies with minimal distortion to the exterior. Also, because the trains operate at speeds of 200 km/h or more, the carbodies are air-tight to minimize interior pressure fluctuations and maintain comfort.

In the driving cab, the driver's seat is surrounded by the master controller together with a variety of switches and monitors. In addition to complying with the standards, the visibility and ease-of-use of the switches were assessed by drivers and "human-factor" experts and their feedback was incorporated into the design.

The passenger compartments are split into first class and standard class, with the seats, tables, and other fittings complying with RGS and PRM-TSI. Along with collision safety and fire safety, the design and layout also take the needs of the disabled into account. The rolling stock is designed to facilitate changes to the interior layout to accommodate changes to services or to the number of cars in the train. The vestibule has a large universal access toilet that incorporates the principles of universal design, and also has a storage area able to hold large items of luggage, including bicycles. A kitchen and preparation room are included to provide suitable catering services to passengers traveling long distances. Hitachi built a full-size mockup of these interior features to allow inspection by the railway operating companies, passenger organizations, railway unions, certification agencies, and other stakeholders. This provided an opportunity to confirm the specifications and to identify and incorporate any design suggestions.

The bogies have a bolsterless configuration and are designed for stability and cornering performance as well as to minimize track damage and maintenance costs, with the structures of the motor and trailer bogies both made as light as possible. The weight of the trailer bogies used for intermediate cars on nine-car trains, in particular, was reduced significantly by using the inner frame structure shown in Fig. 3.

CLASS 800/801 ELECTRICAL SYSTEM

This section describes the features of the safety system, which consists of independent train protection systems: the Train Control and Management System (TCMS), which assists the work of the train crew; a data communication function that aids maintenance work; and a traction drive system that is powered by the overhead lines (catenaries) and GUs.

On-board Information System (TCMS)

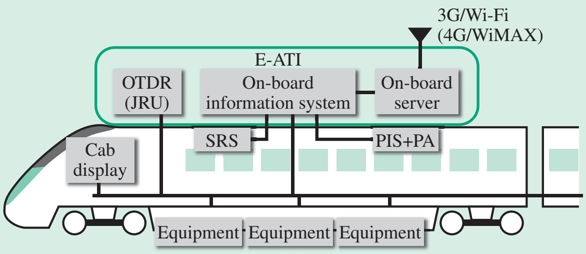
Fig. 4 shows a block diagram of the on-board information system on the Class 800/801, Fig. 5 shows a driving cab screen, and Fig. 6 shows examples of the display panels. The TCMS on the Class 800/801 uses the Ethernet-Autonomous Decentralized Train Integration System (E-ATI), an Ethernet-based communication system. E-ATI is a backbone communication system newly developed by Hitachi that provides improved reliability and redundancy by using fully independent dual routing. The system also complies with IEC 61375, and EN 50128 safety integrity level 2 (SIL2) requirements. The displays in the driving cab are designed with button locations, colors, and fonts that are chosen for their ease of use and affinity with European Train Control System (ETCS) screens (described below). Similarly, the sizes, fonts, scrolling speeds, and information presented on the display panels are chosen to be easy for passengers to read. These also comply with TSI and RGS. The rolling stock is fitted with on-board servers that exchange data with wayside systems via third-generation (3G) and Wi-Fi[*1] communications. The design also supports use of fourth-generation (4G) and WiMAX[*2] communications as an option.

In addition to the above, an RGS-compliant integrated on-train data recorder (OTDR) and juridical recording unit (JRU), and an EN-compliant energy meter to record energy consumption and regeneration are fitted to the train.

*1 Wi-Fi is a registered trademark of the Wi-Fi Alliance.
*2 WiMAX is a trademark or registered trademark of the WiMAX Forum.

