Ticket to Ride

High-speed maglev trains hover within reach of the United States, as China puts one on the ground.

By Paul Sharke, Associate Editor, Mechanical Engineering, 2002

The last minutes of the flight back from Germany demonstrated what a two-day visit to Trans- rapid International's headquarters in Berlin and its maglev test track near Bremen had not. As the 747 descended toward New York, the German-speaking woman in an aisle seat fished from her seat pocket a little gray bag that the prep crew had stowed there earlier.

Although the cabin had warmed slightly, the woman's own sense of temperature must have climbed high enough that she was now using the bag to fan herself.

As the packed plane undulated on its final approach, nausea overcame her. A sympathetic response may have prompted an Indian man seated nearby to reach for his own gray bag. The smooth taxiing of the plane after landing did nothing to smooth the ensuing chain reaction inside the cabin.

Few commercial fliers experience that kind of discomfort much anymore. Yet, it points out how travelers sometimes sacrifice comfort to shorten transit time. It's the rare sightseer who'll take a train across the country when an airplane can deliver the same destination in a quarter-day. Seven hours airborne hardly compare to the week at sea it once took to cross an ocean.

For many travelers, though, the greatest discomfort of all is sitting still. Stuck.

Final preparations wind down as a Shanghai maglev train awaits its journey from the factory in to China. When operation begins near year-end, the train will run at 430 km/hr. Testing will take it to 500 km/hr.

It is precisely that discomfort the airlines and airports are accused of doling out lately: making fliers arrive hours before flight time; stacking airplanes unendingly to await takeoff; delaying flights for weather; occasionally, missing a landing.

In the United States, however, rail service offers little alternative. Except in a few corridors, passenger trains shimmy over wavering tracks whose profitability comes mainly from service to slow, heavy freight traffic. The needs of passenger trains don't match the requirements of freight haulers.

Transportation planners in Pittsburgh and the Baltimore-Washington region, mindful of these points, are finishing up the details of two proposals for high-speed maglev trains that will tie each city's downtown closer to local airports. Both areas made it into the semi-final round of a seven-region playoff for nearly a billion dollars in federal funding for a maglev demonstrator. Eventually, the short lines being proposed may grow long enough to provide real alternatives to short-hop flights.

Not quite flying, but not railroading either, maglev represents the not-so-new technology that some industry observers hail as an idea in search of an economic need. But the 30-year-old technology is closer than ever to gaining a toehold on these shores. If it does, it won't be until after the Chinese get theirs. They are already part of the way through a deal with Transrapid for a maglev project in Shanghai.

The Flying Kilometer

Situated in the rural Emsland region of Germany near the North Sea, the Transrapid test guideway has been operating for more than 18 years. For $25, anyone can buy a two-hour tour, which includes a couple of laps over the 31.5-kilometer circuit.

One tour began with a bus ride out to a wayside observation hill, where the group watched the Transrapid TR-08 enter the north loop of the test track at about 100 mph. Accelerating on its way around the loop, the train shot past again a few minutes later.

This time, a wisp of vapor trailed the train, dispersed from rain puddles on the flat guideway. Transrapid's project manager, Robert Budell, gauged the speed at 230 mph.

There was noise, mostly aerodynamic. But the squeaks and squeals of steel on steel were noticeably absent. Any commotion stirred up as the train passed faded quickly.

On its way back to the maglev station, the group stopped to look at one of three giant switches along the twin loop track. Supported by eight columns, the 150-meter steel switch could bend from one track to the other in 30 seconds. A cam and moment arm arrangement on every other pier pushed the big beam into position. Pins locked it fast.

Transrapid was supplying switches for the Shanghai project, Budell said. But it would ship the Chinese rack-and-pinion arrangements rather than the cam and moment arm style in place here. The cam style didn't work for three-way transfers.

Transrapid was also providing the Chinese with trains and the propulsion system that runs the length of the double-wide guideway. For the guideway itself, the Chinese had already tacked down some 500 of the 2,500 hybrid concrete and steel beams that they'll make to complete the course. The beams will delineate a 30-km route from Long Yang Road to the airport in Pudong.

