AMERICAN MAGLINE GROUP
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Technology Comparison: High Speed Ground Transportation

Transrapid Superspeed Maglev
and
Bombardier JetTrain

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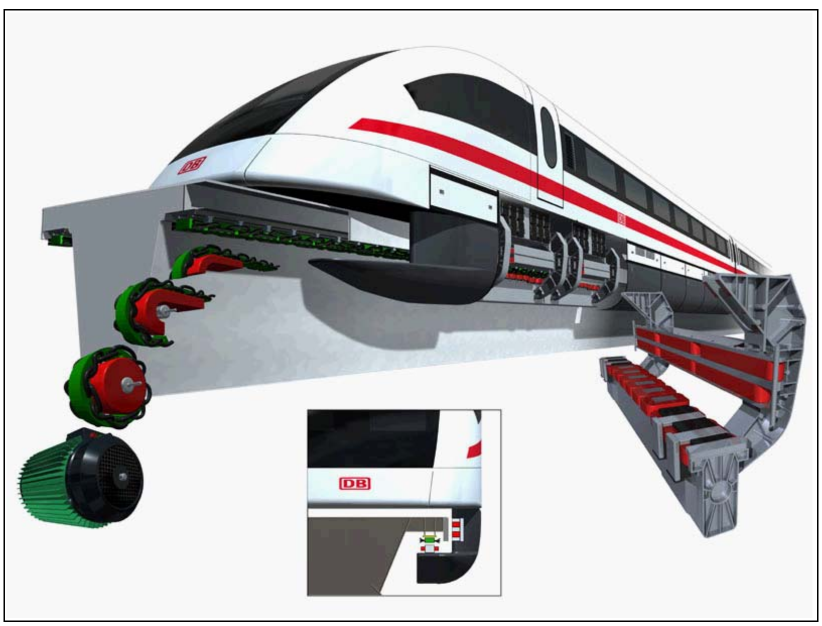
Introduction

This paper compares known features of two ground transportation systems: 300-mile per hour Superspeed *Transrapid* Magnetic Levitation (Maglev) and 150-mile per hour high-speed Bombardier JetTrain. Its purpose is not to recommend one technology over the other, but to address performance and marketing claims being made in the media and to eliminate misconceptions when considering possible application in corridors of interest by responsible public officials.

Technology Overview

Transrapid

The *Transrapid* Maglev System is the world's only commercially-available high speed Maglev technology. As a result of over 25 years of continuous design, testing and refinement, the *Transrapid* Maglev technology is the first such transportation system approved for public use. Achieving routine operating speeds of up to 500 kilometers per hour (310 miles per hour), vehicles travel along a fixed guideway using non-contact levitation, lateral guidance and propulsion.



Source: Transrapid International-USA, Inc.

Figure 1 – *Transrapid* Linear Motor Principle

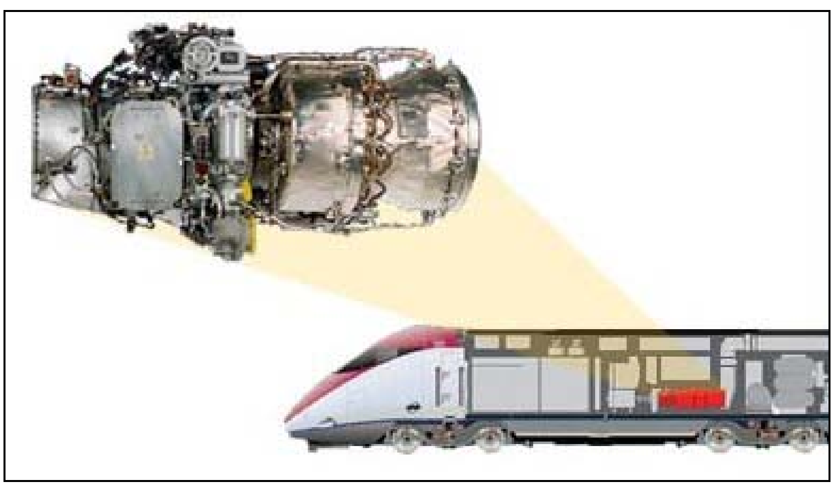
The system utilizes conventional electromagnets (not superconducting magnets) to attract the bottom frame of the vehicle upward to within 10 mm (3/8 in.) of the bottom of the guideway. Propulsion is achieved through the same principle as a standard rotating electrical motor, but with the stator cut, unrolled and placed lengthwise into the guideway

(See Figure 1). The levitation/support magnets mounted in the frame of the vehicle serve as the rotor (excitation portion) of the electric motor. When current is run through the stators along the guideway, a linear traveling magnetic field is created, propelling the vehicle. As a result, no separate locomotive car or on-board motor is required to be part of the *Transrapid* trainset, significantly reducing overall weight and eliminating concentrated loads on the guideway.

