Federal Transit
Administration
Office of Mobility
Innovation

Proceedings of the Federal Transit Administration's Urban Maglev Workshop

Washington, DC
September 8-9, 2005

Notice

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

Notice

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

Table of Contents

Executive Summary iii

Morning Session: Thursday, September 8

Opening Remarks 1
Welcome and Introduction 1

MagneMotion Maglev System 5
Discussion, Q & A Session 5

General Atomics (GA) Maglev System 9
Discussion, Q & A Session 10

California University of Pennsylvania (CUP) Maglev Demonstration System 11
Discussion, Q & A Session 11

Afternoon Session: Thursday, September 8

Colorado Maglev Project 13
Discussion, Q & A Session 13

Maglev 2000 15
Discussion, Q & A Session 16

Maglev Urban System Associates (MUSA) Project 17
Discussion, Q & A Session 17

First Day Wrap-up 19

Morning Session: Friday, September 9

Day in Review 21

The First Commercial Application of HSST 23
Discussion, Q & A Session 23

Korean Maglev 25
Discussion, Q & A Session 25

Old Dominion University (ODU) Maglev Effort, Progress, and Goals 27
Discussion, Q & A Session 27

Table of Contents (continued)

Summary, Lessons Learned, and Benefits to Transit 29
Discussion, Q & A Session 29

Next Steps in Urban Maglev Program 33

Closing Remarks 35

Appendix A. Glossary 37

Appendix B. Workshop Participants 43

Appendix C. Workshop Agenda 45

Appendix D. Presentations 47

FTA Maglev Program Objectives 49

Urban Maglev Workshop – MagneMotion 57

General Atomics Maglev System 73

California University of Pennsylvania – Maglev Demonstration System 89

Colorado Maglev Project 99

Federal Transit Administration Workshop 115

MUSA Maglev Project 133

The 1st Commercial Application of HSST 153

Korean Maglev 161

Old Dominion University Maglev Efforts: Progress and Goals 173

Summary, Lessons Learned and Benefits to the Transit Industry 189

Executive Summary

The Federal Transit Administration's (FTA) Urban Maglev Workshop was held at FTA Headquarters in Washington, DC, on September 8-9, 2005. The key workshop goals were to review progress, share lessons learned among the grantees, and discuss future direction for the program.

Five competitively selected grantees, including Maglev Urban System Associates (MUSA) (Baltimore, MD), General Atomics (GA of San Diego, CA), MagneMotion, Inc. (Acton, MA), Colorado DOT (CDOT, Denver, CO), and Maglev 2000 (Titusville, FL), as well as the guest presenters of overseas maglev systems (Chuba High Speed Surface Transportation (CHSST) of Japan and Rotem of Korea) presented their project summaries and lessons learned. Old Dominion University (ODU) of Virginia also presented a summary of the American Maglev Technology (AMT) Maglev project.

The FTA Urban Maglev Program (UMP) was subject to the Transportation Efficiency Act for the 21st Century (TEA-21) process, in an effort to develop a safe, cost-effective, reliable, and environmentally sound urban transit system, that would also provide an option for relieving roadway congestion. The initial FTA UMP announcement was published in the *Federal Register* on January 20, 1999. The program goal was to advance the application of low speed magnetic levitation technologies identified to have comparative advantages in urban transit, and to translate the efforts of subsystem research and development (R&D) and a full-size prototype development into deployable technologies and a full-scale demonstration of the integrated system.

TEA-21 provided $5 million annually for low speed maglev from fiscal year (FY) 1998 through FY 2003 and provided a total of $5 million for R&D on low speed superconductivity maglev. Funding for the program through FY 2004 was provided through TEA-21 extensions. Additional funds were earmarked in FY 2004 and FY 2005 for demonstration planning of the maglev system at California University of Pennsylvania (CUP).

During the 2-day workshop, information exchanges and vigorous discussions were held on the direction of the technological improvements, performance requirements, subsystem comparison, and market entry relative to deployment. Key issues identified or addressed during the workshop became suggested topics of discussion for an additional workshop in the near future. FTA also requested feedback from the participants on the following key issues:

- Cost comparison matrix
- Key innovations
- Commercialization
- Obstacles to further deployment and the FTA's role in overcoming the barriers
- Application to rail transit
- Partnering options
- Comprehensive comparison and subsystem comparison matrix

- Funding
- Obtaining more information from existing systems overseas, including cost data
- Future areas of focus

The workshop achieved its goals, resulting in a number of suggestions on technological improvements and options for the future. The issues identified during the discussions will be the building blocks for a possible future workshop. Meanwhile, shared lessons learned and ideas for improvements and innovations will be beneficial to each team in pursuing the next step.

Morning Session: Thursday, September 8

Opening Remarks

Karen Facen, Federal Transit Administration (FTA)
Transportation Program Specialist for Office of Research Management

The Low Speed Urban Maglev Workshop opened at 8:30 a.m. (EST). Ms. Karen Facen, the FTA Transportation Program Specialist for the Office of Research Management, greeted the workshop participants and introduced Walter Kulyk, the FTA Director for Office of Mobility Innovation.

Welcome and Introduction

Walter Kulyk, FTA Director for Office of Mobility Innovation

Mr. Walter Kulyk, the FTA Director for Office of Mobility Innovation, welcomed all the participants to the workshop and expressed appreciation to the guest speakers from overseas for sharing their maglev experiences. He encouraged a vigorous exchange of ideas through sharing their maglev project experiences and lessons learned. He emphasized the importance of information sharing and collaborative discussion within an industry team setting to achieve the workshop goals.

Mr. Kulyk laid out the workshop objectives such that the collegial discussions and lessons learned would culminate in potential identification of the appropriate technologies, technological gaps to overcome, near-term issues and strategies, and future directions of the program with respect to funding. Self-introductions followed as each individual provided their name and affiliation (see Appendix B for a list of participants). After an overview of the schedule, Mr. Kulyk asked presenters to provide the latest version of their presentation for the workshop proceedings.

Mr. Kulyk began reviewing the statutory basis of the FTA Urban Maglev Program (UMP) in chronological order. He started with the Transportation Equity Act for the 21st Century (TEA-21) Reauthorization, which authorizes the FTA to support further development of maglev technologies for potential application in the U.S. mass transit industry. Section 1218 authorized a total of $5 million over the 6-year life of TEA-21 to research and develop low speed super conductive maglev technology. The FTA UMP is subject to the TEA-21 process and has an overall objective to develop maglev technology that is cost-effective, reliable, and environmentally sound, providing transportation options for urban mass transportation in the U.S.

Mr. Kulyk stated the FTA UMP contained in the January 29, 1999 Federal Register Notice had three primary phases: (1) evaluation of the maglev concept; (2) development of the prototype system; and (3) system integration for deployment. The program also includes a research and development (R&D) aspect intended to overcome critical technological gaps, but the emphasis is

on deployable technologies with participation by end users. He indicated the ultimate goal of the program is to "demonstrate;" however, beyond the prototype, there might not be enough funding available, and the decision on additional funding would be up to Congress.

Mr. Kulyk explained that the maglev program was included in each bill with obligated funding. The emphasis of TEA-21 was on low-speed maglev and its funding carried the program from fiscal year (FY) 1998 through FY 2003. The additional funding through FY 2004 was mainly for research and a demonstration of the 4-mile test track at California University of Pennsylvania (CUP). In FY 2004, FTA obligated $2.5 million to CUP to conduct technology improvements and pre-construction planning for a low-speed maglev system.

Mr. Kulyk called for the participants' insights into four specific maglev performance requirements:

1. Larger levitation (mechanical) gaps (greater than 10 mm).
2. High peak speeds (faster than 60 mph for both urban and metropolitan application).
3. Steeper gradient negotiation (more than 7 degrees).
4. Tighter curve negotiation (larger than a 62 ft. radius).

Other desirable attributes include powerful propulsion motors, improved linear induction motors (LIM) and linear synchronous motors (LSM), low cost guideways, and alternatives to an electromagnetic system to generate magnetic fields, such as permanent magnets (PM) and superconducting magnets.

Competitively selected maglev program participants were then introduced as follows:

- MagneMotion, Inc, Acton, MA
- General Atomics (GA), San Diego, CA
- Colorado Maglev Project (CDOT), Denver, CO
- Maglev Urban System Associates (MUSA), Baltimore, MD
- Maglev 2000, Titusville, FL

Mr. Kulyk continued with a presentation to summarize each project's accomplishments by complimenting the team efforts, which "pushed the state of the art." The highlights of these accomplishments are:

General Atomics (GA)

- Demonstrated levitation by electrodynamic principle using PM in a Halbach arrangement.
- Built a 120 m long active guideway with LSM.
- Built one vehicle chassis with levitation magnets and propulsion coils.
- Carried out a demonstration of propulsion and levitation.

Colorado Maglev Project (CDOT)

- Developed cost-effective guideway concepts for downtown and metropolitan environments.
- Advanced the LIM concept.

MagneMotion

- Demonstrated levitation using full-size PM on a 1/7th scale model (in weight).
- Demonstrated propulsion, guidance, and gap control using PM and LSM.
- Same magnets are used for guidance and levitation.

Maglev 2000

- Fabricated, in part, a superconducting magnet in the laboratory for a levitation demonstration.

Maglev Urban System Associates (MUSA)

- Evaluated viability of Japanese low speed maglev (Chuba High Speed Surface Transportation (CHSST)) system for use in the U.S.

Mr. Kulyk also added Sandia National Laboratories' achievement of concept development of an advanced induction motor, resulting in greater LIM efficiency.

To set the tone for the discussion, Mr. Kulyk described what would comprise desirable workshop outcomes. As the closeout of the project's first R&D phase nears, the FTA may select possible options for pursuit in the near future. Based on the result of the workshop discussions, near-term proposed activities will be identified. Complete testing at General Atomics is anticipated, and another workshop will be planned. Lessons learned on subsystems may contribute not only to maglev, but also to existing urban transit systems. With an emphasis on the "spirit of collegiality," he then turned the floor over to Dr. Richard Thornton, CEO of MagneMotion.

MagneMotion Maglev System

Richard Thornton, Ph.D., CEO
Todd Webber, President

Dr. Richard Thornton made a presentation summarizing the MagneMotion Maglev (M3) system and its operational aspects, also highlighting major accomplishments. MagneMotion chose Electromagnetic Suspension (EMS) using permanent magnets and coils for levitation and LSM propulsion with guideway-based control and power regeneration. The individual vehicles can be small and light, carrying up to 20 people. Box beam guideways were identified to be suitable for the vehicle weight and speed. Detailed specifications and descriptions of the levitation, propulsion, guidance, communication, control system, and performance were also presented with charts and simulations. MagneMotion President Todd Webber then made a video presentation of their 1/7th scale model demonstration in the laboratory.

The MagneMotion team, which includes EarthTech and TPI Composites, took a system approach to design a cost-effective maglev system for urban applications, and built key pieces of hardware to demonstrate the design. The design was based on system level tradeoff studies.

According to Dr. Thornton, test results indicated their maglev system has better performance than the existing maglev systems. He cited MagneMotion's achievements of having obtained larger magnetic gap (20 mm), a higher acceleration/deceleration rate (2 m/s^2), and small headways (less than 30 s). The system cost estimates and energy usage in comparison to other comparable modes of transportation were also presented. The MagneMotion team emphasized the maglev's advantages and suitability to an urban transit system. Dr. Thornton shared their lessons learned and future plans to implement the full-size model and demonstration. MagneMotion's future plans include building a 33 m indoor test track which would allow for further testing of the system with speed capabilities up to 10 m/s. The follow-on phase would consist of an outdoor track of approximately 200 m with a switch and two vehicles.

Discussion, Q & A Session

Mr. Kulyk facilitated the Q & A and discussion session. He reiterated the importance of exchanging information and experiences among teams and laid out six questions essential to the goals of this workshop. He also called upon each presenter to include the answers to these questions in their presentation, and potentially extend the issues to further discussion items. The following are Mr. Kulyk's questions and the responses from MagneMotion.

Q1. How do you compare the system cost to existing (traditional) systems?

A1. By Dr. Thornton
The system cost was compared to the existing Oakland Airport Connector, which cost approximately $100 million/mile. Reduction in MagneMotion's system cost was achieved mainly by using a light-weight vehicle and through their guideway design.

Q2. What is the key innovation?

A2. By Dr. Thornton and Mr. Webber
MagneMotion's achievements included the permanent magnet EMS system that increases the levitation gap and thus relaxes guideway tolerance; and improvement of LSM propulsion and its major attributes, such as the control system, cost, manufacturing, and design control of clustered small modular vehicles, which also contributed to higher capacity. One of the key innovations was applying a systems approach to the design, especially with the effective use of Computer-Aided Design (CAD) design tools. The key to LSM efficiency is the position sensing technology; improving the position sensing technology will not only benefit maglev, but other transit systems as well.

Q3. How close is the project to commercialization?

A3. By Dr. Thornton and Mr. Webber
MagneMotion is ready for commercialization, but there is some skepticism about the market readiness. Eliminating the technical risks is the key, but actualization requires funding, and the shortage of funding may impose some obstacles.

Q4. What is the next step?

A4. By Dr. Thornton and Mr. Webber
Short-term plans include construction of an indoor full-size test track and a short vehicle (12-passenger size) within a 12-month timeframe. The advantages of the U.S. maglev system and its potential for deploying leading technology around the world were emphasized.

Q5. What particular application can be utilized in the existing system?

A5. By Dr. Thornton
LSM technology will achieve better performance in steep terrain. Position sensing technology is essential in any transit system.

Q6. Are you willing to partner with others?

A6. By Dr. Thornton and Mr. Webber
MagneMotion has already formed teams with various companies providing technological and systems solutions. The FTA maglev team is composed of diverse groups with fundamentally different design bases, but MagneMotion can contribute to their concerted efforts. A small team containing members with targeted technology will be more effective than a big team approach.

Additional comments by MagneMotion included:

- Reduced headway for increased capacity may call for safety precautions at crowded stations.
- A wraparound design for a small guideway is the determining factor in cost efficiency.
- LSM is suitable for light rail applications.

- Smaller vehicle clearance areas for tunnels in comparison to existing rail systems were pointed out.
- Using different comparison bases for low-speed versus high-speed maglev was suggested.
- Clarification of the share of the vertical force created by PM was requested (which is 100 percent). The lateral versus vertical force ratio is 40 percent.

General Atomics (GA) Maglev System

Sam Gurol, Ph.D., Program Manager

Dr. Sam Gurol made a presentation on the GA Maglev System's project history, the composition of the GA Team, system specifications, and performance attributes. GA selected Electrodynamic Suspension (EDS) with PM in a Halbach array for levitation, LSM for propulsion, and a lightweight vehicle for cost considerations. A hybrid girder with laminated guideway is part of the system design. Laminated track is also potentially cheaper to manufacture, and adjustable to alignment requirements. He introduced their collaborative effort with CUP and an existing alignment chosen for the initial deployment. Test results of the full-scale 120 m test track built at grade were also presented.

Citing the 80-page document of systems requirements, Dr. Gurol highlighted some of the key system performance measures and safety features in the communication and control system. He noted the importance of accounting for the local terrain (grade) and severe weather in the system design due to the demonstration site-specific requirements. The system cost estimates included hypothetical engineering, construction, and commissioning costs.

GA's major achievements and innovations are as follows:

- Developed a passive PM levitation and propulsion system based on a Halbach array configuration.
- Built a 120 m test track.
- Built a full-scale, lightweight vehicle chassis with modular construction.
- Developed levitation system with fail-safe on power failure.
- Developed low lift-off speed EDS system.
- Implemented inductive housekeeping power pick-up.
- Utilized high strength fiber-reinforced advanced concrete.
- Utilized an Insulated Gate Bipolar Transistor (IGBT)-based variable frequency inverter.
- Eliminated the shielding equipment, so that magnetic field levels in the passenger compartment are below the 1 Gauss level (for comparison, the Earth's ambient magnetic field is about 0.5 Gauss).
- Achieved acceleration of 1.6 m/s^2 for exhibit.
- Achieved large air gap (25 mm) operation.
- Received R&D 100 award for one of the leading technology developments for 2004.

The vehicle control system was identified to be a weakness and required more research and development. He emphasized the team concept with a focus on deployment and laid out the future plan. GA plans to continue test runs, build a second chassis, deploy a block switch, build hybrid girders, and improve inductive housekeeping power pick-up.

Dr. Gurol added that LSM and the system control technology could be applicable to conventional wheeled mass transportation systems. The guideway design has an advantage of utilizing existing right-of-way. Inductive housekeeping power pick-up can be adapted to a conventional system and will be valuable in emergency scenarios and for safety purposes. He

concluded their system is not ready for commercialization, and the current emphasis is on building a test system for verification and improvement of the system.

Discussion, Q & A Session

Participants then began asking questions, and the discussion flowed into the details and issues of the system's performance. Following are the main discussion items captured during the Q & A and discussion session.

- No thermal effect (heat-up) was detected during the PM performance test in ambient temperature. The thermal sensor behaved "exactly the way it was predicted." (Gurol) The test did not go over ambient temperature.
- Rust can be fatal to the Niobium-Iron-Boron (NIB) PM and make it friable, and due to thermal cycling (external temperature, or eddy current heating) to 80 degrees Celsius, it may be demagnetized. However, GA's system uses encapsulated robust magnets, and thus is protected from environmental degradation.
- EDS may give rise to dynamic instability. There was an opinion on LSM's superior performance, but it was at too early a stage to reach a conclusion. Damping and suspension is the area that needs more research and testing.
- The ratio of car body weight to the chassis is 80 percent.
- A question was raised on the 20 second switching time being realistic or not for a short distance between stations. The GA model uses switching only to move to a yard or maintenance facility.
- In cases of magnet replacement, non-magnetic tools must be used. The maglev project also created an opportunity for tooling innovation. GA's modular vehicle design allows taking a chassis off-line for easier fault inspection and maintenance.
- A hybrid track with adjustability built in allows fine-tuning should undesired oscillations occur during vehicle movements.
- LSM can achieve higher steep negotiation than one of the performance goals of 7 percent, but the question was raised on the effect of 7 percent or higher grade on the ride comfort.
- In response to a question on the critical lessons learned, GA "would have or should have" focused on control systems earlier because the improvement of the control system took longer than expected.

California University of Pennsylvania (CUP) Maglev Demonstration System

Allan Golden, Ph.D., Vice President for Administration and Finance
California University of Pennsylvania

Dr. Allen Golden provided a presentation on the CUP proposed maglev project, which would serve a needed transportation function both on campus and for local events. Dr. Golden started with the history and background of the maglev project, including funding information. He showed the alignment and the candidate sites with some artist renderings of the maglev system at its completion.

Dr. Golden explained that the site-specific system performance requirements, such as all-weather operation, grade negotiation (7 percent), quiet operation, tight turning capabilities, and low operation and maintenance cost, turned out to be good demonstration items for maglev capability and suitability. He emphasized the significance of the maglev project, the goal of which is to (1) serve a needed transportation function for the campus and the Borough of California; (2) provide an area of R&D in academia, a learning environment, and lead to new curricula in technology, business, marketing, and economic studies; and (3) create an opportunity for economic development in the western Pennsylvania region. He concluded by stating that the project maintained viability through the partnership with Pennsylvania Department of Transportation (PennDOT) and emphasized the importance of timely funding.

Discussion, Q & A Session

Dr. Golden then invited the participants to take part in a Q & A and discussion session. Some clarifications were requested on the technical and system specifications, but the focus of the discussion was mainly on operational and maintenance aspects. Safety certification was identified to be one of the key issues of deployment. The rest of the questions were on project financing, environmental impact, and power supply venues. Some of the major points raised were as follows:

- The CUP maglev system comprises 3-vehicles (each 13 m long) with a capacity of 100 passengers, on a dual track system.
- $40 million state budget funding is to be designated for the California University of Pennsylvania Shuttle System (CUPSS) cost share. Large funding gaps were pointed out (estimated total project cost of $180M), and PennDOT expressed concerns on the funding shortage, especially for the final Phase 3.
- Contacts have been made with local power companies for power supply at stations.
- The maglev system design takes the local climate, including the strong wind load, into consideration. The design specification of lateral stability is 100 mph.
- No significant environmental impacts were identified, and a Finding of No Significant Impact (FONSI) was filed at the planning stage.
- Certification of safety is required and mandated by FTA before system deployment.
- The project seeks partnership because of limited federal funding.
- The maglev project at CUP is under public domain.

