



Technical issues raised by the proposal to introduce a 500 km/h magnetically-levitated transport system in the UK

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Contents

Technical issues raised by the proposal to introduce a 500 km/h magnetically-levitated transport system in the UK	1
Contents	2
1 Background to the work.....	3
1.1 The Authors	3
2 Objectives of this preliminary report	3
2.1 Sources of information.....	3
2.2 Project definition.....	4
2.3 Terminology	4
2.4 Questions for Government.....	4
3 The Transrapid technology.....	5
4 Safety issues	6
4.1 Safety of Magnetic Levitation Systems	6
4.2 Passenger evacuation	8
4.3 Vehicle strength.....	8
4.4 Operations and train rescue.....	9
5 Environmental impact	10
5.1 Train energy consumption and CO ₂ emissions.....	10
5.2 Calculation of train resistance	10
5.3 Comparison with rail "best practice".....	14
5.4 Train performance.....	15
5.5 Other impacts of a Maglev line on CO ₂ emissions	16
5.6 Energy consumption over a realistic route.....	17
5.7 Noise levels.....	19
6 Civil engineering costs and feasibility	20
6.1 Vertical curvature and passenger comfort	20
6.2 Maintenance of guideway	21
6.3 Switching system	21
7 Supporting infrastructure and enabling works	21
7.1 Power supply.....	21
7.2 Land acquisition and diversion of services.....	22
7.3 Feeder services to out-of-town stations	22
7.4 Intraoperability	23
8 Technical standards	23
8.1 Proprietary technology.....	23
8.2 Track-train interface.....	23
8.3 European Legislation	24
9 Conclusions	25

1 Background to the work

A commercial group (Ultraspeed UK) has proposed the construction of an 850 km 500 km/h line from Heathrow Airport, through Birmingham, Manchester, Leeds, Newcastle and Edinburgh to Glasgow. The proposal is that this system, based on the Transrapid project in operation in Shanghai (see photo below), would become the main intercity transport backbone of the UK, replacing some intercity trains and internal airlines, leading to increased regional development and a diminution of the "North-South divide".



The construction of a major new transport system could have significant effects on regional development, land use and other issues. These are for consideration elsewhere but DfT has a specific responsibility to evaluate the impact of such a system on the UK transport infrastructure and to consider the technical issues raised by this proposal. The DfT has asked the authors of this report to provide an independent assessment of these issues.

1.1 The Authors

Professor Roderick Smith is the Royal Academy of Engineering Research Professor of Advanced Railway Engineering at Imperial College London. He was Head of Mechanical Engineering at Imperial from 2000 to 2005. He has had many research contacts from the railway industry, has published widely on railway matters, has acted as expert witness in many legal cases arising from railway accidents and has over 30 years experience of Japanese railways.

Professor Roger Kemp has been with Lancaster University for 3 years. Previously he was UK Technical & Safety Director for Alstom Transport, before which he was Project Director of the consortium that built the cross-channel Eurostar trains. While working for GEC and later Alstom he was involved in several overseas proposals for building high-speed rail lines under PFI-type contracts.

2 Objectives of this preliminary report

A comprehensive report on all the technical issues surrounding the introduction of a Transrapid system in the UK would be a major study involving full-time researchers for many months. This preliminary study has the more limited objective of identifying critical areas that would need in-depth studies before it would be possible for a Transrapid system to go ahead. As transport energy consumption is of crucial importance in UK energy policy, this area of work has been covered in more detail than some others.

2.1 Sources of information

Ultraspeed UK have made a number of presentations to the DfT on their proposals and have provided data on noise, drag, energy use and associated CO₂ emissions. Some of this is difficult to use in direct comparisons with UK alternatives as it is expressed relative to other projects (typically the DB ICE3 train operating on 16.7 Hz supplies using the

German electricity generation mix), rather than absolute data. There are other data available in technical articles and from the proceedings of a conference in Dresden attended by Professor Smith, but some of this information has to be interpreted to be relevant to the UK situation.

The written information has been supplemented by information gained from a visit to Shanghai to look at the system installed there but, because of the sensitivity of the Chinese authorities, it was not possible to see "behind the scenes" in the substations and drive system area. Similarly, it was not permissible to make measurements (such as of sound pressure levels) on an operating train.

2.2 Project definition

At various times the project has been described as an 800 km, 500 km/h Anglo-Scottish transport backbone that would compete head-on with domestic airlines, a "corridor", such as the Northern Way (where the maximum speed would be significantly less than 500 km/h), or London – West Midlands or a "demonstrator" over a restricted route, such as Edinburgh – Glasgow or Manchester – Leeds.

There has also been some uncertainty over the financial arrangements envisaged. The authors originally understood this to be a privately financed project where private-sector investors, led by the Transrapid consortium and their (as yet unidentified) civil engineering partners, would provide share capital, while loan finance would be raised on the London financial markets. In such a situation the project would be financed by an SPV with little or no Government involvement. It later emerged that the proposal is for a Government-backed project with state funding providing much of the capital cost and carrying the *farebox risk*. The difference is not significant in terms of technical risk. However the difference *is* important in defining the train frequency to be considered. If the system is privately-funded, the investors will need maximum commercial exploitation to recoup the high infrastructure costs. However, if much of the infrastructure cost is to be met by Government on the basis that this will boost regional development, a more relaxed train service can be considered. This has an effect on the total load imposed on the electricity supply network which is one of the technical issues considered.

2.3 Terminology

Ultraspeed UK have stressed that a Transrapid system should be considered as a new form of transport, not on the same terms as conventional systems. In their literature, the terminology is different to that used by other transport systems – for example the term "vehicle" is used to mean a complete 5 or 10-section unit. To aid understanding and comparisons with other transport systems, this report uses conventional British railway engineering terminology. A complete passenger-carrying entity is referred to as a "train" which consists of a number of "vehicles" or "cars". Trains stop at "stations" and run on "track". It is recognised that, if a system is built in the UK, this might not be the terminology that is eventually used but it is adopted for convenience – the use of railway terms seems more appropriate than aircraft or road vehicle terms as Transrapid has a greater similarity to a high-speed rail network than to any other existing system.

Throughout this report, *maglev* has been used as a generic term for magnetically-levitated transport systems and *Transrapid* has been used for the specific variant of maglev developed in Germany and proposed by Ultraspeed UK.

2.4 Questions for Government

Unsurprisingly, this report concludes that the proposed Transrapid system contains no "magic". The technology complies with the laws of physics and its implementation is entirely comparable with the development of any other complicated engineering system. It is not the only way of providing a very high speed system of land transport. The French TGV (new world record of 574.8 kph on 3 April 2007) and the Japanese

Shinkansen trains have made demonstration runs at greater than 500 km/h but 300 km/h has been adopted as a maximum service speed. The Japanese railway operator, JR East aim to operate at 360 km/h in service by the end of the decade. Transrapid or any other design of maglev can be considered as providing basically the same passenger service as steel wheel alternatives. In some respects, it is better than conventional rail; in other ways, it is less good.

It must also be recognised that the German Transrapid is not the only implementation of maglev transport available. For several decades, Japanese companies have been developing a superconducting Maglev system (discussed in section 8.2) which is based on different principles to Transrapid. However, the Japanese system is not yet in commercial service and no definite plans have been announced to build a commercial system. In terms of track-train interface, the German and Japanese technologies are completely incompatible and one cannot consider a "half and half" solution: commitment to Transrapid would lock the UK into one of the systems available. This report does not attempt to identify a "best buy" maglev technology but concentrates on the Transrapid system used in Shanghai.

