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**Author**
Sands, Brian D.

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# The Transrapid Magnetic Levitation System: A Technical and Commercial Assessment

Brian D. Sands

Working Paper
UCTC No. 183

**The University of California
Transportation Center**
University of California
Berkeley, CA 94720

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**University of California Transportation Center**

108 Naval Architecture Building
Berkeley, California 94720
Tel: 510/643-7378
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# The Transrapid Magnetic Levitation System: A Technical and Commercial Assessment

Brian D. Sands

Institute of Urban and Regional Development
University of California at Berkeley
Berkeley, CA 94720

CALIFORNIA HIGH SPEED RAIL SERIES

*Working Paper*
*March 1992*

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The University of California Transportation Center
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# LIST OF FIGURES

# PREFACE.

This is one of a series of reports now being published as the first output of IURD's study of the potential for a high-speed passenger train service in California. Each report deals with a specific high-speed train technology; it attempts an evaluation, standardized as far as available data permit, of its technical and economic viability.

Specifically, each report assesses the particular high-speed technology on a number of criteria:

1. *Technical performance:* configuration of roadbed in terms of gradients, curvature, and construction cost; power sources; capacity and speed; capacity to integrate with existing transportation facilities.

2. *Economic performance:* traffic levels; revenues; financial appraisal and overall cost-benefit analysis; level of public subsidy required, if any.

3. *Resource consumption and environmental performance:* type and amount of energy required; impact on non-renewable resources; environmental impact, including emissions, noise, visual intrusion and effect on local communities.

The present series includes five studies. Two companion studies, on British Rail's Inter-City 125 and 225 services and on Tilting Trains (the Italian *Pendolino* and the Swedish X-2000 service), will follow shortly. Thereafter, a systematic comparative analysis will be published.

The CalSpeed study will continue with preliminary route alignments, also to be published shortly, followed by market assessments, to be published in Fall 1992. These will bring to a close the present phase of work, which will be the subject of an overall report also to be published in Fall 1992.

**PETER HALL**
**Director and Principal Investigator**

# 1. INTRODUCTION

Magnetic levitation is the first truly new transportation technology in one hundred years and comes at a time when advances in transportation are sorely needed. The German Transrapid magnetic levitation train is the first commercially available system to use this technology. Based on technology that originated in the United States, the Transrapid system has been under development for approximately 15 years in Germany. During the last decade a number of serious proposals have been made for its use in the United States and Germany. However, to date, none have left the planning stage and all remain speculative at best. This is a function of the high level of risk associated with such a new technology, which has yet to prove itself in commercial operations, despite holding great promise for high levels of service.

Based on the proposals made for its use reviewed in this paper, the Transrapid's service level is potentially higher than that of conventional rail technology. This is a function of its high speed and level of comfort. However, the Transrapid is unable to use existing conventional rail tracks, requiring passengers to transfer between the two systems to reach destinations not served by the Transrapid. This is a severe constraint to its service level.

The Transrapid system's engineering is based on integrated circuit technology which controls electromagnetic fields between the vehicle and guideway. The gap created by the electromagnetic fields obviates the need for contact between the vehicle and guideway, and allows the vehicle to float on a cushion of electromagnetic waves and air. The Transrapid has repeatedly proven itself during test runs at the Emsland Test Facility in Germany. However, the Emsland Test Facility has a very short course without geographical aspects that would be found along any commercial route, such as significant grade changes, tunnels, and parallel tracks. Furthermore, the tests have been made with a vehicle having only two cars; commercial operations are likely to occur with up to ten cars per trainset.

The Transrapid's performance level, as measured by ability to transport passengers quickly over long distances, is potentially very high. Although the Transrapid's speed is theoretically unlimited, it has only reached a maximum speed of 271 mph (436 kmh) due to the small size of the Emsland Test Facility. This speed has been surpassed by the French TGV and approached by the German ICE during test runs. Constraints posed by noise, energy use, and aerodynamic resistance may limit the Transrapid to speeds around 250-300 mph (400-500 kmh). The lack of a commercially operating system makes it difficult to evaluate the Transrapid's reliability and safety.

The environmental impacts from the Transrapid are less than those of its competitors. Like other rail-based transportation systems, it uses much less land than is required for motor vehicle roadways. It also uses less energy and creates less noise than automobiles, trains, and planes while travelling at equivalent speeds. However, questions remain about the effects of electromagnetic fields on passengers and about the noise level at speeds above 250 mph (400 kmh).

The costs and revenues of a Transrapid system are uncertain at best. A number of serious proposals for its use are examined in this paper, but the costs vary widely between them, as do the revenues. It is clear, though, that the cost of building a Transrapid system is very high. The question remains whether it is higher than that of a conventional high speed rail system and whether the revenues generated would be sufficient to support the construction and operating costs.

The status of the Transrapid is currently uncertain. Numerous proposals for its use have been made, but only a very short route between the Orlando Airport and Disneyworld appears as if it will enter commercial operations in the near future. Proposals for Essen-Bonn and Las Vegas-Los Angeles have both recently fallen through. The Las Vegas-Los Angeles proposal will be renewed soon, hopefully with public sector support, a key element which has not been forthcoming in the past. In addition, a new proposal for the Transrapid betweeen Hamburg and Berlin is receiving strong support in Germany. While it is still in the planning stages, it appears to have the greatest chance of any proposal in Germany to date.

Review of the Transrapid system results in the opinion that it has great potential, but that too many questions regarding its commercial performance currently remain unanswered. Numerous technical questions exist about its reliability, safety, and its performance under diverse conditions. The inability to integrate with existing systems or upgrade in a piecemeal fashion, forcing significant up-front financial and planning commitments, is a severe implementation constraint. These issues combine strongly to challenge the current suitability of the Transrapid for intercity commercial operations. The fact that all past proposals for intercity use have been indefinitely shelved only serves to reinforce this position.

## 2. SERVICE

Service level includes such items as the following: density of network, station spacing, frequency of service, integration with other networks, and ticketing. Without a revenue operating system in service, it is difficult to define the Transrapid's level of service, a situation which will occur repeatedly throughout this report. Perhaps the best way to examine its service level is to review the three most serious proposals for use to date: Essen-Bonn, Las Vegas-Los Angeles, and

Orlando-Disneyworld. Although there are numerous other proposals to use the Transrapid, they have varying levels of detail and have not advanced as far toward implementation. The three noted have come close to implementation and therefore serve as good examples for the strengths and weaknesses associated with the Transrapid.

## Essen-Bonn

The Essen-Bonn proposal has a number of variations but is above all designed to connect the Dusseldorf and Cologne/Bonn airports, creating a super-regional airport (see Figure 1). It may also continue on from each of the airports to the main train stations of Essen and Bonn. It will stop in Dusseldorf and Cologne for a total of six stations over its approximately 63 mi (102 km) length. Between 80 and 100 percent of the route will consist of double tracks, allowing a maximum speed over the route of 248 mph (400 kmh), with an average of approximately 124 mph (200 kmh). Time between Essen and Bonn is 30.5 min. and between Dusseldorf and Cologne airports is 14.5 min. Between four and five trains per hour per direction are proposed, giving a maximum wait time of 12-15 minutes.[1]

Air passengers and airline/airport employees will be charged a flat rate of $6.70 or 10 DM (1989 DM at an exchange rate of 1 DM=$0.67); and intercity passengers will be charged $0.12, or 0.19 DM per kilometer.[2] In keeping with other German rail systems, tickets could presumably be purchased in advance at a travel agent or included in the purchase price of an airline ticket.

Integration with the new InterCity Express (ICE) is desired, but as final routing in the Rhein corridor has yet to be set, it is uncertain at which stop this will occur. Both the Bonn and Cologne stations are currently stops for the InterCity (IC), and each has an extensive local public transit system. This corridor is also parallel to a number of major autobahn routes, making it easily accessible to and from urban areas.

## Las Vegas-Los Angeles

The approximately 230-mile route is from the downtown Las Vegas area and to an as yet undecided location in Southern California, with Anaheim or Ontario the most likely (see Figure 2). Anywhere from two to seven stations are proposed, with between 19 and 40 percent double-track. Estimated time between the two terminal stations is 74 to 94 minutes, depending on the terminus in Southern California, with each additional station adding approximately 4 minutes.[3] A maximum of 28 to 34 trains per day per direction on weekends are proposed, with middle stations receiving between 4 and 31 depending on demand.[4] Demand is highly peaked (Friday-

Figure 1. Essen-Bonn Route.

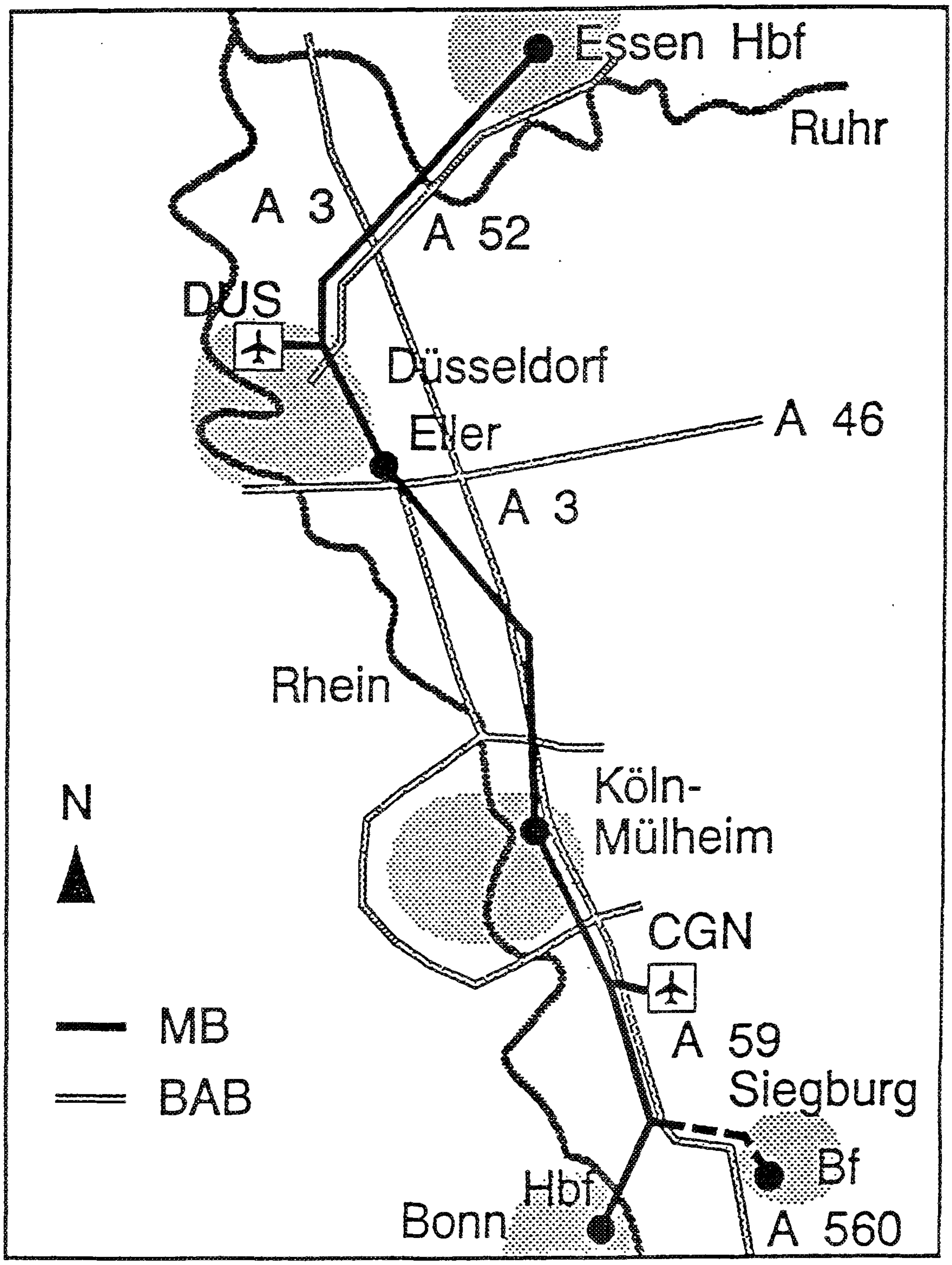
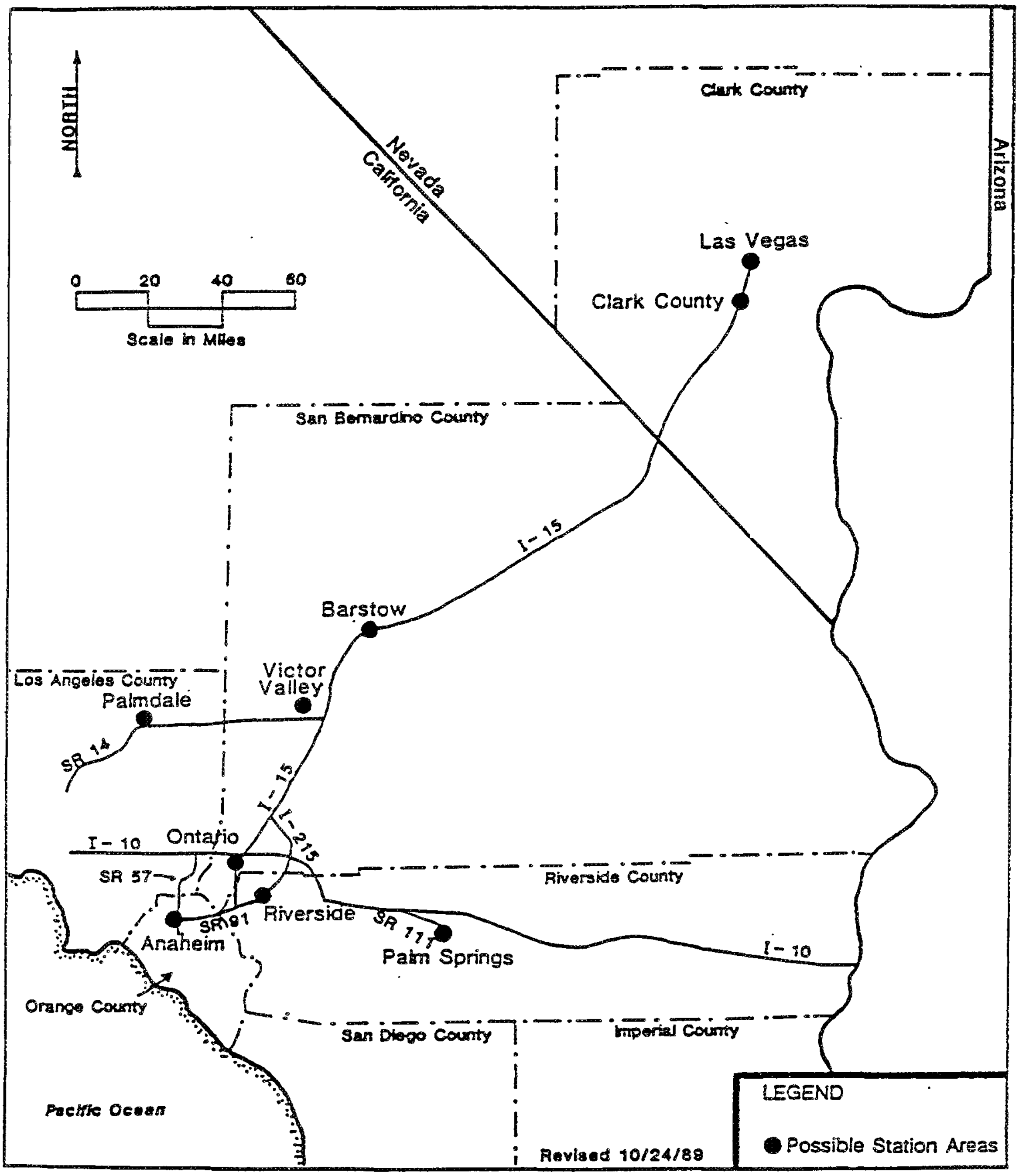