Afternoon Session: Thursday, September 8

Colorado Maglev Project

Gopal Samavedam, Ph.D., Group Director, Foster-Miller, Inc.

Dr. Gopal Samavedam opened the afternoon session by presenting the Colorado Maglev Project summary on behalf of the Colorado Department of Transportation (CDOT) team. The project identified an existing 140-mile alignment along with Interstate 70 to connect Denver International Airport (DIA) and Eagle County Airport. CDOT has also been examining other modes of transport such as bus, road widening, and light rail options. The maglev system is also expected to provide roadway congestion mitigation and better performance in harsh winter weather.

Dr. Samavedam stressed that the Colorado maglev team's focus was on deployability, and that cost determined system viability. Technological and systems innovations and solutions were achieved though collaboration among and contributions from the team members, which include CDOT, Sandia National Laboratory, CHSST, Maglev Transit Group (MTG), and other small companies.

The CDOT team selected Japan's CHSST as baseline and examined its applicability to the Colorado project. The High Speed Surface Transportation (HSST)-200 vehicle had been designed for 200 kph (120 mph) operation on shallow grade, and so is more suitable for the higher speed, inter-urban route of the CDOT maglev. The system has a LIM for propulsion. The vehicle configuration is train-type, modeled after HSST 200. A 6 mm mechanical gap and an 8 mm magnetic gap were obtained by using ferromagnetic materials for levitation and electromagnets for guidance.

He addressed the cost issues directly, indicating that guideways typically account for 60 percent of the system cost, and introduced two variations of the "cost-effective" guideway configurations: Precast Concrete U-Girder and Tubular Steel Space Truss. The visual impacts were also considered in addition to the cost. The cost-effective guideway concepts and advanced liner induction motor concepts are the major accomplishments to date. The CDOT system is not yet ready for deployment, but the alignment has already been identified.

Dr. Samavedam also presented research results on calculated performance of 208 kW COL-200 LIM with improvement options, and unit (USD per mile) cost comparisons of the LIM-driven maglev to the existing Transrapid Systems around the world. There were some questions on the basis of the unit cost comparison, and Dr. Samavedam will follow-up on the issues with more clarifications from Sandia National Laboratory, who conducted the cost analyses.

Discussion, Q & A Session

An enthusiastic exchange of information and ideas ensued on the comparison matrix of LIM and LSM systems. The key issue addressed during the discussion was "how do we determine the

best system (core technology)?" Maglev systems overseas presented a view of "total system comparison" rather than looking at a subsystem. There was a suggestion on differentiating the Colorado maglev application from a low speed urban transit application. The following are some of the main discussion points:

- There was discussion on how to compare the energy efficiency of an LSM versus LIM for urban maglev applications. The energy efficiency in LSM is up to 90 percent, and for LIM the maximum energy efficiency is 70 percent. There are major differences between the two propulsion systems.
- The issue of cost effectiveness for the LSM option has not been solved.
- Selection of the "Best available technology" (BAT) is driven by the customer (customers are interested in operational and maintenance (i.e., cost) aspects of the system).
- Sandia's system comparison table on slide 21 raised validity questions.
- A total system comparison including construction, operation, and maintenance, is a more realistic approach. For example, energy efficiency (consumption rate) in Tobu Kyuryo Line (TKL) is 20 to 30 percent worse than the conventional rail system. The energy consumption cost accounts for 5 percent of the total operation cost, but its [LIM] advantage in comparison to the conventional systems is in maintenance cost. There is no need to touch the rail at all.
- LIM could be more expensive when it is applied to a high-speed system (over 100 mph).
- Clarification on guidance system cost was requested.
- CDOT's system is a "suburban" application with higher speed.
- Cost reduction in guideway construction was discussed – using innovative materials, applying innovative design, no earthquake proofing, cost for civil work component, etc.
- Vehicle clearance area for tunnel was discussed, which is better than the conventional rail system.
- Clarification of the improvement cost on the CHSST-200 was requested.
- A view was presented that cost efficiency comes with length of application (i.e., the alignment's distance, and over time).
- Unit cost comparison of $50 million/mile for the CDOT guideways shows the CDOT system's competitiveness. Cost for the land is not included.
- One of the long-term options to improve the CHSST LIM is to achieve a higher thrust, for higher speeds.

Dr. Samavedam also mentioned that a list of reports on the Colorado Maglev Project are posted on the FTA Web site.

Maglev 2000

James Powell, Ph.D., Co-Founder of Maglev 2000

Dr. James Powell made a presentation on the Maglev 2000 project. The Maglev 2000 team selected EDS, and LSM for propulsion and braking. Their concept uses levitation from quadruple superconducting magnets (SCM) inducing currents in aluminum guideway loops. Wireless and fiber optic systems are used for safety surveillance. The system is expected to produce vertical and horizontal vehicle stability with 4-inch gap levitation; Dr. Powell pointed out that the large gap would be suitable for mitigating settlement problems on guideways.

The Maglev 2000 vehicle travels on elevated narrow beam and planar guideways. A planar guideway is a flat surface guideway. Dr. Powell explained that their system design would serve as a transportation method for both people and freight. Maglev 2000 would contribute to intercity congestion mitigation.

Major accomplishments and key innovations by Maglev 2000 include:

- Fabrication of four full-scale quadruple SCM magnets and cryostats that enable traveling on narrow beam and planar guideways and very low magnetic fringe fields.
- Fabrication of a full-size reinforced concrete box beam used for guideways, at acceptable cost.
- Fabrication of full-size prototype aluminum guideway loops encapsulated in polymer concrete, at acceptable cost.
- Fabrication of a full-size vehicle aluminum undercarriage and wooden “fuselage.”
- Used conventional low-temperature NbTi SCM cooled to 4 degrees Kelvin with liquid helium, using cryostats.
- Designed the guideway for mass production and prefabrication, which will save construction time and cost.
- Design of an electronic high-speed switch to off-line stations at high speeds.
- Transport capability (carrying capacity of 3000 ton or 150,000 people).
- Using existing railroad tracks for Maglev 2000’s Maglev Emplacement on Railroad Infrastructure (MERRI) Maglev service.

The Maglev 2000 team used an aggregate component cost approach to estimate the total cost of major subsystems. A detailed cost estimate (3-digit level) was developed for the system components at each fabrication step. The major subsystem cost was derived from the aggregated component costs. The cost estimate was based on the premise of construction on a flat surface. Dr. Powell noted that more improvements to the cooling system were required. The Maglev 2000 team plans to fabricate magnets using high temperature superconductors and demonstrate levitation of the full vehicle at zero speed. He stressed the importance of funding for the continuation of the project.

Dr. Powell noted that the conditions under which maglev operates will be different in the future by pointing out the projected increase in travel demand, demand for a faster mode of intercity transportation, shortage of petroleum-based fuels, increases in the price of petroleum-based fuels,

and the necessity of using cleaner energy sources. He concluded his presentation by emphasizing the advantages in a maglev system that would provide some solutions to the constraints of the future.

Discussion, Q & A Session

At the conclusion of Dr. Powell's presentation, workshop participants asked questions about the cost matrix, system characteristics—particularly on cooling systems—and performance issues such as pitch and the dumping control. The discussion flowed into the market aspects of Maglev 2000 system deployment. Mr. Kulyk suggested a follow-up on the maintenance cost comparison by looking at the existing Shanghai and CHSST systems, although Shanghai might be a fundamentally different system.

The following are additional comments by Maglev 2000.

- 300 m radius negotiation is achieved by fixed magnet pods.
- The EDS system's weakness is in its lack of damping control, but an improvement is underway.
- The Japanese system has experienced vibration at 5 Hertz, but no significant problem was observed.
- The ideal solution is the future superconducting maglev system using high temperature superconductor (HTS) materials.
- The adoption of HTS materials is promising, but the development will take time.
- The Maglev 2000 SCM has an aluminum shield to protect it from quenching.
- An 8-shaped coil system with aluminum is cheaper than an 8-shaped coil system with copper wiring.
- Market, industry, and business enhancements hold the key to maglev application.

Maglev Urban System Associates (MUSA) Project

Pierre Brunet, EarthTech

Pierre Brunet of EarthTech made the last presentation on the MUSA maglev project. The MUSA team members include EarthTech, CHSST, and Kimberly-Horn. MUSA investigated the adaptability of the Japanese low speed maglev technology (CHSST) system that has been tested and commercially operated. The vehicle chosen was CHSST 100, with EMS for levitation and guidance and LIM for propulsion. The MUSA team determined that the maglev system was suitable for urban transit application. Drawing upon comparisons of technical specifications and performance criteria, the team made recommendations to modify the CHSST system to meet applicable U.S. standards.

Mr. Brunet gave a brief overview of the history of the CHSST project, system specifications, and principal mechanisms of the major subsystem. Performance data to date, indicative of the system's low maintenance requirements, were also presented. Mr. Brunet provided the group with a more detailed explanation of the guideway structure and its civil works element. Appropriate switching and headway intervals were discussed during the presentation.

Mr. Brunet then went on to introduce a CHSST-maglev deployment plan for Bethesda Transit. A maglev system based on the modification and upgrading of the CHSST 100 has been proposed to link the Montgomery Mall to the Washington Metropolitan Area Transit Authority's (WMATA) Grosvenor Street metrorail station. The plan also contains two intermediate stations for local employment centers. Based on the alignment and the local demographic and employment characteristics, capacity estimates and operational specifications were introduced. Analyses of the total cost and the unit cost (per mile) were also presented.

Mr. Brunet identified the implementation of needed changes as future tasks to meet U.S. requirements, provide a revenue-generating environment, verify and refine capital and operation cost estimates, and further analyze the Tobu Kuryo Line (TKL) operation.

Discussion, Q & A Session

The following are Mr. Brunet's answers to workshop attendees' questions:

- Montgomery County, MD, is interested at a funding level of approximately $50 million/mile. This is less costly than the conventional metrorail system ($80 million/mile above ground).
- The cost comparison for the proposed maglev system was made to an existing light rail system in Baltimore, and management and administrative costs were factored in.
- Safety certification requirements are expected to be higher than light rail.
- A list of certification items needs to be developed.
- MUSA looks for an urban application of the CHSST maglev (versus CDOT's proposed suburban application).

- Heating, cooling, and ventilation must comply with Occupational Safety and Health Administration (OSHA) standards.

First Day Wrap-up

Walter Kulyk, FTA Director for Office of Mobility Innovation

Mr. Kulyk closed the first-day proceedings by thanking the workshop participants for their presentations, comments, ideas, and contributions. The questions and comments from the participants highlighted some key issues for U.S. maglev transit applications, and Mr. Kulyk suggested further examination of these issues with presentations of maglev experiences in foreign countries slated for the next day.

Morning Session: Friday, September 9

Day in Review

Walter Kulyk, FTA Director for Office of Mobility Innovation

Mr. Kulyk opened the session with a recap of the workshop objectives: (1) How do we get to the next step? (2) What is the federal role in promoting maglev efforts? and (3) What is the next step with respect to a specific timeframe? He set the stage for the morning session by reviewing the purpose of the session, which was to look at examples in other countries in an effort to further refine the strategy for a U.S. maglev application and deployment. He then introduced the guest speakers: Mr. Michio Takahashi from CHSST, Japan, and Dr. Peter Gaede and Dr. Ryong-kyu Lim from Rotem, Korea.

The First Commercial Application of HSST

Michio Takahashi, Director for Chubu HSST Development Corporation
HSST Systems International Inc., Japan

Mr. Takahashi gave a presentation on the first commercial application of Japan's low speed maglev (namely the Tobu Kyuryo Line, TKL Linear Motor Car, or LINIMO) using slides and video. The TKL LINIMO Maglev has been operating successfully since March 2005, as a people mover for the World's Fair, *Aichi Expo 2005*, in the Aichi Prefecture near the city of Nagoya. Several alternatives were considered in connecting the Expo site to the existing rail network, but maglev was chosen from among the alternatives because it had met the practical needs of mass transit, had the ability to negotiate the hilly terrain (6 percent) of the alignment, and provided R&D opportunities with local industrial conglomerates (Toyota, etc.). It was also suitable for the environmental theme of the Expo and the high-density residential areas along the alignment.

The LINIMO system utilizes EMS electromagnets for both levitation and guidance on elevated guideways. The short-stator LIM on the vehicle is used for propulsion and braking. The system requires 1500 Volts-Direct Current (VDC), similar to the conventional wheeled electric transit system. It covers 5.6 mi (approximately 9 km) with 9 stations in 15 minutes, and carries 30,000 people per day on average.

The major issue identified so far was overcrowding of the trains and stations by Expo visitors. The vehicle operation is fully automated, but due to safety precautions at the Expo in times of extremely high ridership, an attendant is stationed on board. Six months of operational data supports the low maintenance requirement, on-time performance, and safety record of the LINIMO maglev system. After the Expo, it will remain as a permanent mass transit line at the location.

Discussion, Q & A Session

Workshop participants requested more detailed information on the switching configurations, headway intervals, door opening time, delay and maintenance, funding, cost, and operational budget. The following were summary responses to the questions and comments during the session.

- The LINIMO can negotiate a 7 percent grade and 100 m radius.
- The operational hours are 5:00 a.m. to midnight.
- Two-way and scissor cross-switches are used. A three-way switch is used only at tunnels and to depots.
- The switch configuration enables the existing depots to be utilized by the maglev system.
- Manned control centers will be automated after the Expo (only two will remain open).
- Train configuration is a fixed three-car design. Nine vehicles are in operation and two are kept as backups.

- Vehicles are designed for automated operation, but Japanese railway regulation requires attendants on board for alignments that have tunnel sections.
- Screen doors are installed for safeguarding passengers.
- Of $900 million capital cost, $600 million was spent on the civil work, and the remaining $300 million was used for the systems.
- Construction fees were higher due to nighttime-only construction and earthquake resistant design requirements. Generally, the labor part of the construction cost is high in Japan and it is the major cost factor.
- Terminal to terminal (9 stops) fare is $3.20.
- Budget for operation is $25 million per year. $5 million is allocated for maintenance.
- The system is running successfully with 5-minute headways, and the total delay for the past 6 months is 4.4 hours. Only 15 cases exceeded a 3-minute delay. The main cause of trouble is electromagnetic interference from the vehicle on the signal system.
- The onboard train management system (TMMI) alerts the control system, which makes the decision to allow or withdraw the train for inspection or maintenance.
- It was difficult to expect and predict electrical noise that affects the Variable Voltage-Variable Frequency (VVVF) signal noise. The electromagnetic interference problem is also common in conventional train systems. The major EMS noise source has been identified, and CHSST continues testing to mitigate the interference.
- Currently, 150 personnel are working for the Expo LINIMO maglev operation. Once the Expo concludes, the staffing level will be reduced to one third.
- A 15-minute trip includes going through 9 stations with a 20-second door opening time at the stations, and a 30-second door opening time at the Expo terminal.
- Due to overcrowding, rider complaints have focused on ride comfort.
- 1500 VDC is required for the power supply, which is comparable to the existing systems.
- Speed indicators are on board.
- The LINIMO reached 94 kph maximum speed during a 15-minute trip.
- Currently, attendants are on board and also at terminals for safety and security purposes, but surveillance cameras, videos, and other systems are suggested for crime prevention.

Korean Maglev

Peter Jürgen Gaede, Ph.D., Senior Maglev System Engineer
Rotem, Korea

Dr. Jürgen Gaede presented a summary of the Korean maglev experiences. The prototype of the Korean maglev (HML-03) was in service for 93 days at the Daejeon Expo in 1993, located in the city of Daejeon, about 160 mi south of Seoul. The system is levitated and guided by electro-magnets on U-shaped, track-sided rails. Propulsion is made by asynchronous linear motors, and power is controlled by VVVF Inverters. The maglev system is based on the German system and is similar to the HSST system.

After the Daejeon Expo, the model was donated to the government. Rotem, a unit of Hyundai Motor, in conjunction with the state-run Korea Institute of Machinery and Materials (KIMM) and supported by the Ministry of Science & Technology of Korean Government (MOST), has developed and remodeled the original with a view toward commercialization in 2007. The team has conducted a successful test run on a 1.3 km guideway in Daejeon. The test track has 6 percent maximum gradient and a minimum of 60 m curve radius. In 2007, the maglev system will be set up inside the Expo Park for public use, connecting the adjacent science museum. The maglev system will have a top speed of 110 kph, and each vehicle will carry a maximum of 135 passengers.

The government plans to support more than $450 million in funding for the national maglev project, and there is a plan to set up the system between the passenger and cargo terminals of Incheon International Airport. Local authorities of the city of Daejeon, Incheon, and Gwangju have endeavored to introduce the maglev system in their regions.

Dr. Gaede noted that the technological development phase was over. He identified four key issues in commercialization: availability, cost, maintenance, and environmental factors such as noise and emissions. He emphasized the fact that commercialization of the system was largely driven by contract specifications imposed by the clients. Dr. Gaede mentioned the increased interest in Rotem's maglev technology from not only local markets, but also many Southeast Asian countries, such as Malaysia and Indonesia. He cited the Jakarta case and pointed out the necessity of designing a system suitable to the local situation and requirements.

Discussion, Q & A Session

Some questions were asked on the detailed system configuration. Some proprietary cost information was not shared. The following is a summary of the discussion and Q & A session.

- Two m wide gauge is the same as the regular track configuration, and it is also based on the road configuration.
- Some methods of damping noise, such as using sand, may not be viable due to the safety hazard (corrosion inside).
- The Jakarta system would require 96 cars to meet the high demand in ridership.

- As the total system provider, cost becomes Rotem's competitive advantage.
- "Profit" is the key target in the Korean maglev model.
- Korean civil work cost is relatively lower, which also contributes to the competitive total cost.
- An acceleration rate of 2 m/s^2 is easy to obtain in the maglev system, but there was a debate on the maximum acceleration rate with respect to ride comfort versus performance.
- 10 percent grade negotiation is possible, but 7 percent is optimal for ride comfort.
- Maglev has an advantage in Jakarta due to its ability to negotiate the steep grade. The system's weather (rainfalls) resistance capability is also an advantage among alternatives.

Old Dominion University (ODU) Maglev Effort, Progress, and Goals

Thomas Alberts, Ph.D., Professor, Department of Aerospace Engineering
Old Dominion University, Norfolk, Virginia

Dr. Thomas Alberts gave the final presentation for the maglev projects. Dr. Alberts briefly summarized the history of the ODU maglev people mover project, and provided the participants with performance and simulation test results. American Maglev Technology, Inc. (AMT) of Tampa, FL, donated the maglev system and ODU has acted as the host for the project. It was intended to provide a functional transportation system on campus and serve as a research opportunity.

The system is similar to the Orlando Airport People Mover, and is composed of a single vehicle (45 ft long) with a carrying capacity of 100 passengers. Maximum speed is 40 mph on a 3400 ft. track, and the elevated guideway spans 90 ft. The small gap EMS system is levitated by conventional electromagnets. Stabilization uses a centralized approach at a bogie level. The test results indicated that key improvements are required in levitation control stability, guideway rigidity, and ride quality suspension. A test bogie was built and tested.

Future plans include a full-scale test of the car. Dr. Alberts explained a potential vulnerability in continuing the project because of the funding situation. He called for a partnership by emphasizing that ODU offers an excellent test bed for maglev projects with the existing maglev facilities, laboratory, and research capabilities.

Discussion, Q & A Session

Questions were mainly asked about the test results. The following is a summary of the discussion and answers provided by ODU.

- AMT and Lockheed Martin are no longer associated with the project. They built the system and turned it over to ODU.
- A flexible guideway concept is one of the ODU's accomplishments.
- The magnitude of guideway and vehicle resonant oscillation depends on the gap.
- Test rig model verification showed the correlation of vehicle amplitude and location with frequency (Hz).
- Flux sensing will be suitable for improving the gap-dependent control system.
- Moving vehicle simulations are needed.
- The system needs an active control, and a whole system approach will be necessary.

Summary, Lessons Learned, and Benefits to Transit

Gopal Samavedam, Ph.D., Group Director, Foster-Miller, Inc.