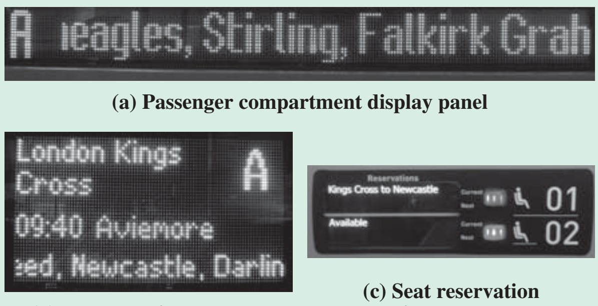
ETCS: European Train Control System

Fig. 5—Example Driving Cab Screen.
The design uses button locations, colors, and fonts that are chosen for their ease of use and affinity with ETCS screens.



SIL: safety integrity level Wi-Fi: Wireless Fidelity
SRS: seat reservation system OTDR: on-train data recorder
JRU: juridical recording unit
E-ATI: Ethernet-Autonomous Train Integration System
PIS: passenger information systems PA: public address

Fig. 4—Block Diagram of On-board Information System.
Reliability and redundancy have been improved by using fully independent dual routing based on Ethernet technology. The system is certified as satisfying SIL2.



(a) Passenger compartment display panel

(b) External display panel

(c) Seat reservation display panel

TSI: Technical Specification for Interoperability
RGS: Railway Group Standards

Fig. 6—IEP Display Panels.
The sizes, fonts, scrolling speeds, and information presented on the display panels are chosen to be easy for passengers to read (and are compliant with TSI and RGS standards).

The main functions of the TCMS on the Class 800/801 are described as follows.

(1) Automatic train identification function

To simplify the rearrangement and management of train configurations, functions are provided for identifying the train (Class 800/801), for automatically determining the cars in the trainset and its total length, and for coupling and uncoupling up to 12 cars in normal and 24 cars in rescue or emergency mode.

(2) Data communications

Communication with wayside systems is used to transmit rolling stock status information in realtime; to return the monitor data stored in the OTDR and other on-board devices to wayside systems in response to on-demand commands; and to receive daily schedules (timetables) and seat allocation data. It also provides easier maintenance by allowing the updating of public address announcements and the on-board system software.

(3) Train control functions based on location

The train location is identified by using the global positioning system (GPS) and used for such functions as automatic control of internal and external display panels and systems for providing information to passengers [passenger information systems (PIS) and public address (PA)]; door interlock control [selective door operation (SDO) control] for stations where the platform is shorter than the train; seat reservation system (SRS) control for displaying seat allocations for each section of the route; and a driver advisory system (DAS) that instructs drivers how to optimize operation for minimum power consumption based on the timetable and the type of line they are travelling on. It is also used by the automatic function for selecting the correct power supply on the current section of track.

(4) Passenger support function

The system counts the number of passengers on each car and can use public address announcements to inform passengers about which cars are less crowded, while also transmitting information about the passenger load to the wayside systems in real time.

Traction and APS System

Fig. 7 shows an overview of the traction and auxiliary power supply (APS) system. The system can select the appropriate power source from either the main transformer or the GUs. Also, the size and weight of the system were minimized by designing the power supply converter to be able to work with both power sources. To ensure that the Class 800 and 801 are able to adapt to future changes in operating practices, they both have the same traction system and the rolling stock can be operated as either class by simply adding or removing GUs. On the Class 800, which is intended to run on both electrified and non-electrified track, each traction system has its own GU. On the other hand, the Class 801 is designed only for electrified lines and has one or two GUs depending on the length of the trainset (one GU for trainsets of five to nine cars, two GUs for trainsets of 10 to 12 cars). These GUs supply emergency traction power and auxiliary power in the event of a power outage on the catenary, and as an auxiliary power supply on non-electrified lines where the Class 801 is in service and pulled by a locomotive. This allows the Class 801 to operate on lines it would otherwise not be able to use and provides a backup in the event of a catenary power outage or other problem on the ground systems as well as non-electrified routes in loco-hauled mode.

To simplify the APS and make it easier to control, it draws power from the direct current (DC) stage of the traction system. Additionally, the on-board APSs operate in parallel to provide redundancy.