**Figure 2. Las Vegas-Los Angeles Route.**



Sunday), so weekday frequency would presumably be considerably less. A one-way ticket will cost $52.00 (1989 dollars).[5] Some tickets may be a part of package deals (hotels and meals).[6]

Integration into existing mass transit is negligible. However, the final location of the Southern California terminus is highly dependent on access from highway traffic. The meeting point of I-10 and I-15 near Ontario appears advantageous.

### Orlando-Disneyworld

The Florida Magneteic Levitation Demonstration Project route travels 20 miles between the Orlando airport and the EPCOT Center at Disneyworld, with no stops in between (see Figure 3). Speeds up to 250 mph will be achieved, with an average travel time of seven minutes over a single guideway.[7] Ticket prices are $9.00 and $12.00 (1988) one way.[8] Tickets may be purchased directly as a part of air fare or hotel reservation.[9]

Integration with other transportation systems is not a great issue with such a short route. Automobile access is assured at the airport and Disneyworld, as well as access to local taxis and shuttles. However, the route could be expanded, and there are several other transportation systems under consideration in the area. There are proposals for several people-mover systems nearby, and the Florida High Speed Rail Transportation Commission is currently examining the use of conventional rail for a high-speed rail system in Florida.

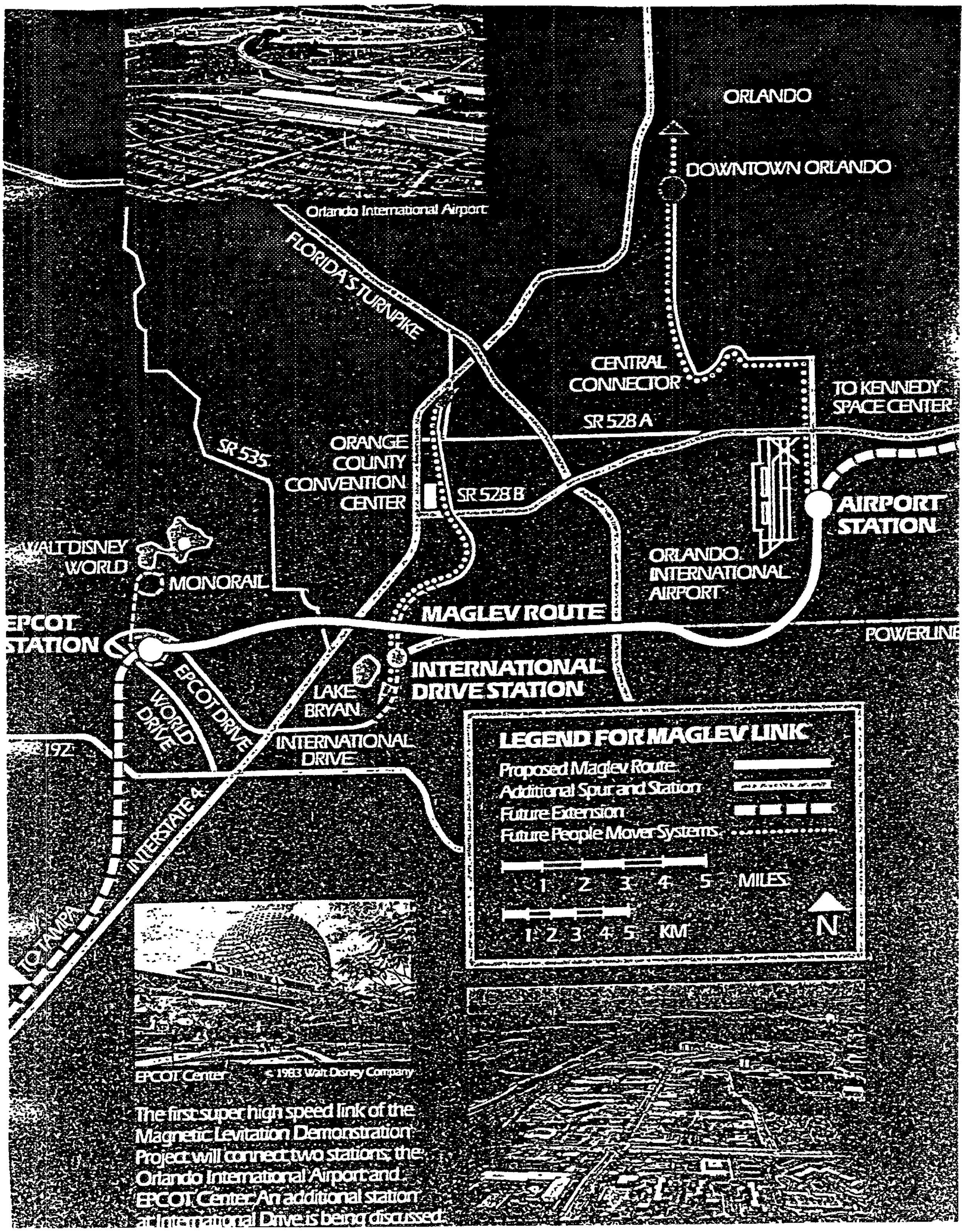
## 3. ENGINEERING

Magnetic levitation (Maglev) represents the first revolutionary advance in propulsion technology since the invention of the internal combustion engine, and it is the first new form of transportation since the airplane. The Transrapid is the culmination of more than fifteen years' worth of concentrated research in Germany, built upon technology origninating in the United States. It is a sophisticated system, relying on highly integrated electronic control systems. Instead of the Maglev system currently under development in Japan, in which the vehicle sits within the guideway and is pushed off of it from below, the Transrapid wraps around the guideway, allowing the magnets which are suspended below the vehicle to be drawn up toward the guideway, thereby lifting the vehicle (see Figures 4 and 5).

### Long-Stator Linear Motor

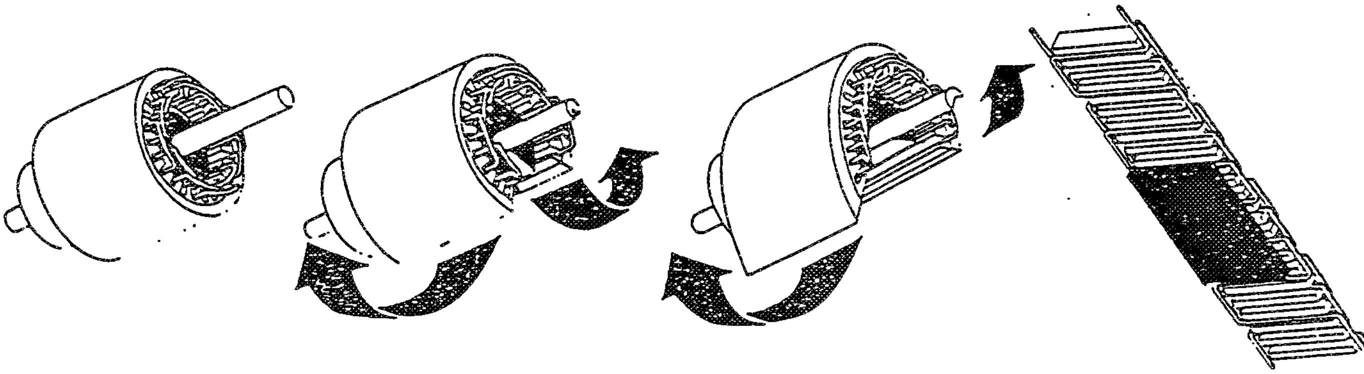
The long-stator linear motor is equivalent to a rotary electric motor in which the stator (fixed outside portion) is cut open and stretched out to become the guideway, with the inside

**Figure 3. Orlando-Disneyworld Route.**

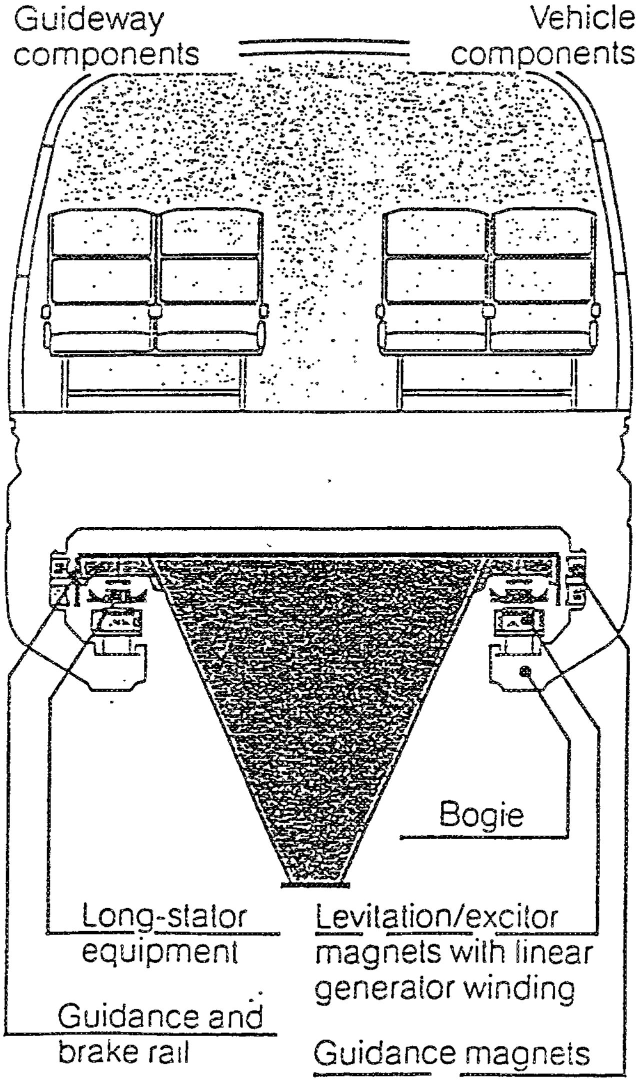


The first super high speed link of the Magnetic Levitation Demonstration Project will connect two stations: the Orlando International Airport and EPCOT Center. An additional station at International Drive is being discussed.