Due to the *Transrapid* levitation technology's use of electromagnets, no wheels are needed either on or under the vehicle. Levitation can be achieved at all speeds, including when the vehicle is stopped. Levitation and guidance accomplished by the electromagnets is powered by on-board batteries. During normal operation, vehicle batteries are continuously charged through linear generators built into the vehicle frame. Typically, for energy saving purposes, the vehicle is de-levitated during station stops, where skids under the vehicle allow it to rest atop the guideway.

JetTrain

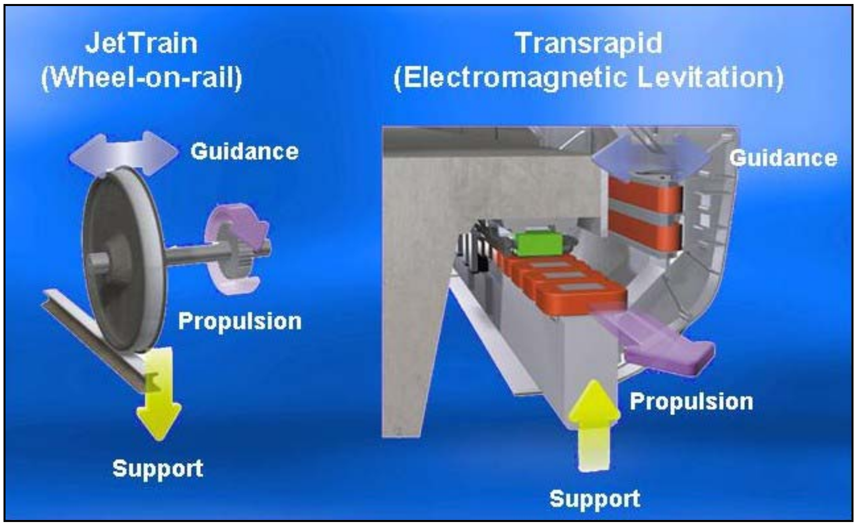
Built and marketed by Canadian Bombardier Transportation, JetTrain is a recent advancement in conventional steel-wheel-on-steel-rail technology. The product is the result of more than 15 years of development and is based on the Acela Express trainset technology now being used in Amtrak's Northeast Corridor. The typical trainset involves one or two locomotives and a set of passenger cars running on non-electrified, standard-gauge railroad track. Powered by a Pratt & Whitney turbine engine, the JetTrain locomotive is capable of sustained operating speeds of 240 km/h (150 mph) and is 20-percent lighter than a conventional diesel locomotive (See Figure 2).



Source: Bombardier Transportation

Figure 2 – JetTrain Locomotive

Figure 3 provides a comparison of the JetTrain (Railroad) and Transrapid (Maglev) system principles. It graphically illustrates locations and methods for support, guidance and propulsion for each technology.



Source: Transrapid International-USA, Inc.

Figure 3 – Comparison of JetTrain (Railroad) and *Transrapid* (Maglev) functions

Operational Experience

<u>Transrapid</u>

Since 1984, the *Transrapid* Maglev System has been in operation at a full-scale test facility in northwest Germany. This facility has allowed the opportunity for design, endurance testing and continuous refinement that have led to today's deployment-ready system. The eighth-generation vehicle is currently operating at the facility, where nearly 400,000 passengers have ridden around the 40-kilometer (25-mile) closed loop. The *Transrapid* vehicles have accumulated over 500,000 miles of travel, equivalent to 20 trips around the equator, since the opening of the facility without major interruptions or safety incidents (See Figure 4).

Source: Transrapid International-USA, Inc.

Figure 4 – *Transrapid* Operation at the Test Facility in Germany

The first commercial application of high-speed Maglev is only a few months away from revenue service with the deployment of *Transrapid* technology in Shanghai, China. The 30-kilometer (19.5-mile) connection—between Pudong International Airport and Shanghai's financial center—will feature an operating speed of 430 km/h (267 mph) resulting in an eight-minute trip time, with five-section trainsets running each direction every ten minutes. Operation will begin by the end of 2002, with full revenue service commencing in late-2003. The system is expected to be carrying 10 million annual passengers by 2005.