3 The Transrapid technology

Unlike some previous designs of magnetically levitated vehicles, the Transrapid Maglev uses largely passive vehicles propelled by linear motors mounted under the edges of the concrete guideway, as shown in Figure 1, below:

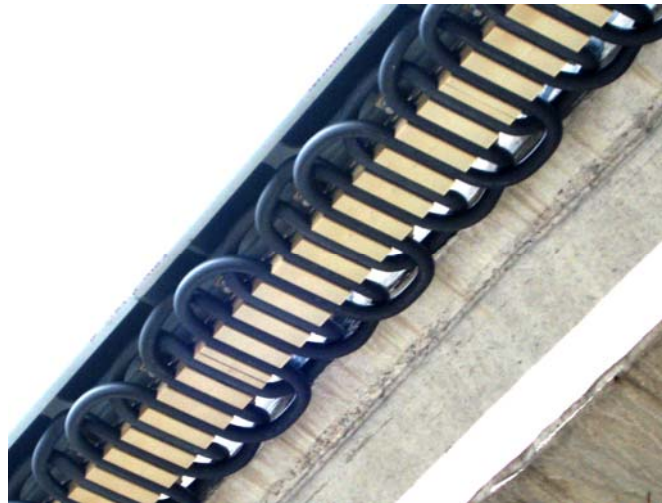


Figure 1: Linear motor

The sides of the vehicles are extended downward and a reaction rail wraps round the linear motor, as can be seen in cross-section in Figure 2:

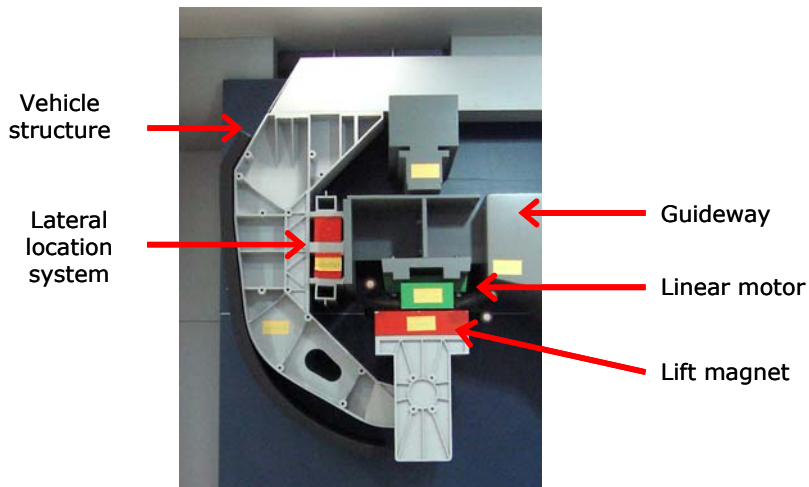


Figure 2: Cross section of lift magnet and reaction rail support

The lift magnets, which are attached to the vehicle, are attracted to the motor stator and the gap is controlled to between 8 and 14 mm \pm 0.1 mm (depending on speed) by varying the current in the coils. One set of these vehicle-mounted magnets is shown in Figure 3, below. Also visible in this photo is one of the vertical magnets that control the lateral position of the vehicle on the guideway.



Figure 3: Lift magnets and lateral location system

4 Safety issues

4.1 Safety of Magnetic Levitation Systems

Before a magnetically levitated system could be adopted for use in the UK, it would be necessary to conduct a full safety analysis to ensure that it did not pose an unacceptable risk to passengers or to neighbours. The tragic accident in September 2006 at the Emsland test facility near the German/Dutch border in west Lower Saxony (not directly concerned with maglev technology) and the fire in August 2006 on the operational system in Shanghai have emphasised the need to ensure safety is well-managed.

4.1.1 American investigations

About 15 years ago substantial work was undertaken in the USA into the safety risks of maglev systems, centred on the Transrapid technology; the results were generally satisfactory for an initial feasibility study but left some questions to be answered later - were it be decided to pursue a commercial system.

The American work could provide a starting point for similar studies in the UK but, because of the very different legislative situation, and differences in the application, proposed route and local environment, much of this work would have to be repeated before a fully satisfactory safety case could be established.

The preliminary work in the USA was to identify the safety issues of the use of a Transrapid maglev system operating in the United States.¹ In effect, this "set the agenda" for future work. The report concluded that additional work would need to be undertaken to ensure the safety of such a system. An analysis was made of the German Safety documentation² but this was not considered entirely appropriate for the very different situation existing in the USA.³

A further report was commissioned that contains the results of a detailed review of safety requirements to evaluate their suitability to Transrapid systems proposed for operations in the U.S. environment. The major focus of this report was the evaluation of German Standards Institute standards (DINs) cited in the German document titled, German High-Speed Maglev Train Safety Requirements (*Regelwerk Magnetschnellbahnen – Sicherheitstechnische Anforderungen*, known by the abbreviation RW MSB).⁴

One of the potential problems that was identified was the possibility for long-term dimensional instability of the guideway under the effects of thermal cycling, due to the heating effect of the passing vehicles. A report was commissioned to undertake a theoretical analysis predicting the temperature distributions, thermal deflections and thermal stresses that may occur in typical steel Maglev guideway under the proposed Orlando, Florida thermal environment.⁵ Although the environmental conditions in, for example, the M62 corridor are different to those in Florida we are not convinced that they are more benign. We would welcome more work in this area – particularly in relation to the long-term stability of elevated structures over peat moors and the possible shrinkage and settlement effects due to the likely effects of climate change.

Because of the concern over possible (but unproven) biological and environmental damage caused by stray magnetic fields, substantial work has been undertaken in the USA on the emissions from transport systems.^{6 7} This work includes a review of the

¹ Safety Review of the Transrapid Maglev System, Robert M. Dorer/William T. Hathaway November 1990 DOT/FRA/ORD-90/09 DOT-VNTSC-FRA-90-3 NTIS #: PB91 - 129684/HDM

² High-Speed Maglev Trains; German Safety Requirements RW-MSB, RW MSB Working Group January 1992 DOT/FRA/ORD-92/01 DOT-VNTSC-FRA-92/1 NTIS #: PB92-167006

³ German High-Speed Maglev Train Safety Requirements - Potential for Application in the United States, R.M. Dorer, S.H. Markos, R.A. Wlodyka, H.S. Lee, M. Coltman, W.T. Hathaway, A.E. Barrington, A. Brecher February 1992 DOT/FRA/ORD-92/02 DOT-VNTSC-FRA-92-3 NTIS #: PB92-167014

⁴ A Comparison of U.S. and Foreign Safety Regulations for Potential Application to Maglev Systems, Arthur D. Little, Inc., September 1993 (Final Report for external distribution) DOT/FRA/ORD-93/21 DOT-VNTSC-FRA-93-10

⁵ Safety of High Speed Magnetic Levitation Transportation Systems, Thermal Effects and Related Safety Issues of Typical Steel Guideways, Foster-Miller, S.J. Kokkins, A. Purple, G. Samavedam September 1994 DOT/FRA/ORD-94/10 DOT-VNTSC-FRA-94-9 NTIS #: PB96-131354

⁶ Safety of High Speed Guided Ground Transportation Systems, Electromagnetic Fields (EMF), Broadband Magnetic Fields: Their Possible Role in EMF-Associated Bioeffects, U.S. Environmental Protection Agency, Office of Air and Radiation, Dr. B. Wilson, Dr. R. Reiter, et al. August 1993 DOT/FRA/ORD-93/29 DOT-VNTSC-FRA-93-17 NTIS#: 94-129780

⁷ Safety of High Speed Guided Ground Transportation Systems, Potential Health Effects of Low Frequency Electromagnetic Fields Due to Maglev and Other Electric Rail Systems, Information Ventures, Inc., W.A. Creasey and R.B. Goldberg. August 1993 DOT/FRA/ORD-93/31 DOT-VNTSC-FRA-93-18 NTIS#: 94-12117

biological effects, with emphasis on laboratory animal and human exposure to EMF fields that have components over a range of frequencies produced by maglev systems. We understand from Ultraspeed UK that the magnetic fields are low and we do not see this as a significant problem. However, in the light of the concern over mobile phone transmitters⁸ and the use of wi-fi in schools, we are not convinced that the general population would be so sanguine.

4.2 Passenger evacuation

The Transrapid position is that the guideway does not need a continuous walkway, as was used on the Birmingham maglev or on all new elevated railways in the UK, because the battery supply on the vehicle will keep the vehicle levitated come-what-may and, in the event of loss of power, the control system will allow the train to coast to the next station or to an intermediate emergency stopping point. (A power failure while the train is going uphill would be particularly complicated as there is no intrinsic roll-back protection.)

Service braking relies on the track-based linear motor. If it loses power, the train is unbraked and then relies on a battery-supplied eddy-current brake to bring the speed down to 10km/h when it is dropped onto skids. Levitation is treated as a "cannot fail under any circumstances" system with multiple power equipment and control duplication; nevertheless the skids are designed for a one-shot stop from 500km/h. The whole system depends on safe communication between the track and the train and on distributed safety-critical software.

Although it would be premature to judge the outcome of the investigation into the deaths in Emsland, several newspaper reports commented on the difficulty rescuers had in reaching those trapped in the accident, due to the height of the infrastructure above ground and the lack of access. Unfortunately, modifying the structure to incorporate a walkway, as was used on the Birmingham maglev, with suitable handrails to comply with the *Working at Heights* regulations, would be far from straightforward as the lift magnets on the vehicles come below the support structure and infrastructure maintenance relies on "cherry pickers" running on the guideway to access the underneath.