## Figure 4. Linear Stator Motor.



## Figure 5. Vehicle and Guideway Cross-Section.



portion of the electric motor hanging below the vehicle. The stator is made of parallel, horizontally oriented iron magnets that electromagnetically draw the vehicle up, thereby creating a gap between the vehicle and the guideway. Additional parallel electromagnets oriented vertically below the vehicle hold it laterally in place relative to the guideway. Propulsion and braking power are controlled by the stator, which generates a three-phase travelling electromagnetic field to push and pull the magnets on the vehicle forward or create resistance to slow it down. Energy for the support and guidance system, as well as for the other systems on the vehicle, are supplied by linear generators in the stators. Energy is drawn across the gap between the vehicle and guideway as needed. No contact is made with the guideway at any time. The power needed to accelerate/decelerate is generated as needed by designing the stator to meet the requirements of the location.[10] Individual sections of approximately 18.6 mi (30 km) are powered up at one time.[11] The following are the motor specifications:[12]

| | |
|---|---|
| Section Size | 984-3936 ft (300-1200 m) |
| Voltage | 0-4250 |
| Current | 1200A |
| Frequency | 0-215 Hz |

**Vehicle**

The Transrapid 07, a lighter and more technically advanced version of the preceding Transrapid 06, has two major components: the upper body for the passengers and the hanging propulsion systems (see Figures 6-8). Connecting these are two suspensions systems, one dampening the sudden motion of sections of the propulsion/guidance systems as they adjust their distance from the track. The second system compensates for the distribution of weight in the vehicle, especially shifts during curves.[13] Vehicle specifications are as follows:[14]

| | | |
|---|---|---|
| Length/Section | | |
| Cab-End | 88.5 ft | (26.99 m) |
| Intermediate | 81.2 ft | (24.77 m) |
| Height | 13.3 ft | (4.0 m) |
| Width | 12.1 ft | (3.7m) |
| Empty Weight | 45 t/section | |
| Payload | 20.0 t/section | |
| Seats/Section | | |
| Cab End | 40-78 | |
| Intermediate | 56-113 | |
| Sections/Train | 2-10 | |

Figure 6. Levitation Frame with Support and Guidance Magnets.

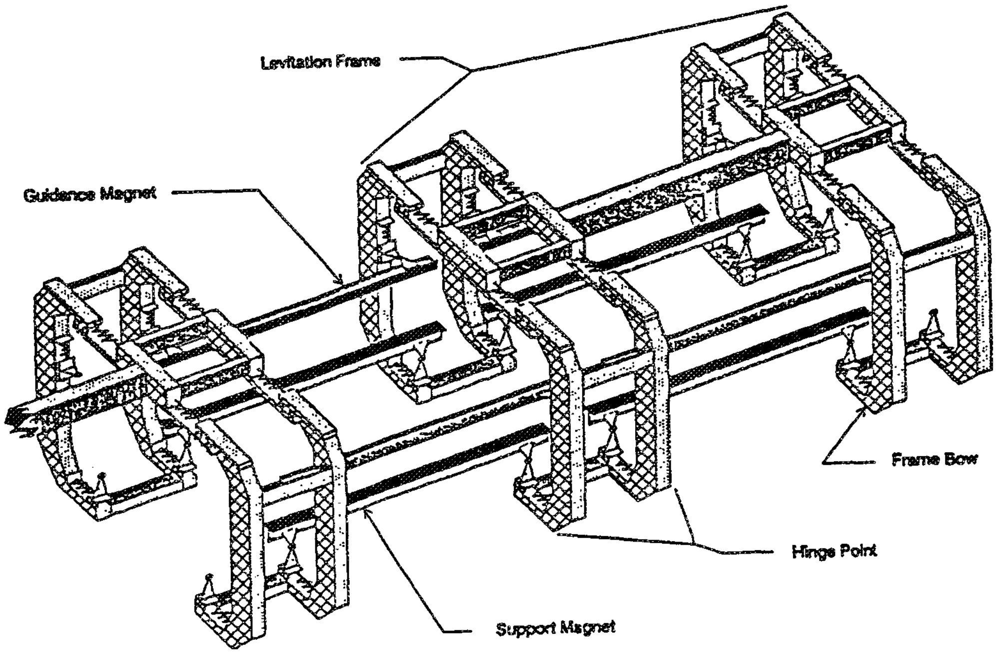


Figure 7. Transrapid Vehicle with Suspension Configuration.

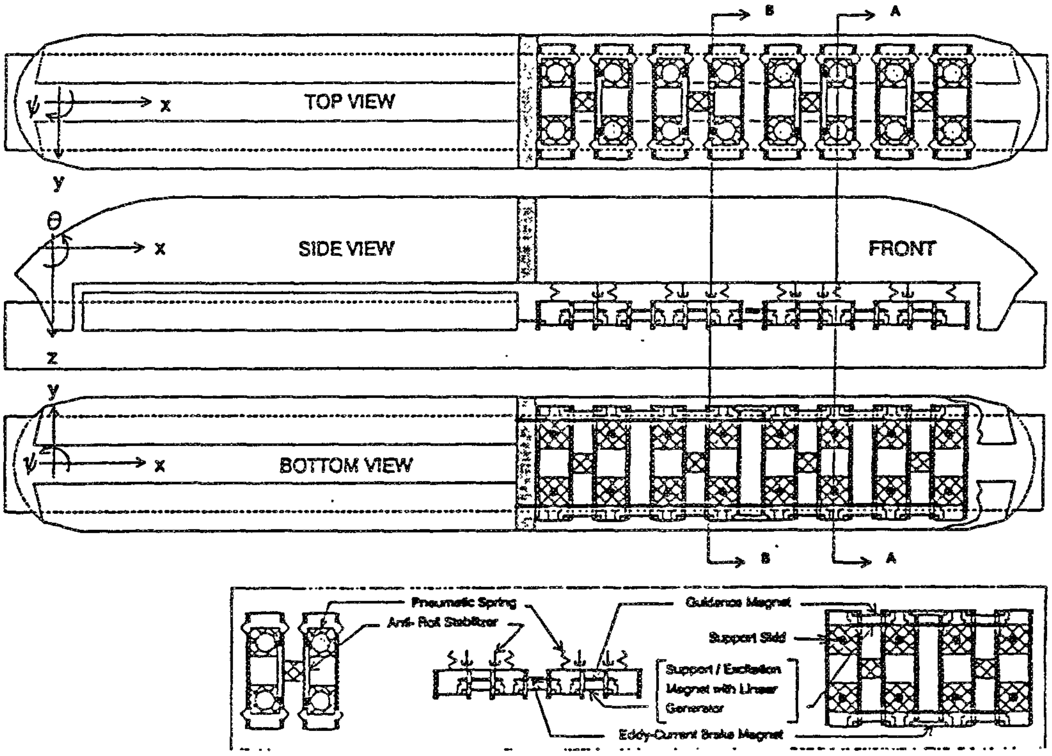
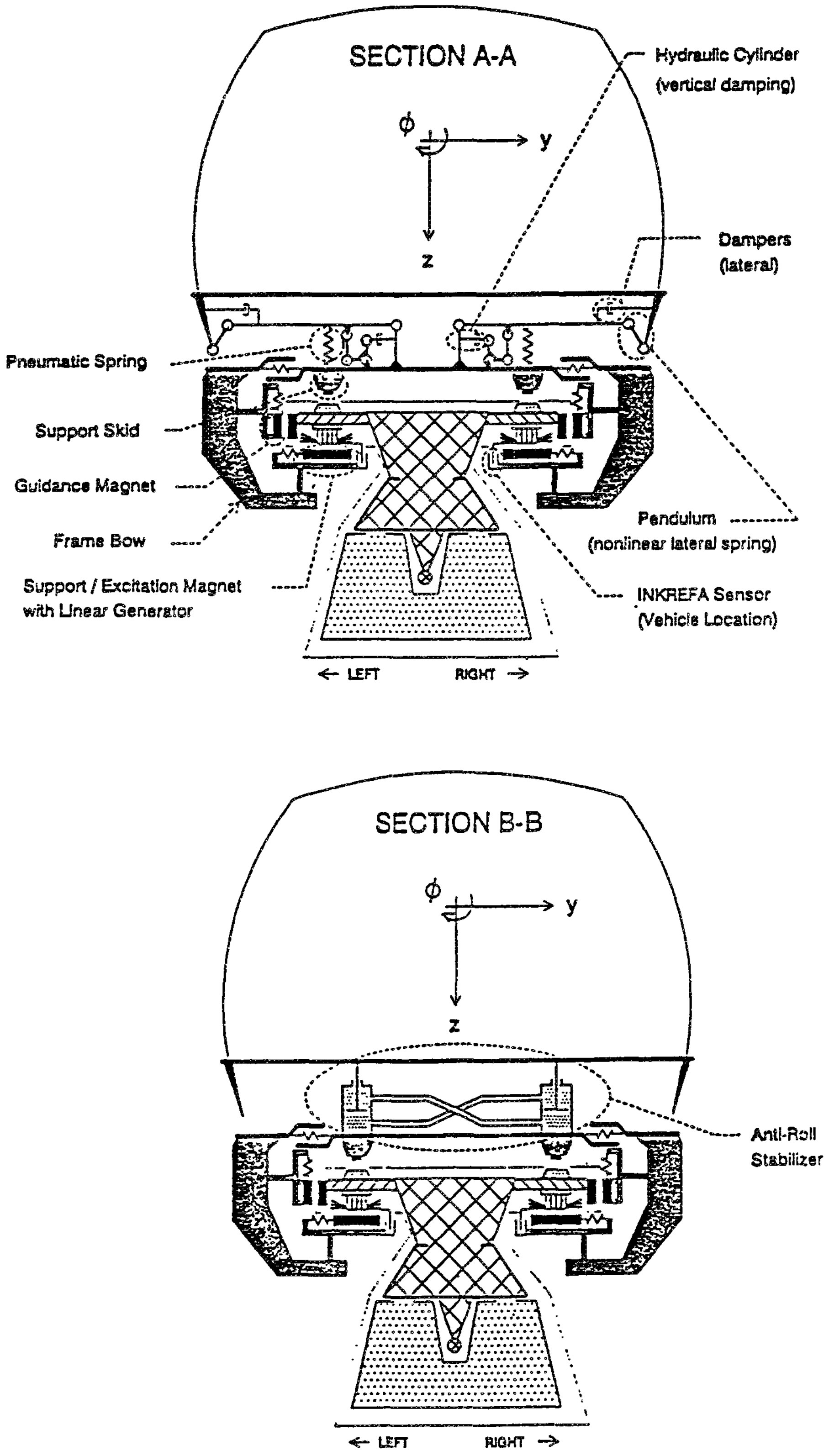


Figure 8. Primary and Secondary Suspension Systems.



## Guideway

As previously noted, the guideway is also the motor. It is made of three sections: an underground support piling, an A-shaped concrete support structure, and the pre-manufactured triangular concrete or steel guideway (see Figure 9). The following are guideway specifications:[15]

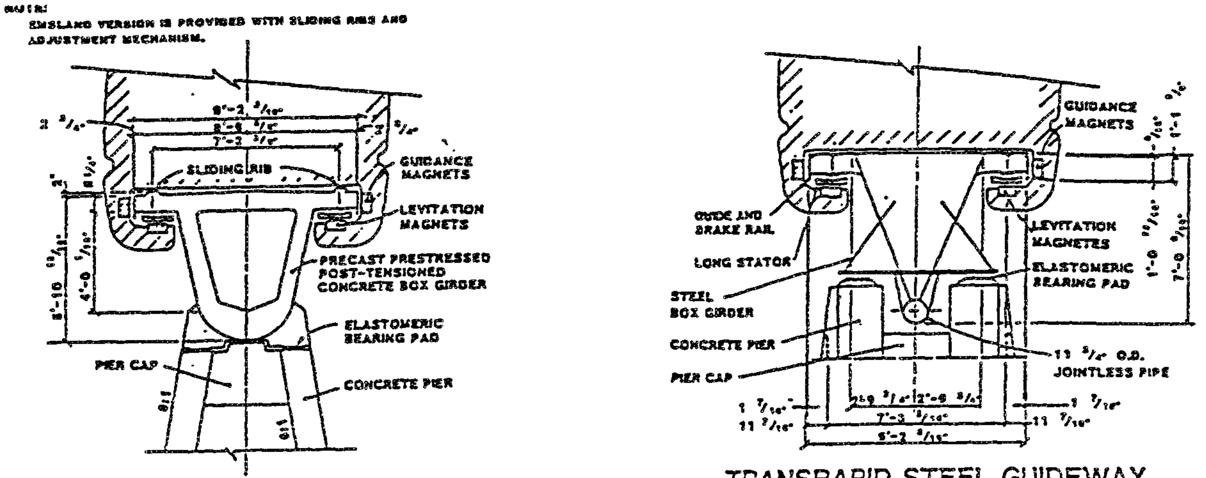
| | | |
|---|---|---|
| Height | 16.4 ft, max 131.2 ft | (5 m, max 40 m) |
| Section Length | 82.0 ft, max 121.4 ft | (25 m, max 37m) |
| Guideway Width | 9.2 ft | (2.80 m) |
| Guideway Weight | 90-120 t | |
| Tolerance | 0.039 inch | (1 mm) |