JetTrain

The JetTrain technology is based on the technology used in electrified Acela Express trainsets now operating in the northeastern U.S. Although no complete JetTrain consist exists or is currently in commercial operation, testing has been performed with a single locomotive and conventional rail cars at the Association of American Railroad's Transportation Test Center in Pueblo, Colorado to evaluate performance and confirm compliance with relevant Federal Railroad Administration (FRA) rail equipment standards (See Figure 5).

Source: Bombardier Transportation

Figure 5 – JetTrain Locomotive in Test Operations in Colorado

Guideway / Track

Transrapid

The *Transrapid* system uses its own dedicated track, commonly called a 'guideway,' built of steel or concrete beams supported by concrete substructures. The guideway may be built in the following three ways:

- Elevated, to avoid conflicts with existing infrastructure and ground surface activities
- At-grade, where land is available and safety can be maintained
- In tunnels, to route the guideway under sensitive or densely populated areas

The use of a dedicated and separate guideway ensures no safety conflicts with other transportation modes and allows uninterrupted Maglev operations.

JetTrain

JetTrain can operate on existing railroad tracks, although high train speeds may be limited by the existing track conditions. These conditions may include accommodating freight operations, poor track quality, frequent at-grade crossings with roads and highways, significant curves and steep grades. In many cases, true high speed operation of JetTrain may require new or significantly improved rail infrastructure.

Performance

Transrapid

In addition to its 500-km/h (310-mph) speed capability, the *Transrapid* system offers other significant performance advantages designed to overcome the limitations of steel-wheel systems. The technology allows for routine climbing and descending of grades up to 10-percent (10 feet of elevation for every 100 feet of guideway length), almost three times steeper than conventional rail systems. *Transrapid* vehicles can round 50-percent tighter curves (horizontal and vertical) at the same speeds as conventional high-speed rail. Similarly, they can travel through a curve of the same radius at much higher speeds than conventional systems. The guideway can be banked to 12 degrees of superelevation, allowing vehicles to travel through tight-radius curves while still at high speeds. Adequate banking eliminates uncomfortable sideward forces, ensuring ride comfort.

Acceleration and braking capabilities of the *Transrapid* system result in minimal loss of time for station stops. The vehicles reach high operating speeds in a quarter of the time and less than one quarter of the distance of conventional high speed rail systems. The system is controlled in all directions of movement to ensure ride comfort throughout all phases of operation. Seat belts are not required and passengers are free to move about the cabin at all speeds.

JetTrain

JetTrain technology incorporates tilting technology into both locomotives and passenger cars for better travel in curves. The computer-controlled and hydraulically activated system allows the body of the car to tilt into the direction of a turn, resulting in reduced side forces and improved passenger comfort. Grade-climbing ability and track banking are typical of conventional high speed rail. However, when sharing track with freight operations, compromises on track grade and banking are required, further reducing performance.

Safety

Transrapid

Transrapid's technical concept has eliminated the safety risks associated with the operation of conventional rail transportation systems. Redundancies achieved through the duplication of components as well as the automated, radio-controlled system ensure that operational safety is never jeopardized. The principle of synchronized propulsion makes collisions between vehicles virtually impossible. If two or more vehicles were ever placed simultaneously in the same guideway segment, they would be forced by the motor in the guideway to travel at the same speed in the same direction.

Collision risk with other transportation systems is avoided as the *Transrapid* uses its own dedicated guideway without intersections with other modes such as roads and highways. Nevertheless, the vehicles are designed to withstand collisions with small objects on the guideway. In addition, since the *Transrapid* vehicle wraps around the guideway beam, a derailment is virtually impossible.

JetTrain

JetTrain operation has levels of safety similar to conventional railroad equipment, with some enhancements. Locomotives and passenger cars will feature high-strength protection zones for passengers and crew, and energy-absorbent crushable sections in non-occupied areas. The equipment will be designed to meet federal standards related to crash energy management, rollover strength and the ability to withstand compressive forces at high speeds.

An important factor in the safety of JetTrain operation is the conditions of the railroad used. Mixed operation with freight trains and heavy locomotives as well as frequent highway grade crossings increase risks for operation. Investment to increase corridor capacity and eliminate obstacles such as grade crossings would add to the safety of JetTrain operation.