4.3 Vehicle strength

The Transrapid cars are not built to normal railway standards for end-loads. The American Railway Engineering Association (AREA)⁹ suggested that *"there is no justification for lowering railway passenger car strength requirements below that of existing high-speed wheel-rail systems simply because they are on a maglev guideway. In fact there is considerable reason to require maglev vehicles to be even stronger than normal railway passenger equipment for the following reason:*

Because the maglev train is wrapped around the guideway, any collision with another train, objects on the guideway, devices at the end of the line, or a damaged guideway would have to be absorbed by the crushing strength of the maglev train because [...] it has no alternative in energy absorption as a wheel-rail train does. Once something serious goes wrong, the ability to derail, as strange as this statement may seem at first, can sometimes be a safety benefit¹⁰. The maglev train would have no such alternative and the entire impact of the incident would have to be absorbed in the crushing of the vehicles with their passengers. Thus a maglev train [...] should have more compressive strength than normal railway vehicles."

⁸ Burgess, A. *Cellular Phones, Public Fears, and a Culture of Precaution*, pub. 2004

⁹ Letter from Louis T. Cerny, Executive Director, to Florida HSR Commission, 21 March 1990

¹⁰ See, for example, the Grayrigg derailment of 23 February 2007.

Figure 4 gives an idea of the catastrophic overriding of the maintenance car over the leading Transrapid car in the Emsland accident.

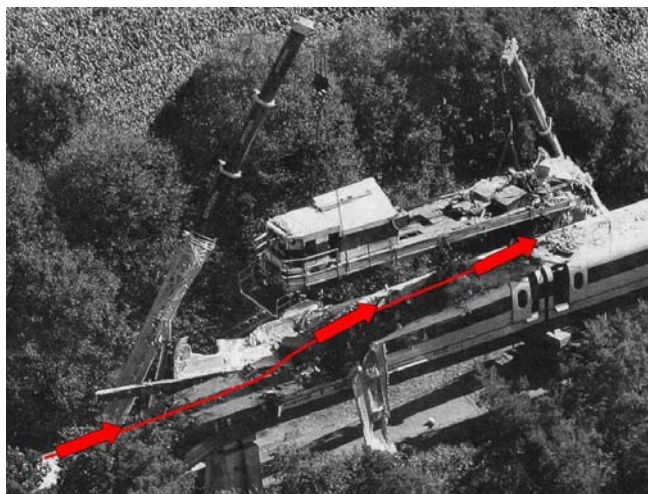


Figure 4: Path of maintenance vehicle relative to train

The avoidance of overriding and the preservation of passenger survival space were the cornerstones of BR's pioneering crashworthiness programme of the early 1990's. Requirements for two criteria above and for maximum allowable decelerations and energy absorption of the structure are now mandatory requirements of UK rail vehicles. The arrows have been added to show an approximate path of the maintenance vehicle. The lightweight aluminium structure of the maglev car has been peeled apart – as one can see from the torn aluminium on the side of the car nearest the camera. At first sight, this flimsiness is surprising, given that the declared mass per seat is 571kg, compared with 537kg for the Shinkansen 700 series. Given that the 700 series has the additional mass of bogies and electric drive motors, the non-structural weight of Transrapid must be considerable. If the crashworthiness were to be improved it would probably be at the expense of severe weight and therefore energy penalties.

The Transrapid policy is that vehicles do not need inherent crashworthiness as they will be under close computer control and thus will not crash. The Emsland accident reinforces the fact that, even if there are rigorous procedures to prevent an accident they are never foolproof. The same is true of automatic systems. Even with a block signalling system, there are times when it can be defeated – such as at Clapham Junction. In the light of experience, it is difficult to argue that a collision can never occur and, while we do not suggest that the standards should be identical to those on a main line railway, we are not convinced that the requirements for vehicle crashworthiness can be discounted. This is particularly true if one considers issues of vandalism, or even terrorism, that are more likely in an urban UK context than in rural Germany or the well-policed environment of Shanghai airport.

4.4 Operations and train rescue

To date Transrapid trains have been operated only in a closely controlled environment where they run a very relaxed service and where there is ready access to the guideway from nearby roads. The principle is that the trains have sufficient redundancy that they can always be driven to the next station, or an intermediate detraining point. A failed TGV or ICE can be parked in a siding and rescued by a locomotive with little effect on other services. This option does not exist for Transrapid and, after the fire in Shanghai, the damaged vehicle was towed back to the depot, at low speed and on its skids, by the

other vehicles in the rake. While this is possible on the short and mainly flat route in Shanghai, we are not convinced of the feasibility of such a rescue strategy on long hilly sections of a route like Manchester to Leeds. Further work is needed in this area.

5 Environmental impact

5.1 Train energy consumption and CO₂ emissions

On any vehicle, at higher speeds, irrespective of the propulsion system, aerodynamic resistance dominates. This increases with the square of the velocity, thus the power to overcome the resistance at a given speed varies with the cube of the velocity. This is fundamental physics and has been discussed for many forms of transport by Gabrielli and von Karman.¹¹ It is well known that, like for like, the train has some energy benefit because of the convoy system (that is, one vehicle carried along in the wake of the vehicle in front).

The other component of train resistance is rolling resistance and it is sometimes claimed that a maglev system has benefits over a steel wheel/rail system because it has no direct contact interface. However, it is interesting, and probably counter intuitive, that up to the maximum speed achievable for conventional rail, it has, in fact, some energy advantage over maglev. The essential energy question to be answered is therefore, do we need the extra speed beyond say 300 or 350 km/h, which is achievable by steel wheel on rail, up to the 500 kph being suggested by the proponents of Transrapid? As a corollary, are we prepared to pay the energy cost of the extra speed. And, if Transrapid aims to be a substitute for the plane, is there sufficient advantage (journey time as well as energy) over the plane?

Furthermore, it is not the use of energy in itself that is a problem, but the production of CO₂ from the burning of hydrocarbon fuel, and the effect of CO₂ on climate change. In this respect, both a conventional high-speed rail system and a maglev would be electrically powered. The impact on CO₂ production would depend on the energy mix of the supply. It is possible by a combination of renewables, nuclear power and carbon sequestration at power stations, to substantially decarbonise this supply: this option is not, at least in the foreseeable future, available for aircraft.

5.2 Calculation of train resistance

5.2.1 Choice of train formation

In principle, one could calculate train resistance for any number of different train formations which might be run on the Transrapid network. In practice, it is likely for operational reasons that a standard train formation will be used. Like any railway, the interval between trains is determined by their braking performance, rather than their length so the maximum number of seats available per hour is a function of train length. Preliminary calculations suggest that, because of the high capital cost of the track and its associated drive systems, it would be necessary to exploit the infrastructure intensively to keep the ticket cost per passenger-km to an acceptable price (and/or the subsidy to an acceptable level). Therefore it seems unlikely that an operator would choose to use short trains, other than during service introduction. For this reason it has been decided to base all calculations on a train of 10 vehicles, having a seating capacity of 876 passengers.¹²

¹¹ Gabrielli, G & von Karman, Th., "What Price Speed?" Mechanical Engineering, 72, 1950, pp775-781.,

¹² This figure has been derived from information provided by Ultraspeed UK. It is based on the 10-car train formation given in the *Factbook* and their July 06 response to Professor Roderick Smith which gave a 5-car unit capacity of 438 seats. They have stated (meeting 3/8/06) that this passenger density is compatible with UK

5.2.2 The drag equations

At the meeting on 13 June 06, Ultraspeed UK provided formulae giving the drag equations for different train formations. The total drag F_W has three components: F_A is aerodynamic drag (directly comparable with aerodynamic drag on other transport systems), F_M is magnetic drag (similar to the rolling resistance of rail vehicles) and F_B is the drag created by the electrical system producing auxiliary power for the train to feed levitation, air conditioning, lighting and so on. Up to 20 km/h (5.5 m/s), auxiliary power is collected via a contact system, and so it does not contribute to F_B . The conductor rails can be seen in Figure 5 on the vertical edge of the guideway:



Figure 5: Auxiliary power pick up rails

Above 20 km/h, on-board power is derived by electromagnetic induction from the traction system. As the demand for on-board power is largely independent of train speed, the drag imposed by the auxiliary system drops as speed increases (roughly a constant power curve). The power taken from the propulsion system by the auxiliary power arrangements for both levitation and hotel services has been calculated (by reverse engineering) and is shown on the Figure 6, for speeds up to 500 km/h (160 m/s):

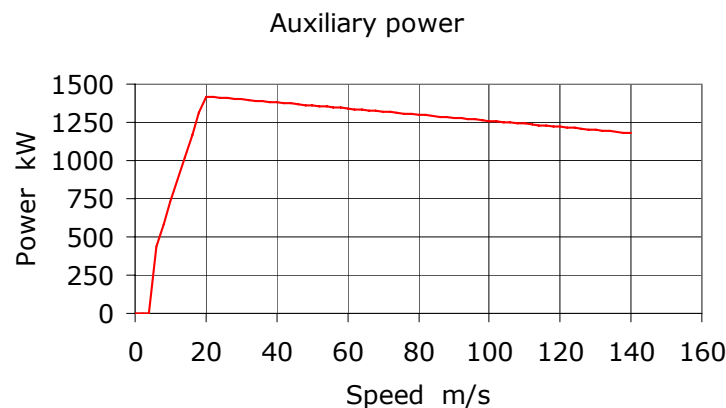


Figure 6: Auxiliary power demand vs. speed

regulations, such as the DDA, but this has not been completely verified although, following the visit, this seems plausible.