The design tolerances for the guideways and, especially, the stator packs hanging from them are very small (see Tables 1-3). This made previous construction and installation techniques expensive and time-consuming. However, this was mainly because the guideway was built to withstand a maximum load scenario in which the TR 06 loses power and subsequently slams into the guideway.[16] The more recently built southern loop of the Emsland test facility was constructed for the Transrapid 07, which has redundant systems that essentially render it incapable of such a scenario. This has allowed the automation and in-shop attachment of the guidance rail and stator packs, reducing time and cost.[17]

Compared to convential wheel-on-rail systems, the Transrapid has few design limits. However, the following are considered maximum allowable figures for safety, comfort, and design limits:[18]

| | |
|---|---|
| Max. Horiz. Force | 3.28 ft/sec$^2$ (1.0 m/sec$^2$) |
| Max. Vert. Force | |
| Trough | 1.97 ft/sec$^2$, max 3.28 ft/sec$^2$<br>(0.6 m/sec$^2$, max 1.00 m/sec$^2$) |
| Peak | -1.64 ft/sec$^2$ (-0.5 m/sec$^2$) |
| Max. Braking Force | 2.62-3.28 ft/sec$^2$ (0.8-1.0 m/sec$^2$) |
| Max. Reverse Force | 1.64 ft/sec$^3$ (flat/clear guideway)<br>(0.5 m/sec$^3$) |
| Max. Lateral Tilt | 12°, max 16° |
| Max. Distortion | 0.024°/ft (0.08°/m) |
| Max. Grade | 10% |

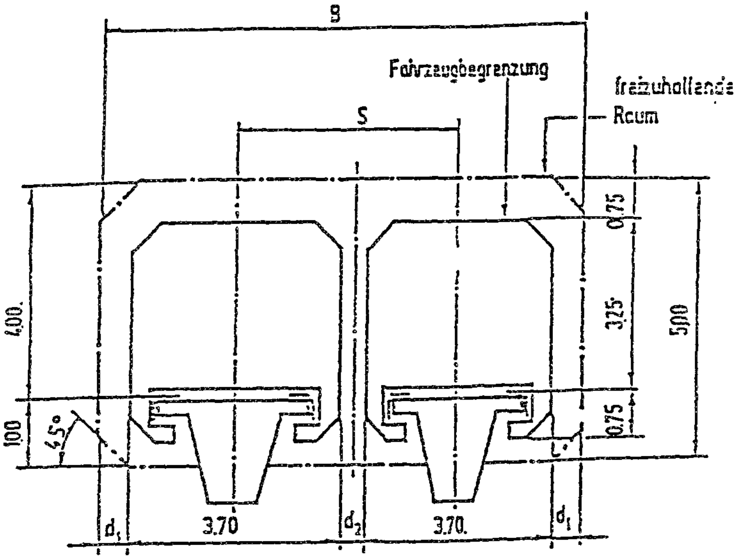
## Figure 9. Support Structures.



TRANSRAPID CONCRETE GUIDEWAY

TRANSRAPID STEEL GUIDEWAY

## Figure 10. Loading Guage.



| V(km/h) | 200 | 300 | ≥400 |
|---|---|---|---|
| B (m) | 9.10 | 9.70 | 11.60 |
| S (m) | 4.20 | 4.40 | 5.10 |
| $d_1$ (m) | 0.60 | 0.80 | 1.50 |
| $d_2$ (m) | 0.50 | 0.70 | 1.40 |

Table 1. Guideway Deflection Tolerances.
(U.S. Dept. of Transportation, 1990).

| GUIDEWAY | Dimension | Tolerance |
|---|---|---|
| Beam Camber<br>vertical upward precurvature for 25 meter span | 3.4 (mm) | — |
| Lateral Beam Deviation<br>lateral tolerance in a 25 (m) span | — | 4.1 (mm) |
| Vertical Beam Deviation<br>vertical tolerance in a 25 (m) span for a single perturbation | — | 8.0 (mm) |
| Vertical Beam Deviation<br>vertical tolerance in a 25 (m) span for a periodic perturbation | — | 6.2 (mm) |

Table 2. Guideway Tolerances of Components Between Girders.
(U.S. Dept. of Transportation, 1990).

| GUIDEWAY | Dimension | Tolerance |
|---|---|---|
| Gliding Plane<br>longitudinal gap tolerance between gliding plane | 50 (mm) | +33(mm)<br>-17(mm) |
| Gliding Plane<br>vertical step tolerance between gliding planes | — | 0.6 (mm) |
| Guidance Rail<br>longitudinal gap tolerance between guidance rails | 50 (mm) | +33 (mm)<br>-17 (mm) |
| Guidance Rail<br>lateral step tolerance between guidance rails | — | 1 (mm) |
| Stator Pack<br>longitudinal gap tolerance between bottom surfaces of stator packs | 37 (mm) | +33 (mm)<br>-17 (mm) |
| Stator Pack<br>vertical step tolerance between bottom surfaces of stator packs | — | 0.6 (mm) |

## Table 3. Guideway Tolerances of Component Position Variation.
(U.S. Dept. of Transportation, 1990).

| GUIDEWAY | Dimension | Tolerance |
|---|---|---|
| Track Gauge<br>outside distance between guidance rails | 2800 (mm) | +/- 2 (mm) |
| Gliding Plane<br>vertical tolerance | — | +/- 3 (mm) |
| Gliding Plane<br>cant tolerance | — | +/- 0.11 (deg) |
| Guidance Rail<br>lateral tolerance | — | +/- 2 (mm) |
| Stator Pack<br>vertical tolerance for bottom surface of stator pack | — | +/- 2 (mm) |
| Stator Pack/Gliding Plane<br>vertical distance from top of gliding plane to bottom surface of stator pack | 365 (mm) | +2 (mm)<br>-5 (mm) |

Minimum curve radii at various speeds are as follows:[19]

| | 125 mph (200kmh) | 190 mph (300kmh) | 250 mph (400kmh) | 310 mph (500kmh) |
|---|---|---|---|---|
| Horizontal | | | | |
| ft | 3,280 | 7,380 | 13,710 | 21,418 |
| m | 1,000 | 2,250 | 4,180 | 6,530 |
| Vert. Trough | | | | |
| ft | - | 22,960 | 41,000 | 63,960 |
| m | - | 7,000 | 12,500 | 19,500 |
| Vert. Peak | | | | |
| ft | - | 45,920 | 82,000 | 127,920 |
| m | - | 14,000 | 25,000 | 39,000 |
| Air Gap (all speeds) | | | | |
| in | 0.39, +/-0.08 | | | |
| mm | 10, +/-2 | | | |

The above figures lead to the loading gauge shown in Figure 10 (see p. 13 above). One of the inherent problems with the Transrapid is that all guideway sections must be built new, although integration of wheel/rail guideways and Maglev guideways is possible. However, given the speeds at which the Transrapid operates, bivalency is applicable only in limited circumstances; for example, in urban areas or at stations.

A unique element of the Transrapid is the switching system, which utilizes a flexible, moveable guideway section to act as a switch (Figure 11). To date, three of these have been built at the Emsland Test Facility. All have been built to have a straight-through speed of 400km/h but with switching speeds of 100-200km/h.

| | | |
|---|---|---|
| Switch 1 | | |
| Length | 220.0 ft | (67.1 m) |
| Turn Radius | 1,640 ft | (500.0 m) |
| Max. Turn Speed | 62 mph | (100 kmh) |
| Support Distance | 42.6 ft | (13.0 m) |
| Switch 2 | | |
| Length | 433.3 ft | (132.1 m) |
| Turn Radius | 5,953.2 ft | (1815 m) |
| Max. Turning Speed | 125 mph | (200 kmh) |
| Support Distance | 60.7 ft | (18.5 m) |
| Switch 3 | | |
| Length | 490.7 ft | (149.6 m) |
| Turn Radius | - | |
| Max. Turning Speed | 125 mph | (200 kmh) |
| Support Distance | 60.7 ft | (18.5 )m |
| Sideways Movement | 4.9 $ft/s^2$ | (1.5 $m/s^2$) |
| Return Movement | 16.4 $ft/sec^2$ | (5.0$m/s^2$) |

Figure 11. Bending Switch.

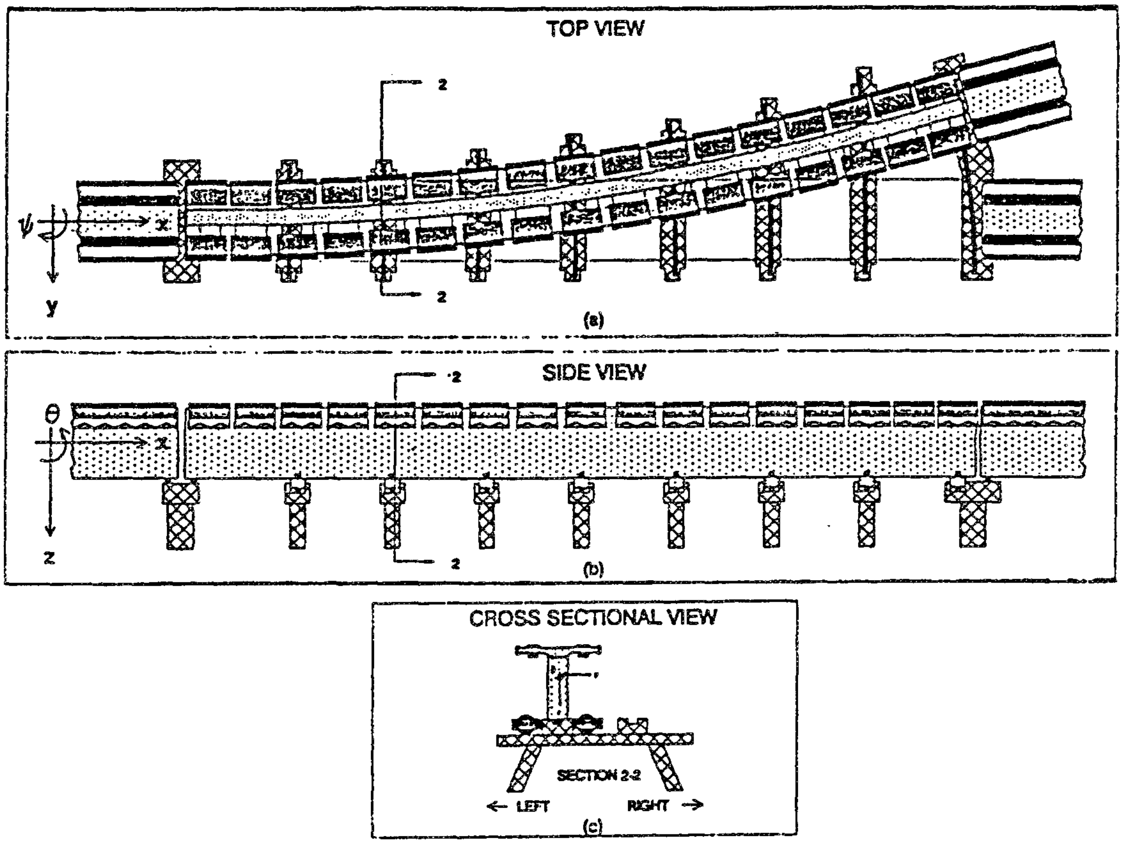
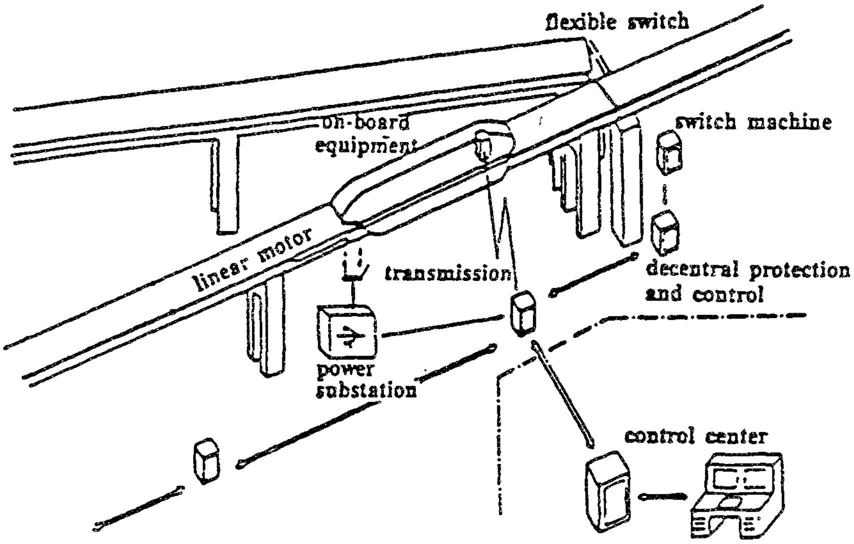


Figure 12. Control System.



Switches 1 and 2 are moved by electromagnetic motors, and switch 3 is moved by a hydraulic motor.[20] No problems with these have been reported to date, but they are cumbersome in operation.