While the group examined the switch, the three-car train rushed by overhead. Budell said the train transmitted about 90 decibels as it crossed the long steel switch. Along ordinary elevated guideway, the 250-mph train emits a sound pressure of 88 dB (about the same as a noisy factory) at the pass-by level when measured from 25 meters out. A train passing over guideway at grade emits less noise.

From the second observation post, the group rode back along the service road below the guideway. The mile cruncher above could eat distance at five or more times the rate at which the bus was then consuming it. The group soon found out what that was like from the inside.

Round Trip

Landscape going by at 250 mph looks about the same as it does going past at 70. Trees and windmills in the distance come easily into focus. Nearer objects blur by.

Inside the train, an overhead speedometer kissed 411 km/hr during the high-speed run. As the train rounded the curves, even a walk through the aisle didn't spill a drop from an imaginary cup of coffee. It was easy to imagine speeding up the Northeast rail corridor in the States on one of these machines.

After a fast tour of the German countryside, the train dropped off most of its passengers. Some stayed aboard to ride it to the maintenance shop, where it parked for the night. Inside the shop, Budell pointed out various aspects of the design from beneath the vehicle.

Synchronous linear stators run down both sides of the guideway. Energized a section at a time, the stator pulls the "rotor" and the maglev carriage along with it. Support and guidance magnets on the carriage levitate and center the vehicle.

During a power loss, each car needs only two of its four independent power supplies and

NiCad battery packs to move it to a safety stop.

Stopped vehicles and those moving below 50 mph draw electricity via power rails located along station platforms and designated stopping areas. Above 50 mph, the maglev vehicle touches nothing, instead tapping power from the guideway through induction.

This eighth generation of vehicles to ply the track at Emsland rode along a first-generation guideway. The track had settled just 1.5 mm in the span of 20 years.

The train relies on classic block control. Depending on the interval between trains, substations could be spaced anywhere from two to 30 miles apart. Transrapid preferred short trains at frequent intervals to long trains far apart. Ten cars make up the longest permissible consist, adding up to a trainset 250 meters long.

Transrapid's central control occupies the same building as the maintenance shop. This one location oversees all train movements. A three- to four-man shift runs the operation from central control with the help of triple redundant computers.

Working Out the Issues

Both the Baltimore-Washington and Pittsburgh maglev semi-finalists have selected Transrapid systems in their proposals. Federal funding requires that the project include 70 percent American content. That would likely be met by building the guideway domestically, as the Chinese are doing.

Transrapid, a joint venture of Siemens and Thyssen-Krupp, joined recently with Lockheed Martin Mission Systems of San Diego to investigate four possible maglev routes in southern California. Originally proposed as a 92-mile segment between Los Angeles International Airport and Riverside, the California route may have been too long to qualify for federal funding as a demonstrator, according to Tom Palmer, Lockheed Martin's maglev project director.

Yet, L.A. planners and the 165-city Southern California Association of Governments had been looking into maglev even before the federal government launched its initiative. They have commissioned a handful of maglev studies along five corridors over the last four years.

The 20-meter test track at Lawrence Livermore Laboratory used drive coils in its first 4.5 meters for propelling a 20-kg cart to 20 m/s. That was about six times the speed needed to levitate the vehicle.

Lockheed Martin expects to determine, by June 2003, which of several smaller operating segments within the LAX-Riverside corridor will be the best place for a maglev project to begin, Palmer said. Phase II will cover preliminary engineering and environmental impact assessments for the portion selected. Financing plans will follow.

As the systems integrator, Lockheed Martin is also working out compliance issues that surround the import of German maglev technology. In some instances, the company may be able to find areas where costs can be reduced in adapting the system to U.S. regulations and environmental standards. It is also comparing European and American passenger perspectives to see which amenities could encourage drivers to go back aboard mass transit.

Meanwhile, Lockheed Martin Missiles and Fire Control of Dallas has teamed up with American Maglev Technology Inc. of Edgewater, Fla. Along with Dominion Virginia Power, American Maglev is developing a low-speed maglev system on the campus of Old Dominion University in Norfolk, Va. Less than a mile long, the shuttle will be dedicated in November.