The formulae are as follows (v is velocity in m/s and train resistance is in kN. The integer N is the number of vehicles per train):

$$F_A = 2.8 * v^2 * (0.265 * N + 0.30) * 10^{-3}$$

$$F_M = N * (0.1 * v^{0.5} + 0.02 * v^{0.7})$$

$$F_B = 0 \quad \text{for } v \text{ between } 0 \text{ and } 20 \text{ km/h}$$

$$F_B = N * 7.3 \quad \text{for } v \text{ between } 20 \text{ and } 70 \text{ km/h}$$

$$F_B = N (146/v - 0.2) \quad \text{for } v \text{ between } 70 \text{ and } 500 \text{ km/h}$$

The following graph, Figure 7, was plotted from these equations; it shows the three components of drag for speeds up to 140 m/s (500 km/h). It is comparable with data in a recent paper by Lui and others.¹³

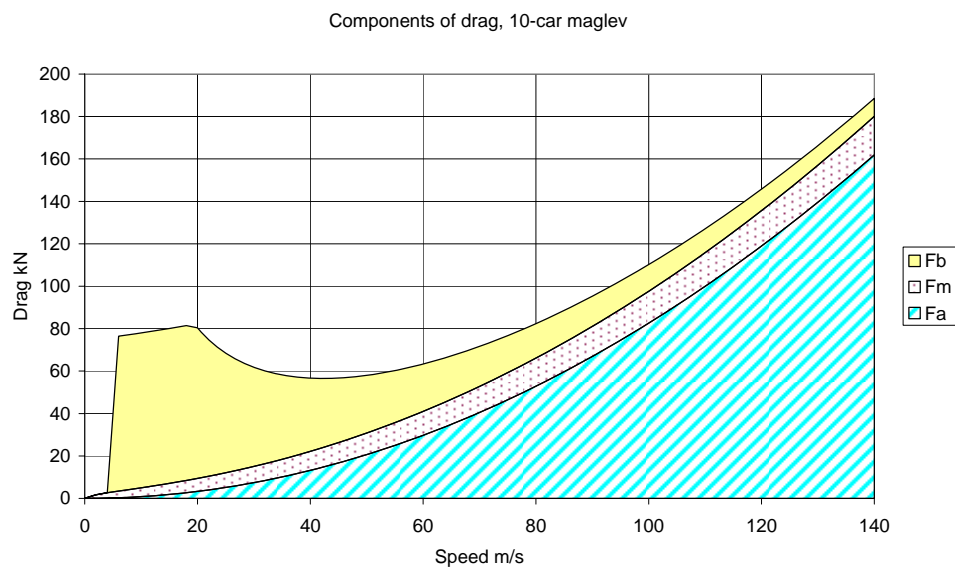


Figure 7: Components of train drag

It is relevant to compare the drag of a Transrapid train with that of the 10-car double-deck TGV. The following graph extrapolates TGV data¹⁴ (available only up to 60 m/s) using a best-fit polynomial. A definitive figure for the drag caused by the Transrapid levitation power is not available, so it is assumed that half of the auxiliary power demand goes to provide the lift magnets. This seems reasonable, as the "hotel power" on a conventional 10-car train is around half the 1.2 MW calculated above. If the fully laden

¹³ Liu Wanming (National Maglev Transportation Engineering R&D Center, Shanghai), Yao Jinbin, Zu Baofeng (Department of Road and Railway Engineering, Southwest Jiaotong University, Chengdu, Sichuan), Study of Optimal Design Speed of High-speed Maglev Project. 19th International Conference on Magnetically Levitated Systems and Linear Drives, September 2006, Dresden.

¹⁴ Delfosse P, *Les TGV-Réseau et le Duplex*. Revue Générale des Chemins de Fer, Déc. 1996

mass of a 10-car train is 640 tonnes (see later section) the implication is that the levitation system demand is around 1 kW/tonne. This is roughly one third of the figure quoted by Riches and Nenadovic for a low speed Maglev,¹⁵ partly due to a lower air gap than was used on the Birmingham system. The TGV has no comparable energy demand for suspension (the aerodynamic drag caused by the bogies and rolling resistance are included in the drag equations). The expression $F_T = F_A + F_M + 0.5 F_B$ has been evaluated and plotted in Figure 8:

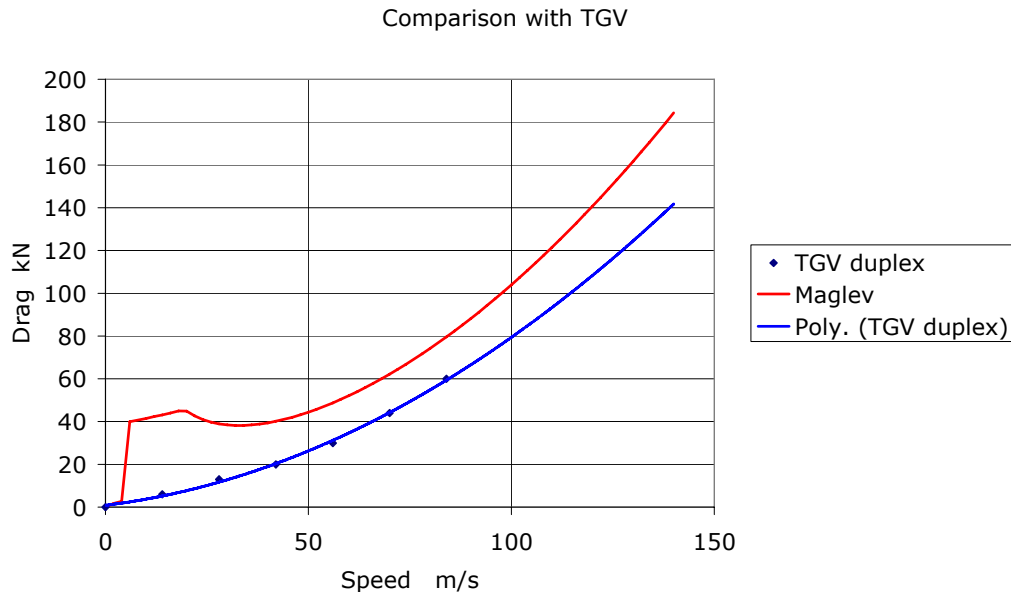


Figure 8: Comparison of TGV and Transrapid drag curves

Both trains are 10 vehicles long but the TGV is narrower than Transrapid (2.9m compared with 3.7m)¹⁶ and higher (particularly if the skirts over the lift magnets are discounted). The TGV is also shorter (200m compared with 252m). One would therefore expect the drag to be lower, as indeed is shown in the graph. However the TGV has a lower passenger capacity of 545 passengers in a 2-class configuration, compared with the Transrapid capacity of 876 passengers.

This comparison suggest that, in terms of rolling resistance and aerodynamic drag, Transrapid is comparable with TGV. This is to be expected as, for both trains, the dominant contribution to train resistance is aerodynamic drag which is independent of the type of suspension. When expressed in "per seat" terms, Transrapid shows a considerable benefit, but this is because the whole train length is assumed to be usable for passengers, without 20% of the floor area being taken up with power equipment (but see the following proviso on safety issues). Further, the greater train width allows 60% more passengers with only a 25% increase in length¹⁷. Transrapid has a more efficient width : length ratio than TGV (c.f. wide-bodied aircraft) but this mainly because it is not constrained by the 19th Century loading gauge of the rail network; it has little to do with the type of suspension.

¹⁵ Nenadovic V and Riches E E, Maglev at *Birmingham Airport: from system concept to successful operation*, GEC Review Vol. 1, No. 1, 1985

¹⁶ Taken from www.acmaglev.com/SECII-CDE.pdf

¹⁷ If one subtracts 2 x 100mm for wall thickness and 600mm for a gangway, the usable widths of TGV and Transrapid are 2.1m and 2.9m, an increase of 38%.