Dr. Gopal Samavedam summarized the presentations and then moved on to a brief discussion on the key issues. The participants expressed consensus on maglev's comparative and competitive advantages, but further research and testing were suggested in determining what the best technologies and optimal performance goals should be.

He briefly summarized each team's accomplishments, the lessons learned, and the issues identified during the workshop. Key performance standards were also revisited. Benefits of maglev development to the transit industry include reduced travel time, steep gradient negotiation capability, and significantly improved ride comfort. Reduced noise and maintenance, use of cleaner energy (compared to diesel), and energy efficiency that will be reflected in the total cost were identified as advantages in the maglev systems.

Due to time constraints, Dr. Samavedam moved on to the final discussion and Q&A session.

Discussion, Q & A Session

Discussion led by Walter Kulyk, FTA Director for Office of Mobility Innovation

Mr. Kulyk led a group discussion, after reviewing the program goals and providing current funding information. Feedback concerning the workshop outcome was requested. He encouraged a "U.S. Maglev Team" approach to further enhance American maglev system deployment. He asked each team to provide a brief statement of their plans and visions for the next step. The following is a summary of the remarks from each team.

MagneMotion

Dr. Thornton, in response to Mr. Kulyk's question, stated that maglev is the key answer to transit and the transportation industry of tomorrow. The U.S. should pursue a next generation, "Generation 3" maglev system. The maglev system that MagneMotion has developed meets all the specifications, such as having a levitation gap larger than 10 mm. Safety specifications need to be provided by the government, and the MagneMotion team will meet the requirements. Dr. Thornton emphasized the importance of funding the project that will enable the next-generation U.S. maglev system.

Mr. Webber added that a partnership should be sought "where [the] market is asking [for it]." Deployment of a maglev system involves a commerce and commercialization potential far beyond the U.S. market. Large corporations may hold the key to commercialization.

General Atomics

Dr. Gurol first expressed his gratitude to Mr. Kulyk and other participants for the workshop opportunities and contributions. He believes that maglev is a form of transportation that will benefit society and make a difference due to its quiet operation, speed to cover distance, and ability to negotiate steep terrain. The GA and CUP team will realize a full-scale demonstration, and Dr. Gurol emphasized that the scarce resources should follow the demonstrations.

California University of Pennsylvania

Dr. Golden highlighted the importance of the economic development resulting from a successfully implemented maglev system as well as the maglev project's ability to meet a transportation need at CUP.

Colorado Maglev Project

Dr. Samavedam also emphasized the maglev system as being a useful and suitable transit system for connecting the Denver Airport to downtown. A small maglev segment between DIA and downtown will provide a useful demonstration site to build confidence in maglev transportation.

Maglev 2000

Dr. Powell cited as an example of funding, the hydrogen fuel and infrastructure initiative, that have been made available due to the government, industry, and public perception of hydrogen fuel being a desirable future solution. Unfortunately, a similar case was not established for maglev system development, partly because it is not perceived as the long-term solution for urban transit. Dr. Powell compared the funding levels of air transportation R&D to those for maglev R&D, and stated that the maglev deserves a much better image as a potential major player in the whole transportation scenario in the U.S.

Maglev Urban System Associates

Mr. Brunet envisioned that a value-added project could be done in the U.S. that would generate jobs and other positive economic effects, and on behalf of the MUSA team, he would continue making improvements to the international application. Mr. Brunet indicated that EarthTech could take up studies for non-proprietary portions that would benefit the entire maglev team. He identified the research gaps, technical and non-technical, that need to be studied including guideway costs, the optimal design for switches, and some common elements for all the maglev systems, such as having a common guideway design. Dr. Aviva Brecher added that comparisons of Automated People Mover (APM) and communications-based train control standards and guidelines for Electromagnetic Interference and Compatibility, and for human exposure safety to electromagnetic fields and radiation, also needed to be looked at.

High Speed Surface Transportation

Mr. Takahashi first expressed his appreciation for being invited to the workshop, and stated, "we [who had been engaged in maglev projects around the world] all ride in the same boat, and we can learn from each other's experiences." He still was not sure whether the definition of "Urban Maglev" could include systems whose speed is greater than 100 kph. HSST maglev is an urban application and cannot be directly applied to a high-speed system.

In general, the government has strict rules in advancing new technologies to commercial application, and the government needs to be involved in the verification process of maglev technologies. He cited the High Speed HSST Maglev project and noted that verification of the HSST 100 model was made, but the government made strict rules for revising and transferring technologies to a new system.

Mr. Takahashi concluded his remarks by suggesting a review of existing standards such as ATM requirements and specifying "Standards of Maglev" in general would be a key step. A jointly developed evaluation team will be beneficial to the national maglev project as well.

Dr. Gordon T. Danby, a co-founder of Maglev 2000, added a comment to Mr. Takahashi's remark that patent aspects of potential "American HSST" and a potential of partnering should also be considered. Business costs and other cost information from the HSST experience would be beneficial.

Rotem

Dr. Ryoung-Kyu Lim of Rotem responded to Mr. Kulyk's last comment, and noted that Rotem is a total system provider and it sees its future in both conventional rail and maglev systems. Dr. Lim, on behalf of Rotem, expressed his willingness to share knowledge and experiences.

Old Dominion University

Dr. Alberts presented ODU's view that they are at the point where a decision must be made of what to do with the existing facilities for the maglev research. The university would like to utilize the facility for the return of the $7 million investment from the state's fund. The advancement of the maglev project will be beneficial to future transportation needs on campus as well as providing educational opportunities. He suggested ODU would be a great resource for maglev projects by welcoming collaboration, proposals, and any other ideas from the teams.

At this time, Mr. Venkat Pindiprolu, Office of Mobility Innovation, FTA, also presented his account of the maglev R&D phase; that it had brought about communal understanding of the problems and that each team had responded with different solutions. He emphasized that what is now needed is concentration on what the maglev system could satisfy in terms of public transportation needs, such as bus, light rail, APM, or creating a new niche. Mr. Pindiprolu mentioned an example of the Pennsylvania maglev development case that promoted a regional rail system and noted that a niche needs to be found that is ready to be used by customers. He

believes that one of the strategies to promote maglev systems in the U.S. is to have one successful maglev application, and then "[other applications of the technology and the commercialization] will follow."

Next Steps in Urban Maglev Program

Walter Kulyk, FTA Director for Office of Mobility Innovation

Mr. Kulyk led the final session with the FTA maglev team. He summarized the issues highlighted and captured during the 2-day workshop. He recast these issues as questions for the participants and requested written answers. The next workshop will be planned based upon the feedback from the participants. The questions Mr. Kulyk posed were as follows:

1. Cost comparison: A need for developing a standardized cost comparison matrix was identified during the workshop. FTA has cost reference materials on a benchmark section on a hypothetical route, but there were some concerns that each maglev application with different specifications would be hard to put on the same horizon. Cost of a light rail system, for example, might be better suited for comparison. Some of the cost matrices considered are: What should be the individual components that make up the overall cost comparison? Is there one metric, such as cost passenger (seat) per mile, operating cost/passenger, or other? Can all grantees provide these estimates?

2. Key innovations: What makes something a key innovation? What patents have been registered? What key innovations should the FTA Maglev Program claim?

3. Close to commercialization: How close are maglev systems to commercialization? What is the best way to present maglev systems to potential users? What are their areas of interest? What is the best way to publicize maglev?

4. Next steps: What obstacles to further development/deployment do you see, and how can FTA affect them?

5. Application to rail transit: What aspects of maglev are applicable to general rail transit?

6. Willing to partner: Have you seen anything in the past two days that could be utilized to make your approach better?

7. LIM vs. LSM: How do you create and articulate a fair and comprehensive comparison of these concepts? The question on how to compare the proven maglev technologies versus the leading edge was also asked.

8. Should FTA sponsor/commission collaborative studies with a follow-up workshop for vetting? Possible issues: LIM vs. LSM; power transfer; damping mechanisms; and cost comparisons. Switch design configuration will also be a topic.

9. U.S. national labs have research funding for maglev. What could they be asked to do that would benefit the FTA Maglev Program? Invitations to corporate interests were also suggested.

10. Shanghai Maglev has identified needed improvements to the Transrapid system. Would their (and other) lessons learned be helpful to the FTA program?

11. Should FTA Urban Maglev focus on a short shuttle people mover; for example, in an airport as an airport to parking connector?

12. What are practical constraints on very short headways?

13. Is there value or usefulness to partial implementations? (e.g., LIM/LSM rail transit; levitated cable-drawn people mover.)

14. What are annual operating costs of CHSST and Rotem Test and Development centers?

15. How could FTA promote technology neutral RFPs for transit systems/lines?

16. Can we identify an objective technology readiness methodology to assess maturity/deployability of urban maglev concepts?

17. Are comparisons with existing, conventional transit systems justified for an innovative technology like maglev?

18. Are federal subsidies justified to introduce maglev to the U.S., as done for space technology projects?

19. Should the next steps be the usual FTA Planning and Environment requirements for "new start" transit approval?

20. U.S. DOT has a memorandum of understanding (MOU) with Japan MOT. What technology and knowledge exchanges should FTA negotiate to assist you?

21. Are you willing to provide written answers to these questions?

Closing Remarks

Walter Kulyk, FTA Director for Office of Mobility Innovation

Mr. Kulyk, on behalf of the FTA, expressed his great appreciation for the contributions of all the presenters and participants who attended the 2-day workshop. After calling for final comments, he adjourned the meeting.

Appendix A. Glossary

AMT - American Maglev Technology, Inc., which developed and installed the maglev system on the ODU campus.

APM - Automated People Mover.

CBTC - Communications-based Train Control.

CDOT - Colorado Department of Transportation.

CHSST - Chubu High Speed Surface Transport (CHHST) Development Corporation developed and commercialized the HSST maglev, now in service as LINIMO (Linear Motor Car) on the Tobu Kyuryo Line (TKL) in Nagoya. Itochu Corporation now owns the HSST International, Inc (HII), which is the exclusive technology licensee for marketing the HSST maglev system worldwide.

Cryostats - An apparatus or vessel designed to maintain a superconducting magnet (SCM) at the low temperature (below 4 degrees Kelvin in the case of the Japanese MLX prototype and the Maglev 2000 proposed maglev). The cryostat may include active cryo-coolers (like a Sterling cryo-pump), or passive thermal insulation layers to ensure the liquid helium does not evaporate.

CUP - California University of Pennsylvania.

CUPSS - The California University of Pennsylvania Shuttle System.

Damping - The mechanism provided for attenuating excessive oscillations, or other instabilities (mechanical deformation, vibrations, noise) in a transportation system. In a maglev system, electrical, mechanical or other type of damping is usually necessary in the primary and secondary suspension, to ensure good ride quality and prevent resonant coupling between vehicle and guideway and the amplification of undesirable oscillations.

EDS - Electrodynamic Suspension, refers to the type of maglev technology requiring repulsive magnetic forces between vehicle and guideway, generally characterized by larger gaps and intrinsic stability. An example of a maglev using EDS technology is the Japanese maglev at Yamanashi using superconducting magnets, see explanation at:
http://www.rtri.or.jp/rd/maglev/html/english/maglev_frame_E.html

EMS - Electromagnetic Suspension, refers to the type of maglev technology using magnetic attractive forces between the vehicle and guideway, generally characterized by smaller gaps and intrinsic instability requiring active gap control. An example is the HSST Japanese maglev.

Energy Efficiency - The amount of energy required in the production of a unit service; for example, the amount of steel that can be produced with a certain amount of energy units, e.g.,

one billion British Thermal Units (Btu) or other metric equivalent unit (Joules). Energy efficiency is improved when a given level of service is provided with reduced amounts of energy inputs, or services or products are increased for a given amount of energy input.

Energy Intensity (EI) - EI is measured by the quantity of energy required to perform a particular activity (service), expressed as energy per unit of output or activity measure of service. The transportation sector uses units of passenger-miles, or energy per passenger-km, and/or freight ton-miles.

Flux (sensing) - The magnetic flux is a measure of magnetic field strength, which must be measured by sensors across the maglev levitation gap, to ensure proper gap control. A **maxwell (Mx)** is the CGS unit of magnetic flux, equal to 10^{-8} weber. In a magnetic field of strength one gauss, one maxwell is the total flux across a surface of one square centimeter perpendicular to the field. The Maxwell unit honors the British physicist James Clerk Maxwell (1831-1879), who presented the unified theory of electromagnetism in 1864.

FTA - Federal Transit Administration.

Gap - Is the vertical levitation, and lateral (horizontal) guidance separation between the maglev vehicle and the guideway, which must be maintained within specified limits, in order to ensure contactless propulsion and operation of a maglev system. Gap maintenance requires sensors for active or passive suspension control. The gap is 4-7 mm in the EMS Transrapid maglev, but up to 10 cm in the EDS Japanese superconducting maglev.

GA - General Atomics, Inc.

Gauss (G) - An unit of magnetic flux density, named for the German mathematician and astronomer Karl Friedrich Gauss (1777-1855). A field of one gauss exerts a force of 0.1 dyne per ampere of current per centimeter of conductor. One gauss represents a magnetic flux of one maxwell per square centimeter of cross-section perpendicular to the field. In SI units, one gauss equals 10^{-4} tesla. It is also the unit of magnetic dipole moment per unit volume, more commonly written emu/cm^3 or emu/cc. In this use the gauss equals 1000 amperes per meter in SI units.

Guideway - The name given to the elevated track, along which a magnetically levitated system operates, analogous to the tracks along which conventional steel wheel on rail transit and railroad systems operate.

Halbach array - A permanent magnet configuration that concentrates magnetic flux on one side of the array and cancels it on the other. Named for the late Klaus Halbach of Lawrence Berkeley National Laboratory (LBNL), who originally designed it for focusing the beams of particle accelerators. Lawrence Livermore National Laboratory (LLNL) scientists (Post and Ryutov) used permanent magnets in Halbach array configuration in their proposed 'Inductrack' Maglev. The advantages include minimized drag from eddy current effects (drag decreases as speed increases), reduced power consumption (no giant electromagnets needed), and reduced exposure of train passengers to high magnetic fields.

Hybrid guideway - A maglev guideway employing structural members with both concrete and steel elements to optimize weight and cost.

IGBT -based variable frequency inverter- Insulated Gate Bipolar Transistor (IGBT) is a common, solid-state electronic switch used for rapid switching (on and off) the current supply in modern power electronics, using very low (biasing) voltages and currents applied to a semiconductor "gate."

Inductive power pick-up - Contactless power transfer via electric currents in conductors induced when exposed to a moving or otherwise time- varying magnetic field. This is the principle of an electric motor or generator.

KIMM - Korea Institute of Machinery and Materials.

Laminated track - A track reaction plate composed of metal sheets bolted or epoxied together, rather than a thick solid metal bar, in order to limit power losses and associated heating of the track (reaction rail) due to eddy currents induced as the vehicle magnets pass over it. The thinner the laminations are, the smaller the size and intensity of eddy currents, and the lower the power losses and temperature rise will be.

Levitation - The lift achieved by a maglev system above a guideway, due to either attractive (EMS) or repulsive (EDS) magnetic fields and forces.

LIM - Linear Induction Motor. In a LIM, the stator and rotor magnetic fields may be out of phase. The LIM for maglev can have a short stator (as in the active vehicle, passive guideway used by CHSST), or a long stator (as in the active guideway, passive vehicle used by Transrapid).

LSM - Linear Synchronous Motor. In a LSM, the stator and rotor magnetic fields are always in phase (synchronous). The LSM is considered more efficient, but more complex than the LIM.

M3 - MagneMotion Maglev, which is an LSM-type urban maglev transportation system concept developed by MagneMotion, Inc.

MOST - Korean Ministry of Science and Technology.

MTG - Maglev Transit Group.

MUSA - Maglev Urban System Associates is the team which studied the implementation of the CHSST maglev in Bethesda, MD for the FTA Urban Maglev Program (UMP). The consortium included EarthTech, Inc., CHHST Corporation, Kimley-Horn Associates, Chamberlain Engineering, Inc., and Delon Hampton and Associates.

NIB - Neodymium Iron Boron (NdFeB) Magnet is a powerful permanent magnet (PM) in the Rare-Earth class. It is sintered from powders and requires coatings and plating to prevent PM corrosion due to weathering of the iron and mechanical damage.

ODU - Old Dominion University.

Oscillations - The periodic (usually sinusoidal) variations in time and amplitude, in this context denoting undesirable resonant instabilities in the maglev guideway-vehicle interactions.

OSHA - Occupational Safety and Health Administration, an agency of the U.S. Department of Labor, which regulates the protection of worker's health and safety.

PennDOT - The Pennsylvania Department of Transportation.

Permanent magnet (PM), including NIB **-** is a category of magnets in which magnetic properties are intrinsic and preserved below a critical temperature, at which they become demagnetized, and below a critical magnetic field (coercive force) in excess of which they may become demagnetized. The PM magnetization might also decay slowly over time due to thermal cycling (hysteresis losses) and corrosion or mechanical fractures (see NIB). Very light and strong PMs can now be fabricated to specifications to provide the desired levitation and propulsion forces for urban maglev systems. In contrast, the magnetic field strength of electromagnets (solenoids) varies with the current intensity through the solenoid windings and can reverse direction when the current flow is reversed.

Propulsion - The method by which a maglev vehicle "rides a magnetic wave" to move forward at variable speeds along the guideway, more generally "power and propulsion" denotes the motor for a transit, rail, or other transportation system.

Rotem - The Rotem company is part of the Hyundai Motor Group in Seoul, Korea. It developed and tested a Korean EMS maglev system now being commercialized by the Korean Ministry of Science and Technology (MOST).

Superconducting (magnets) (SCM) - Solenoids made out of superconducting wire can achieve very high conductivity, or very low resistance to electric current flow. Magnets made with superconducting wire can produce very high magnetic fields (< 5 tesla) and very strong currents with very low resistive losses and high-energy efficiency. Type II superconductors such as niobium-tin and niobium-titanium are used to make the coil windings for superconducting magnets. These two materials can be fabricated into wires and can withstand high magnetic fields without losing their properties. Typical construction of the coils is to embed a large number of very fine filaments (20 micrometers diameter) in a copper matrix. The solid copper gives mechanical stability and provides a path for the large currents in case the superconducting state is lost. These superconducting magnets must first be pre-cooled with liquid Nitrogen, and then cooled with liquid helium at 4 degrees Kelvin and are called Low-Temperature superconductors (LTS). The Yamanashi MLX maglev system uses LTS SCMs, and requires cryostats and cooling pumps to maintain SCMs at low temperatures. Newer superconductors with higher transition temperatures are called High Temperature Superconductors, and are being studied demonstrated by Japan Central Railroads (JCR) at Yamanashi for the next generation EDS maglev.

TEA-21 - Transportation Efficiency Act for the 21st Century funded surface transportation R&D activities from 1998 to 2004. Section 3015 (c) of TEA-21, Advanced Technology Pilot Project, authorized the Secretary to make grants for the development of low-speed magnetic levitation technology for public transportation purposes in urban areas to demonstrate energy efficiency, congestion mitigation, and safety benefits. TEA-21 also created the Low Speed Project, under 23 U.S.C., §322 (i) based on superconductivity technology. These two statutory provisions were combined in FTA's Urban Magnetic Levitation Transit Technology Development Program (Urban Maglev Program, UMP) that was initiated through a *Federal Register* Notice dated January 29, 1999.

TKL - Tobu Kyuryo Line is a 5.6 mi double track guideway with 9 stations in Nagoya, Aichi Prefecture, Japan, where the CHSST LINIMO (Linear Motor) maglev has been operating in commercial service since May 2005 at Aichi Expo 2005.

Transrapid - The EMS high-speed maglev originally developed and demonstrated in Germany and proposed for U.S. transit and intercity applications (see postings at http://www.transrapid-usa.com/content.asp). A modified Transrapid maglev is now operating commercially in Shanghai by the Shanghai maglev Transportation (SMT) corporation, as an urban transit system.

UMP - Urban Maglev Program is an R&D program for low-speed maglev advanced transit options administered (see TEA-21 above).

VVVF - Variable voltage variable frequency converter is the typical controller for Alternating Current (AC) motors. The VVVF drive allows the voltage (and current) to vary, thus varying the rotor speed, hence the motor torque and power. This converter (or inverter if the input is Direct Current (DC)) is used to control induction motors and the current flowing to the maglev electromagnets. In the Transrapid maglev the VVVF is used to vary both voltage and the frequency of the current flow through electromagnets, and thus vary the propulsion speed.