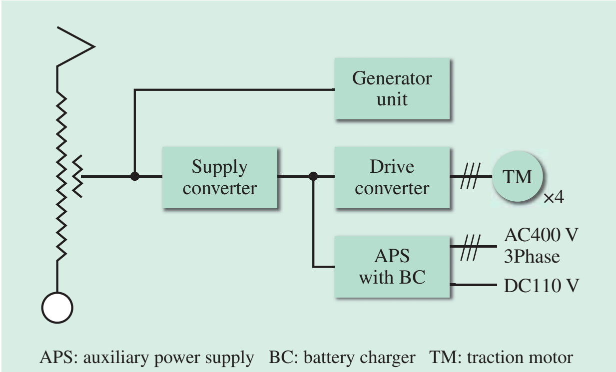


Fig. 7—Overview of Traction/APS System.
The system provides both energy efficiency and operational flexibility, being able to draw power either from the catenary on electrified sections of track or from the engine-generator on non-electrified sections.

On-board Safety Systems

Fig. 8 shows an overview of the safety systems, and Fig. 9 shows the driver machine interface (DMI) of the ETCS. The Class 800/801 is fitted with the Train Protection and Warning System (TPWS) as a legacy signaling system and Automatic Warning System (AWS) widely used on UK trains, and the British Rail-Automatic Train Protection (BR-ATP) system used between Paddington and Bristol on the GWML. It also has an ETCS (Level 2), which is planned to be introduced in the UK. The on-board ETCS was

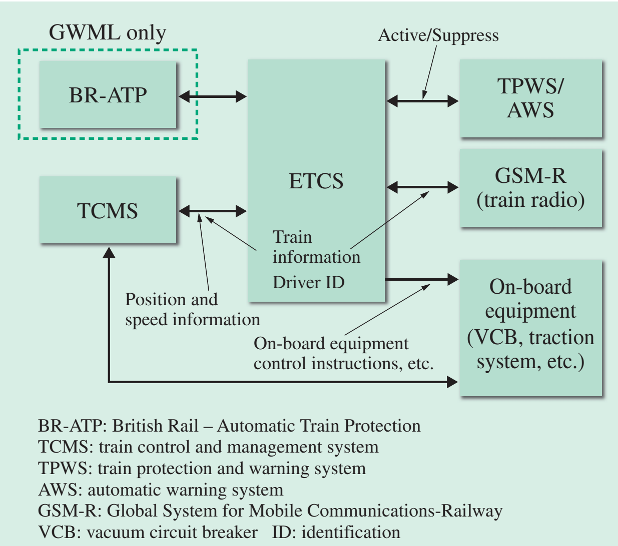


Fig. 8—Overview of On-board Safety Systems.
The rolling stock is equipped with TPWS/AWS, which is used throughout the UK; BR-ATP, which is used on the GWML; and ETCS (developed in-house by Hitachi), which is to be deployed in the future. The system is designed to use the on-board safety functions that match the line being used and the wayside systems. Train information is also exchanged by TCMS and train radio (GSM-R).

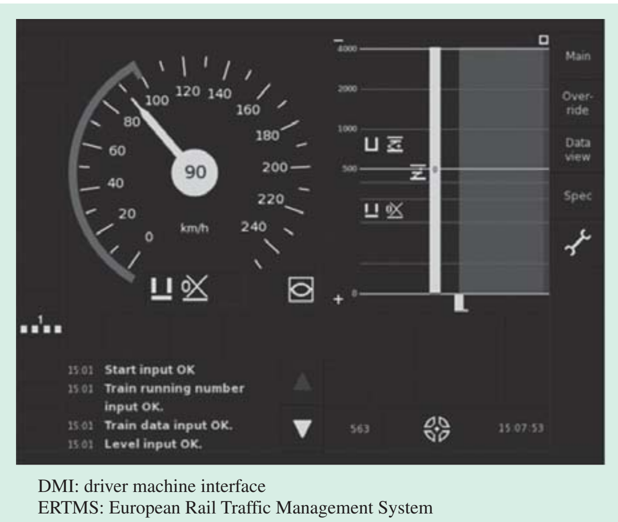


Fig. 9—ETCS DMI.
The interface complies with the ERTMS/ETCS and RGS standards.

developed by Hitachi and underwent an EN012x series audit as part of the V-Train 3 project, receiving certification for compliance with SIL4 and the ETCS standard.