5.3 Comparison with rail “best practice”

The best practice high-speed rail chosen for comparison is the Japanese 700 series.¹⁸ (It may be possible later to get data for the new JR East experimental train E954, Fastech 360, which is pushing operational speeds up to 360 km/h). Figure 9 compares train resistance of a 10-car Transrapid (876 seats) with the standard 16-car Shinkansen 700 (1323 seats). In both cases, drag has been expressed per seat; because data are available for the Shinkansen only up to 300 km/h, characteristics above this have been extrapolated using a best-fit 3rd order polynomial to show the trend line.

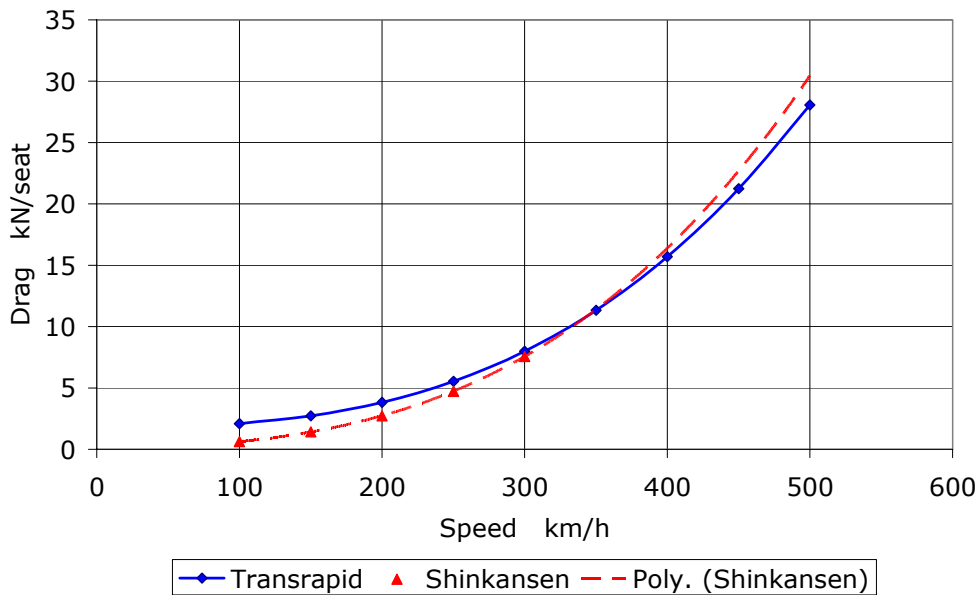


Figure 9: Comparison of Transrapid and Shinkansen drag per seat

This is a very significant result. At all speeds up to the maximum of the Shinkansen 700 series, the drag per seat, and hence the power requirement, is marginally lower than for the 10-car Transrapid. The power penalty of increasing the Transrapid speed from 300 to 500 kph is approximately 3.5 times roughly equivalent to the ratio of the speeds raised to the power of 2.5.

5.3.1 Impact of safety regulation on energy consumption

The energy consumption of a train is dependent on mass and aerodynamic drag. If this is expressed in terms of energy consumption per seat, it is also dependent on the number of seats that can be accommodated.

Following the accident in Lower Saxony and the battery fire in Shanghai, discussed earlier, there is a question mark over the safety of the technology and/or how it has been applied. As it stands, the system in Shanghai does not comply with the UK regulations for rail infrastructure.¹⁹ In particular the structural integrity and emergency egress arrangements fail to meet UK rail standards.

¹⁸ Y Hagiwara et al, *Quantitative analysis of running energy saving effect of Shinkansen high-speed train*, International Symposium on Speed-up and Service technology for Railway 7 Maglev systems, STECH'03, Tokyo Japan, pp162-165.

¹⁹ See, for example, The Railways and Other Guided Transport Systems (Safety Regulations) 2006 (ROGS) and associated regulations.

At this time, it is premature to hypothesise on exactly what changes might be needed for the technology to be used in the UK but it is likely that these could increase the weight of the vehicles (to increase their structural integrity), reduce the seating capacity (to provide passenger-free crumple zones at the ends of the train) and increase the aerodynamic drag (due to emergency walkways impinging on the vehicle boundary layer). Such considerations have been ignored in the calculations in this paper but should be borne in mind when considering energy use. The energy figures in this paper therefore represent a "best case" from the point of view of the Transrapid technology and the actual values could be significantly higher.

5.4 Train performance

5.4.1 Steady-state energy consumption vs. speed

The cruise power on level track is given by the product of drag and speed. This is plotted for a 10-car Transrapid in Figure 10 (this represents mechanical energy propelling the train, not electrical energy provided at the trackside). The figures provide the input for later calculations of electrical power demand.

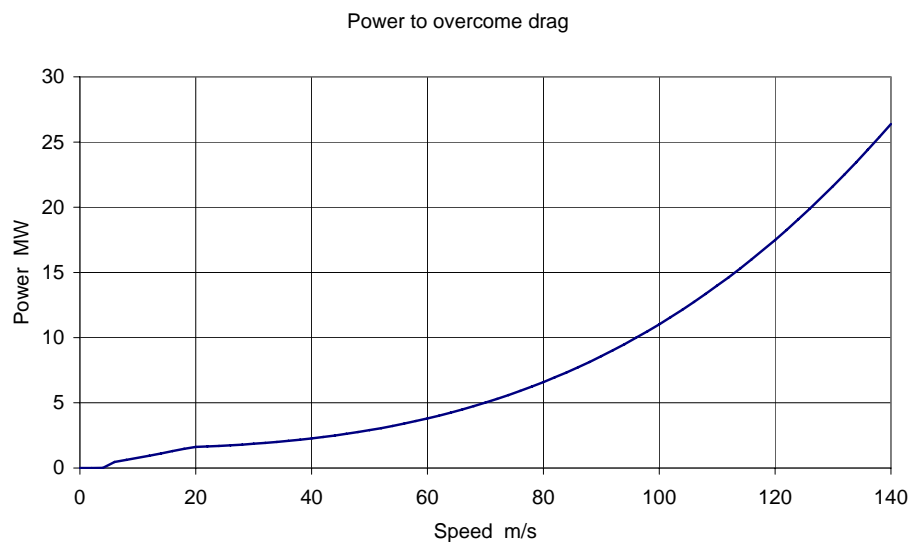


Figure 10: Power demand (ignoring acceleration)

5.4.2 Train mass and acceleration

When a train is accelerating, the drive system has to overcome the train resistance forces (as above) and also accelerate the mass of the train (force = mass x acceleration). Data from Transrapid²⁰ shows the mass of a 10-vehicle train to be 472t empty and 640t fully laden. Data from Ultraspeed UK²¹ gives the time to accelerate from 0 to 100 km/h, 100 to 200 km/h, etc. and this has been used to calculate the average acceleration over that period. This is shown in the following table.

²⁰ Taken from www.acmaglev.com/SECII-CDE.pdf

²¹ Information provided to Professor R Smith (as before)

Average speed (km/h)	Time for 100km/h (s)	Acceleration (m/s)
50	31	0.90
150	30	0.93
250	36	0.77
350	51	0.54
450	108	0.26

5.4.3 Total power demand

From the above data, it is possible to calculate the accelerating force needed for a fully-loaded train which is then added to the train resistance forces, calculated in an earlier section to allow calculation of the power demand.

Figure 11 shows the total power demand at the supply point for one train. This uses data provided by Ultraspeed UK on the efficiency of the drive system and electrical supply system: substation transformer 97%, converter 96%, transmission to track 95% and motor 87.3% giving an overall efficiency of 77.2%.