## Control Systems

There are three major control systems: central, station, and vehicular. The central system is a three-level, top-down system utilizing radio and cable communications with high-speed computers to relay, analyze, and act on information (see Figure 12, above). A central control center monitors vehicle speed and location, adjusts vehicle speed, and monitors guideway conditions. The decentralized middle level adjusts the propulsion system in order to maximize performance in relation to the speed of the vehicle. The lowest level is a decentralized safety system that monitors the guideways, stations, and vehicles.[21]

The on-board control systems are divided into a number of separate but related systems. The first includes the on-board electrical system and the collector/converter. The collector/converter receives energy from the linear stator motor in the guideways, constantly adjusting for vehicle speed in order to receive energy in the correct frequency and phase, and subsequently converting it to the 440v system on-board. The second system monitors vehicle location on the guideway and has a gap sensor to magnetically detect the distance between the vehicle and the guideway. The third system uses the information provided by the gap sensor to adjust the vehicle's vertical and horizontal position relative to the guideway, by changing the strength of the magnetic fields generated by the vehicle's propulsion and guidance magnets. Each of these systems are highly integrated, redundant, and are constantly adjusting the vehicle's progress along the guideway and its position relative to the guideway. The vehicle also has complete on-board control capabilities; that is, it is able to adjust its speed independently of the control center. The vehicle is in constant voice and data contact with the control center through relayed radio transmission.[22]

No specific station control systems are mentioned in the literature. However, it may be safely assumed that the best available current technology will be used, particularly in order to allow close headways and/or through-running if desired.

## 4. PERFORMANCE

High speed is Maglev's strong point relative to other ground-based transportation systems. Its higher speed, compared to these other systems, and shorter departure and arrival times than those for aircraft, make Maglev superior to other systems over distances of approximately 125-350 miles (200-550 km). The following travel times at various speeds indicate Transrapid's potential to reduce travel time:

| Route Length | In-Route Stops | Max. Speed mph (kmh) | Travel Time |
|---|---|---|---|
| 125 mi (200km) | None | 186 (300) | 42 minutes |
| | | 248 (400) | 33 |
| | | 310 (500) | 28 |
| 125 mi (200 km) | 2 | 186 (300) | 50 minutes |
| | | 248 (400) | 44 |
| | | 310 (500) | 40 |
| 248 mi (400 km) | 3 | 186 (300) | 97 minutes |
| | | 248 (400) | 80 |
| | | 310 (500) | 71 |
| 496 mi (800 km) | 4 | 186 (300) | 179 minutes |
| | | 248 (400) | 144 |
| | | 310 (500) | 124 |

These figures were computed for a flat route and a station halt time of two minutes.[23]

## Vehicle

To date, the Transrapid has attained a maximum speed of 271 mph (436 kmh) at the Emsland Test Facility, but is unable to go faster due to the size of the guideway.[24] Although maximum speed is theoretically unlimited, a number of constraints indicate that 250 mph (400 kmh) is its maximum usable speed, although occasional increases to 310 mph (500 kmh) remain possible.

One constraint on speed is energy use, which rises considerably with speed. Secondary energy use increases 40 percent from 185 mph (300 kmh) to 250 mph (400 kmh), increasing from 73 to 102 Watts/seat/mi (45 to 63 Watts/seat/ km).[25] Rapidly rising energy use is partially a result of the second factor, aerodynamic resistance. Some resistance from the magnetic fields of the propulsion and guidance magnets is initially encountered, but these are rapidly overtaken by aerodynamic resistance:[26]

|  | Resistance Fx [kN] |  |  |  |
|---|---|---|---|---|
| mph (kmh) | Linear-generator | Magnets | Aero-dynamic | Total |
| 100 (160) | 10 | 3 | 3 | 16 |
| 125 (200) | 8 | 4 | 12 | 24 |
| 155 (250) | 6 | 4 | 28 | 38 |
| 186 (300) | 4 | 5 | 48 | 57 |
| 7250 (400) | 3 | - | - | - |

Finally, maximum speed is also a function of station spacing, maximum acceleration rate, and maximum deceleration rate.

Although energy use may currently limit the Transrapid's maximum usable speed, it is more efficient than other transportation systems at comparable speeds. Primary energy use measures use in its original form. This includes the cost of converting energy to a usable form, particularly energy loss, and allows comparison between different energy types. Secondary energy use compares after conversion; for example, energy use in the form of electricity for two different train systems.

|  | Primary Energy Use Watts/Seat/mi (km) |  |
|---|---|---|
| mph (kmh) | TR 07 | ICE/V |
| 125 (200) | 132 (82) | 166 (103) |
| 155 (250) | 148 (92) | 229 (142) |
| 186 (300) | 180 (112) | 296 (184) |
| 250 (400) | 253 (157) | - |

|  | Secondary Energy Use Watts/Seat/mi (km) |  |
|---|---|---|
| mph (kmh) | TR 07 | ICE/V |
| 100 (160) | 53 (33) | 66 (41) |
| 125 (200) | 60 (37) | 92 (57) |
| 155 (250) | 73 (45) | 119 (74) |
| 186 (300) | 102 (63) | - |
| 250 (400) |  |  |

These estimates were calculated for a 372-mile (600 km) model route over flat land with four stops spaced 75 mile (120 km) apart, with the Transrapid carrying 400 seats and the ICE 402 seats.[27] For comparison, an Airbus A 320 with 134 seats would use 842 Wh/seat/mi (523 Wh/seat/km), and an automobile with a catalytic converter at 71 mph (115 kmh) would use 450

Wh/seat/mi (279 Wh/seat/km).[28] As can be seen from these figures, the Transrapid is very efficient when compared to these transportation systems.

The maximum grade attainable ascending or descending is 10 percent, as previously noted. This is considerably greater than the 2-3 percent maximum grade ascending which normal rail/wheel trains are able to attain. As with normal rail/wheel trains, although no literature addresses this question, energy use is sure to rise considerably with grade. No limitations on speed or distance at any grade have been noted in any of the literature reviewed.

Wear and maintenance of the Transrapid is quite different than for normal wheel-on-rail systems, since no contact is made between the vehicle and guideway. As such, maintenance and wear then becomes mainly a matter of servicing the electronics on the vehicle and the guideway. No formal wear or maintenance information is currently available.

The difficulty or ease of changing train length is not discussed in any literature examined. This can be a major hinderance to efficient operations, as exemplified by the San Francisco Bay Area Rapid Transit (BART), which requires that trains return to a major switching yard before cars can be coupled and uncoupled.

## Carrying Capacity

A function of section size, number of sections, and frequency of service, carrying capacity has a very large range. Using the seats/section range (72-100) and sections/train (2-10) noted previously, the following range is available:

| Seats | Sections | Pax/Train |
|---|---|---|
| 72 | 2 | 144 |
| 100 | 10 | 1000 |

The daily passenger total then becomes a function of the number of trains/hour and their capacities. Assuming an average section seating capacity of 86, double guideways, and a reasonable headway of ten minutes, six trains/hour/direction are possible, giving a maximum capacity of approximately 10,000 passengers/hour. If a business day of 12 hours is used, 120,000 passengers/day are possible, for a yearly maximum of 43.8 million passengers. These are obviously rough estimates and could vary widely depending demand, but it is important to realize the ability of the system to adjust to demand.

The speed of loading and unloading of the Transrapid is not likely to be a limiting factor. Currently, two doors approximately two meters wide per section on one side are used, but but more could be added if necessary.[29] The train is also quite accessible for handicapped passengers, because loading is at grade and the vehicle is 3.7 meters wide. Seating for handicapped passengers could easily be integrated into vehicle design.

Amenities are potentially numerous, including dining cars, television, and telephones. Their integration into vehicle design is a function of the expected passenger type and trip length.

### Reliability

Since the system is not in commercial operation, its reliability is difficult to evaluate. The Canadian Institute of Guided Ground Transport has estimated vehicle availability as a function of the failure rate of a vehicle "magnetic wheel" (an electromagnet, an electronic controller, a magnet-current-drive power unit, and gap/acceleration sensors). Using what they consider a mean-time-between failure (MTBF) of 9,000 hours (about one year), the following availability rate was computed for the Transrapid 06, with a redundant design system (as on the TR07) requiring the failure of two magnetic wheels before the vehicle can't be used.[30]

| | |
|---|---|
| Operating Hours/day | 18 |
| MTBF (hours) | 9000 |
| Days between repairs | 7 |
| Magnetic Wheel/Group | 4 |
| Groups/Bogie | 4 |
| Bogies/Vehicle | 4 |
| Vehicles/Trainset | 6 |

Probability of Failure/Week
= [(18/9000)2 x 7] x 4 x 4 x 4 x 6
= 0.45%

Trainset Availability/Week
=100-0.45
=99.55%

This figure is obviously highly dependent on the MTBF, for which no independent confirmation is available. If the MTBF were twice or four times as frequent, the availability/week falls to 95.70 percent and 82.80 percent respectively for an equivalent trainset.

Interviews of engineers and planners working with the system are confident of its reliability and perceive any problems at this point to be technical in nature.[31] In August of 1990, the system underwent a major endurance test at the Emsland Test Facility, but the results of this test have yet to be made public. Recent indications from Germany, though, are that technical questions remain and it is at least five years away from certification for use in Germany.[32]

An acknowledged problem exists with the screws holding the magnet packs to the guideway. Water enters the screw housing, then expands and contracts, eventually causing the screw to break. This leaves the pack out of position and may lead to contact with the vehicle.[33] This situation happened at the Emsland Test Facility in 1988, forcing its closure for some months while all screws were checked and many replaced. Since then, a new screw design has been used and appears to be without problems.[34] Other potential wear or maintenance problems include on-board battery lifetime, the effect of heat and cold on the guideway, and dust or sand in desert environments. Those involved with the system consider these problems more technical than system defficencies.[35]

## Safety

The Transrapid 07 and guideway design are currently under review by the TUeV Rheinland, a German state agency, and the U.S. Department of Transportation (DOT). No final reports or certification have been issued by either agency. A preliminary report from the DOT indicates that many normal regulations are inapplicable to Maglev technology. The DOT appears to be very interested in the outcome of the Florida Magnetic Levitation Demonstration Project.[36]

The following safety issues were identified by the preliminary DOT report as requiring resolution before revenue operations commence:

> fire safety, vehicle crashworthiness, on-board battery supply reliability, suspension system failure at high speeds, safe hovering reliability, emergency preparedness (emergency evacuation with wraparound vehicle design, programmed controlled operations during emergencies, enhanced emergency braking/stopping, vehicle evacuation, lightning protection, earthquake impact, etc.), air quality of the passenger cabin during emergency conditions, and fail-safe mechanical guideway switching.[37]

A number of "undesired events" were identified by the report which, despite their low probability of occurrence, require mitigation due to the severity of their consequences.[38] These include the following:

> fire/explosion in vehicle, fire in other critical systems, vehicle collision, vehicle leaves guideway, sudden stop, vehicle does not slow/stop at station, vehicle stranded between stations or safe evacuation points, inability to rescue Maglev passengers in case of breakdown or accident, and passenger injury or illness.[39]

As could probably be expected, passenger injury is the outcome of nearly all of these events.

Most of the issues requiring further attention concern the reliability of the autonomous, redundant, failure-tolerant systems, such as the on-board batteries, microprocessors, gap sensors, magnetic wheels, and computer control systems. The tolerance of failure of these systems has raised concern about the abuse of failure tolerance, emergency evacuation if vehicle is not at a preestablished evacuation point, and emergency braking.[40] In addition, the 1988 situation at the Emsland Test facility, in which screw housings expanded when wet, serves to point out the low tolerance of error with the gap between the vehicle and guideway of 0.39 +/- 0.08 in. (10mm +/- 2).[41]

The Transrapid 07 is designed with a "safe hovering" concept to insure that the vehicle will come to a stop only at locations where auxiliary power and means of evacuation are provided.[42] The vehicle will not proceed unless it is able to reach the next safe location independently of guideway power. For this purpose, the vehicle has a minimum of 7.5 minutes' reserve electricity stored in the on-board batteries.[43]

In the event of an emergency, the Transrapid 07 is equipped with a primary and secondary braking system. The primary system is enacted by reversing the thrust from the linear stator motor, with excess electrical energy dissipated at a substation. The secondary system consists of two eddy-current brakes per vehicle. The brakes are magnets which create a disruptive magnetic field by interacting with the guideway, thereby reducing speed. However, the eddy-current brake currrently only reduces speed to 150 kmh (93 mph), at which time the vehicle's levitation magnets must be depowered and the vehicle will skid to a stop on landing skids. It is suggested that this problem will be corrected for revenue operations.[44]

## 5. IMPACTS

In comparison to the alternatives, the Transrapid creates considerably less environmental impacts. It uses significantly less land than freeways and emits less pollution/seat than either autos or aircraft. It does create considerable noise, however, and questions remain about the hazards of magnetic fields.

### Land Use

The following is a comparison of Transrapid land use to that of conventional rail and freeways in Germany:[45]

|  | Guideway<br>Road ft (m) | Area<br>ft2 (m2) |
|---|---|---|
| 4-Lane Freeway | 98 (30) | 1,070 (100) |
| Normal Rail (2-guideway) | 46 (14) | 430 (40) |
| Transrapid (2-guideway) | 40 (12) | 246 (23) |

The road/guideway is the right-of-way needed for each type. The Transrapid's right-of-way is 60 percent of a freeway and 85 percent of conventional rail. The total area includes all system facilities (train stations, rest stops, gas stations, entrance and exit ramps, and so on). It is here that Transrapid's lower land use is evident: 23 percent of a freeway and 60 percent of conventional rail.