Along with the system integration of a number of different safety devices, the design and development of these safety systems implemented the following functions, with a particular focus on rolling stock system integration to allow for more sophisticated rolling stock control.

(1) A function that includes selecting the correct on-board signaling devices for the ground side signaling system before and after the installation of ETCS. This is a fundamental function for operating the train safely on lines that have different ground side signaling systems (GWML and ECML).

(2) A function includes sharing train information between the ETCS, TCMS, and Global System for Mobile Communications-Railway (GSM-R) (to simplify train data entry procedures for train crew and minimize errors).

(3) On-board equipment control functions that use train location information and are implemented by the interoperation of TCMS and ETCS [the selection of power source (catenary or engine) is based on type of line, SDO, airtightness control, and vacuum circuit breaker (VCB) switching control for neutral sections].

DISTINCTIVE TECHNOLOGIES

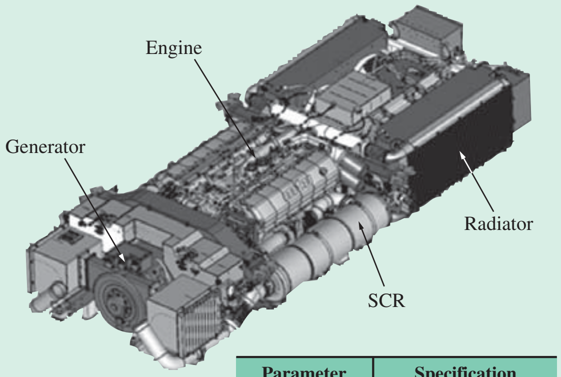
These sections describe the GUs and the crashworthy structure, two distinctive technologies developed for the Class 800/801.

Engine-powered Generators

This section describes the features of the GUs and peripheral systems on the Class 800/801.

Fig. 10 shows a GU and its main specifications. Since the GUs developed for the Class 800/801 are installed under the floor of the motor cars, the engine, generator, radiator, and other components are installed as a package to save space. The engines are designed with consideration for the environment, being fitted with a urea selective catalytic reduction (SCR) system, a technology for cleaning exhaust emissions, and complying with the Stage IIIB European Union (EU) exhaust emission standard. The engine cylinders have a V-configuration to minimize vibration and prevent any loss of comfort in the passenger compartments.

In addition to the GU, other components installed under the floor of drive cars include the traction converter, fuel tank, fire protection system, and brake system. An automatic fire-fighting system is installed to deal with fires in the top part of the engine. This system is designed to quickly extinguish any fire by using high-pressure nitrogen gas to spray it with water. Side-cowls are fitted to the sides of the GU to reduce external noise. The GU is attached to the body by vibration-isolating mountings and the



Parameter	Specification
Engine	V12
Cubic capacity	21.0 L
Max. speed	1,900 rpm
Rated output	700 kW

SCR: selective catalytic reduction rpm: revolutions per minute

Fig. 10—GU and Main Specifications.
The engine, generator, radiator, and other components are installed as a package to save space, and mounted under the floor.

Scenario	Crash mode	Acceleration	Other
1	18 km/h⇒ ⇐18 km/h, 40 mm (40 mm vertical offset)	Below 5.0 g	Securing of the survival space
2	80ton wagon ⇐ 36 km/h		
3	15ton Lorry ⇐ 110 km/h	Below 7.5 g	

Fig. 11—Collision Safety Requirements.
Collision safety requirements are specified by the High-speed TSI, EN 15227, and GM/RT2100 standards.

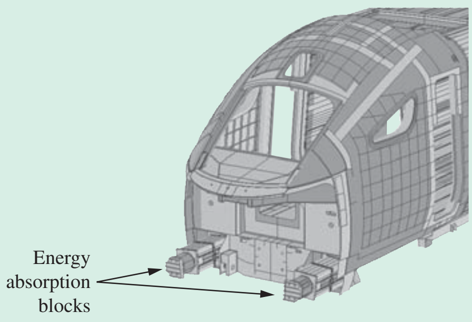


Fig. 12—Front-end Crashworthy Structure.
The crashworthy structure at the front end crumples during a collision to absorb as much energy as possible, and to minimize the accelerations associated with the collision.

passenger compartment floor is supported on resilient mountings. These provide a comfortable environment in the passenger compartment by minimizing the transmission of vibrations from the engine to the carbody. And, the cable duct that runs on top of the GU is protected by thermal insulation to minimize the influence of engine heat.