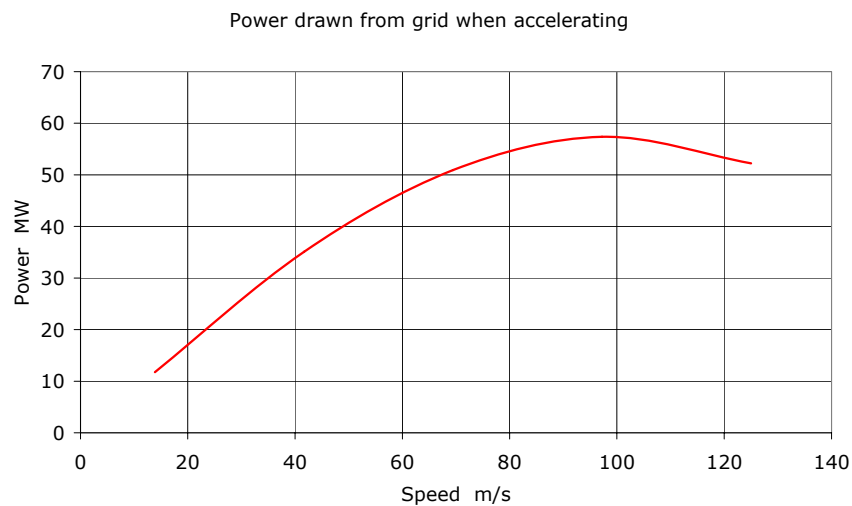


Figure 11: Grid power demand

5.5 Other impacts of a Maglev line on CO₂ emissions

5.5.1 Modal shift

A full study into the effects of a Transrapid system on CO₂ emissions would have to take into account the energy used by the system itself and also the savings of CO₂ from reducing the number of cars on the road and the number of conventional trains or planes. As Transrapid would substitute vehicles using electrical power for some using petrol, diesel or aviation fuel, the calculations need to take into account the fuel used to generate the electricity. In a complete study one could consider three cases: electricity generation using the 2006 fuel mix, DTI predictions for a 2020 gas-dependent mix and a scenario with 10GW of nuclear generation and a high-end estimate of renewables penetration.

5.5.2 Generation of new travel

A new transport system that significantly reduces journey times between centres of population would not simply result in a modal transfer from air, road and rail transport but would generate new traffic. The classic model for the number of passengers between two centres with populations Pop_a and Pop_b is represented by the following formula:

$$N_{pass} = k \times \frac{Pop_a \times Pop_b}{Journey_time^2}$$

While one might debate the accuracy of such a model and the value of the constant k , it is clear that the construction of a high-speed transport system (of whatever technology) would increase the total number of people travelling between the centres it serves. Depending on the pricing structure and the timetable, such a system might also increase the distances that people commute to work so that, rather than commuting 10 miles each way by car, someone might decide to commute 50 miles each way by the high speed network. Because of the creation of new travel patterns, a complete analysis of the effects on energy use of a high-speed network cannot consider only a comparison of kWh per passenger-km, but has to look at the energy use before and after the introduction of the system.

5.5.3 Energy to construct infrastructure

Constructing an elevated system of the type used by Transrapid would take large amounts of concrete, steel, aluminium and other materials (including construction of the linear motor, power supply cables and other equipment). A comprehensive report would have to look at the energy used for earth-moving to construct the infrastructure as well as the concrete, steel, etc. to build bridges, flyovers and other structures. It would also need to consider the implications of any additional transport systems or infrastructure planned to provide passenger feeder services to the Ultraspeed stations (e.g. approaches to stations from the existing road network, new car parks at stations, increasing the capacity of Heathrow Express . . .).

5.6 Energy consumption over a realistic route

Without more information on the route profile (and the time to undertake a detailed simulation), it is not possible to make an exact calculation of train energy consumption. However it is possible to make a rough estimate based on train resistance and mass. As a comparison with rail, the route London to Edinburgh has been analysed. The route has been simplified and is assumed to consist of 400 km with a speed limit of 500 km/h and 300 km with a speed limit of 300 km/h. (This gives a total track length of 700 km, compared with the direct rail route of 600 km.) The energy absorbed by the train at these speeds can be calculated on the basis of $work = force \times distance$ and the kinetic energy to accelerate the train to these speeds as $\frac{1}{2}mv^2$. Information from Ultraspeed UK²² suggests the train will accelerate from rest 12 times on the London to Edinburgh trip. To this could be added an estimate of 8 accelerations due to intermediate speed restrictions and out-of-course operations. It is assumed that there will be some 500km/h running between station pairs and so the kinetic energy appropriate to this speed has been calculated. Similarly, the regenerated braking energy has been calculated.

5.6.1 Energy consumption per seat-km

If one computes the energy used by Transrapid on the above basis, ignoring regenerative braking, the total energy demand is 76 MWh representing 87 kWh per seat. This compares with 30 kWh/seat for an IC225 train operating at 200 km/h and 62 kWh/seat

²² Factbook, page 23

for a NoL Eurostar running at 300 km/h.²³ (It has to be stressed that these figures are approximate and are intended only to give an order of magnitude estimate.)

Repeating the calculation and assuming 100% of the energy used to accelerate the train (but not that used to overcome drag) is available during regenerative braking (probably an optimistic assumption that depends on the receptivity of the local power supply) and that the efficiency of regeneration is the same as during acceleration, gives a net energy demand of 59 kWh/seat. (Most rail vehicles built in the last 10 years have the capability of regeneration so similar reductions in net energy would also apply to any replacement IC225 or TGV.)

5.6.2 Journey time

Data provide by Ultraspeed UK suggests that the Transrapid journey time from London Heathrow to a station on the outskirts of Edinburgh would be 160 min. This timing relates to the route through Birmingham, Manchester, Leeds and Newcastle. The present journey time for an IC225 is 260 min, including make-up time, and the calculated journey time for a 300 km/h Eurostar is about 185 min, with two stops. Both these are from Kings X to Waverley. Whether passengers find this more attractive than 160 min between out-of-town termini depends on the exact start and finish points of their journeys; for city-centre to city-centre the TGV would probably be quicker. The situation is even more marked for trips such as central London to central Birmingham where the door-to-door journey time for a Transrapid passenger, via Heathrow and Birmingham airport, would, in all probability, be longer than that for someone travelling by Pendolino at today's speeds.

5.6.3 Air travel substitution

Part of the rationale for building a maglev line would be to transfer air passengers to a surface transport mode and therefore reduce CO₂ emissions. To some extent this is tilting at windmills. For most passengers (except those arriving at a London airport by plane from long-haul flights) the journey times between central London and Birmingham, Manchester or Leeds are shorter by existing rail services than by internal airlines, if the time from the city to the airport, check-in and security are included. Unlike the situation in the 1980s when BA ran a shuttle with guaranteed seats, generous hand luggage allowances and a 10-minute check in, the current schedules are not time-competitive. (Many air fares are cheaper than fully-flexible rail fares but this is likely to change when environmental taxes are introduced.) Maglev would thus only improve the time-competitiveness of surface transport, compared with flying, for longer journeys, such as London to Glasgow or Edinburgh. However current data show traffic flows for most of the day of fewer than 1000 pass/h/direction between the Scottish Lowlands and the London area. Many of these, such as those from long-haul flights or passengers who live south of London and presently use Gatwick, are unlikely to find travel from either Heathrow or the M25/M1 junction particularly attractive.

Unless very heavily subsidised, the throughput of a north-south maglev system would have to be around 10 trains/h/direction giving a capacity 8000 pass/h, if the capital charge per passenger were not to be prohibitive. This suggests that fewer than 10% of the seats would be occupied by passengers captured from the airlines. For this fraction of passengers, the carbon footprint would be reduced; for the other 90% their carbon footprint would be increased (as a 500 km/h maglev would use more energy than any competing surface transport). On average, the increased footprint of the 90% would far outweigh the reduced footprint of the 10% resulting in a net increase of CO₂ emissions.

²³ Kemp R J, *The European High Speed Network*, Discussion Meeting at the Royal Society, "Passenger transport after 2000 AD" June 1993. (Reprinted in *Passenger Transport after 2000 AD*, edited Feilden, Wickens and Yates, ISBN 0 419 19470 3)

5.6.4 Comparison with road vehicles

Previous work²⁴ compared a fuel-efficient car (Audi A4 1.9 TDI) with rail transport and concluded that the primary energy demand (and hence CO₂ emissions) were roughly comparable with a 225 km/h train and less than a 350 km/h train, when measured on a per-seat basis. The comparison depends on the fuel mix used for electricity generation so can only be approximate and a valid comparison should take into account the relative load factors on the alternatives. By this comparison, Transrapid is likely to create more CO₂ per seat-km than a fuel-efficient car, unless there is a major switch to nuclear generation, comparable with that in France.

If a 500 km/h maglev line were to serve the same destinations as a 200 km/h rail line, it is likely that it would capture most of the traffic, assuming prices were comparable. However it is not clear that there would be a similar modal shift to maglev from cars on a parallel motorway. Many people drive, rather than take the train, because they are carrying bulky luggage or because they are travelling from and/or to a location far from public transport, such as a house in a village or an office in an inaccessible business park.

Unless there is evidence to the contrary, it would be reasonable to assume that a significant proportion of the passengers on a maglev line would either transfer from parallel rail routes or would be people who would otherwise not have made the journey. A comparison of CO₂ emissions from cars is thus less relevant than a comparison with electrically powered railways.