Appendix B. Workshop Participants

Dr. Thomas E. Alberts
Aerospace Engineering Department
Old Dominion University
Norfolk, VA 23529-0247

Ms. Mary Anderson
Federal Transit Administration
400 7th Street, S.W. Room 9402
Washington, D.C. 20590

Mr. Robert W. Baldi
General Atomics
3550 General Atomics Ct.
San Diego, CA 92121-1122

Mr. Paul Bousquet
Volpe National Transportation Systems Center
55 Broadway DTS-75
Cambridge, MA 02142

Dr. Aviva Brecher
Volpe National Transportation Systems Center
55 Broadway DTS-46
Cambridge, MA 02142

Mr. Pierre A. Brunet
EarthTech
7 St. Paul Street, Suite 900
Baltimore, MD 21202

Dr. Gordon T. Danby
12 Sound Rd.
Wading River, NY 11792

Dr. Peter-Jürgen Gaede
Rotem Company, R&D Center
#140-2, Kae-Dong
Chongro-Gu, Seoul
110-794 Korea

Dr. Allan J. Golden
California University of Pennsylvania
Campus Box 95
250 University Ave.
California, PA 15419-1394

Dr. H. (Sam) Gurol
General Atomics
3550 General Atomics Ct.
San Diego, CA 92121-1122

Mr. Roger Hoopengardner
Science Applications International Corporation
1710 SAIC Drive
McLean, VA 22102

Mr. Christopher Johnson
Delta Development Corp.
2000 Technology Pkwy, Suite 200
Mechanicsburg, PA 17050

Mr. Koji Kubota
Itochu Corporation
TOKMV Section
5-1 Kita-Aoyama 2-Chome
Minato-Ku, Tokyo 1078077

Mr. Walker Kulyk
Federal Transit Adminstration
400 7th Street, S.W. Room 9402
Washington, D.C. 20590

Mr. Ryoung-Kyu Lim
Rotem Company
837-36, Yeoksam-Dong
Gangnam-Gu, Seoul
135-937 Korea

Ms. Sheri Little
Pennsylvania Department of Transportation
P.O. Box 3151
Harrisburg, PA 17120-0064

Mr. Ronald Mauri
Volpe National Transportation Systems Center
55 Broadway DTS-42
Cambridge, MA 02142

Mr. Tsuyoshi Okada
HSST Systems International
C/O ITOCHU International, Inc.
335 Madison Avenue
New York, NY 10017

Mr. Venkat Pindiprolu
Federal Transit Administration
400 7th Street, S.W. Room 9402
Washington, D.C. 20590

Dr. James Powell
Maglev 2000
P.O. Box 547
Shoreham, NY 11786

Dr. Gopal Samavedam
Foster-Miller, Inc.
350 Second Avenue
Waltham, MA 02154

Ms. Motoko Shimizu
Science Applications International Corporation
1710 SAIC Drive
McLean, VA 22102

Mr. Michio Takahashi
CHUBU HSST Development Corporation
3-14 Kafuku-Cho, Minami-Ku
Nagoya 457-0837 Japan

Mr. Ken-ichi Takao
HSST Systems International
C/O ITOCHU International, Inc.
725 Figueroa St, Suite 3050
Los Angeles, CA 90017-5418

Dr. Richard Thornton
MagneMotion
20 Sudbury Road
Acton, MA 01720

Mr. Todd Webber
MagneMotion
20 Sudbury Road
Acton, MA 01720

Appendix C. Workshop Agenda

Low Speed Urban Maglev Workshop
Federal Transit Administration
400 Seventh Street, SW, Room 2301
Washington, DC 20590

September 8 and 9, 2005

Thursday, September 8

8:00 a.m. -8:30 a.m.	Registration and Continental Breakfast	
8:30 a.m. -9:00 a.m.	Welcome and FTA Maglev Objectives	Walter Kulyk, Director Office of Mobility Innovation, FTA
9:00 a.m. -9:45 a.m.	MagneMotion Maglev	Richard Thornton, President MagneMotion and Todd Webber, CEO MagneMotion
9:45 a.m. -10:05 a.m.	Discussion, Q & A	
10:05 a.m. -10:20 a.m.	Break	
10:20 a.m. -11:05 a.m.	General Atomics Team Maglev Project	Sam Gurol, Project Manager General Atomics
11:05 a.m.-11:20 a.m.	Discussion, Q & A	
11:20 a.m. -12:05 p.m.	California Univ. of PA (CUP) Maglev Demonstration System	Allan Golden, V.P. for Admin. & Finance California University of Pennsylvania
12:05 p.m.-12:25 p.m.	Discussion, Q & A	
12:25 p.m.-1:30 p.m.	Lunch	
1:30 p.m.-2:15 p.m.	Colorado Maglev Project	Gopal Samavedam, Group Dir. Foster-Miller
2:15 p.m.-2:35 p.m.	Discussion, Q & A	
2:35 p.m.-3:10 p.m.	Maglev 2000	Jim Powell, Co-Founder Maglev 2000
3:10 p.m.-3:30 p.m.	Discussion, Q & A	
3:30 p.m.-3:45 p.m.	Break	
3:45 p.m.-4:30 p.m.	MUSA Project	Pierre Brunet, Sr. Engineer EarthTech
4:30 p.m.-4:50 p.m.	Discussion, Q & A	
5:00 p.m.	Adjourn for the Day	
5:30 p.m.-6:30 p.m.	No Host Dinner	

Friday, September 9

8:00 a.m.-8:30 a.m.	Continental Breakfast	
8:30 a.m.-9:15 a.m.	The First Commercial Application of HSST	Michio Takahashi, Director Chubu HSST
9:15 a.m.- 9:35 a.m.	Discussion, Q & A	
9:35 a.m.-10:20 a.m.	Korean Maglev	Peter Jurgen Gaede, Senior Maglev System Engineer ROTEM
10:20 a.m.-10:40 a.m.	Discussion, Q & A	
10:40a.m.-11:25 a.m.	Old Dominion University Maglev Effort, Progress and Goals	Thomas Alberts, Professor Aerospace Engineering Old Dominion University
11:25 a.m.-11:45 a.m.	Discussion, Q & A	
11:45 a.m.-12:30 p.m.	Summary/Lessons Learned and Benefits to Transit	Gopal Samavedam, Group Dir. Foster-Miller
12:30 p.m.-1:30 p.m.	Lunch	
1:30 p.m.-2:30 p.m.	General Discussion, Q and A	
2:30 p.m.-3:00 p.m.	Next Steps in Urban Maglev Program	Walter Kulyk, Director, Office of Mobility Innovation, FTA
3:00 p.m.	Adjourn	

Appendix D. Presentations

FTA Maglev Program Objectives

Walter Kulyk
Director, Office of Mobility and Innovation
Federal Transit Administration

FTA Maglev Program Objectives

Walter Kulyk

Director, Office of Mobility and Innovation

Federal Transit Administration

FTA Maglev Program Objectives

- To perform research and development in magneticall levitated and propelled systems, particularly in areas where technological gaps exist.
- To evaluate Maglev systems' safety, cost and viabilit for urban transportation
- To evaluate the benefits of emerging Maglev systems for urban transportation and make recommendations to the transit industry

Statutory Basis of FTA Maglev Program

- Published in the Federal Register Notice, January 29, 1999
- Program Elements
  - Evaluation of system concepts
  - Prototype system development
  - System integration and deployment plans
- Selected concepts must have R & D purpose to overcome critical technological gaps

Statutory Basis of FTA Maglev Program (cont.)

- Emphasis is deployable technologies with participation by the end user. The projects must demonstrate:
  - Energy efficiency
  - Congestion Mitigation
  - Safety and other benefits

FTA Maglev Program Objectives

Speed Definition

A "speed" definition is required. For our purpose, let us define the peak values of:

Low Speed	< 100 mph
Moderate Speed	100 to 150 mph
High Speed	> 150 mph

Low speed Maglev is suitable to compete with Metro, Light Rail, Monorail and bus on routes with average station stops under 1 mile. Travel time is controlled more by acceleration and deceleration capability than maximum speed in the case of short station stops.

FTA Maglev Program Objectives

The FTA Maglev systems should have the following advantages over conventional urban transportation systems:

- **Public Acceptance**
- **Reduced travel time**
- **Steep gradient negotiation for hilly terrains**
- **Fully operated train without drivers**
- **Significantly improved ride quality**
- **Almost noise free environment for passengers and communities**
- **Low maintenance and operational costs**
- **Low initial costs**

FTA Maglev Program Objectives

- Chubu HSST has been developed over many years of extensive research and development in Japan. It has recently been successfully deployed in Nagoya. The operational experience, and maintenance and operational costs will be a valuable reference system for Maglev research communities. The Chubu system can serve as a benchmark for emerging Maglev technologies.
- To understand and evaluate the Chubu HSST applicability to U.S. Urban Maglev transportation, the FTA sent technical experts to the Chubu facility in Nagoya in 2002 and 2004.

  2002 team: Consultants and MUSA contractors

  2004 team: Consultants, MUSA, and selected transit planners.

FTA Maglev Program Objectives

The FTA awarded contracts to the following primes:

- MUSA, Baltimore, MD
- General Atomics, San Diego, CA
- MagneMotion, Acton, MA
- CDOT, Denver, CO
- Maglev 2000, Titusville, FL

In addition, California University, PA, has received earmarked funds from Congress to plan an elevated Maglev system on the campus.

FTA Maglev Program Objectives

- The FTA contractors will present their work and accomplishments during the Workshop. The concepts are generally different from each other and are expected to address specific gaps they identified in the Maglev technology.
- In addition, there will be special presentations b Chubu HSST and Korean Maglev as invitees by the FTA. The Koreans will likely be deploying a Maglev system in a couple of years.
- Old Dominion University had also planned Maglev transportation on their campus. They were also invited to the Workshop to share their technology and experiences in Maglev.

FTA Maglev Program Objectives

In the selection of concepts for R & D, the FTA hoped that these different concepts have some of the following attributes desired for U.S. Maglev:

- Larger levitation (Mechanical) gaps (≥ 10mm)
- Higher peak speeds (≥ 62 mph)
- Steeper gradient negotiation (≥ 7°)
- Tighter curve negotiation (side line track: 62′)

FTA Maglev Program Objectives

- Powerful propulsion motors
  - Improved Linear Induction Motor
  - Linear Synchronous Motor
- Low cost guideways
- Alternate systems other than electromagnets to generate magnetic fields
  - Permanent magnets
  - Superconducting magnets

FTA Maglev Program Objectives

- The FTA encourages partnerships among U.S. and foreign contractors and will exploit deployment opportunities in the U.S. or abroad.
- The FTA stresses that it is very important that the FTA Maglev programs be successful to rekindle U.S. Government interest and retain U.S. public and transit planners interests .

Urban Maglev Workshop

Presentation by MagneMotion
September 8, 2005

Richard Thornton and Todd Webber

M3 MagneMotion
Maglev

Urban Maglev Workshop

Presentation by MagneMotion
September 8, 2005

Richard Thornton, Todd Webber

MagneMotion
A Force in Electro Magnetic Systems

M3 MagneMotion
Maglev

1. Project Purpose, Duration and Team Roles

- Purpose
  - Design a cost effective maglev system for urban applications and build key pieces of hardware to demonstrate the design. Base the design on system level tradeoff studies.
- Duration
  - FTA Urban Maglev Project kickoff meeting Feb. 1999
  - Cost sharing support from FTA June 2001 to June 2004
  - Company funded work has continued up to the present
- Team members
  - MagneMotion: suspension, propulsion, control
  - EarthTech: guideway design and simulation
  - TPI Composites: vehicle design

Copyright © 2005 MagneMotion, Inc 2

MagneMotion
A Force in Electro Magnetic Systems

M3 MagneMotion Maglev

2. System Requirements & Overview

- Designed with a system perspective to achieve:
  - Low capital and operating cost
  - Short travel time, including wait time
  - Minimum environmental impact
  - Excellent ride quality
- Design requirements:
  - Speeds up to 45 m/s (101 mph), higher speeds possible in the future
  - Acceleration to 2 m/s^2, limited to 1.6 m/s^2 when there are standees
  - Capacity up to 12,000 pphpd, can be increased by using larger vehicles
  - Small vehicles operating with headways as short as 4 seconds
  - Lightweight guideways with minimum cost and weight

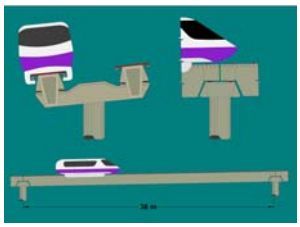
Copyright © 2005 MagneMotion, Inc 3

MagneMotion

M3 MagneMotion Maglev

2a. System Requirements & Overview

- Major features
  - Permanent magnet EMS with 20 mm magnetic gap
  - LSM propulsion with guideway-based control and power regeneration
  - Box beam concrete guideways matched to vehicle weight and speed
  - Composite vehicles that are light and streamlined



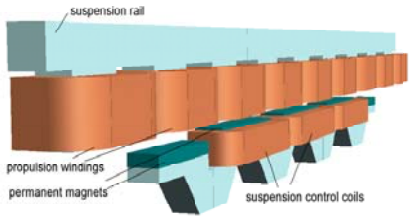
Copyright © 2005 MagneMotion, Inc 4

MagneMotion

M3 MagneMotion Maglev

3. Levitation/Propulsion/Guidance

- Permanent magnet ElectroMagnetic Suspension
  - Each magnet contributes to force in all directions
    - Provides most of the force for control in all degrees of freedom
    - Reduces cost and weight of vehicle and guideway
  - Active suspension control improves ride quality
    - Provides damping in all degrees of freedom
  - Magnetic gap is 20 mm for typical load
    - Gap changes with load so as to minimize suspension power
  - Very little power required for levitation



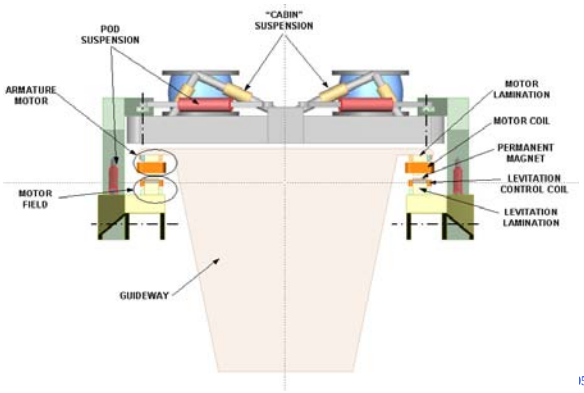
MagneMotion

Copyright © 2005 MagneMotion, Inc 5

M3 MagneMotion Maglev

3a. Guidance

- Guidance uses same magnets as levitation
  - Eliminates the need for separate guideway structures
  - Only one gap interface to control



MagneMotion

05 MagneMotion, Inc 6

3b. Propulsion

M3 MagneMotion Maglev

- LSM propulsion
  - Reduced vehicle weight
  - Force can be adapted to the terrain and station location
  - Precise position sensing of all vehicles all of the time
  - The preferred choice for all high speed designs
    - Transrapid changed from LIM to LSM with TR05
- High power components are all on the guideway
  - No need to transfer large amounts of power to the vehicle
    - This is a major advantage of the LSM as compared with the LIM
    - +900 VDC for the LSM on one side, -900 V for the other side
    - Use 1,700 V IGBTs while transmitting most power at 1,800 VDC
    - Inverters use state-of-art IGBT modules to reduce cost
  - Short vehicle headway and high voltage leads to high efficiency
    - Most regenerated power can be reused
    - Power usage less than half that for conventional transit

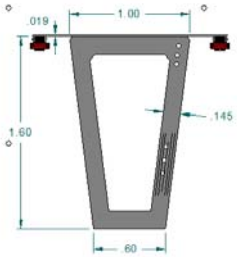
Copyright © 2005 MagneMotion, Inc 7

MagneMotion

4. Guideway Structure

M3 MagneMotion Maglev

- Lightweight and compact
  - Optimized for low cost for vehicle weight and speed
    - Limit of one vehicle per beam allows lower cost guideways
  - 20 mm gap relaxes dimensional tolerances
    - Achieves most of the advantages of EDS designs
- Reinforced concrete box beam
  - Designed for good ride quality at minimum cost
  - Stiffness-based design is necessary to achieve good ride
    - Large reserve of strength for handling rescue vehicles
  - 1.7 meter gauge
- Double span concrete box beams
  - Light weight and 36 m (118') column spacing simplifies installation
  - Double-span reduces deflection and temperature distortion

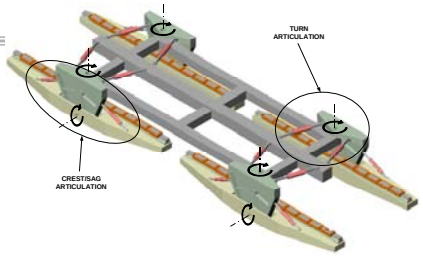


Copyright © 2005 MagneMotion, Inc 8

MagneMotion

5. Vehicle Structure

M3 MagneMotion Maglev



- Composite construction
  - Reduced weight
  - Streamlined shape
- Supported by pivoting magnet pods
  - Like a small bus with magnet pods replacing wheels
  - Secondary suspension only needed for high speed installations
- Onboard power via inductive power transfer
  - Operation at all speeds reduces battery needs
  - Power requirements low because of efficient suspension
  - Major need is for HVAC, total estimated to be 8 kW
- Size and layout can be varied
  - Up to 48 passengers for low speed with mostly standees
  - Shorter vehicles reduce cost for lower capacity applications
  - Vehicle size can be increased for capacity >12,000 pphpd

Copyright © 2005 MagneMotion, Inc 9

MagneMotion

6. Vehicle Dynamics and Stability

M3 MagneMotion Maglev

- Active control of suspension magnets for stability
  - Suspension power negligible when stationary
  - Suspension power estimated to be 100 W/Mg at 100 mph
    - More than an order of magnitude less than most EMS designs
- Suspension magnets provide passive and stable guidance
  - Active control of magnets provides damping in all dimensions
- Secondary suspension only necessary at high speed
  - Passive secondary suspension for 50-100 mph
  - Active pneumatic suspension for >100 mph
- Simulations show excellent ride quality
  - Light vehicles lead to small deflections, even with light beams
  - Can use precamber of beams because of known load
  - With somewhat larger beams speed can be increased to 150 mph

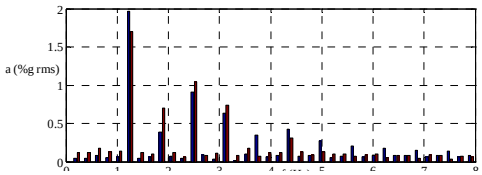
Copyright © 2005 MagneMotion, Inc 10

MagneMotion

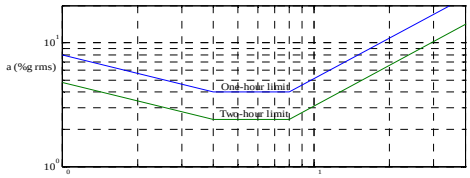
6a. Simulated Ride Quality

M3 MagneMotion Maglev

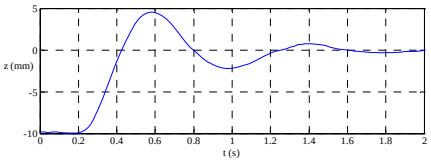
Vertical acceleration at 45 m/s (101 mph)