Crashworthy Structure

European standards stipulate the collision safety standards shown in Fig. 11 for reasons that include past accidents and trains sharing the same track. As shown in Fig. 12, the lead car of the Class 800/801 has an crashworthy structure that crumples during a collision to absorb as much of the energy as possible and to minimize the accompanying accelerations. The crashworthy structure for the Class 800/801 is a further development of the technology used for the Class 395[(4), (5), (6)] rolling stock. In addition to being lighter and taking up less space, it complies with the latest TSI, the EN 15227 European standard for collision safety, and the GM/RT2100 UK railway standard for strength. The front of the car accommodates the crashworthy structure in the limited space available, while also balancing aerodynamic performance and exterior design, and housing the headlights and other similar devices, along with the switchgear, coupling system, and other equipment used when connecting rolling stock together in a trainset.

The first step in the development of the crashworthy structure was to determine its basic performance through dynamic crash testing of a full-size front end. This also included confirming that numerical analysis simulations could reproduce the test results. This numerical analysis technique was also used to verify collision safety performance by simulating a crash for a multi-car train, something that is difficult to test by experiment.

Fig. 13 shows the results of the tests and numerical simulation. In keeping with the concept behind the A-train, the crashworthy structure is made from aluminum alloy to satisfy all of the structural criteria, including reducing the weight and saving space as well as the collision characteristics and strength. The test results show that buckling occurs cleanly, as intended, and that the structure crumples evenly to absorb the energy of the collision. This same behavior is also accurately reproduced by the numerical analysis, with the prediction accuracy for deformation, crumpling force, and energy absorption each being within 1%.

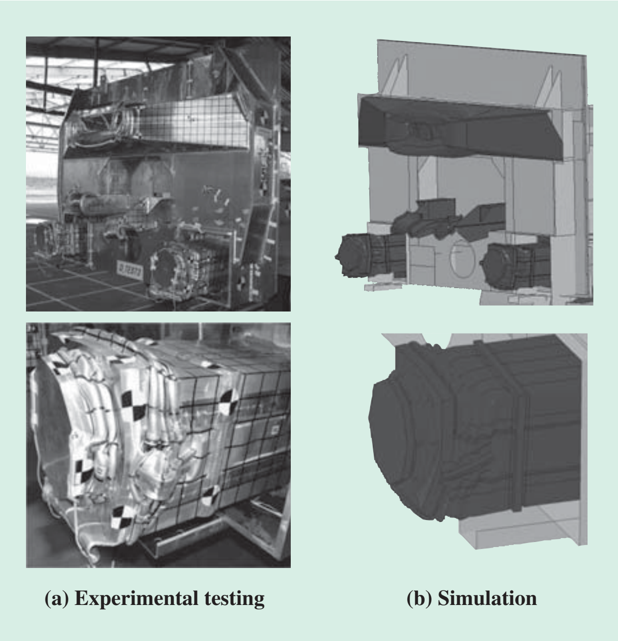


Fig. 13—Results of Dynamic Crash Testing and Numerical Simulations.
Dynamic crash testing of a full-size car front-end was used to determine the basic characteristics of the crashworthy structure. It was also confirmed that simulation (numerical analysis) could reproduce the experimental test results with sufficient accuracy.