Environment

Transrapid

Transrapid is one of the first transportation systems to be specially developed to protect the environment. The system can be co-located with existing transportation corridors and needs a minimum amount of land for the support of guideway beams. Use of elevated guideway minimizes disturbance to existing land, water and wildlife, while flexible alignment parameters allow the guideway to adapt to the landscape.

With its non-contact levitation and propulsion technology, highly efficient linear motor (mounted in the guideway) and low aerodynamic resistance, the energy consumption of the *Transrapid* system is very economical when compared to other transportation modes. It typically requires 25 to 30 percent less energy per passenger than conventional high-speed rail systems. In addition, there are no direct emissions from the moving vehicles to affect air quality.

The *Transrapid* technology is much quieter than other transportation systems as it does not produce any rolling, gearing or engine noise. Noise, predominantly aerodynamic, is minimal at speeds up to 250 km/h (155 mph) and is significantly less than conventional trains at higher speeds. *Transrapid* is the quietest high-speed ground transportation system available today. Electromagnetic fields (EMF) produced by the *Transrapid* system are negligible and are roughly equivalent to the Earth's natural magnetic field. Due to their exposed sources of high voltage, a typical electrified conventional train and a subway system have approximately four and eight times the field strength, respectively, of the *Transrapid* system.

JetTrain

JetTrain technology improves upon conventional diesel railroad locomotives by utilizing a specialized lightweight jet engine. As a result, its greenhouse gas emissions and noise are less than traditional rail equipment. However, although the high-pitched whine of the jet engine is muffled, it is still quite noticeable. Each JetTrain locomotive operates on conventional diesel fuel and carries an 8,330 liter (2,200 U.S. gallon) fuel tank.

JetTrain technology is designed to utilize existing railroad tracks or new rail infrastructure. Rail bed is typically at ground level and includes spread rock ballast stabilizing cross ties and rails.

Cost

Transransrapid

Initial capital investment for the construction of a *Transrapid* system has been shown to be comparable to the construction of a conventional European high-speed rail line. Building new infrastructure for any transportation mode will require a significant initial investment. However, construction of a dedicated *Transrapid* line will allow large capacities to be transported at high speeds without interference from or delays due to other transportation modes. In addition, since the guideway can be flexibly adapted to the topography, *Transrapid* infrastructure costs become even more favorable as terrain becomes more difficult.

Due to the use of automated non-contact technology, maintenance costs for *Transrapid* system operation are significantly less than for conventional high-speed rail technology. Vehicle operation causes neither misalignment nor wear of the guideway structure, equipment and surfaces. Most moving mechanical components that wear down for other technologies have been replaced by non-wearing electronic and electromagnetic components in *Transrapid*. In addition, vehicle weight is evenly distributed by the full-length levitation magnets (no point loading from wheels), resulting in less stress and lower dynamic loads on the guideway.

JetTrain

While JetTrain equipment is designed to operate on existing railroad tracks, investment will usually be required to improve the corridor or increase capacity to allow high-speed operation. Such necessary improvements may include constructing new infrastructure, eliminating grade crossings, straightening curves, leveling grades and adding sidings for the passing of trains. In addition the Acela-style coaches require high level platforms for boarding at stations. Providing these facilities may entail additional costs to modify existing station areas.

Maintenance costs for the operation of JetTrain equipment are typical of conventional high-speed rail technologies, with JetTrain offering some improvement due to its lower trainset weight. Necessary activities will include routine maintenance of rolling stock, track inspection and periodic ballast, cross tie and rail replacement. For continued safe high-speed operation, rails must be constantly maintained for reduced wear and precision alignment.

Comparison of System Characteristics

The tables on the following pages provide data comparisons between the *Transrapid* Maglev and JetTrain technologies. Significant comparisons include:

- From a station stop, *Transrapid* attains two and a half times the speed and covers twice the distance of JetTrain in the same amount of time.
- *Transrapid* requires only one-quarter the time and distance to attain JetTrain's top speed.
- JetTrain is almost twice as noisy as *Transrapid* at similar operational speeds.
- *Transrapid* can climb grades from two and a half times to eight times steeper than JetTrain with no loss of speed.
- *Transrapid's* unique guideway precludes interfacing with heavy freight trains, locomotives and grade crossings.