5.7 Noise levels

Manufacturer's figures²⁵ show the following noise data:

Transport system,	Weighted sound level in dB(A)	
	50m	100m
Transrapid line, 10 trains/hour, 500 seats at 400km/h (six-section vehicle, elevated track)	61	56
ICE line, 10 trains/hour, 500 seats at 250km/h	64	59
Regional Express (S-Bahn) 10 trains /hour, 500 seats at 100km/h	67	62
Motorway with 3000 vehicles/hour	70	65

This implies that the noise level of a Transrapid line with trains passing at 400 km/h is lower than an ICE line with trains passing at 250 km/h and significantly lower than an S-Bahn line with trains travelling at 100 km/h. We understand that the current proposal is that trains would run at 500 km/h in open country and that speeds would be reduced to 300 km/h in built-up areas. The authors of this report do not have the expertise to make a definitive judgement on this proposal but our subjective view is that, so long as the line follows existing transport corridors and local barriers are constructed for any neighbours particularly close to the line, this is likely to be acceptable.

²⁴ Kemp R J, *Take the car and save the planet?* A study of comparative energy consumption in inter-city transport. IEE Power Engineer October/November 2004

²⁵ Transrapid website

6 Civil engineering costs and feasibility

6.1 Vertical curvature and passenger comfort

It is suggested by the Transrapid team that their system can operate with smaller radius curves, in both the horizontal and vertical planes than can high-speed rail. It is difficult to understand the justification for this claim. The limits set on track curvature, cant and tilt on conventional track are principally concerned with passenger comfort, and are independent of the propulsion system. It is likely therefore that a long distance intercity route, unless extremely straight and level, would not permit running at 500 km/h and considerable variations of speed would be dictated by the track route geometry. These changes of speed would be energy-intensive: 300 km/h running would require fewer speed changes, and, surprisingly, would not lead to massively increased overall journey times.

The acceleration experienced by passengers as a vehicle rounds curves in either the horizontal or vertical planes need to be limited for comfort. This can be achieved, in the horizontal plane, by canting the track and tilting the vehicle.²⁶ For a design speed of 300 km/h and cant of 150 mm, a zero acceleration requirement leads to an unfeasibly large horizontal track radius of nearly 7km. In practice, either the speed is limited, somewhat greater cant is used (possibly by tilting) or a degree of horizontal acceleration is allowed. This allowable acceleration has been determined experimentally: a widely accepted value is 1m/s² or 0.1g, which is equivalent to 6° of cant deficiency, a value allowed as an limiting case on most European railways. It appears that Transrapid is proposing a value 50% greater than this and 9° deficiency was measured over one curve on the Shanghai system. but it is not apparent how this value is justified, as it is a feature of passenger comfort, not technology. Given the nature of the test track, it is unlikely that Transrapid have confirmed this figure is acceptable. If tests demonstrate that passengers will not tolerate such high acceleration levels, the train speeds would have to be reduced over vertical curves.

This is of crucial importance, not only for the layout of the route, but as a limit to which sections can be traversed at high-speed. The critical point is that time saving is best achieved by uninterrupted travel at high speed. The basic kinematics of the relationship between the time taken, t , to traverse a section, length l , at speed, v , i.e.:

$$t = \frac{l}{v}$$

By differentiation, the saving of time, δt , associated with a speed increase δv , is inversely proportional to the square of the current speed (the law of diminishing time saving with speed):

$$\delta t = -\frac{l}{v^2} \delta v$$

This also leads back to the whole question of 300 or 500 km/h. Unless the connections at the ends of the journey needed to make the complete door-to-door journey are also reduced, the overall time saving enjoyed by the increase in speed can be very small.

The point is made that Transrapid has a significantly superior acceleration than a high-speed train. But this acceleration will need a traction force much greater than the resistance force, with associated extra power requirements. The superior acceleration is of greatest advantage when going from very low to high speeds. But, as discussed above, this is exactly the regime where the resistance forces on the Transrapid are highest.

²⁶ D Rogg, et al, *Technical & economic comparisons of high-speed-rail and maglev systems*, Railway Technical Review, No 1, 2006, pp 8-18

6.2 Maintenance of guideway

The air gap on Transrapid is between 10 and 12mm. The track must be installed to tolerances much closer than this to achieve a satisfactory passenger ride and prevent fouling between magnet and track. Importantly, a very close tolerance on guideway dimensions has to be maintained throughout the life of the system. We have seen no evidence that this is practicable over the challenging terrain of the proposed route.

Engineers at the Rail Technology Research Institute (RTRI) in Japan argue that, to cope with realistic track roughness and settlement of civil structures, it is not practicable to use conventional magnets, such as are used on the Transrapid, because of their limited gap, and therefore superconducting magnets must be used.²⁷

The other major maintenance intervention will be on the electrical system. Transrapid has a three-phase variable frequency inverter next to the track every 20km. The track itself has hundreds of thousands of electrical windings, each prone to earth faults, shorts, etc. (It is basically the same as the stator of an alternator but "unrolled".) Although the system is duplicated, it is difficult to imagine that there will never be failure modes that stop the whole system. One can envisage lightning strikes or a fire caused by line-to-line faults that would have the potential to cause localised damage to several parallel systems. This is an area that requires further specialist study.

6.3 Switching system

The switching system of maglev involves the movement of large parts of the guideway. This is inevitably more cumbersome than the switches (points) of the conventional wheel/rail system. In order to serve intermediate stations and to allow the possibility of "leapfrogging" services to increase the flexibility of operations as exemplified by the Nozomi, Hikari and Kodama services of the shinkansen, a smooth, reliable and practical method of switching is extremely important.

7 Supporting infrastructure and enabling works

The construction of a Transrapid system would represent a major civil and electrical engineering exercise. However construction of the guideway, its drive systems and the trains would represent only part of the total infrastructure investment. This section considers some of the other areas in which investment would be needed.

7.1 Power supply

Ultraspeed UK have suggested that the train service can be managed to ensure that no more than one train is ever in the zone fed from a single supply point. We are sceptical that this could be possible. There will occasionally be delays to the service in one direction – snow clogs one of the massive points machines, a wheelchair user joining at an intermediate station finds her allocated space blocked with luggage, a faulty door interlock indicates a door is not closed, so a technician has to be called to investigate before a train can leave the terminal station, disruptive passengers are removed by police, etc. Unless the operator is prepared to impose an identical delay to the service in the opposite direction, services in different directions will become "out of sync". This implies an occasional peak demand of up to 120 MVA at a single grid supply point and a regular demand fluctuating between 0 MVA and 60 MVA every 2 to 5 minutes (bearing in mind both directions of track).

We have consulted experts at Manchester University and employees of Network Rail involved in negotiations with the power supply companies. Their unanimous view is that

²⁷ The Engineer, 24 July 1997.

loads of this type will have to be fed from the 275 kV or 400 kV supergrid network, which will impose additional costs on the infrastructure.

Transrapid have said that there is a policy of using duplicated feeders at each supply point. Assuming the line is 800 km long and there is a supply point every 40 km, there will thus be a need for about 20 duplicated feed points from the supergrid. While this is not technically difficult, it will require a significant financial investment. Current costs for supergrid lines in Scotland are estimated at £863,000/km²⁸ so, assuming an average distance from the supergrid to the maglev line of 20 km, the costs of the lines themselves will be around £0.5bn, excluding the costs of connecting into the grid and the associated transformer stations.

7.2 Land acquisition and diversion of services

In section 6 we discuss the trade-off between vertical and horizontal curvature and speed that might be necessary to ensure passenger comfort. These translate into the need to obtain the rights of way for reasonably straight routes without too many sharp changes in gradient (the definitions of "reasonably" and "sharp" are still to be defined). Whatever criteria are eventually adopted, it is likely that minimum horizontal radii on high-speed sections will be at least 3 km, which will have implications on the exact line of the route and how it can avoid built-up areas. Because of the limitations on vertical curvature, changes in level will need to be gradual which has implications on overbridges and other infrastructure. It is thus likely that other infrastructure and services will have to be diverted to allow the construction of a maglev line.

We have not attempted to assess the costs of land acquisition, noise barriers and landscaping, restitution to affected neighbours or the diversion of other infrastructure and services but, if CTRL is any guide, they are likely to be significant.

7.3 Feeder services to out-of-town stations

We have discussed in section 5 that, for a line to be attractive to private investors, it will either be necessary to "sweat the assets" by fully utilising the infrastructure or receive a significant financial subsidy from public funds. The capacity of a high-speed line, whether maglev or using conventional technology, is between 6,000 and 30,000 pass/h/direction. The former figure could represent 10 trains/h with 600 seats, similar to the WCML and ECML; the latter is the figure for the Tokaido Shinkansen.