ISO Ride quality standard



Step response showing lateral damping and roll torque compensation



MagneMotion

7. System Safety

M3 MagneMotion Maglev

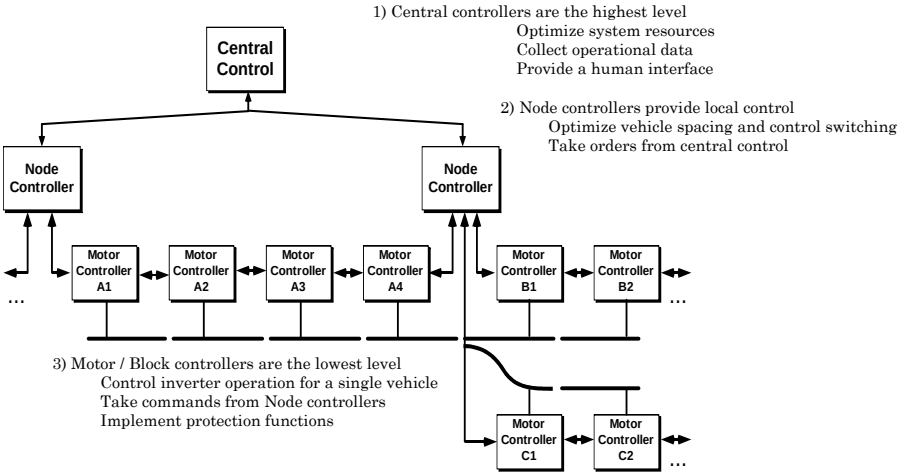
- Can not derail
  - Wrap-around design prevents overturning
- Guideway-based propulsion and control
  - Control does not depend on radio communication
  - Vehicle locations precisely known at all times
  - Not dependent on delivering propulsion power to vehicle
- Elevated guideway is key to safety
  - Most transit-related fatalities involve people not on transit vehicles
- Redundant controls and power systems
  - No single-point failure will cause suspension failure
    - This approach has been proven by Transrapid
  - Separate port and starboard LSM power systems
    - Can operate at lower speed with only one LSM
- Rescue vehicles can drive on guideway
  - This approach has been used by Disneyland for many years
  - Can avoid the need for parallel walkways

Copyright © 2005 MagneMotion, Inc

MagneMotion

8a. Control Hierarchy - Three levels of Control

M3 MagneMotion Maglev



Copyright © 2005 MagneMotion, Inc 13

MagneMotion

8b. Communications and Control

M3 MagneMotion Maglev

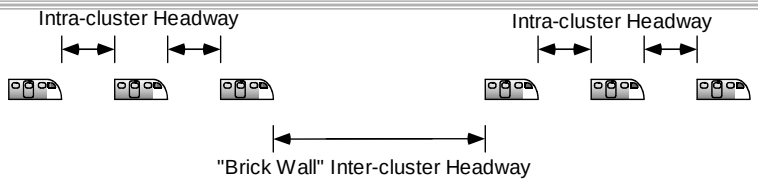
- Vehicles operate in clusters to increase capacity
  - Inter-cluster spacing based on brick wall headway
    - Prevents compound control problems
  - Inter-vehicle spacing based on safe-follower headway
    - Safer than using long trains to achieve high capacity
    - Brick wall headway possible with slightly lower throughput
  - Clusters achieve the capacity of trains
    - Preserve the advantage of small vehicles & short headway
    - Allows a simple way to reduce capacity for off-peak operation
  - Station skipping can reduce travel time and vehicle requirements
    - Clusters can be dynamic with some vehicles skipping some stations

Copyright © 2005 MagneMotion, Inc 14

MagneMotion

8c. Control of Vehicle Clusters

M3 MagneMotion Maglev



Movement Permissions for vehicles within a cluster (6X real-time)

Existing monorail, Safe-follower headway, Brick wall headway (6X real-time)

Clusters at max throughput (not shortest travel time) (6X real-time)

Video can be seen on the FTA Maglev Workshop CD.

Copyright © 2005 MagneMotion, Inc 15

MagneMotion

9. Specific Innovations

M3 MagneMotion Maglev

- Permanent magnet EMS
  - Each magnet contributes to suspension, guidance & propulsion
  - Allows magnetic gap of 20 mm
  - Control coils stabilize suspension and provide damping of all motion
  - This novel concept has been proven by POC constructed during this project
- Guideway uses conventional construction
  - Achieves low cost through careful matching to vehicle weight and speed
- Simplified manufacture of LSM stator
  - Externally wound coils simplify manufacture
  - Winding fill factor is high with good thermal transfer

Copyright © 2005 MagneMotion, Inc 16

MagneMotion

9a. Specific Innovations & Test Results

M3 MagneMotion Maglev

- **Uses vehicle clusters**
  - Allows high capacity with small vehicles
  - Similar to a fleet of buses operating on a highway
- **LSM design and control are based on proven commercial product design**
  - Controller similar to one used for small vehicles in automated factories
  - Design Proven on products producing forces from 50 to 50,000 pounds
  - The result of many years of development and manufacturing
  - There is very little risk that the LSM can not achieve its objectives
- **Proof of Concept Test Results**
  - Test vehicle with full size magnets validated key concepts
    - Permanent magnet EMS with 20 mm magnetic gap
    - Position sensing accurate to 10 mm
    - LSM propulsion with acceleration of 2 m/s2
    - Damping of motion in all degrees of freedom
  - Detailed modeling and simulation verified many features
    - POC results agreed very well with finite element modeling
    - Guideway ride quality was shown to be outstanding
  - Energy usage is less than 50% of competing wheel-based designs

Copyright © 2005 MagneMotion, Inc 17

MagneMotion

10a. M3 Demonstration

M3 MagneMotion Maglev

Video can be seen on the FTA Maglev Workshop CD.

Copyright © 2005 MagneMotion, Inc 18

MagneMotion

11. System Cost Estimates

M3 MagneMotion Maglev

M3 Cost Per mile	$K
1. Guideway Structure Cost	$11,220
Girders/Beams, Supports, Footings	
2. Vehicle Costs (6 per mile)	$5,874
Body/Bogie/Suspension	
2.2 Levitation, Guidance and Propulsion System	$7,855
2.3 Power Distribution and Conditioning	$6,483
2.4 Communication and Control	$4,216
Total	$35,648
2.5 Energy Cost/Passenger-mile	$0.01
3. Operation and Maintenance Costs/mile/year	$<190

Note: Based on dual guideway, 12,000 pphpd
Contingencies are included, but not stations or land
Energy cost based on BTU estimate and DOE Federal Register costs
O&M based on public transit (rail) budget per mile calculations

Copyright © 2005 MagneMotion, Inc 19

MagneMotion

12. Summary: System Characteristics

M3 MagneMotion Maglev

- Designed from a system perspective with the objective of achieving:
  - Low capital and operating cost
  - Short travel time, including wait time
  - Minimum environmental impact and energy usage
  - Excellent ride quality
- All objectives were achieved and demonstrated
  - POC demonstrated LSM and permanent magnet EMS
  - Detailed costing showed that *M3* is very cost effective
  - Simulations show excellent ride quality and high energy efficiency
  - Comparison with existing technology for typical applications is encouraging

Copyright © 2005 MagneMotion, Inc 20

MagneMotion

Application Examples

M3 MagneMotion Maglev

	Shuttle	*Loop*	*Airport*	*Intercity*
Capacity, pphpd	12,000	3,600	4,300	6,000
Maximum speed, m/s mph	45 101	30 67	60 134	75 168
Distance, km	1.6	4	30	250
Stations	2	4	2	17
Average speed, m/s mph	25 55	20 44	35 78	45 101
Average power , kW/veh	60	80	230	
Energy, J/pas-meter BTU/pas-mi	524 843	400 644	814 1,310	
Regeneration energy savings, %	50	45	6	

Copyright © 2005 MagneMotion, Inc 21

MagneMotion

Comparison of Energy Usage

M3 MagneMotion Maglev

	Energy usage, 10^{12} BTU	*Average trip length, miles*	*Energy Intensity, BTU/pas-mi*
M3			1,180
Intercity rail	23.0	238	4,137
Commuter rail	25.9	22.8	2,671
Heavy rail	42.7	5.1	3,140
Light	6.0	4.4	4,024
Transit bus	91.6	3.6	4,125
Certified air carriers	2,599	842	3,802
Autos	9,100	9.1	3,581

Copyright © 2005 MagneMotion, Inc 22

MagneMotion

12a. Summary: System Characteristics

M3 MagneMotion Maglev

- This project convinced us that our design choices were right
  - EMS has major advantages for speeds up to 150 mph
  - Permanent magnets can provide most of suspension and guidance forces
  - For maglev a long-stator LSM is superior to a short stator LIM
  - Small vehicles with short headway are safe and have major advantages
  - Maglev should be the preferred choice for all urban guideway-based transportation

Copyright © 2005 MagneMotion, Inc 23

MagneMotion

12b. Lessons Learned

M3 MagneMotion Maglev

- The greatest impediment to continued success is not technical risk, but program funding, sponsorship and subcontract issues
  - We achieved all technical design goals
  - Intermittent funding hinders progress
  - Finding industrial sponsors for deployment has been elusive
  - Subcontract performance difficult to achieve with small quantity purchases spread out in time
- Our key concepts led to reduced cost without compromising performance
  - Permanent magnet EMS
  - Small vehicles with operating with short headway
  - Lightweight and low cost guideway
- *M3* has lower capital and operating cost than competing transit systems
  - Costs well below lower performing wheel-based systems
  - Costs lower than other maglev designs with published cost data
  - Performance comparable to Transrapid for distances to 50 km

Copyright © 2005 MagneMotion, Inc 24

MagneMotion

13b. Future Plans

M3 MagneMotion Maglev

- We are actively pursuing several potential applications
  - The plan includes the following short term objectives
    - Construct an indoor test track and vehicle; the track will be full size but the vehicle will be shorter
    - Construct an outdoor track capable of full speed testing, possibly near a potential application
  - The first application should be short with time and funds allowed for thorough testing
- There is clearly a large market for urban maglev, applications include:
  - Airport transportation, both air-side and land-side
  - Rapid transit and commuter rail extensions
  - An alternative to light rail or monorail
  - Theme parks, including parking lot connectors

Copyright © 2005 MagneMotion, Inc 25

MagneMotion

13c. Development Specifics

M3 MagneMotion Maglev

Continue R&D (18 month plan):

- Build 33m test facility with a full length, full gauge bogey
- Test Inverter hardware block switching transition
- Test stator alignment and track tolerance (movable track section)
- Verify ride quality simulation with yaw, pitch, roll measurements
- Test curve transition (track will have first segments of a 18m radius curve)

Copyright © 2005 MagneMotion, Inc 26

MagneMotion

Summary

- M3 offers dramatic improvements for transit systems
  - Less than ½ the operating cost
  - Less than ½ the capital cost for new systems
  - Less than ½ the travel time for typical trips
  - Improved safety and reliability
  - Reduced environmental impact: less noise and smaller guideway
- Improvements are made possible by enabling technologies
  - Permanent magnets provide lift and guidance: larger gap, less power loss
  - Linear synchronous motor propulsion: high efficiency, rapid acceleration
  - Small, light vehicles: reduce guideway size and cost
  - Operation in clusters: high capacity with small vehicles
  - Guideway based propulsion and control: safer and more reliable
- It is time to focus on the market opportunities, not maglev technology
  - There is virtually no technical risk
  - Focus on reduced cost and travel time, increased safety and reliability
  - Huge potential savings for FTA constituents

Copyright © 2005 MagneMotion, Inc

MagneMotion
A Force in Electro-Magnetic Systems

General Atomics Maglev System

Sam Gurol and Bob Baldi

FTA Low Speed Urban Maglev Workshop

September 8-9, 2005

General Atomics Maglev System

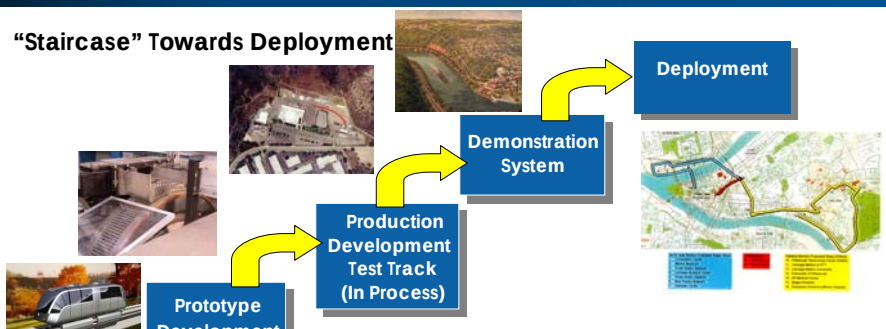
Sam Gurol and Bob Baldi

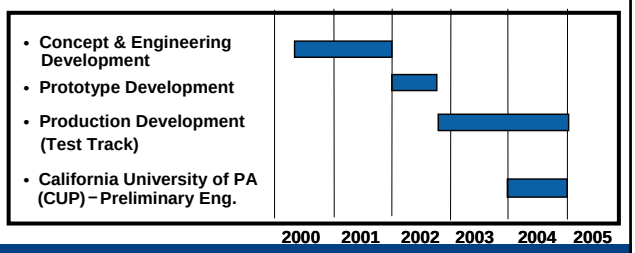
FTA Low Speed Urban Maglev Workshop
September 8-9, 2005

Sponsored by
Federal Transit Administration
1710 SAIC Drive
McLean, VA 22102

1. Project Purpose/Duration/Team Roles

"Staircase" Towards Deployment





The General Atomics Urban Maglev Team

GENERAL ATOMICS
Project Leader, Levitation, Propulsion, Control Systems

Demonstration Site Host

WPMDC
Commercialization

Lawrence Livermore National Laboratory
Levitation Systems

UNION SWITCH & SIGNAL
Communications & Signaling

Booz | Allen | Hamilton
Systems Engineering

Carnegie Mellon
Magnetics

PENNDOT
Transportation Studies

Mackin
Civil Engineering

hi
Vehicle

PJD
Civil Construction

SARGENT
Electrical

GENERAL ATOMICS

2. System Requirements and Brief Overview

12 February, 2001

General Atomics Low Speed Maglev
Technology Development Program

Requirements Document

Sponsored by:
Department of Transportation
Federal Transit Administration
Office of Research Demonstration & Innovation
TRI-20, Room 9401
400 7th Street, SW
Washington, D.C. 20590

Submitted by:

General Atomics
3550 General Atomics Court
San Diego, CA 92121-1122

Approved by:

R. W. Baldi
Systems Engineering Manager

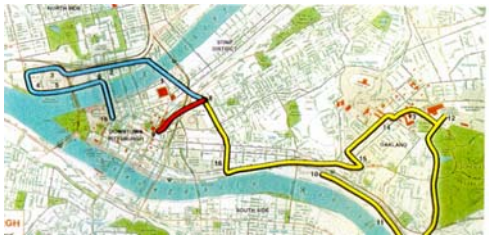
H. Gurol, Program Manager

DISTRIBUTION STATEMENT

Distribution authorized to U.S. Government agencies only to protect information not owned by the U.S. Government and protected by a contractor's "limited rights" statement, or received with the understanding that it not be routinely transmitted outside the U.S. Government. Other requests for this document shall be referred to or FTA/TRI-2.0 and/or the Recipient Administrator.

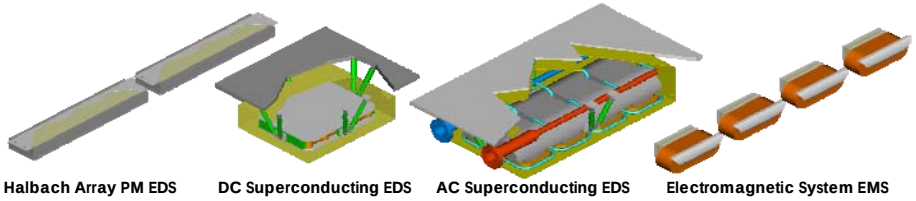
- 13.5 km total length
- 15 stations
- 7 % maximum grade
- 25 m radius turn
- 12,000 passengers/hr/direction

1.1 Service Characteristics
1.2 Acceleration/Speed Performance
1.3 Braking Performance
1.4 Passenger Comfort
1.5 Noise Characteristics
1.6 Guideway
1.7 Operating Environment
1.8 Allowable Magnetic Fields
1.9 Reliability, Availability, Maintainability & Safety
1.10 Security
1.11 Aesthetics
1.12 System Lifetime
1.13 System Costs

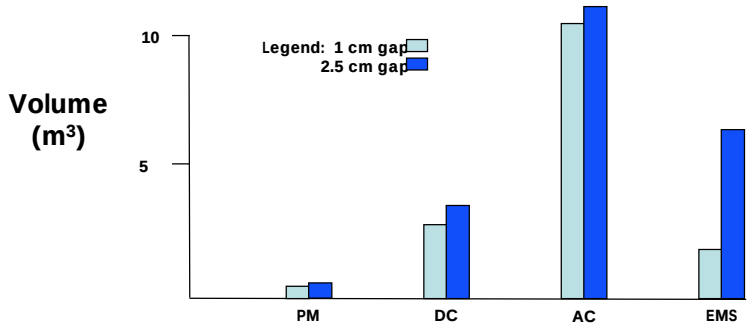


GENERAL ATOMICS

Levitation Magnet Options Considered



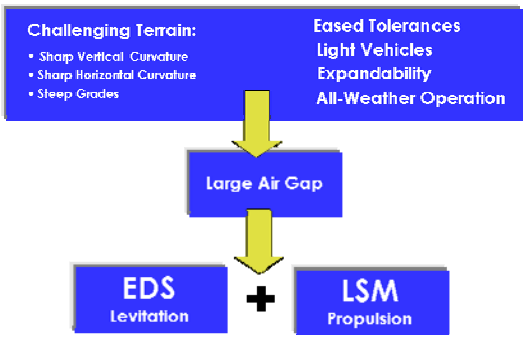
Halbach Array PM EDS | DC Superconducting EDS | AC Superconducting EDS | Electromagnetic System EMS



Total volume per vehicle includes magnets, cryogenics, associated power electronics (as applicable).

GENERAL ATOMICS

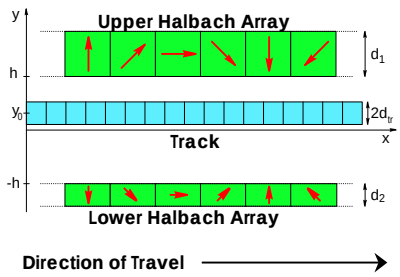
Levitation/Propulsion Technology Selection

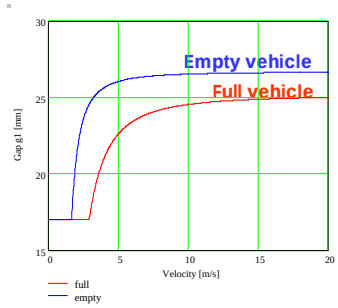


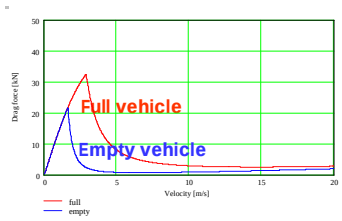
- Simple, passive permanent magnet levitation and propulsion system.
- Large air gap (~25mm) operation.
- Lightweight vehicles (~1 tonne/meter).
- Requires no shielding; field levels in passenger compartment below 1 Gauss level.
- Levitation and propulsion technology suitable for urban (low speed), suburban (higher speed), and inter-city (high speed) operation.
- Enables tight turns, steep grades, quiet.
- Major system cost savings (avoids tunneling, which costs from $200M to $400M per mile).
- O&M costs are expected to be very low, reducing life-cycle costs.