**Pollution**

As noted earlier, noise is a significant by-product of the Transrapid. However, when compared to other rail systems it performs quite well. Its nearest competitor in Germany, the ICE, is 4 to 7 percent noisier at all speeds than the Transrapid:[46]

|  | Noise in dB(A) at 82 ft (25 m) |  |
|---|---|---|
| mph (kmh) | TR 07 | ICE/V |
| 100 (160) | 74 | 79 |
| 125 (200) | 79 | 83-84 |
| 155 (250) | 82.5 | 88 |
| 186 (300) | 86.5 | 90-91 |
| 250 (400) | 93.5 | - |

For comparison, an automobile at 62 mph (100 kmh) produces 67 dB(A) and an S-Bahn at the same speed produces 91 dB(A).[47] Note that a 10 dB increase is equivalent to doubling the sound level. The Transrapid is also 12 percent quieter than the TGV, as noted in the following table, at a speed of 186 mph (300 kmh) and a distance of 164 ft (50 m):[48]

| Vehicle | dB(A) |
|---|---|
| TGV | 92 |
| InterCity Express | 87 |
| Transrapid | 81 |

In urban areas the Transrapid will probably travel around 200 kmh, making it slightly more than twice as loud as an automobile. How often the sound occurs and its length are also important points to consider. While temporarily creating an intermittent noise louder than an automobile, six train loads of 820 passengers each would carry nearly two and one-half times as many persons as one lane of a typical freeway in an hour (maximum 2,000 autos/lane/hour).

Noise reduction is possible by speed decrease, noise barriers, and tunnels. Slowing down is the simplest and probably cheapest method but is balanced by additional travel time. Current proposals for the Transrapid connecting the Essen and Bonn airports run through numerous urban areas, probably one of the reasons proposed speeds are often less than 200 kmh. Sound barriers are a suggested method of limiting sound, although they are considered incompatible with the Transrapid because they are visually monotonous for passengers.[49] In addition, they create severe barrier effects. Tunneling is an extremely expensive method of reducing sound and has the same problem of monotony for the passenger. However, if required by the terrain and/or because of densities in urban areas, tunneling reduces noise to nil. On the Essen-Bonn route, tunneling is to be used for approximately 12 percent of the 100km route.[50] All of this occurs in highly urbanized areas, with only about half near stations.[51] For comparison purposes, the Fulda-Wuerzburg section of the new DB high-speed Hannover-Wuerzburg line is 94 km in length, with approximately 16 km lined by embankments; a total of 40 km are in 20 tunnels.[52]

All surface-based transportation systems create visual pollution and barrier effects. The height of the Transrapid guideway is normally about 5 meters, with support columns 25 meters apart, but these may vary. The higher the guideway and the closer the support columns, the greater the visual intrusion. No studies examining the perceived visual intrusion from the guideway at the Emsland Test Facility exist. As with all transportation networks, the guideway can be hidden by plants or sunken if so desired.[53] All power cables at Emsland are underground or within the guideway itself. If this were not done, visual impact would be considerably worse. Barrier effects from the guideway are minimal since it normally will be raised, allowing through-sight and access underneath. This will not be the case, however, if sound barriers or security fencing are necessary. Security fences are not envisioned in Germany, although they may be a consideration in the United States.[54]

No site-specific gas or liquid pollution is produced by the Transrapid.[55] However, electrical generation creates large amounts of pollution at electrical generation plants. The amount of pollution is a function of the generation process and the amount of energy needed. Comparison of emmissions in milligrams/ seat km for various transportation systems is shown in the following table:[56]

| | Emissions in mg/seat/km | | | | |
|---|---|---|---|---|---|
| | CO | NOx | SO2 | CH | CO2 |
| Transrapid | | | | | |
| 200 kmh | 2.0 | 8.5 | 7.1 | 0.20 | 11,000 |
| 300 kmh | 2.8 | 11.7 | 9.7 | 0.27 | 15,000 |
| 400 kmh | 3.9 | 16.4 | 13.5 | 0.37 | 21,000 |
| ICE | | | | | |
| 200 kmh | 2.6 | 10.7 | 8.9 | 0.25 | 14,000 |
| 300 kmh | 4.6 | 19.2 | 15.9 | 0.44 | 25,000 |
| Airbus A 320 <600 km | 225 | 449 | 44 | 17 | 139,000 |
| Automobile | | | | | |
| Catalytic Converter | 510 | 132 | 12 | 42 | 71,000 |

Although both the ICE and the Transrapid receive their energy from the electrical grid, for which energy is produced at power plants, the Transrapid's greater efficiency allow it to consume less energy and therefore produce fewer pollutants. At 186 mph (300 kmh), Transrapid produces approximately 60 percent the emissions of the ICE. In addition, it is responsible for far fewer emmissions than an Airbus or automobile.

Shuddering or ground shaking is a common effect caused by trains moving along the guideway. This effect is a function of vehicle weight, speed, guideway materials, and ground composition. Although the Transrapid doesn't make contact with the guideway, interaction between the vehicle and guideway magnetic fields creates stress on the guideway, producing shuddering or shaking as the train passes by. The Transrapid creates 30-60 percent as much shuddering as the quieter of traditional wheel/rail systems at 2-3 times the speed.[57]

Another concern about the Transrapid has to do with its electromagnetic field. In this area, there are two types of considerations: the degree of electromagnetic interference, and human health dangers. Electromagnetic interference (EMI) can disrupt normal electrical systems, such as televisions, radios, and electrical tranmission systems, as well as the on-board control systems or the guideway magnets. EMI may be caused by the guideway, vehicle, or electrical transmission system. Given repeated successful guideway runs of the Transrapid, it is reasonable to discount EMI disruption of vehicle or guideway systems. The strength of this field decreases according to the inverse-square of the distance from the origin. Tests at Emsland indicate a magnetic field strength at 2 m from the guideway and vehicle, the same as the earth's magnetic field.[58] Of concern, though, is EMI generated by the power supply systems with its various transmissions lines, substations, and converters. However, these problems are well understood and can be eliminated with good engineering.[59]

The impact of human exposure to electromagnetic fields includes biological changes and effects on pacemakers. The following are measurements from the Transrapid 07:[60]

| Location | Gauss |
|---|---|
| Vehicle Floor | 0.1 |
| Seat Level | 0.02 |
| Next to Vehicle | 0.02 |
| Beneath Vehicle | 0.001 |

These figures are significantly lower than the 5 gauss reported by the Canadian Institute of Guided Ground Transport in 1986 for the TR06, indicating either large reductions or erroneous measurements.[61] The impact of human exposure to magnetic fields has been intensely studied, but conclusive evidence of biological effect levels is lacking.[62] However, the U.S. Department of Energy has established the following voluntary guidelines:[63]

| Gauss | Body | Duration |
|---|---|---|
| 100 | Whole | 8 hr workday |
| 1000 | Extremities | 8 hr workday |
| 1000 | Whole | < 1 hr |
| 10000 | Extremities | < 1 hr |
| 5000 | Whole | < 10 min |
| 25000 | Extremities | <10 min |

German exposure limits are 250 gauss for frequencies up to 2 Hz and 10 gauss at 3000 Hz.[64] Older pacemakers may be sensitive to electromagnetic fields as low as 11 gauss.[65] For reference purposes, the earth's magnetic field ranges from 0.5-1.0 gauss, a video monitor produces 0.3 gauss, a hair dryer produces 9.7 gauss, and an egg beater produces 25.0 gauss.[66]

## 6. COSTS

Costs are a function of numerous interactive factors combining to determine the final price: land, guideway and station construction, vehicles, labor, energy, maintenance, management, marketing, and financing. A technology which is untested commercially, such as Maglev, makes the task of cost estimation very difficult. However, in addition to the construction of the Emsland Test Facility, numerous proposals have been made which required cost and revenue estimates. Financing is not examined in this report, as it is too project-specific and subject to rapid change depending on market conditions.

To date, the Canadian Institute of Guided Ground Transport (CIGGT) has done the best comparative analyses of the capital and operating/maintenance costs of numerous high speed rail proposals. In 1985, the CIGGT compared the costs of 12 corridor proposals, including the Las Vegas-Los Angeles proposal, using Maglev and other high speed rail systems, at a fine level of detail. The most notable features of the CIGGT comparison were the wide range in costs between routes using the same technology, between technologies along the same routes, and the level of risk associated with the different technolgies. Total capital cost per track-mile of Transrapid 06 infrastructure varied between $4.0 and $16.4 million (1984), and, according to the CIGGT, "some, but not all, of these variations are related to corridor-specific characteristics, predominantly the terrain to be traversed."[67] Total operating/maintenance costs also varied substantially for the Transrapid 06, from $5.0 to $58.0/train mile and $102,000 to $463,000 per track mile (1984).[68] Except possibly for the Las Vegas-Los Angeles route, none of the proposals was deemed capable of supporting an all-commercial operation. However, the Las Vegas-Los Angeles route was repeatedly noted as having the lowest or second-lowest cost figures, even lower than those for the Transrapid in Germany, highlighting concern about complete documentation of costs.[69]

**Essen-Bonn**

The following cost figures were generated by Konsortium Anschubsgruppe Transrapid, a consortium of German companies interested in building and operating the Transrapid along this route. All prices are converted from 1989 DM with an exchange rate of 1 DM=$0.67.

Anticipated land costs along the route are relatively inexpensive: 30 DM/m2 or $1.86/ft2.[70] It is difficult to understand why costs would be so low given the relatively high densities encountered in this area.

Construction costs are site-specific, so use of the figures from Germany is risky at best. However, they are examined to give a relative idea of total costs. Standard construction costs for a straight guideway follow:[71]

| | Mio.$/mi | DM Mio./km |
|---|---|---|
| 4 ft (1.2 m) height | | |
| Dbl.Guideway | 7.55 | 7.00 |
| Sgl.Guideway | 4.15 | 3.85 |
| 23 ft (7 m) height | | |
| Dbl.Guideway | 10.47 | 9.70 |
| Sgl.Guideway | 6.28 | 5.82 |
| Bridge | | |
| Dbl.Guideway | 6.47 | 6.00 |
| Sgl.Guideway | 3.51 | 3.25 |

Curved sections are 4 percent higher; geologically unstable ground requiring the sinking of the support posts are 5 percent higher.[72]

Sound barrier construction is anticipated at $540,000/mi (DM500,000/km). An additional $161,000/mi (DM150,000/km) is also anticipated for emergency facilities along the guideway (in case the vehicle were forced to stop and passengers had to be removed)[73]

The specifics of station construction are not discussed other than to say that the costs are for a maximum train size of six sections. For the suggested Essen-Bonn route, six stations are anticipated at a total cost of $222 Mio. (DM311 Mio.) No costs were included for parking, which is to be left to the private sector.[74]

Total construction cost for the desired Essen-Bonn route, including all special construction, control and switching equipment, unforeseen costs, project management, and existing rail reconstruction is $2.283 Billion (DM3.408 Bio.). With a route length of 63.8 miles (102.75 km), this averages out to $35.7 Mio./mi (DM33.2 Mio./km).[75]

Vehicles cost $5.36 Mio. (DM8.0 Mio.)/section. For a fleet of 12 trains, six sections each, an investment of $385.9 Mio. (DM576 Mio.) is required. An estimated 842 seats for a six section train works out to $458,000/seat (DM90,000/seat). The following operations/maintenance costs are estimated for the preferred Essen-Bonn route of 63.8 mi (102.75 km) length, with 124 six-section trains/day:

| | Mio.$ Year | Mio.$/ Track Mile. |
|---|---|---|
| Dispatching | 20.66 | 0.33 |
| Marshalling | 2.52 | 0.04 |
| Running | 10.66 | 0.17 |
| Maintenance | | |
| Facilities | 6.78 | 0.11 |
| Vehicles | 3.31 | 0.05 |
| Energy | 25.06 | 0.40 |
| Workers Comp. | 4.74 | 0.74 |
| Insurance | 5.93 | 0.09 |
| TOTAL | 79.66 | 1.25 |

Capital cost estimates for a Transrapid based on the Essen-Bonn and Hamburg-Hannover routes, having a model route with double guideways 125 mi (200 km) in length, no middle stops, and a maximum speed of 250 mph (400 kmh), resulted in the following capital costs estimates:[76]

| | Mio.$/mi | DM Mio./km |
|---|---|---|
| Flat Terrain | 23.5 | 21.8 |
| Variable Terrain (undefined) | 24.8 | 23.06 |

This results in a capital cost of $11.75 Mio./track mile for flat terrain. This figure is within the range noted by the CIGGT above, but considerably higher than those estimated below for the Las Vegas-Los Angeles route. Unfortunately, no definition of variable terrain is given, particularly the length of tunnels and bridges.