In Japan, a prototype system uses superconducting magnets inside the trains. The trains this year passed the 200,000-km mark for cumulative distance on the Yamanashi Maglev Test Line near Tokyo.

Another approach to rail-free transit—as yet untried—may eventually carve off some of the high track costs that have held back the deployment of commercial maglev. Invented at Lawrence Livermore National Laboratory in California, Inductrack relies on permanent magnets arranged in a Halbach array on the underside of a maglev vehicle. As the train moves along, it produces its own levitating force in coils mounted along the track.

Invented by Livermore physicist Klaus Halbach for use in particle accelerators, a Halbach array orients a group of permanent magnets so that their magnetic fields cancel each other along one edge, while reinforcing each other along the opposite edge.

(The application of the system for launching spacecraft was discussed in an article in the February 2000 issue, "Induction for the Birds," page 66.)

A second-generation test at General Atomics' Dynamic Test Facility holds the cart stationary while the track rolls by below it.

The Inductrack maglev does not levitate while it's standing still. The train needs motion to rise off the track. Theoretical studies predict that a speed of only few miles an hour is enough to lift the vehicle. A small-scale test track at the lab confirmed these predictions.

Because the energy to lift the vehicle comes from the motion of the train, electrical power losses, such as those associated with the magnet coils of the German or Japanese systems, need not be considered with this system. Induced current in the track coils does produce drag forces, however. But these electrodynamic forces decrease with increasing speeds—the opposite of normal frictional and aerodynamic drag.

For propulsion, a maglev vehicle built with Halbach arrays could use induction coils in the track, as the German and Japanese systems do. Because it requires no electrical systems on board for powering its magnets, it could use instead a propulsion system that was completely unlinked to the guideway. Richard Post, the Livermore physicist who invented Inductrack, said a turbofan could propel it beyond electrified territory.

A General Atomics-led team in San Diego is evaluating the low-speed, urban maglev capabilities of the Inductrack system for the Federal Transit Administration. The team has constructed a test track, resembling a giant hamster wheel, for studying the interaction between a full-size guideway and a full-width array.

By reversing the normal order of things, project engineers designed the 3-meter-diameter test track to roll beneath a stationary vehicle, said Sam Gurol, General Atomics' maglev program manager. The track consists of a ladder of litz wire loops that glide between double Halbach arrays. The vehicle, restrained in every direction but the vertical so it can levitate above the track, holds the arrays in a five-over-three arrangement.

For intracity transit, maglev's quiet operation at speeds below 125 mph suggest a major economic advantage over traditional subways. No track needs to run below ground to squelch the noise of operation. A train can travel nearly silently on elevated ways—even around tight urban curves—according to a General Atomics' senior staff engineer, Philip Jeter. Minimizing tunneling and straightening should help to lower a maglev project's overall cost.

The TR-08's bank of guidance magnets. By keeping a constant distance from the guidance rails, the magnets orient the train laterally. Sup-port magnets below follow the track-mounted stators.

"Fail-safe" is another attribute that inventor Post ascribes to Inductrack. Because it levitates only above a certain transitional speed—close to that of walking—and operates on induced currents and repulsive forces, any electrical system failure means only that the vehicle coasts down to its slow transitional speed before rolling to rest on auxiliary wheels. Levitating forces lifting the train while it's under way strengthen exponentially as the gap between train and track closes, easily accommodating load variations.

The Japanese superconducting maglev uses a similar strategy, but doesn't reach its transitional speed until about 100 km/hr., Post said.

Transrapid's train always levitates in service, relying on a precision track and air gap and the ability to vary the strength of an electromagnetic field for circumventing the assumptions of Earnshaw's theorem.

During the 19th century, Rev. Samuel Earnshaw said that stable suspension of an object in a gravity field—static levitation—was impossible through any combination of fixed magnets and electrical charges. But feedback coupled with exquisite control of the electromagnetic field strength levitates the Transrapid maglev. At a station, the train hunts slightly, seeking static equilibrium.

It's a testament to German engineering, Post said, that allows the control of a "fundamentally unstable" system.