GENERAL ATOMICS

3. Principles of Levitation, Propulsion and Guidance





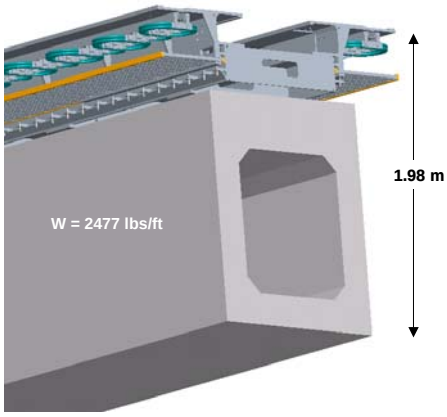


- Magnets are arranged in Halbach Arrays
- Track consists of transposed conductors
- Fields are focused on the track, cancellation occurs on back side
- Motion of magnets drives currents in track
- Currents react against magnet fields to produce lift

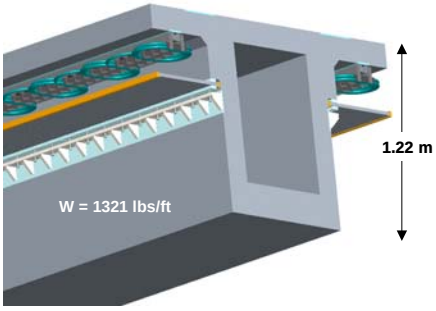
GENERAL ATOMICS

4. Guideway Structure

Baseline Guideway



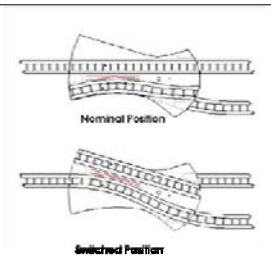
"Hybrid Girder" Guideway



	FREQUENCY (Hz)	
GIRDER LENGTH (Meters)	SINGLE SPAN	DOUBLE SPAN
18	10	10.4
24	5.67	5.92
30	3.45	3.87
36	2.52	2.61

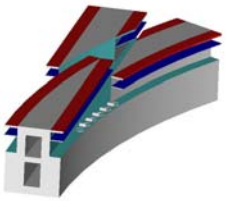
GENERAL ATOMICS

Switch Concepts Considered



Baseline "Rotational Switch"

- 16.6 Degree Rotation
- 60 Metric Tons
- 25 hp Electric Motor Rack & Pinion Drive
- Air Bearing
- 20 Meter Length
- 130.6 m^2 Area
- Switch Time ~ 20 sec
- End of Line Safety Stops - 3 places
- Super Elevation can be Accommodated



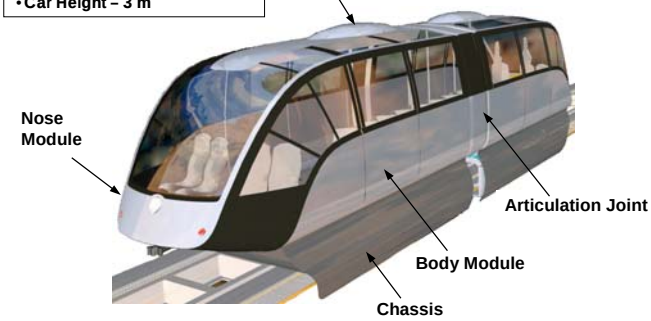
"Electromagnetic" Switch

- AC Magnets Provide Guidance
- Rollers Used in Case of Power Outage
- Dynamics of Vehicle Analyzed

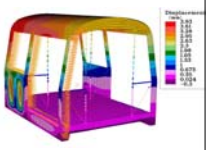
GENERAL ATOMICS

5. Vehicle Structure – Modular Architecture

- 2 Chassis Car Length – 13 m
- Car Width – 2.6 m
- Car Height – 3 m



Analysis Examples



Wind Loads on Body

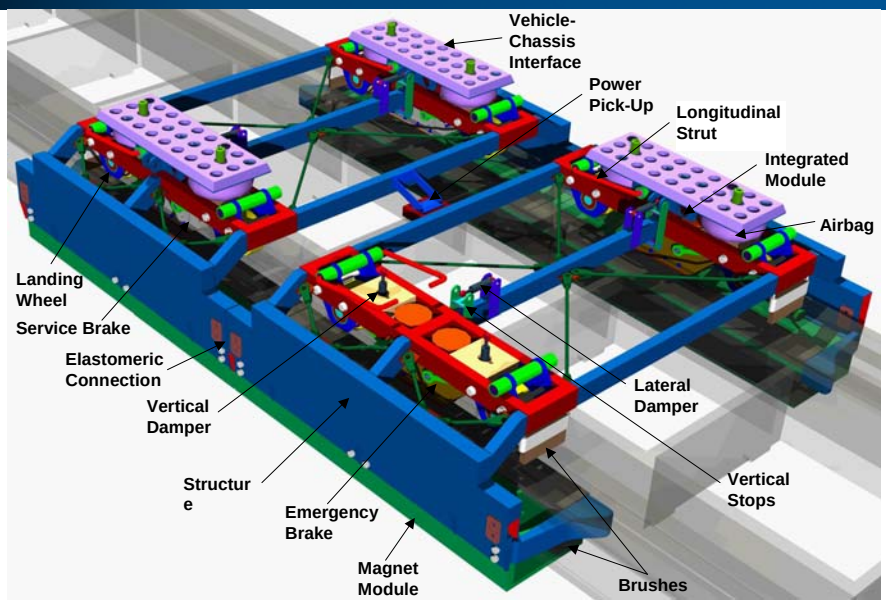
Chassis Stresses

Component Stresses

Chassis units can be connected to produce different vehicle configurations

GENERAL ATOMICS

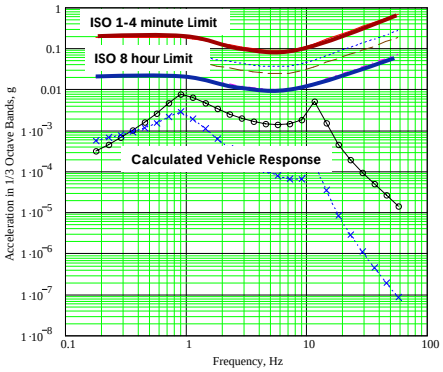
Chassis Unit Details

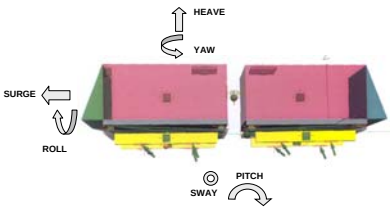


GENERAL ATOMICS

6. Vehicle Dynamics and Stability

- 6 degree-of-freedom Nastran model
- Simulation of lift, drag, lateral forces
- Control system linked to LSM through feedback control loop.
- Mass and inertia of all major components included.
- Non-linear and time-dependent effects, including vibration, magnetic coupling dynamics and translations are simulated.
- Dynamics will be verified by testing.





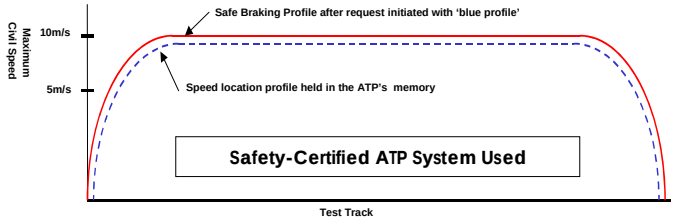
GENERAL ATOMICS

7. System Safety

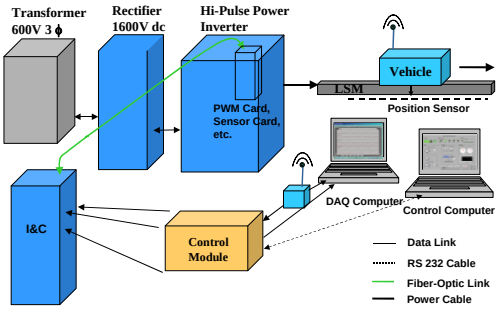
- Levitation system fail-safe on power failure.
- No high voltage systems on vehicles.
- No third rail on guideway.
- Safety-certified Automatic Train Protection System (ATP).
- Driverless operation.
- LSM block switch architecture powers each train individually – collision avoidance.
- Wrap-around design – cannot derail.
- End-of track power switches and eddy current brakes.
- Emergency electro-mechanical braking system.
- Elevated system – no rail crossing mishaps; easier evacuation than tunnel systems.
- Security monitoring systems: guideway intrusion prevention/detection system, visual and audio vehicle communication.

GENERAL ATOMICS

8. Communication and Control



US&S Mikrolok



Vehicle Control System Architecture

GENERAL ATOMICS

9. Specific Innovations

- Simple, passive permanent magnet levitation and propulsion system based on Halbach array configuration.
- Low lift-off speed EDS system.
- Levitation system fail-safe on power failure.
- Large air gap (25mm-30mm) operation.
- Lightweight vehicles (~1 tonne/meter) with modular construction.
- Requires no shielding; field levels in passenger compartment below 1 Gauss level – all fields DC.
- IGBT-based variable frequency inverter.
- High strength fiber-reinforced advanced concrete.
- Inductive housekeeping power pick-up.
- LSM and control system can be applied to wheeled vehicles.
- Levitation and propulsion technology suitable for urban (low speed), suburban (higher speed), and inter-city (high speed) operation.
- Minimal disruption during construction.

15 GENERAL ATOMICS

10. Proof of Concept/Test Data

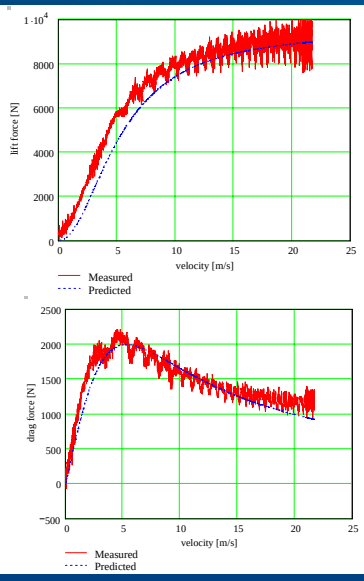
Dynamic Test Facility Demonstrates Levitation

Lift-Off @ ~ 3 m/s

Air Gap > 25 mm

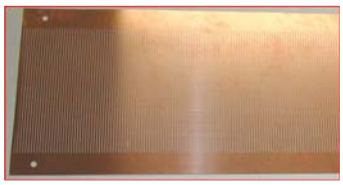
Levitated Weight ~ 900 kg

Equivalent to Full Vehicle With 100 Passengers

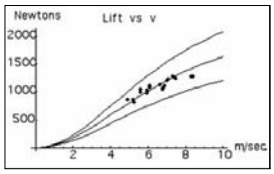


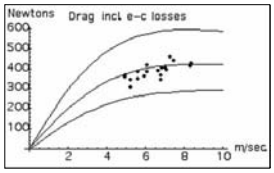
16 GENERAL ATOMICS

Laminated Track Testing



- Laminated track is potentially cheaper to manufacture.
- Provides stiffer primary suspension.
- Is "tunable" to alignment requirements.





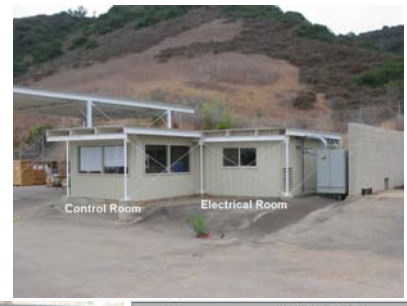
GENERAL ATOMICS

Test Track Uses Full-Scale "Building Blocks"

Completed Test Track and Team (September 2004)

GENERAL ATOMICS

Control and Electrical Room



Data Acquisition

Vehicle Control Panel

Inverter Cabinet Interior View

GENERAL ATOMICS

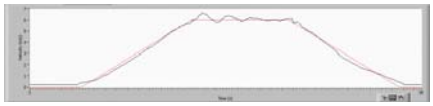
Vehicle Undergoing Dynamic Testing

System Parameter	Value for Full-Size Vehicle	Value for Test Vehicle
Levitation	PM Halbach array	Same
Propulsion	PM LSM	Same
Guidance	Attraction to LSM iron rails	Same
Permanent Magnets	NdFeB; Br=1.4 T; 50 mm^2	Same
Halbach Wave Length, λ	0.432 m	Same
Halbach Array M Number	M=8 (45 degrees)	Same
Operation/safety	ATC (driverless)	Same
DC magnetic field to passengers	< 1 Gauss	Same
Speed, maximum goal	160 km/hr (100 mph)	36 km/hr (22.5 mph)
Speed, average	50 km/hr (31 mph)	36 km/hr (22.5 mph)
Vehicle size	13 m x 2.6 m x 3 m	4 m x 2.6 m x 3 m
Vehicle weight	18 tonnes (100 passengers)	6–10 tonnes (test pilots)
Acceleration, max	1.6 m/s^2	Same
Jerk, max	2.5 m/s^3	Same
Grade	7% (design = 10%)	0%
Turn radius, minimum	18.3 m design, 30 m for demo	30 m
Ride quality	ISO 2631 (1987)	Same

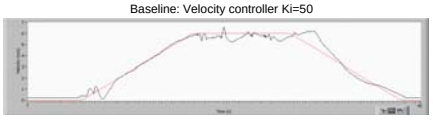
GENERAL ATOMICS

Recent Testing is Focused on Tuning Control System

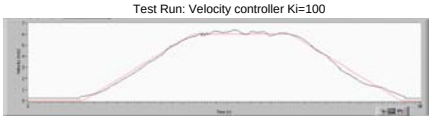
Tuning Test Control Parameters



Baseline: Velocity controller Ki=50



Test Run: Velocity controller Ki=100



Test Run: Velocity controller Ki=200

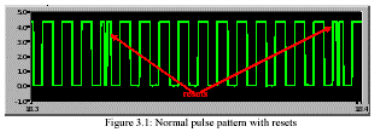
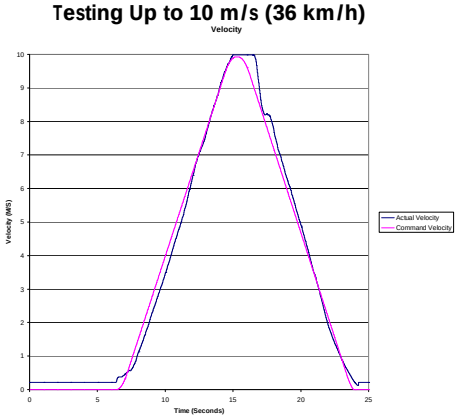


Figure 3.1: Normal pulse pattern with resets

Testing Up to 10 m/s (36 km/h)



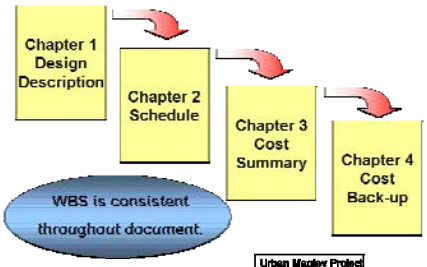
- **Sensor currently being used is optical**
- **We plan to use eddy-current sensor in future**

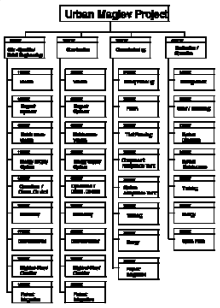
GENERAL ATOMICS

11. System Cost Estimates

Cost Estimating Methodology

- **Develop System Requirements**
- **Baseline a Full-Scale Maglev System**
  - **Conceptual Design & Analysis**
  - **Preliminary Assembly Drawings**
- **Document Baseline Design**
- **Create Engineering & Construction Schedule**
- **Prepare Budgetary Cost Estimate**
  - **Get Vendor Quotes for High $/New Technology Items**
  - **Document Estimate with Backup Information**
  - **Consistent & Traceable WBS / Schedule / DBS**

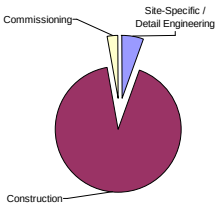


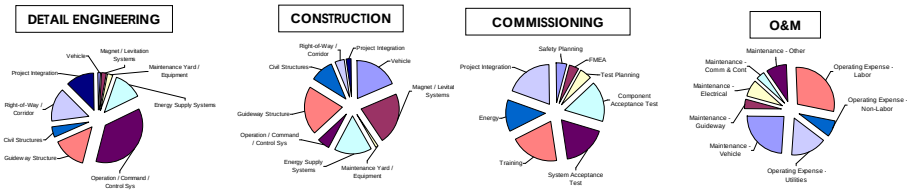


GENERAL ATOMICS

System Costs (12,000 passengers/hour/direction)

1. GUIDEWAY STRUCTURE COSTS	
1.1 Guideway Girders/Beams	$9.2 M/mile *
1.2 Guideway Support Columns	$0.9 M/mile *
1.3 Footings/Foundations	$6.3 M/mile *
2. VEHICLE COSTS	
2.1 Vehicle Body/Bogie/Suspension	$1.45 M/vehicle
2.2 Levitation, Guidance, and Propulsion	$11.8 M/mile *
2.3 Power Distribution and Conditioning	$14.3 M/mile *
2.4 Communication and Control	$6.4 M/mile *
2.5 Energy Cost/Passenger/mile	$ 0.0035
3. OPERATION & MAINTENANCE COSTS	$3.67 (Cost/vehicle-mile)





* Costs Are For Double Track System Based on the "Primary Alignment

23

GENERAL ATOMICS

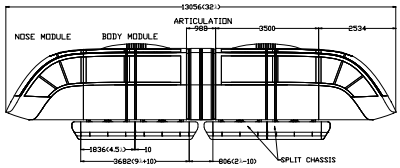
12. Summary of System Characteristics

I. Operational Characteristics

- Max. Operation Speed – 50 mph (100mph goal)
- Max. Initial Acceleration – 1.6 m/s^2
- Service Brake Max. Deceleration - 1.6 m/s^2 (standing); 2.5 m/s^2 (seated)
- Emergency Brake Max. Deceleration – 3.6 m/s^2
- Max. Gradient – 7% (10% goal)
- Min. Horizontal Curve Radius – 50 m (18.3 m goal)
- Min. Vertical Curve Radius – 1,000 m
- Max. Super-Elevation Angle – 6 degrees
- Passenger Capacity (One Car) – 100 passengers
- Temperature - minus 26F to plus 122F
- Max. Wind Speed (Operational) – 50mph (ride comfort limited)

II. Vehicle Configuration

- Modular construction
- Nominal vehicle consists of 2 chassis units
- Chassis units can be connected to obtain desired vehicle length
- Magnetically coupled cars operate as a train
- Nominal (2-chassis) car body length – 13 m
- Car width – 2.6 m
- Car height – 3 m
- Rail Gauge – 1.7 m
- Vehicle weight (empty) – 12 Metric Tons
- Vehicle weight (75% loaded-AW2) – 17.6 Metric Tons
- Car body structure – fiberglass
- Chassis structure - aluminum



24

GENERAL ATOMICS

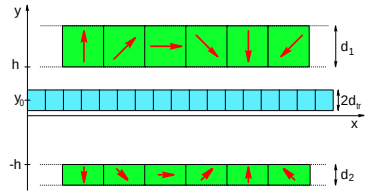
System Characteristics Data Sheet (cont'd)

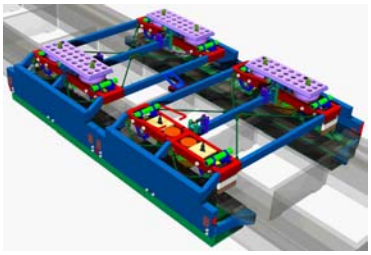
III. Levitation and Guidance System
- NdFeB permanent magnets arranged in Halbach array
- Levitation gap – 25 mm

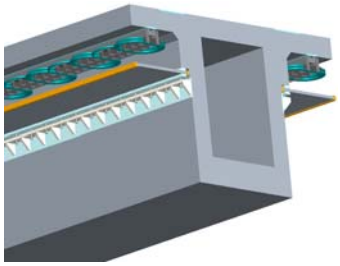
IV. Propulsion System
- Linear Synchronous Motor (LSM)
- IGBT-based variable frequency inverter

V. Suspension System
- Secondary suspension – air bags and MR dampers
- Module frame – 6061-T6 aluminum

VI. Brake System
- Service brake – LSM
- Emergency brake – electromagnetic
- Parking brake – permanent magnet







25

GENERAL ATOMICS

WORKSHOP GOALS	GENERAL ATOMICS SYSTEM - LESSONS LEARNED
Status of GA Urban Maglev program, research findings, recommendations, standards used or developed, and other pertinent information.	• Concept and prototype development completed. • Detailed Requirements Document published for Urban Maglev deployment. • Test track construction completed. • Testing on-going. • Received R&D 100 award for one of the leading technology developments for 2004.
Lessons learned from the approach taken.	• Full-scale hardware is cost-effective and strong building blocks for deployment. • Use of safety-certified ATP system enhances early deployment. • All-weather operation requires use of non-optical sensors. • Vehicle control system development requires much dedication and commitment. • Team capabilities should encompass all aspects of transportation.
Future needs of research in low speed urban maglev technology.	• Extended testing • Second chassis with articulation • All-weather position sensing • Block switches • Inductive housekeeping power pick-up system • Elevated hybrid girder • Laminated track • Optimized magnet configuration • Vehicle body
Readiness of system for deployment and application in the industry.	• Ready to start demonstration system at CUP in 2007 with 3.5 year construction period for Projects 1 and 2.
Identify research results that may be transferable to, and useful in improving, rail transit operations.	• Use of LSM propulsion for wheeled vehicle transport results in lighter, more efficient, and expandable high throughput system. • Electrical architecture based on fixed block system is inherently safe; only one train per powered section. • Fiber-reinforced hybrid girder can lead to significantly lighter and cheaper elevated system. • Inductive pick-up system can lead to non-contacting power for vehicle housekeeping systems. • Dual-use guideway (existing rail and maglev) can be configured. • Modular pulsed electronic propulsion and control system off DC bus with regenerative braking.