The following estimated operation and maintenance costs are based on 60 percent capacity, an average line-haul speed of 175 mph (280 kmh), four station stops, and a headway of ten minutes during the peak period:[77]

| | $/seat/mi | |
|---|---|---|
| Route | 5 Sections | 8 Sections |
| Flat | | |
| 375 mi | 0.018 | 0.026 |
| 500 mi | 0.017 | 0.024 |
| Variable (undefined) | | |
| 375 mi | 0.019 | 0.026 |
| 500 mi | 0.017 | 0.024 |

These figures highlight two interesting points. First, costs/ seat/mi actually increase with a larger number of seats. Second, there are slight reductions in cost with increasing distance. It should be noted that if these figures were rounded to the nearest cent, the former point would be exaggerated, while the latter would disappear.

### Las Vegas-Los Angeles

Very detailed cost estimates have been made for this route.[78] The large range of costs between various proposals for the route is shown in Table 4. Total capital costs for the three Maglev proposals in Table 4 vary between $6.652 and $8.567 Mil./track mile, and total operating/maintenance costs vary between $120,400 and $248,600/track mile or $9.55 to $11.91/vehicle mile/year (1984).

Cost estimates such as these are difficult to compare with each other or to apply to other routes, because the assumptions on which they are based are obscure and route specifics may vary. This calls attention to the need for detailed and see-through cost and revenue computations, as well as validation of the assumptions on which they are based.

### Orlando-Disneyworld

Total capital costs for this route are estimated at $450 to $650 million (1988). This works out to $22.5 to $32.5 million/mile. Total operating and maintenance costs (with 350 employees)

## Table 4. Capital and Operating/Maintenance Estimates.

(California-Nevada Super Speed Train Commission, 1989).

SUPER SPEED TRAIN COSTS - CAPITAL and OPERATING/MAINTENANCE
COSTS IN MILLION $

| ESTIMATE SOURCE | PHASE I[1](1982$) Maglev[2] | Hi-speed Rail[3] | CIGGT(1984$) Maglev[4] | TGV[5] | BUDD[6](1984$) | TGV[7](1984$) |
|---|---|---|---|---|---|---|
| COST CATAGORY | | | | | | |
| INITIAL CAPITAL | | | | | | |
| Fixed facilities | 1264 | 1091 | 1606 | 1421 | 1341 | S |
| Vehicles | 124 | 173 | 286 | 218 | 248 | A |
| Design/manag'm't | 200 | 181 | 209 | 185 | 197 | M |
| Contingency | 277 | 251 | 435 | 215 | 356 | E |
| TOTAL CAPITAL | 1865 | 1696 | 2536 | 2038 | 2142 | |
| OPERATIONS (1995) | | | | | | |
| Power | 14.05 | N | 23.45 | 15.13 | 23.46 | A |
| Train crews | 3.34 | O | 6.32 | 4.74 | 5.63 | S |
| Traffic control | 1.00 | T | 1.00 | 1.00 | 1.00 | |
| Ticket sales | * | | 6.63 | 6.42 | 6.63 | C |
| Insurance | * | I | 3.00 | 3.00 | 3.00 | I |
| Station operation | * | N | 1.65 | 1.65 | 2.30[8] | G |
| Administration | * | C | 2.19 | 2.19 | .60 | G |
| Other | * | L' | 2.81 | .75 | 4.31 | T |
| Contingency | 4.30 | D | 8.49 | 6.67 | 6.00 | |
| TOTAL OPER. | * | " | 55.54 | 41.55 | 52.93 | |
| MAINTENANCE (1995) | | | | | | |
| Vehicle | * | " | 8.31 | 11.01 | 5.25 | E |
| Facilities | * | " | 9.81 | 13.67 | 6.00 | S |
| TOTAL MAINT. | * | " | 18.12 | 24.68 | 11.25 | T. |
| TOTAL O & M COSTS | 33.00 | " | 73.66 | 66.23 | 64.18 | |

---

1. These costs are 10/12% lower due to the 1982 vs. 1984 estimates
2. This Budd estimate was for a maglev system of 22 trains/day (33 vehicles) each way on a 230 mile route, with 44 miles of passing siding. O&M not broken down.
3. This Budd estimate was for a generic high speed rail system (77 vehicles) of 254 miles length with a maximum grade of 3.5%.
4. This CIGGT estimate was for a maglev system of 34 trains/day (74 vehicles peak) one way and 27 the other way with 66 miles of passing sidings.
5. This CIGGT estimate was for a modified TGV-Altantique system of 230 mile length with a maximum grade of 5% and 19 train sets.
6. This Budd estimate was for a maglev system of 33 trains/day (80 vehicles peak) each way and 92 miles of passing siding. It also includes a new, low cost electrification system, that CIGGT did not have time to assess.
7. The TGV estimate was essentially the same as the CIGGT and it was based on actual TGV experience.
8. This amount includes manpower for security.

is estimated at $38 to $48 million annually. The project is to be financed through a combination of traditional construction loans and private equity investment. This was determined using an annual interest rate of 9 to 13 percent and a debt/equity ratio of 70 percent/ 30 percent.[79]

## 7. REVENUES

Revenue is a function of the balance between price and demand. This is generally estimated by utility models measuring the passengers' value of money, time, accessibility, and comfort. Again, with no commercial Transrapid system in operation, revenues are difficult to estimate. Utility models for competing modes– in this case air, auto, and Maglev– are compared, and the passengers decide which mode has the highest utility for them. These models allow comparison of ridership at various prices, trip time, station access, and so on. Although the specifics of the utility models used are not stated, predicted revenues for the three routes most likely to be implemented are detailed below.

### Essen-Bonn

The revenue figures for this route were generated by Konsortium Anschubbesgruppe Transrapid. For intercity passengers, prices 40 percent above normal Deutsche Bundesbahn (DB) prices are anticipated.[80] An exchange rate of 1 DM = $0.67 (1989) was used. These prices per passenger distance travelled follow:[81]

| Normal DB | DM/Pass.km (incl.tax) | $/Pass.mi |
|---|---|---|
| First Class | 0.3 | 0.32 |
| Second Class | 0.2 | 0.20 |
| German Average | 0.138(no tax) | 0.15 |

Over the 63.3 mi (102 km) length of the route, these prices generate first- and second-class ticket prices of $20.25 and $12.66 respectively.

This route was projected to generate the following ridership and revenues at these prices:[82]

| | Essen-Bonn 4 (E-DUS-CGN-Bn) |
|---|---|
| Mio.Pass./yr | 12.84 |
| Mio.Pass. mi | 1.634 |
| $/Pass. mi | 0.207 |
| Mio.$/yr | 131.39 |

In addition to normal intercity passengers, the majority of the passengers are expected to be going to or coming from one of the airports. A flat charge of $6.70 (DM 10) will be charged for air passengers. An anticipated 24.5 Mio. passenger trips and 16.0 Mio. employee trips are expected, for a total of $271 Mio. Intercity plus air passengers and employees yield a total of $306.19 Mio./yr.

### Las Vegas-Los Angeles

In 1984, under contract from the California-Nevada Super Speed Commission, a consulting firm was asked to generate revenue figures for this route[83] The revenues were generated on the basis of passengers and freight for 22 trains per day. A one-way fare was $32.50 (1984), with passenger revenues and operating costs assumed to be increasing at 4 percent per year. Based on these fare and inflation assumptions plus the ridership estimates, the first year (1995) of commercial operation had a revenue estimate of $406 million for Transrapid and $375 million for TGV. Freight revenue was forecast at $21 million, with two cargo cars per off-peak train and two "high-value" containers per train. In the first year of operation, revenue before debt-service was $314 million for Transrapid and $288 million for TGV[84]

Since the proposal moved closer to implementation, new ridership and cost/revenue studies have been made. The most recent are from September 1989 by the California-Nevada Super Speed Train Commission. This updates the 1984 study, using a similar utility model with time, price, and frequency used to estimate ridership. First, total trips to Las Vegas from the Los Angeles area were estimated:[85]

| Year | Round Trips (mi) |
|---|---|
| 2000 | 7.84 |
| 2005 | 8.34 |
| 2010 | 8.85 |
| 2015 | 9.35 |
| 2020 | 9.85 |
| 2025 | 10.35 |

Mode shares without high speed rail were estimated at the following[86]

| Mode | Percent |
|---|---|
| Highway | 70 |
| Air | 16 |
| Scheduled Bus | 2 |
| Rail(Amtrak) | <.5 |
| Charter Bus | 12 |

Demand along the corridor is highly peaked, asymmetrical, and discretionary: 50 percent of all travel occurs on Friday night and Saturday morning from Southern California to Las Vegas and returns on Sunday afternoon and evening.[87] As a result, the marketing study was continued in order to identify opportunities for counterflow and off-peak demand. Finally, revenue was based on a one-way ticket price of $52.00 (1989). This resulted in $330.09 to $436.47 million in gross revenues in the year 2000, before the additional market share (counterflow and off-peak) was included.[88] Unfortunately, the construction and operating cost have not been updated since 1984.

### Orlando-Disneyworld

In the first year of operation (1994), estimated ridership is 6.5 to 8.5 million one-way trips. One-way tickets are expected to average $9.00 to $12.00 (1988) per trip, generating an estimated $58.5 to $102.0 million during the first year of operation.[89]

## 8. SYSTEM STATUS

The Transrapid is not currently in revenue operation anywhere in the world, and a number of recent proposals appear to have been shelved indefinitely (Hamburg-Hannover, Essen-Bonn, Las Vegas-Los Angeles). It is the focus of much research and development, however, and has been proposed for numerous routes.

### Research and Development

Development of the Transrapid system has been a cooperative venture between the German Ministry for Research and Development (Bundesministerium fuer Forschung und Technologie or BMFT) and the Test and Planning Company for Magnetic Rail Systems (Versuchs- und Planungsgesellschaft fuer Magnetbahnsysteme or MVP). The BMFT provides government financial and political support to assist new technologies such as the ICE and Transrapid. The MVP is made up of the following three partners: Lufthansa Airlines, the German Federal Railway (Deutsche Bundesbahn or DB), and Industrieanlagen-Betriebsgesellschaft or IABG (a consortium of German industries). The consortium is led by Thyssen Henschel, a large German engineering company, and includes numerous well-known German engineering firms such as AEG, MBB, Krauss-Maffei, Siemens, and others. Lufthansa has a large interest in Transrapid because it perceives it both as a threat and an opportunity. It would like to reduce its intra-German air traffic in order to free up international landing slots at overloaded German airports. Although the Transrapid is perceived as a threat to more traditional operations by the DB, thus making it a source of friction between the DM and the BMFT, the DB is involved in all German rail projects. Less visible but no less important are large financial concerns which are closely integrated with industry in Germany. Frequently noted names are Commerzbank AG, Deutsche Bank AG, Dresdener Bank AG, and others.

Most of the research and development of the Transrapid has taken place at the Transrapid Test Facility (Transrapid Versuchsanlage Emsland or TVE) in Emsland near the German-Dutch border in the state of Niedersachsen. Construction at the facility was begun in 1980 under the direction of MVP, with financing from the BMFT. Since that time, approximately 1.6 billion DM (1990) has been spent on the facility.[90] The Test Facility was completely turned over by the BMFT to the MVP in 1985.[91]

The Test Facility is 19.6 miles (31.5 km) long and has two turn-around loops connected by a single guideway (see Figure 13). The two loops have radii of 3,281 ft (1000 m) and 5,544 ft (1690 m), and are connected by a single straight guideway approximately 5 miles (8 km) long. Maximum speeds are 124 mph (200 kmh) on the smaller loop, 175 mph (282 kmh) on the larger loop, and 248+ mph (400+ kmh) on the straightaway.[92]