Statistical projections for the Berlin-Hamburg maglev project, canceled two years ago with a change of party majority in the nation's government, anticipated only one hour's worth of "non-station" stops for every two years of operation, said Manfred Wackers, Transrapid's marketing director in Germany.

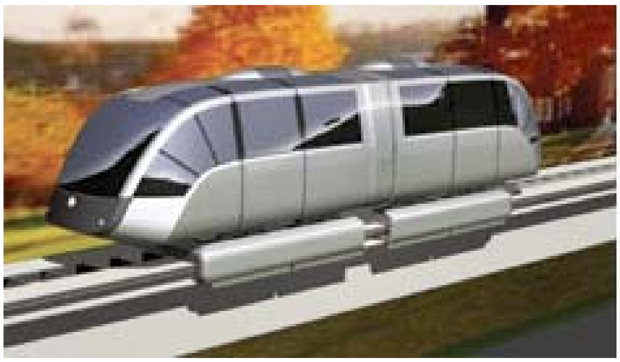
The Here and Now

For the time being, Transrapid alone stands ready for commercial deployment. That's partly by decree, according to Christopher Brady, the president of Transrapid International USA. After Congress authorized an investigation into maglev in 1991, the Federal Railroad Administration delivered a survey of existing technology. The next transportation bill in 1998 made maglev an issue of deployment rather than development, with Congress concluding that reinventing maglev domestically was imprudent given the state of existing technology.

Of the seven regions vying for federal funding, six specified Transrapid, Brady said. The two semi-finalists now await the Federal Railroad Administration's decision in 2003 about which one will receive federal maglev funding totaling $950 million. State, local, and private sources are to provide another one-third to two-thirds of the remaining project cost.

Pittsburgh's hill country could test maglev rigorously in a four-season revenue service, said Fred Gurney to a 2001 railroad subcommittee hearing of the U.S. House of Representatives. Gurney, president of Maglev Inc. of Monroeville, Pa., said that as many as 5,000 tons of steel going into every mile of the 47-mile airport-downtown link could refire demand for the region's former top commodity.

Gurney said the Pennsylvania project, in addition to solving a desperate traffic bottleneck in the region, would provide a crucible in which the company would refine its precision fabrication methods for large steel structures. The savings this advanced manufacturing technology would bring to future maglev systems would eventually spill over into other steel-heavy industries, such as shipbuilding.



L.A. maglev under study could propel a light vehicle around tight curves by limiting levitation pad length to 3.6 meters.

The proposed 40-mile run from Union Station in Washington, to Baltimore, stopping at BWI Airport, would anchor high-speed transit in the bottom terminus of the Northeast corridor. According to Suhair Alkhatib, principal engineer with the Maryland Mass Transit Administration, an under-20-minute ride between Washington and Baltimore would draw 35,000 riders a day.

A Baltimore-Washington maglev could also provide residents with a second airport choice, alleviating crowding at Reagan National Airport. The Baltimore-Washington route, while expected to stand on its own in terms of financial and technological feasibility, would be a "showcase" for a larger maglev line that, by 2040, might duplicate the alignment of the Northeast corridor, Alkhatib said. By then, traditional rail travel could be outdated. Or, maglev would add another layer of service to augment regional and commuter rail. Passengers could select fares and timetables from several travel modes to best suit their needs. Alkhatib's latest projections pegged the ticket price for the Baltimore-Washington maglev trip at $26.

That may be a relatively small price to pay for a system that promises to end the hours of delays that lengthen even the shortest of flights. But waiting is only one discomfort inflicted upon the traveling public. Kinetosis—motion sickness—is another.

A 1999 FRA-sponsored study evaluated the physical effects of high-speed, ground-level travel. Using airplane testing to learn how riders react to a simulated high-speed run up the New York Thruway, the study found only a "small percentage" of them suffered motion sickness. The airplane exposed subjects to slightly higher vertical accelerations and banking forces than a maglev train running through a typical highway corridor might encounter. A simulator later correlated high-speed travel with scenery rushing past a side window. The study again uncovered little incidence of nausea.

Perhaps the time has come for U.S. taxpayers, finally sickened by the country's limited options for high-speed travel, to fund a test of a fast curative agent. Then again, maybe they'd rather wait.