26

GENERAL ATOMICS

California University of Pennsylvania
Maglev Demonstration System

Dr. Allan Golden

FTA Low Speed Urban Maglev Workshop

September 8-9, 2005

California University of Pennsylvania Maglev Demonstration System

Dr. Allan Golden

FTA Low Speed Urban Maglev Workshop

September 8-9, 2005

Sponsored by
Federal Transit Administration
1710 SAIC Drive
McLean, VA 22102

California University of Pennsylvania

Maglev at California University of Pennsylvania Background

- Jan. 2001 – PennDOT Deputy Secretary Rick Peltz expressed interest in the GA Urban Maglev program and requested briefing.
- Mar. 2001 – GA briefed PennDOT Secretary Brad Mallory.
- Nov. 2001 – GA proposed Urban Maglev to CUP, with PennDOT support. CUP President Dr. Angelo Armenti agreed to host the demonstration site using the GA system.
- CY 2003 – The Commonwealth of Pennsylvania approved $40M State budget to be designated for the CUPSS cost share.
- May 2003 – GA briefed incoming PennDOT Secretary Al Biehler.
- Jan. 2004 – PennDOT provides $1M for Project 1 engineering activities using the GA technology.
- CY' 2004 – GA team prepares design/plans for Project 1 piers, foundations, stations, maintenance facility, and electrical systems
- Nov. 2004 – GA briefed CUP and PennDOT on status of maglev development.

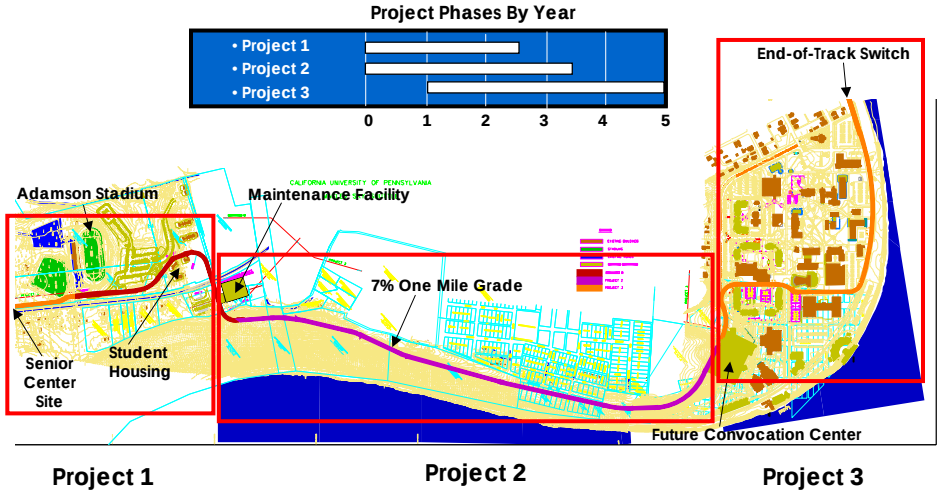
California University of Pennsylvania

Background (cont'd)

- Jan. 2005 – CUP executes MOA with GA to manage project.
- May 2005 – CUP selects Delta Development to provide project oversight to the University.
- FY '04 – U.S. Congress earmarks $2.0 M for "California University of Pennsylvania Shuttle System (CUPSS)".
- FY '05 – U.S. Congress earmarks $2.5 M for "California University of Pennsylvania Urban Maglev".
- SAFE-TEA LU (FY '06-'09) – U.S. Congress earmarks $4.0 M for "California University of Pennsylvania Urban Maglev"

California University of Pennsylvania

Current Sky Shuttle Alignment



California University of Pennsylvania

Project 1 Views

South Grand Stand

James Adamson Stadium – seen from State Route 88

Future Passenger Station

California University of Pennsylvania

Maintenance Facility, Parking Garage & Passenger Station Sites

Looking West

Looking South at Edwards St.

California University of Pennsylvania

Adamson Stadium to Upper Campus Housing

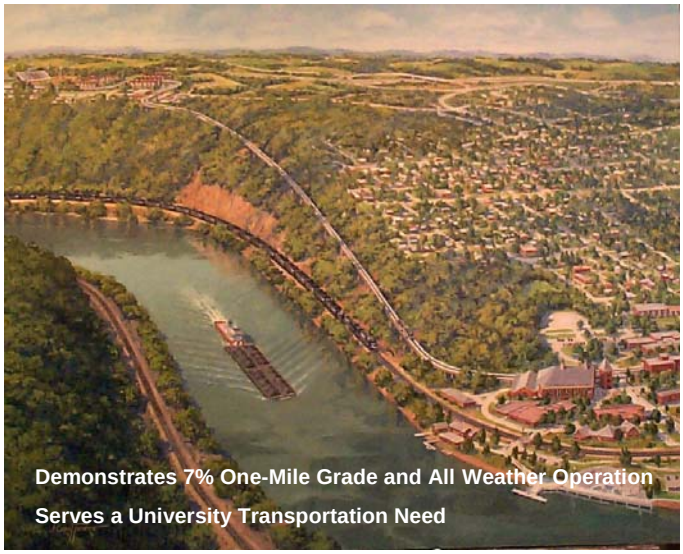
California University of Pennsylvania

Project 2 Views Down the Bluff

Monongahela River Valley

California University of Pennsylvania

Adamson Stadium to Main Campus



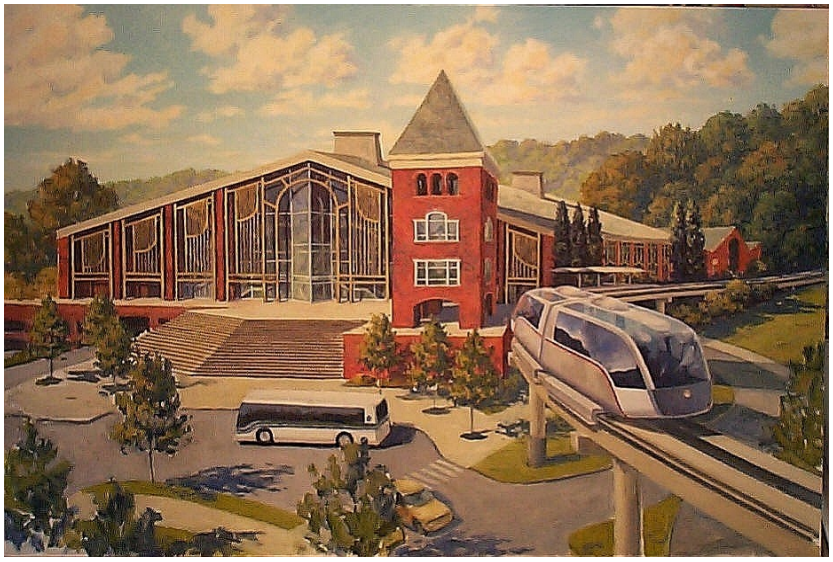
California University of Pennsylvania

Project 3 Starting Point

Future Convocation Center Site

California University of Pennsylvania

Convocation Center to Main Campus and California Borough



California University of Pennsylvania

California University Master Plan

The University Master Plan Includes Maglev to Provide:

- Safe transportation
- All-weather operation
- Ability to serve future convocation center events
- Eliminates significant on-campus parking.

California University of Pennsylvania

Maglev Benefits to California University

- CUP is a great site for demonstrating maglev:
  - 7% grade
  - All-weather
  - Quiet operation
  - Low O&M cost
  - Tight turning capabilities
- Serves much needed transportation function for the campus and the Borough of California
- Unique, innovative, progressive technology
- PennDOT interest and support for the project
- Economic development for Western Pennsylvania, new industry for "rust belt"
- Recognition for the university, leading to new curriculum in technology, business, marketing, economic studies, etc.

California University of Pennsylvania

Concluding Comments

- California University of Pennsylvania Campus Master Plan includes urban maglev.
- The timely release of funds is greatly appreciated.

California University of Pennsylvania

Colorado Maglev Project

Dr. Gopal Samavedam
Group Director
Foster-Miller, Inc.

September 8, 2005

COLORADO MAGLEV PROJECT

Dr. Gopal Samavedam
Group Director
Foster-Miller, Inc.

September 8, 2005

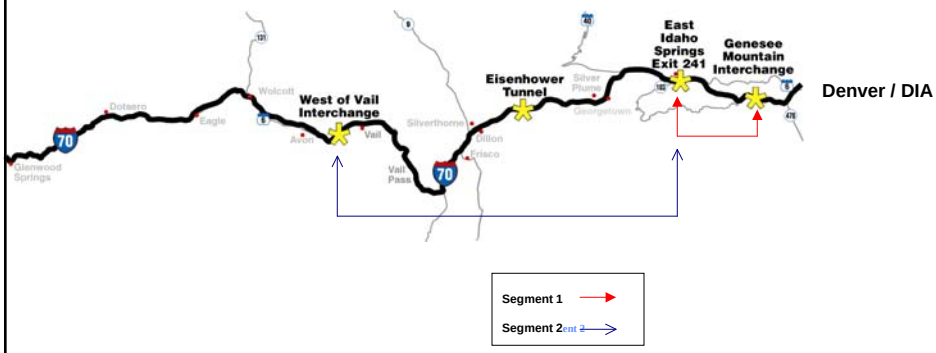
CDOT Team: CDOT, MTG, T.Y. Lin, Sandia, CHSST and others

Colorado Maglev Project Goals

- **Primary Goal is to Assess Urban Maglev Systems Benefit from DIA to Eagle County Airport**
- **Team Focus on** DEPLOYABILITY
  - **Identify Critical Development Gaps**
  - **Identify Technical Obstacles to Overcome**
- **Deployability Success Rests on Technical Feasibility and Cost**
  - **Cost Determines System Viability**

Colorado Maglev Project

Interstate 70 Route Alignment



Colorado I-70 Maglev Project

I-70 Eastbound Toward Georgetown

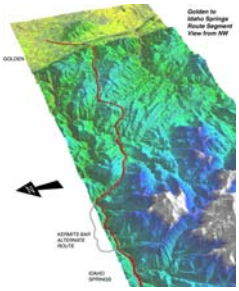
I-70 Westbound at Eisenhower Tunnel

Colorado Maglev Project

Project Issues

- Congestion
  - Economic Impact to State
- Topography
  - Mountains with Grades and Horizontal Curvatures
- Weather
  - Winter Weather Conditions
- Alignment
  - Right of Way including Tunnels and Major Grades
  - Length
- Cost

Colorado Maglev Project



Suitability of Maglev Technology

- **Capability to Satisfy Project Terrain Challenges**
- **Ability to Meet Operational Needs**

Selection of CHSST as Baseline

- **Applicability to Colorado Project**
- **Only Maglev System Ready for Deployment in the United States**
- **Overall Ability to Meet Near-term Deployability Requirement for Colorado**
- **Projected Cost Containment**
- **Ability to Improve Performance with Minor Incremental Improvements to Propulsion, Levitation and Guideway**

MTG

Colorado Maglev Project
Guideway

Guideway Issues and Costs

- *Guideways Typically Account for **60%** of the system cost.*
- Guideway consists of beams, columns and foundations
- Guideway has the Strongest Visual Impact
- Guideway Construction has the Most Impacts

MTG

Colorado Maglev Project
Vehicle Live Loading Criteria for Guideway Design

General:

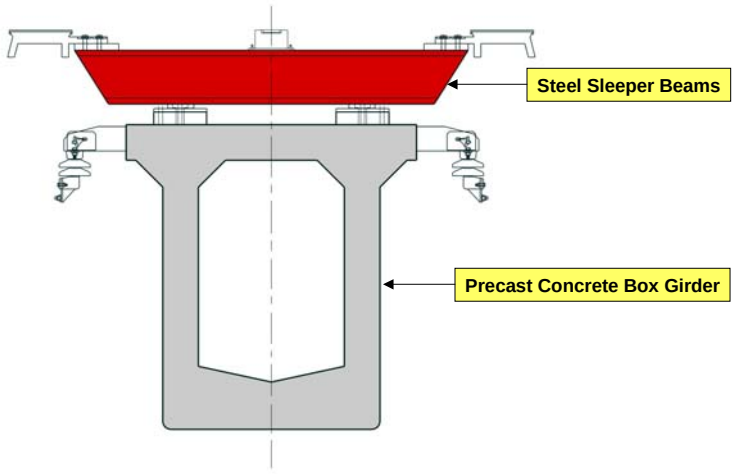
Baseline Maglev Technology:	*Japanese HSST*
Vehicle Type:	*HSST 100 or 200*
Design Speed:	*160 kph*
Track Gauge:	*1700 mm*

Vehicle Live Loading:

Maximum Vehicle Live Loading:	*1,150 kgf/m per rail;*
	2,300 kgf/m per guideway
Live Load Impact:	*24% (Steel Girders);*
	16% (Prestressed Conc. Gird.)
Live Load Deflection:	*L / 1,750*

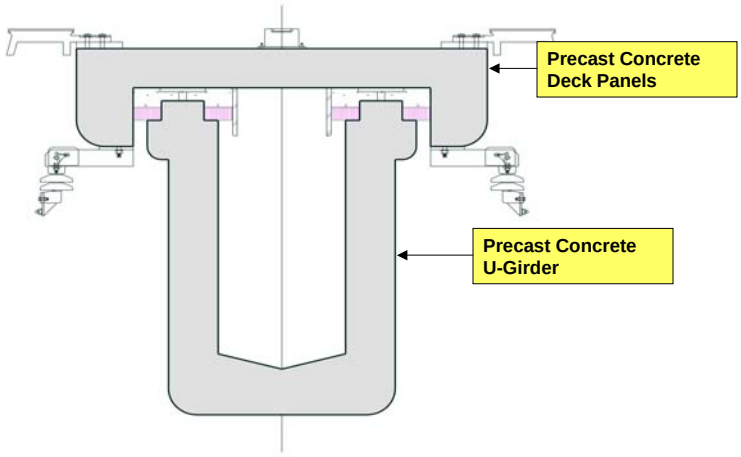
MTG

Colorado Maglev Project
Typical Guideway Section



CHSST

Colorado Maglev Project
Colorado Guideway Types - Precast Concrete U-Girder

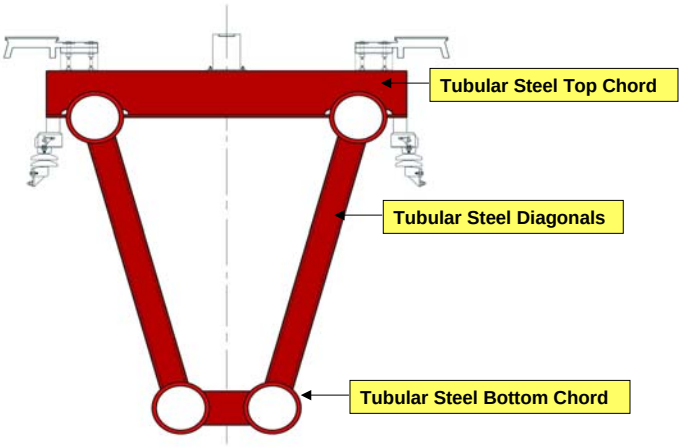


T.Y. Lin

Precast Concrete U-Girder

Colorado Maglev Project

Colorado Guideway Types - Tubular Steel Space Truss



T.Y. Lin

Tubular Steel Space Truss

T.Y. Lin

Colorado Maglev Project

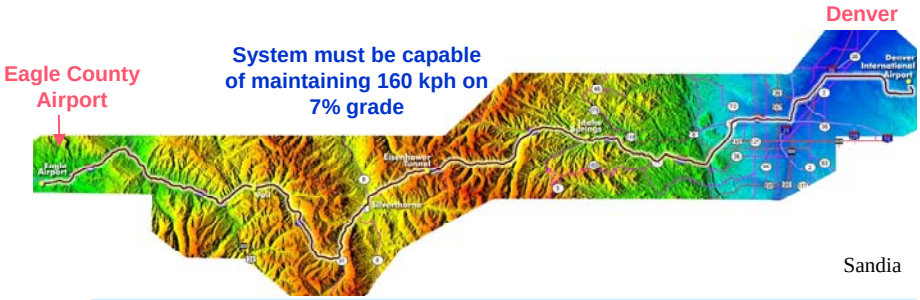
Propulsion Motor

- **The thrust requirements of the 10 LIMs in the 44-tonne, COL-200 vehicle have been defined based upon the requirements for 0.16 g initial acceleration and ability to maintain speed climbing a 7% grade at 160 kph with a 90 kph headwind.**

- **The HSST-200 LIM has been designed for 200 kph operation on shallow grade.**

Propulsion Trade Study Evaluated Options for Linear Motor to Drive Maglev Vehicle

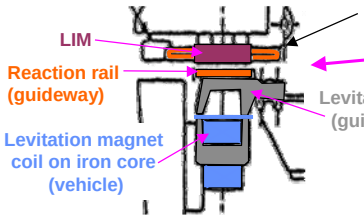
- Specify requirements of motor for COL-200 vehicle.
- Assess electrical power requirements of vehicle.
- Assess improvements to existing LIM technology through simulation.
- Specify on-board power conditioning and motor.

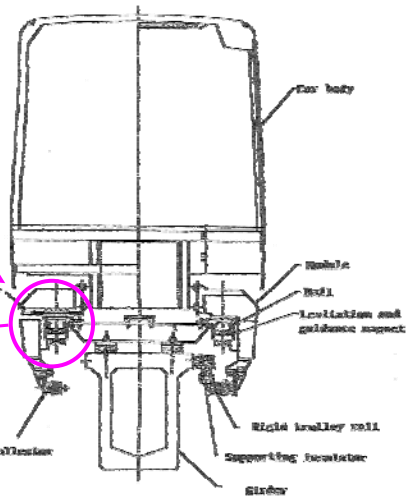


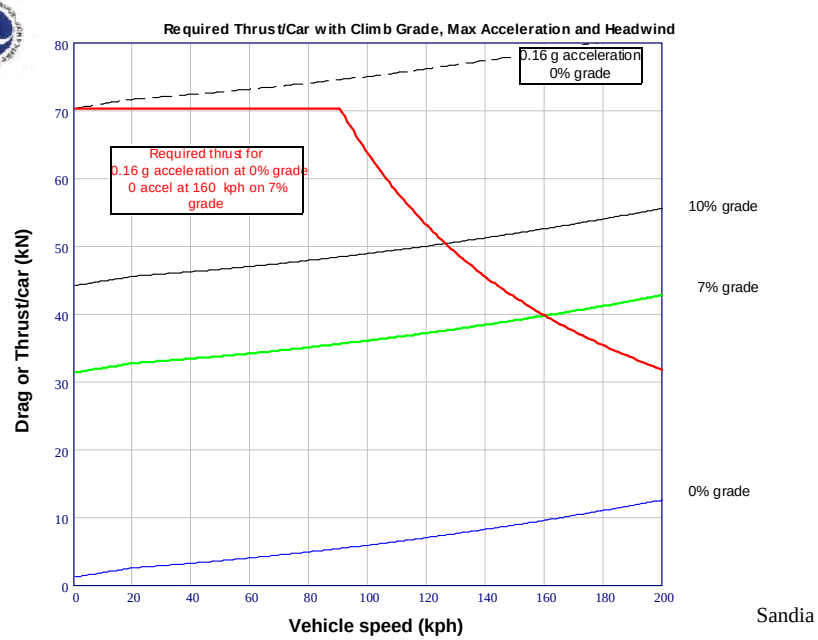
Sandia

Baseline Technology for Design is LIM-driven Chubu HSST-200 Maglev System

Two-car consist HSST-200 maglev



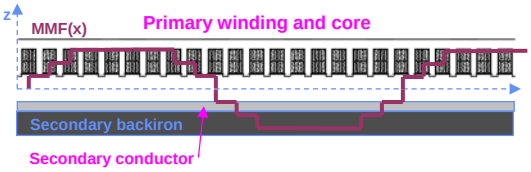


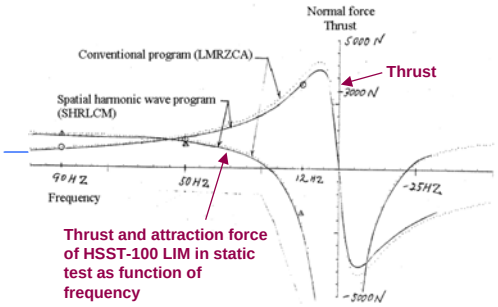


Sandia

LIM Performance Analysis Done in Collaboration with CHSST

- ❖Reviewed design options and analysis methods with CHSST and motor developer.
- ❖CHSST code develops lumped elements for equivalent circuit load to inverters from field analysis based on geometry.
- ❖CHSST code benchmarked with static and low speed testing to within 5-7%.
- ❖Modified code for frequency-sweep evaluation and suggested improvements.
- ❖Evaluated motor improvement options.