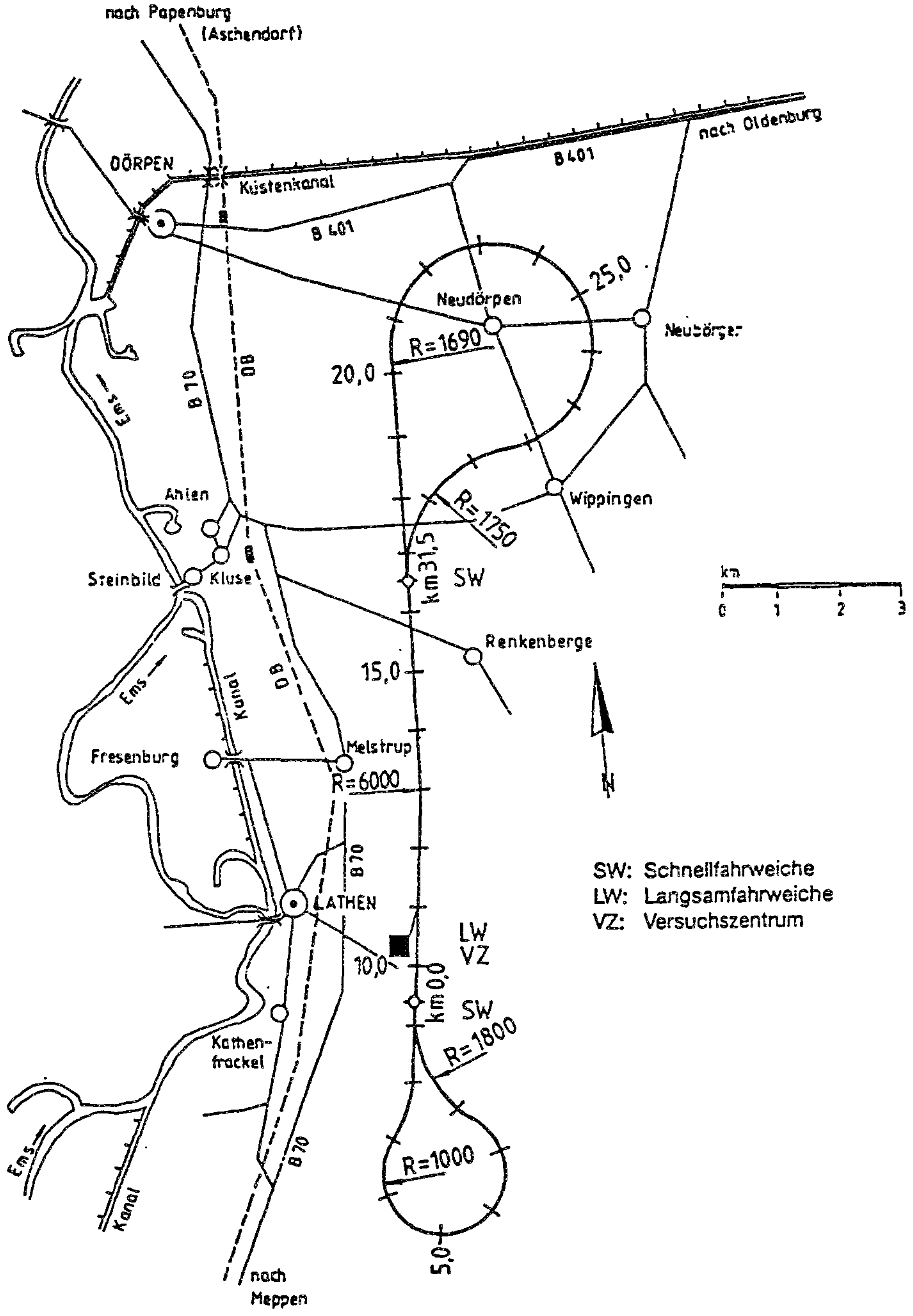
Although numerous test have been conducted at the TVE, its design is a serious limitation in conducting rigorous tests simulating revenue operations. The single guideway linking the two loops does not allow tests with vehicles travelling in opposite directions on parallel guideways. The short length of the connecting guideway and the small radii of the loops limit speed tests. The terrain is largely flat, limiting tests of varying terrain conditions. No tunnels have been built to test the effects of air pressure upon entering the tunnel. Finally, extreme hot or cold weather is rare at the location.

## Recent Proposals

Of the numerous proposals for use of the Transrapid, only the three previously outlined have been developed to any serious degree: Essen-Bonn, Las Vegas-Los Angeles, and Orlando-Disneyworld.

The Essen-Bonn proposal has been shelved indefinitely due to the previously mentioned technical and financial problems. In addition, the planning process in Germany is extremely long and complicated, making it subject to delay for years, if not decades. As an example, applications for approval of the Fulda-Wuerzburg sections of the new high-speed Hannover-Wuerzburg line, a 58-mile (94 km) section running through fairly unpopulated land, were made in stages from 1974 to 1981. The first approvals were issued in 1976, but a major delay lasted until 1982, and to that

**Figure 13. Emsland Test Facility.**



date over 150 lawsuits had been filed.[93] More controversial examples include the New Munich Airport and the Stardtbahnwest, a second starting runway for military aircraft at the Frankfurt airport. Both of these had lengthy delays due to legal challenges. The environmental movement is very strong in Germany. Despite the defeat of the Green Party in national elections during 1991, environmental pollution remains the concern most frequently cited by German residents. In a comprehensive national poll conducted during the summer of 1990, 47 percent polled were "very concerned" about increasing water and air pollution; this is 10 percent more than the nearest other concern.[94] Any proposals for the use of the Transrapid in Germany, even after certification, are bound to meet strong opposition on environmental and financial grounds.

The Las Vegas-Los Angeles proposal is the most extensively planned and most feasible large project to date. Bechtel Corp., in cooperation with Transrapid International and C. Itoh & Co., submitted a bid for the project in Fall 1990. The California-Nevada Super Speed Train Commission was prepared to offer Bechtel an exclusive franchise agreement as of February 1991, with Bechtel to submit finalized route alignments, station locations, fare structuring, and financial/organizational plans by the spring of 1992. Land assembly was to take place while these finalized plans were being reviewed for final approval, and construction was to begin in 1993. However, in February 1991 Bechtel asked to postpone the project for five years due to financial uncertainties caused by the war in the Middle East and German unification. The California-Nevada Super Speed Train Commission reviewed the request and agreed to it in May 1991.[95] However, Bechtel backed out of the project in November 1991, losing approximately $150,000 of a $400,000 deposit in doing so. Bechtel's action was at least partially due to California's new governor, Pete Wilson, not approving legislation renewing support for the California-Nevada Super Speed Train Commission.[96] In addition, the recession in the United States and the recent Gulf War probably made Bechtel's investors hesitant. However, new legislation has been proposed in the California legislature to renew the Commission in 1992. In addition, recent hearings at the national level indicating the need for public support for high speed rail is expected to generate at least minimal state-level support in California for environmental studies and perhaps right-of-way guarantees.[97]

This leaves only the Orlando-Disneyworld project, the most modest of any proposal yet. However, it is fully expected to be built, with final approval by the Florida High Speed Rail Transportation Commission awaited in March 1991. At that time, final route alignments will be fixed and detailed engineering plans drawn-up, with construction slated to begin in Spring 1992 and operations beginning in Fall 1994. It is hoped by all involved with the Transrapid, as well as Maglev and high speed rail in general, that this project will prove the ability of Transrapid to perform in commercial operations and open up new opportunities. However, reliance on the Florida Magnetic Levitation Demonstration Project to prove the suitability of the Transrapid for long-distance revenue operations is questionable. In addition, its short length and design undermine its ability to reduce concerns raised in the DOT report. Finally, it is certainly insufficient to provide much of the information required for certification of the system in Germany.

In a surprising about-face, the German government has recently reversed its position with regard to financial suport for the Transrapid. The new Transport Minister, Guenther Krause, is in favor of the Transrapid, particularly a line which would link eastern and western Germany. Toward this end, the Research and Technology Ministry will provide DM 450 million ($300 million) between 1991 and 1995. Animosity between the Deutsche Bundesbahn (DB) and the Transrapid has been overcome by giving the DB responsibility for both the CIE and Transrapid. Proposals exist for Hamburg-Berlin and Berlin-Dresden, with the former favored-- especially if a new airport is built near Parchim in Mecklenburg, between Hamburg and Berlin. This route would generate an estimated 15.3 million passengers over the 291 km (175 mile) route, which would take approximately one hour to travel. Construction costs are estimated at DM 7.4 billion ($4.93 billion), DM 25.4 million/km ($28.2 million/mile). The Berlin-Dresden route would carry an estimated 16.2 million passengers and cost approximately DM 5.9 billion ($3.93 billion). Approval of either project would result in the application of special planning processes designed to speed up projects in eastern Germany. It appears that the construction of a Transrapid route in Germany is beginning to be perceived as a prerequisite to its use abroad.[98]

# NOTES

[1] Konsortium Anschubgruppe Transrapid, 1989: 78-82.

[2] Ibid: 38, 40.

[3] California-Nevada Super Speed Train Commission, 1989: 2-5/2-6.

[4] Ibid: 3-5.

[5] Ibid: 3-10.

[6] Ibid: 3-17.

[7] Maglev Transit, Inc., 1988: 1.

[8] Ibid: 23.

[9] Johnson, Larry, 1991.

[10] Thyssen Henschel, 1988: 6-7.

[11] Versuchs- und Planungsgesellschaft fur Magnetbahnsysteme, 1988: 4.

[12] Versuchs- und Planungsgesellschaft fur Magnetbahnsysteme, 1990: 6.

[13] Heinrich and Kretschmar, 1989: 76.

[14] Magnetschnellbahn, 1991: 7; Versuchs- und Planungsgesellschaft fur Magnetbahnsysteme, 1990: 6; Meyer and Rogg, 1988: 12.

[15] Heinrich and Kretschmar: 21-23.

[16] Canadian Institute of Guided Ground Transport, 1986d: TA 5-57/64.

[17] Heinrich and Kretschmar, 1989: 40.

[18] Versuchs- und Planungsgesellschaft, 1988: 9.

[19] Versuchs- und Planungsgesellchaft fur Magnetbahnsysteme, 1991: 27; Heinrich and Kretschmar: 23; Versuchs- und Planungsgesellschaft, 1990: 6; Budd Company, 1987: 1.

[20] Heinrich and Kretschmar: 32-35.

[21] Ibid: 58-59.

[22] Ibid: 76-79.

[23] Versuchs- und Planungsgesellchaft fur Magnetbahnsysteme: 28.

[24] Merklinghaus, 1990.

[25] Magnetschnellbahn: 32.

[26] Heinrich and Kretschmar: 50.

[27] Versuchs- und Planungsgesellchaft fur Magnetbahnsysteme: 32-33.

[28] Ibid: 33.

[29] Merlinghaus, 1990.

[30] Canadian Institute of Guided Ground Transport, 1986: TA 5-219/221.

[31] Hack, 1990; Merklinghaus, 1990; Wackers, 1990.

[32] Der Spiegel, January 14, 1991: 85-86.

[33] Hack, 1990; Merklinghaus, 1990.

[34] Merklinhaus, 1990.

[35] Hack, 1990; Merklinghaus, 1990; Wackers, 1990.

[36] U.S. Dept. of Transporation, 1990: 7-1.

[37] Ibid: 7-1/7-2.

[38] Ibid: 7-2.

[39] Ibid: 4-3.

[40] Ibid: 7-3/7-4.

[41] Merklinghaus, 1990.

[42] Ibid: 3-4.

[43] Ibid: 3-5.

[44] Ibid: 3-8/3-9.

[45] Versuchs- und Planungsgesellschaft, June 1990: 13

[46] Versuchs- und Planungsgesellchaft fur Magnetbahnsysteme: 32.

[47] TuV Rheinland.

[48] TuV Rheinland.

[49] Hack, 1990.

[50] Konsortium Anschubgruppe Transrapid, 1989: 19.

[51] Konsortium Anschubgruppe Transrapid, 1989: Topographische Anwendungskarte Essen-Bonn.

[52] Schrewe, Friedrich, 1989: 12.

[53] Versuchs- und Planungsgesellschaft, June 1990: 15.

[54] Hack, 1990.

[55] Konsortium Anschubgruppe Transrapid, 1989: 21.

[56] Versuchs- und Planungsgesellchaft fur Magnetbahnsysteme: 33.

[57] Versuchs- und Planungsgesellschaft, June 1990: 22.

[58] Canadian Institute of Guided Ground Transport, 1986c: TA 7-6.

[59] Ibid: TA 7-9.

[60] Versuchs- und Planungsgesellschaft, June 1990: 22.

[61] Canadian Institute of Guided Ground Transport, 1986b: TA 6-3.

[62] Canadian Institute of Guided Ground Transport, 1986b: TA 6-20

[63] Ibid: TA6-30.

[64] Versuchs- und Planungsgesellschaft, June 1990: 22.

[65] Canadian Institute of Guided Ground Transport, 1986b: 27.

[66] Ibid: TA 6-1 - 2.

[67] Canadian Institute of Guided Ground Transport, 1985: TA 3-34/TA 3-35.

[68] Ibid: TA 3-72/TA 3-74.

[69] Ibid: TA 3-76/TA 3-77.

[70] Konsortium Anschubgruppe Transrapid, 1989: 41.

[71] Ibid.

[72] Ibid.

[73] Ibid: 42.

[74] Ibid.

[75] Ibid: 86.

[76] Versuchs- und Planungsgesellchaft fur Magnetbahnsysteme: 29.

[77] Ibid: 30.

[78] Canadian Institute of Guided Ground Transport, 1985; Canadian Institute of Guided Ground Transport, 1986d; California-Nevada Super Speed Train Commission, 1989; Harmon, Robert J., and Associates, 1987.

[79] Maglev Transit, Inc., 1988: 23-24.

[80] Konsortium Anschubgruppe Transrapid, 1989: 38

[81] Ibid.

[82] Ibid.

[83] Harmon and Associates, 1987: OF 5/OF 14.

[84] Ibid.

[85] California-Nevada Super Speed Train Commission, 1989: 3-1/3-6.

[86] Ibid: 3-6.

[87] Ibid: 3-14.

[88] Ibid: 3-10; 3-30/3-31.

[89] Maglev Transit, Inc., 1988: 23.

[90] Hack, 24 July 1990.

[91] Heinrich and Kretzschmar, 1989: 103.

[92] Ibid: 103-104.

[93] Schrewe, 1989: 12.

[94] Der Spiegel, January 1991 (No. 1): 79.

[95] Johnson, RichAnn, 1991.

[96] Johnson, December 23, 1991.

[97] Ibid.

[98] Reinhardt, 1991.

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