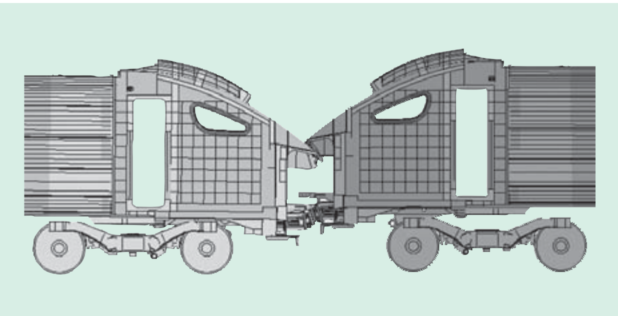


Fig. 14—Numerical Analysis Simulating Collision between Multi-car Trains.
The results verified the design by showing that the integrity of the driving cab and passenger compartments ("survival spaces") is retained without their collapsing, and that the deceleration is kept within the standard of 5G or less.

This demonstrates that the predictions are comfortably within the requirement of the standard, which requires an error of 10% or less. Fig. 14 shows the results of a numerical analysis of a collision between multi-car trains. The results verify the design by showing that the integrity of the driving cab and passenger compartments ("survival spaces") is retained without their collapsing, and that the deceleration is kept within the standard of 5G or less.

CONCLUSIONS

This article has given an overview of the Class 800/801 high-speed rolling stock for the UK IEP, and described the electrical system and distinctive technologies it employs.

Hitachi intends to continue developing more comfortable and attractive rolling stock that is compatible with European railway systems by combining existing technologies, developed in Japan for lighter weight and higher speed, with the advanced technologies developed for the Class 800/801, and to supply these together with maintenance services.

REFERENCES

(1) "Innovative Express – UK Intercity Express Programme," Hitachi Hyoron, 95, 1, pp. 6–15 (Jan. 2013) in Japanese.
(2) M. Iwasaki et al., "Advanced Train Technology and New Development for Global Markets," Hitachi Review **61**, pp. 296–300 (Dec. 2012).
(3) T. Yamada, H. Ohba, "Latest A-Train Railcar Enhancements," Hitachi Review **53**, pp. 10–14 (Feb. 2004).
(4) T. Mochida et al., "Development and Maintenance of Class 395 High-speed Train for UK High Speed 1," Hitachi Review **59**, pp. 39–46 (Apr. 2010).
(5) K. Jordan et al., "Railway Business Strategy and R&D in Europe," Hitachi Review **61**, pp. 190–194 (Sep. 2012).
(6) T. Kawasaki, T. Yamaguchi, T. Mochida, "Railway-vehicle Technologies for European Railways," Hitachi Review **57**, pp. 61–65 (Mar. 2008).

ABOUT THE AUTHORS

Andrew Rogers

Hitachi Rail Europe Ltd. He is currently engaged in coordinating work on the IEP project. Mr. Rogers holds a BEng and Master of Business Administration (MBA).

Chris Robinson

Hitachi Rail Europe Ltd. He is currently engaged in the IEP project. Mr. Robinson is an incorporated engineer (IEng) and a member of The Institution of Engineering and Technology (IET) and Institution of Mechanical Engineers (IMechE).

Koji Agatsuma

Hitachi Rail Europe Ltd. He is currently engaged in work on rolling stock for projects outside Japan.

Mitsuo Iwasaki

IEP Project, Kasado Works, Rail Systems Company, Hitachi, Ltd. He is currently engaged in coordinating the design of rolling stock for overseas markets.

Satoru Inarida, Dr. Eng.

Process Designing Department, Mito Rail Systems Product Division, Rail systems Company, Hitachi, Ltd. He is currently engaged in coordinating work on on-board electrical systems, primarily for projects outside Japan. Dr. Inarida is a member of The Institute of Electrical Engineers of Japan (IEEJ) and IET.

Takahisa Yamamoto

IEP Project, Kasado Works, Rail Systems Company, Hitachi, Ltd. He is currently engaged in the design of rolling stock for Europe.

Kenta Konishi

IEP Project, Kasado Works, Rail Systems Company, Hitachi, Ltd. He is currently engaged in the design of rolling stock for Europe.

Toshihiko Mochida

IEP Project, Kasado Works, Rail Systems Company, Hitachi, Ltd. He is currently engaged in the design of rolling stock for Europe. Mr. Mochida holds a PE (USA) and is a member of The Japan Society of Mechanical Engineers.