The plan produced by Ultraspeed UK is based on stations at out-of-town locations. At present, most of these locations are not served by high-capacity connections to city centres. So, for example, diverting passengers from Manchester Piccadilly station to a new terminal near the airport would require a major upgrade to the services from the airport to the city – unless it is planned that most passengers would arrive and depart by road, in which case there would be implications on the approach roads to that area and the provision of car parking (already crowded and expensive in the area). The situation at Heathrow, where the capacity of Heathrow Express is considerably less than that of the proposed maglev service, is a more extreme example.

This report is restricted to the high-speed link itself. We have not considered how feeder services from city centres would be provided, or how they might be funded. We note, however, that they could represent a significant component of the total cost of the project.

²⁸ ICF Consulting Overview of the Proposed 400kV Overhead Transmission line near Beauuly, Scotland Nov 2005

7.4 Intraoperability

It is most likely that any high-speed system in Britain will be built gradually, even if stand alone "demonstrators" are introduced. This phased introduction is exactly what happened with the motorway network. A major disadvantage of the maglev system would be its incompatibility with existing infrastructure. A conventional high-speed train could run off the special dedicated track to extent the journey into city centres and to permit longer journeys without change of train. This ability is demonstrated by both the TGV and shinkansen systems and significantly enhances the flexibility of their operations.

8 Technical standards

8.1 Proprietary technology

Magnetic levitation is not compatible with the concepts of open access of transport infrastructure, enshrined in European Directives. As the propulsion and braking are track-based, but emergency braking is train based, there is no clear boundary of responsibility that would permit open access, even if the contractual issues could be resolved.

Buy TGV and you can obtain additional or replacement trains from the Italians (ETR500), Germans (ICE3), Japanese (Shinkansen 500) or Swedes (X2000). Buy Transrapid and you are stuck with a sole supplier. Previous transport systems using a unique track-train interface (e.g. Matra VAL in Jacksonville or Von Roll monorail in Newark) have generated difficult client-contractor relations and claims of an abuse of a monopolistic position.

Because only the Transrapid consortium could provide extensions to their proprietary system, it would not be possible to call for competitive tenders. This might breach EU public procurement policies. We have not attempted to analyse this situation but note that it is an area that must be addressed before any decision is taken.

8.2 Track-train interface

Early German experiments used short-stator motors (i.e. windings on the train and a simple reaction rail on the track, like the Birmingham maglev). Recent Transrapid designs use a long stator motor (i.e. windings on the ground). The Japanese design uses superconducting magnets with yet a different track geometry. It is likely that the track-train interface will change again over the next 30 years which would leave present systems obsolete and very difficult to extend or maintain.

8.2.1 Japanese developments

Shirakuni et al.²⁹ have reported test running on the Yamanashi Maglev Test Line (YMTL) since April 1997. Two types of train have been evaluated with different aerodynamic characteristics:

²⁹ Noriyuki Shirakuni, Motoaki Terai, Katsutoshi Watanabe (Central Japan Railway Company), Kiyoshi Takahashi (Railway Technical Research Institute, Tokyo). *The status of development and running tests of Superconducting Maglev*. 19th International Conference on Magnetically Levitated Systems and Linear Drives. September 2006, Dresden



Figures 12 and 13, Japanese maglev trains

Initially the work was to verify the technical practicality as an ultra-high speed mass transport system. In the next five years, they carried out the evaluation of durability and reliability, the improvement of cost performance, and aerodynamic characteristics. The total distance covered is shown on the following graph:

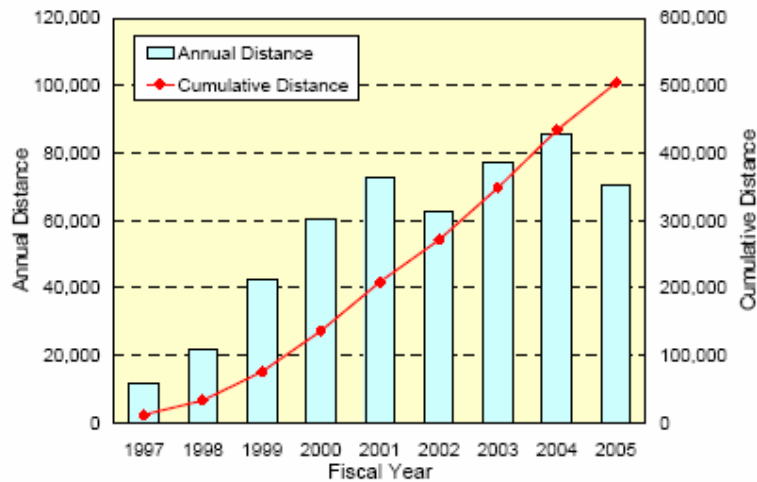


Figure 14: Annual and cumulative distance in Japanese testing

Although this technology has not entered commercial service, it would be premature to discount it, were a decision taken to move from steel wheel-rail technology. In September 2006, the board of JR Central agreed to seek funding to extend the existing test track from 18.4km to 42.8km, to renew the existing facilities and to acquire 14 new vehicles. If funding is forthcoming, work would start in late 2007, and a programme of further test running would begin in 2014 for a three year period.

8.3 European Legislation

Since 1991 there have been several EC directives on different aspects of the trans-European high-speed rail network. (UK regulations are explicit in that maglev systems are treated as any other railway). However it is not clear how these Directives might apply to such a system. It is clear however that a UK decision to build an 800 km maglev system would be entirely counter to the objectives of these EC directives which are to establish an interoperable and competitive network.

The Directives have been amended several times and are now incorporated into two integrated packages, the First & Second Railway Packages. Considerable further work is required on how these items would impact a possible maglev scheme.

9 Conclusions

1. In terms of energy consumption per seat, the proposed Transrapid system operating at 500 km/h would use between 2 and 3 times as much energy as an IC225 and roughly 40% more than a 300 km/h TGV running on a direct route. Replacing conventional train services with Transrapid would increase the UK's CO₂ emissions.
2. In comparison with 200 km/h rail, Transrapid would offer a worthwhile journey time improvement to passengers over longer journeys, such as London to Scotland. Over shorter journeys, such as London to Birmingham, city-centre to city-centre times are likely to be no better than for existing train services, unless the system has direct access to city centres.
3. Encouraging travellers to switch from a fuel-efficient car to Transrapid *might* be beneficial environmentally if there is only one person in a car: it depends on the mix of fuels used for electricity generation. For 2 or more people travelling together, it would be more environmentally friendly for them to use a car. While it is almost always environmentally beneficial to persuade car users to switch to a 200 km/h train, there is no general environmental case to persuade car users to switch to a 500 km/h maglev.
4. Transrapid would not replace conventional train services, as it would serve different communities, but would supplement them. Having stations on the outskirts of cities, not in the centre, would encourage car use and the service would encourage travel growth, including long-distance commuting. Overall, the construction and operation of a 500 km/h maglev system would increase the UK's emissions of CO₂, thus requiring greater economies elsewhere if national targets are to be met.
5. During Transrapid acceleration, the load taken from a grid supply point would be more than 50 MW per train. In addition, trains could regenerate up to 40 MW into the supply. This would require new connections to the EHV grid and, in places, may require its reinforcement. On the assumption that a fully-developed Transrapid system would operate with around 60 trains, the total additional electrical load would be more than 1 GW – equivalent to a nuclear power station with the capacity of Sizewell B.
6. The Transrapid Shanghai project does not comply with UK safety standards for guided transport systems. Major changes to both vehicles and infrastructure would be necessary unless safety standards are relaxed.
7. Prototype running on the largely flat routes in Germany and Shanghai has not demonstrated that the proposed levels of lateral and vertical acceleration, to which passengers on a more hilly and sinuous UK system would be subjected, would be acceptable. Until this issue is resolved, any proposals that define both the route and the journey time can only be hypothetical.
8. It is not clear how an intercity maglev project could be structured commercially to comply with European Directives on interoperability or competition policy.
9. A realistic costing of the whole project should include land acquisition, service diversion, provision of feeder services to city centres and power supply feeds. We have seen no evidence that these are included in the estimates to date.
10. Because the wheel/rail system produces increasing damage as speeds increase, the track maintenance costs also increase sharply with speed. At first sight, the elimination of direct contact in the maglev looks attractive, but experience is limited on the long term maintenance costs of the maglev infrastructure.
11. Maglev systems would not allow the flexibility of interoperability with the existing rail network. This has implications for the phased introduction of a nationwide system and for city centre access. The switching system of maglev is necessarily cumbersome.

Roderick Smith & Roger Kemp,
18 June 2007