System Features	Maglev Transrapid[1]	Bombardier JetTrain[2]
Technology		
Vehicle Support and Lateral Guidance	Non-contact, Electromagnetic Levitation and Guidance (magnetic attraction); 10 mm (3/8 in.) gap from guideway	Conventional Flanged Steel Wheel on Rail
Propulsion	Longstator Linear Synchronous Motor (LSM) Mounted on Guideway No separate locomotive	5,000 hp (3,750 kW) turbine locomotive AC Traction motors, water cooled IGBT-type inverters; continuous 4,400 hp (3,300 kW)
Energy Supply	Electric Public Network (i.e. 110 kV, 50/60 Hz) or Internal Railroad Network (16 2/3 Hz)	Diesel Diesel Fuel 8,330 L (2,200 gal) tank per locomotive
Operation Control System	Fully Automated Communication and Control System, Digital Radio Transmission, Driver optional	Automatic Train Control (LZB), Driver required

[1] Source for Data: Transrapid International-USA, Inc.
[2] Source for Data: Bombardier Transportation

System Features	Maglev Transrapid			Bombardier JetTrain		
Performance						
Maximum Operating Speed	500 km/h (310 mph)			240 km/h (150 mph)		
Average Operating Speed	Dependent on Alignment			Dependent on Alignment, Condition of Existing Rail, Highway Grade Crossings and Co-existence with Freight Operations		
Acceleration Performance[3]	Time	Distance	Time Lost[4]	Time	Distance	Time Lost[4]
0-100 km/h (60 mph)	31 s	424 m (1,391 ft.)	16 s			
0-161 km/h (100 mph)				150s	4,345 m (14,256 ft.)	53 s
0-200 km/h (125 mph)	61 s	1,700 m (5,577 ft.)	30 s	258s	9,978 m (32,736 ft.)	79 s
0-240 km/h (150 mph)				606s	31,858 m (104,544 ft.)	131 s
0-300 km/h (185 mph)	97 s	4,200 m (13,780 ft.)	47 s			
0-400 km/h (250 mph)	148 s	9,100 m (29,856 ft.)	66 s			
0-500 km/h (310 mph)	256 s	22,700 m (74,475 ft.)	93 s			
	Data depend on propulsion layout					

[3] Transrapid Acceleration Data based on an 8-section trainset; JetTrain Data based on a 5-section trainset (one power car and four coaches)
[4] Time lost is relative to instantaneous ramp up to speed

System Features	Maglev Transrapid	Bombardier JetTrain
Performance		
Noise Emission		
Drive-by Noise Level at Speed of [5]	Hybrid Beam (Transrapid); At-Grade Track (JetTrain), 30.5 m (100 ft.) Distance[6]	
100 km/h (62 mph)	75 dB(A)	82 dB(A)
150 km/h (93 mph)	76 dB(A)	84 dB(A)
200 km/h (124 mph)	77 dB(A)	86 dB(A)
300 km/h (186 mph)	86 dB(A)	--
400 km/h (250 mph)	91 dB(A)	--
Features		
Environmental Impact	Low	Medium - High
Space Requirements	Low - Medium	Medium - High
Safety	Safest Mass Transportation System Available	Comparable to Conventional Rail

[5] Maximum Sound Pressure Levels (SPL)
Source: DOT-VNTSC-FRA-02-12, July 2002 and Bombardier Transportation
[6] An increase of 10 dB(A) represents a doubling of noise

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<table>
<tr><th>System Features</th><th colspan="5">Maglev Transrapid</th><th colspan="2">Bombardier JetTrain</th></tr>
<tr><td>Trains</td><td colspan="5"></td><td colspan="2"></td></tr>
<tr><td>Train Configuration</td><td colspan="2">End Section</td><td colspan="3">Middle Section</td><td>Locomotive</td><td>Passenger Car</td></tr>
<tr><td>Train Size</td><td colspan="2">2</td><td colspan="3">0 - 8</td><td>2</td><td>6</td></tr>
<tr><td>Section Length</td><td colspan="2">26.99 m (88.5 ft.)</td><td colspan="3">24.77 m (81.3 ft.)</td><td>21.22 m (69.6 ft.)</td><td>26.64 m (87.4 ft.)</td></tr>
<tr><td>Section Width</td><td colspan="2">3.70 m (12.1 ft.)</td><td colspan="3">3.70 m (12.1 ft.)</td><td>3.18 m (10.4 ft.)</td><td>3.16 m (10.4 ft.)</td></tr>
<tr><td>Section Height</td><td colspan="2">4.16 m (13.6 ft.)</td><td colspan="3">4.16 m (13.6 ft.)</td><td>4.32 m (14.2 ft.)</td><td>4.23 m (13.9 ft.)</td></tr>
<tr><td>Total Trainset Length (8 sections)</td><td colspan="5">202.60 m (664.7 ft.)</td><td colspan="2">202.28 m (663.6 ft.)</td></tr>
<tr><td>Empty Weight / Section</td><td colspan="2">51.7 t</td><td colspan="3">50.6 t</td><td>90.7 t
(200,000 lb.)</td><td>57.6 – 59.9 t
(127,000-132,000 lb.)</td></tr>
<tr><td>Capacity</td><td colspan="5"></td><td colspan="2"></td></tr>
<tr><td>Number of Sections</td><td>2</td><td>4</td><td>6</td><td>8</td><td>10</td><td colspan="2">8 (2 Locomotive and 6 Coaches)</td></tr>
<tr><td>Passenger Seats (high density)</td><td>184</td><td>436</td><td>688</td><td>940</td><td>1192</td><td colspan="2" rowspan="2">304</td></tr>
<tr><td>Passenger Seats (low density)</td><td>124</td><td>292</td><td>460</td><td>628</td><td>796</td></tr>
<tr><td>Passengers or Cargo</td><td>28 t</td><td>63 t</td><td>98 t</td><td>133 t</td><td>168 t</td><td colspan="2"></td></tr>
</table>

<table>
<tr><th>System Features</th><th colspan="6">Maglev Transrapid</th><th>Bombardier JetTrain</th></tr>
<tr><td>Track / Guideway</td><td colspan="6"></td><td></td></tr>
<tr><td>Construction</td><td colspan="6">Steel, Reinforced Concrete, or Hybrid Beams (Superstructure) with Reinforced Concrete Supports/Foundations (Substructure)</td><td>Welded Steel Track (Standard Gauge) with Transverse Concrete/Wooden Ties Laid in Ballast or Attached to a Concrete Slab Base</td></tr>
<tr><td>Alignment Parameters</td><td colspan="6"></td><td></td></tr>
<tr><td>Guideway / Track Gauge</td><td colspan="6">2800 mm (9.2 ft.)</td><td>1435 mm (4.7 ft.)</td></tr>
<tr><td>Gradient Height
(Top of Guideway/Track)</td><td colspan="3">At grade
1.35 - 3.5 m
(4.4 - 11.5 ft.)</td><td colspan="3">Elevated
2.2 - 20 m
(7.2 - 65.6 ft.)</td><td>At-grade
0.4 m (1.3 ft.)</td></tr>
<tr><td>Double Track, Center-to-Center Distance</td><td colspan="2">4.4 m (14.4 ft.)
(<300 km/h)
(185 mph)</td><td colspan="2">4.8 m (15.7 ft.)
(<400 km/h)
(250 mph)</td><td colspan="2">5.1 m (16.7 ft.)
(<500 km/h)
(310 mph)</td><td>4.7 m (15.4 ft.)
(240 km/h)
(150 mph)</td></tr>
<tr><td>Grade Climbing Ability</td><td colspan="6">10%</td><td>4% Passenger Traffic
1.25 % Mixed Traffic with Freight</td></tr>
<tr><td>Superelevation / Cant</td><td colspan="6">12° (special cases 16°)</td><td>7° Passenger Traffic (planned)
5° Mixed Traffic with Freight</td></tr>
</table>

System Features	Maglev Transrapid		Bombardier JetTrain
Track / Guideway			
Example Route Data			
Foundation Area, Double Track	Elevated 1.5 m²/m (4.9 ft.²/ft.)	At-grade 11.8 m²/m (38.7 ft.²/ft.)	At-grade 13.7 m²/m (44.9 ft.²/ft.)
Total Ground Area, Double Track	Standard Case 12.0 m²/m (39.4 ft.²/ft.)	Mountainous Region 22.8 m²/m (74.8 ft.²/ft.)	Average for new rail lines 31.2 m²/m (102.4 ft.²/ft.)
Earthworks, During Construction, Double Track (w/o Tunnels)	Elevated 13,700 m³/m (16,385 cy/y)	At-grade 47,200 m³/m (56,451 cy/y)	Average for new rail lines 201,878 m³/m (241,444 cy/y)

Sources for This Paper
Federal Railroad Administration
Transrapid International-USA, Inc.
Bombardier Transportation