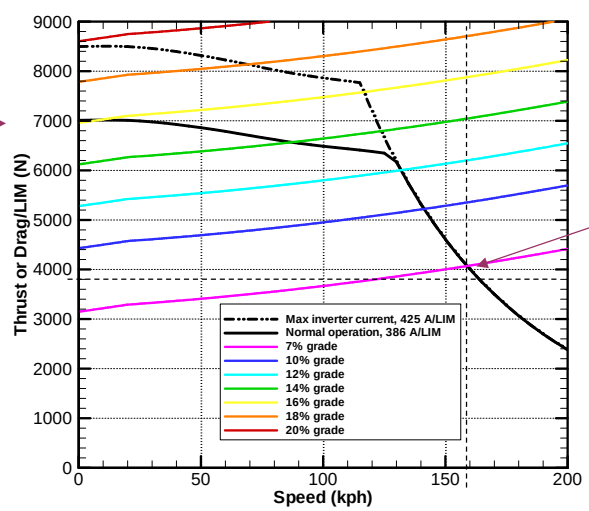
Evaluated Near and Long-term Options to Improve LIM to Achieve Thrust

1. Increasing the maximum voltage per LIM to permit higher "breakpoint" speed.
2. Increase the trolley rail voltage to 3000 VDC.
3. Change the operating point on the motor's thrust vs. slip frequency characteristic curve.
4. Increasing the LIM primary current for a very short duration.
5. Forced cooling to operate at higher, steady-state power, or Cu wire.
6. Decrease clearance gap between the LIM and reaction rail.
7. Utilize solid copper reaction rail only where high thrust needed.
8. Configure the primary windings to allow pole switching.
9. Use double-fed LIM's in regions of track where high thrust needed.
10. Use long-stator LIM in guideway where high thrust needed IN ADDITION to on-board LIM.
11. Incorporate compensation for LIM end-effect .

Sandia

Calculated Performance of 208 kW COL-200 LIM with Improvement Options 1-6

Sufficient thrust for 0.16 g acceleration



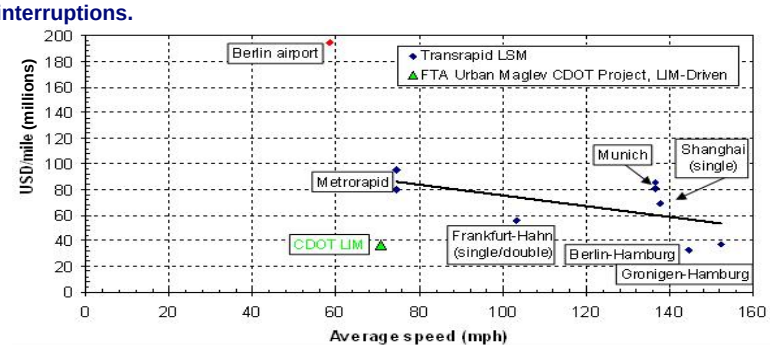
Sufficient thrust to maintain 160 kph on 7% grade

Capable of 230 kph on level grade into 90 kph headwind

Drag forces into 90 kph headwind

LIM-drive Maglev is Better Choice for 200 kph (120 mph) Maglev Project

- Lower capital costs due to simpler guideway components.
- Established technical base since power/operations very similar to induction motor-driven conventional rail.
- Similar energy cost since efficiency to similar Transrapid.
- Higher flexibility to long-term change in ridership and rapid schedule recovery from interruptions.



Sandia

Conclusions

- Cost effective guideway concepts and advanced linear induction motor design are proposed for Maglev technology applications.
- The technology developed for the CDOT Maglev Project is deployable in the U.S. market. The cost of the system is expected to be under $50 million for a two-way mile.
- The range of system costs is highly competitive with other modes of transportation such as LRT and Heavy Rail Systems.

MTG

CDOT System Characteristics

I. Operational Characteristics	
Max. Operation Speed	160 km/h (100 mph)
Max. Initial Acceleration 4.0	1.6 m/sec^2 (.16 g)
Max. Deceleration	
Service Brake	4.0 km/h/s (2.5 mph/s)
Emergency Brake	32 g
Max. Gradient	7% (no degradation) 10% (with degradation)
Min. Horizontal Curve Radius	Side line track 50 m (164 ft)
	Main line track 300 km
Min. Vertical Curve Radius	1000 m
Max. Super Elevation Angle	8°
Passenger Capacity for Two-Car Train	Seated 197 Standing Total 197
Temperature	10°C to 40°C (50°F to 104°F)
Max. Wind Velocity	50 km/h (30 mph) Structure is designed for 140 km/h wind

CDOT System Characteristics

II. Vehicle Configuration	
Train Type and Formation	
(1) Vehicle Type (2) Train Formation	CO 200a Two Cars
Vehicle Dimensions	
(1) Car Body Length (2) Width (3) Height (4) Rail Gauge	24.3m 3.2 m 3.4 m 1.7 m (5'7")
Vehicle Weight	
(1) Empty (2) Fully Loaded	25,370 kkg/car 41,600 kg/car
Car Body Structure	
(1) Material (2) Construction	High Strength aluminum alloy Semi-monocoque
III. Levitation and Guidance System	
(1) Magnet	Ferro-magnet for levitation and guidance (electromagnets)
(2) Levitation Gap	6 mm (0.24") mechanical gap 8 mm (0.32") magnetic gap

CDOT System Characteristics

IV. Propulsion System	
(1) LIM (Linear Induction Motor)	
Quantity	10 LIMs per car
Total Length	1,800 mm (5'11") per one LIM
Secondary	Reaction plate (Aluminum plate on rail)
(2) Power Supply	3000V DC line
Inverter Type	VVVF
V. Suspension System	
(1) Suspension Module	10 flexible pair-modules per car (Module: levitation bogie trucks)
(2) Module Frame	Aluminum alloy
(3) Secondary Suspension	Air suspension
VI. Brake System	
(1) Service Brake	Combination of LIM brake (regenerative or reverse phase) and hydraulic brake (mechanical friction brake)
(2) Emergency brake	Hydraulic brake
(3) Parking Brake	Skids (levitation cut off)

Federal Transit Administration Workshop
September 8, 2005

MAGLEV Presentation
By
Dr. James Powell

Federal Transit Administration Workshop
September 8, 2005

MAGLEV Presentation

By

Dr. James Powell

1

Overview of the Maglev 2000 System

- Extremely safe and reliable system.
- Much lower in cost than existing systems
- Adaptable to existing infrastructure
- Provides common system for Urban/Suburban and High speed Intercity transport with numerous convenient stations
- Construct and test full-size Maglev 2000 components to verify performance and costs

2

Levitation of Maglev 2000 Vehicle

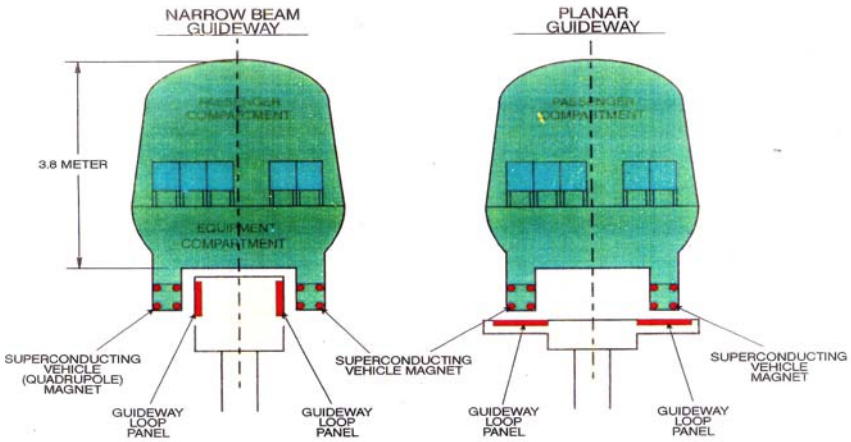
- Vehicle SC magnets induce currents in aluminum guideway loops for automatic levitation with 4-inch gap:
- Levitated vehicle is inherently and strongly stable, vertically and horizontally
- Maglev 2000 quadrupole SC magnets let vehicles travel on narrow beam and planar guideways & electronically switch

3

View of Levitated Maglev 2000 Vehicle

4

View of Maglev 2000 Narrow Beam and Planar Guideways



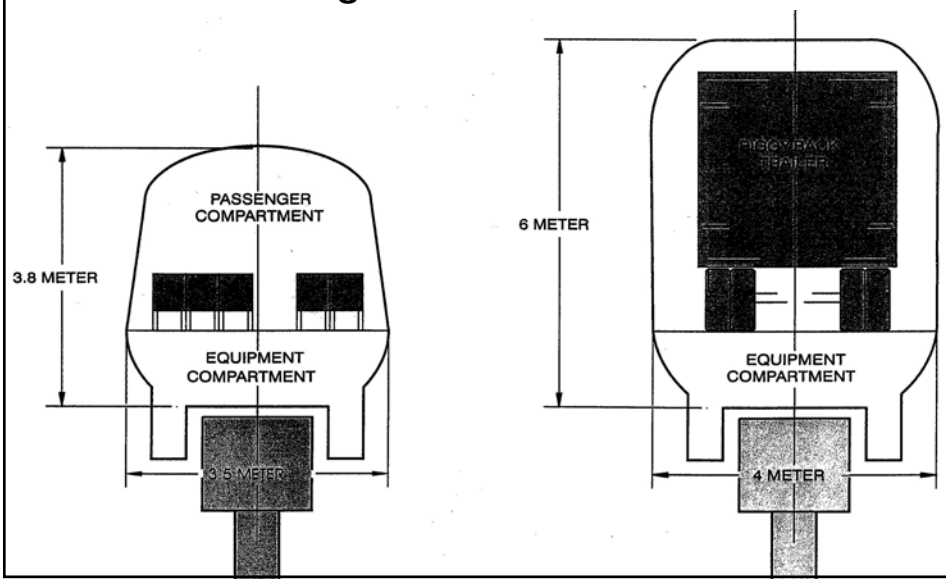
5

Propulsion of Maglev 2000 Vehicle

- Vehicles magnetically propelled and braked by LSM AC current in aluminum guideway loops
- Vehicle speed automatically controlled by AC frequency – not changed by winds, grades, etc.
- Vehicles can accelerate/decelerate like autos – energy use per passenger equals 500 mpg

6

View of Maglev 2000 Passenger and Freight Vehicles



Stability of Maglev 2000 Vehicles

- Vehicles inherently stable both vertically and horizontally against any external force
- Vehicles also stable against pitch, roll, and yaw
- Active control system not needed for stability

8

Safety of Maglev 2000 System

- Loss of stable inherent levitation not possible – Vehicles have many (12 to 16) independent & redundant magnets
- Headway between vehicles controlled by LSM not affected by head or tail winds, up or down grades, etc. – collisions essentially impossible
- Vehicles on elevated beam & pier guideways are isolated from any interference

9

Communications and Control

- Location & Speed of vehicles transmitted to central facility in real time using 2 independent systems
  - Vehicles sense “signposts” along guideway
- Central facility controls speed and location of individual vehicles on guideway and take vehicles off-line if repairs needed

10

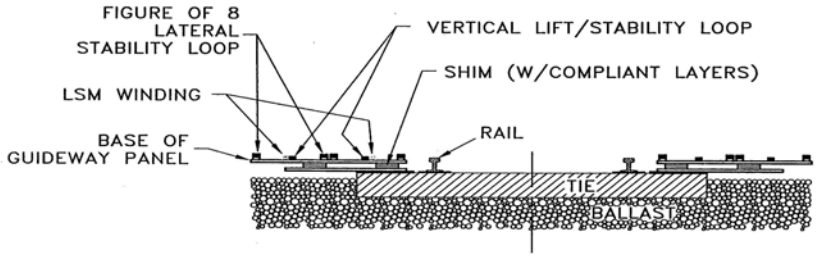
Key Maglev 2000 Innovations

1. Quadrupole superconducting magnets enables travel on narrow beam & planar guideways and very low magnetic fringe fields
2. Mass produced, prefabricated enables a low cost rapidly erected guideway
3. Electronic high speed switch to off-line stations at high speeds
4. Truck transport capability (3000 T = 150,000 P)
5. Use of existing railroad tracks for MERRI maglev service

11

View of Maglev 2000 MERRI System

CROSS SECTION OF MERRI TRACK – INSTALLATION OF LSM WINDINGS

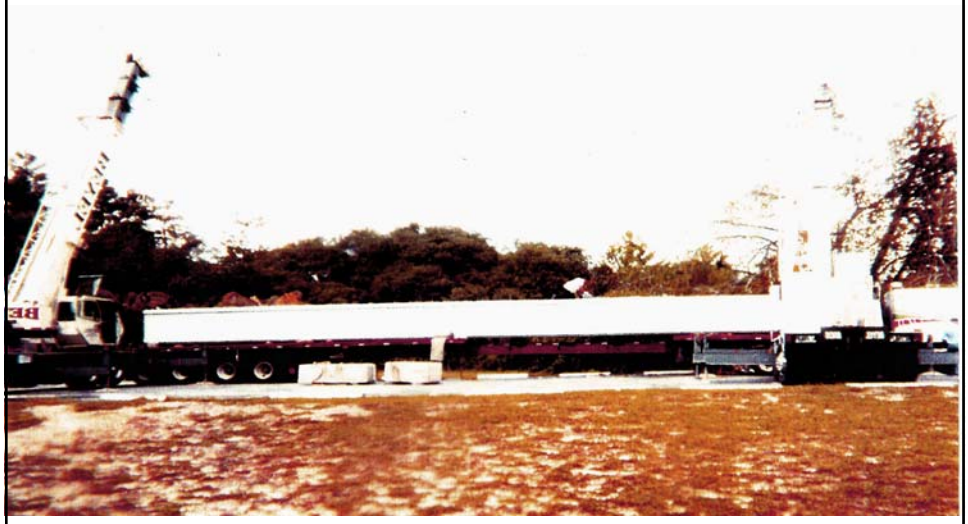


Maglev 2000 Technology Accomplishments

- Fabricated full-scale reinforced concrete box beam for narrow beam guideway systems:
  - 72-feet long, can carry 80,000 # vehicle, calculated center deflection of 1/4 inch
  - Truck transportable (New Jersey to Florida)
  - $42,000 FOAK cost; $25,000 projected cost/beam for large scale production (3.6 Million dollars per 2-way mile)

13

M2000 Test Beam

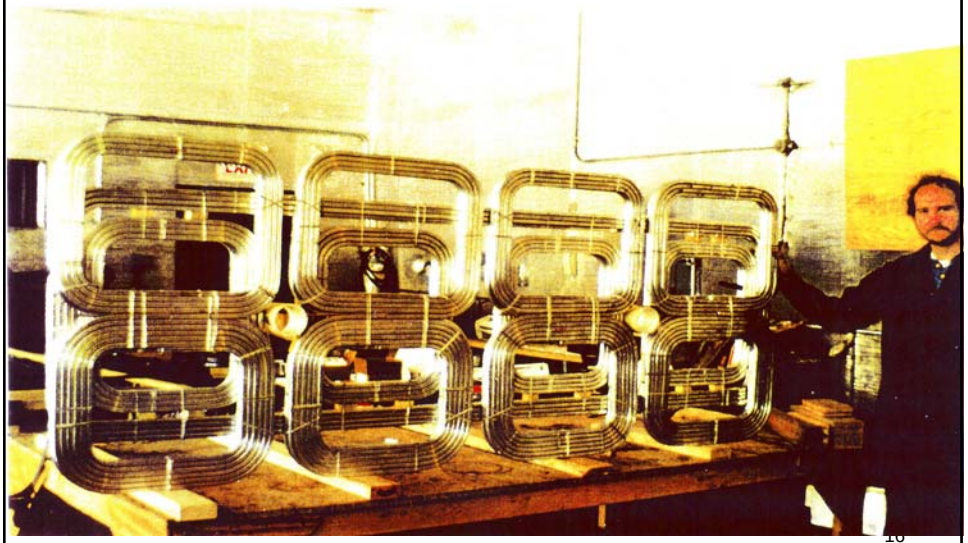


14

- Fabricated full-scale guideway loop assemblies:
  - 9-foot long assembly contained levitation, horizontal stability, and LSM propulsion multi-turn aluminum conductor loops
  - Electrical insulation and current capability verified
  - Assemblies were encapsulated in polymer concrete panels and exposed long term outdoor environment without problems

15

Guideway Loop Assembly



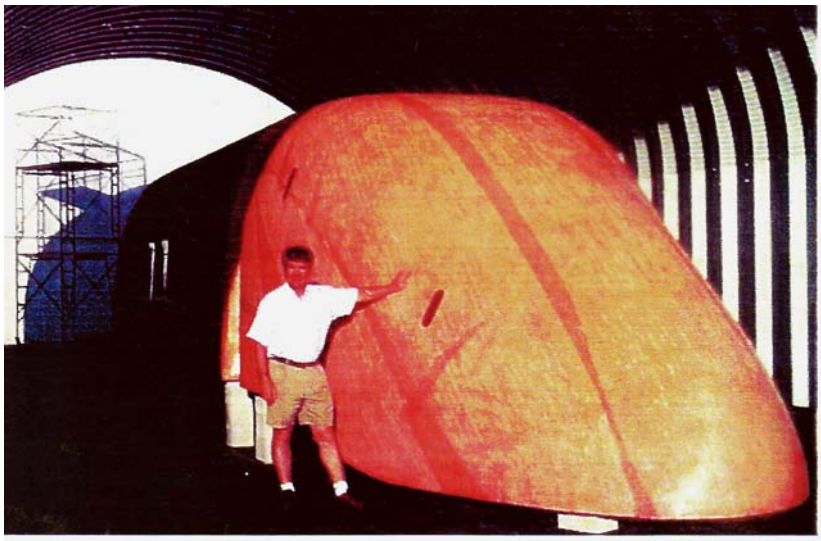
16

- Fabricated 4 full-scale superconducting quadrupole magnets and cryostats:
  - Used Nbti superconductor cooled with liquid helium
  - Verified current capability of 600 kilo amp turns and structural soundness
  - Verified magnet levitation & horizontal stability calculations using energized SC magnet and powered guideway loop

17

SC Magnet Photo

Vehicle Photo-Aeroshell



19

Maglev 2000 Approach to Estimating System Costs (A)

- **Define major subsystems at 1-digit Level (Guideway, vehicle, O&M, etc.)**
- **Break down major subsystems into components at 2-digit level (e.g., guideway components are beams, piers footings, erection, etc.)**
- **Break down components into fabrication steps (3-digit level):**
  - **Project cost for each fabrication step on known material prices, labor time, etc. or best estimate**
  - **Aggregate costs into total cost for component (2-digit level)**
- **Aggregate component costs in total cost of major subsystem (1-digit level)**

20

Summary of Guideway Costs

Two Digit Account Category	20 Metric Ton Vehicle	40 Metric Ton Vehicle
1.1 Guideway Beams	3.60	4.48
1.2 Loop Panels	3.25	3.25
1.3 Footings and Piers	1.11	1.11
1.4 Erect Piers	0.84	0.84
1.5 Power Management and Distribution (PMAD)	1.42	1.42
1.6 Safety Systems	0.16	0.16
1.7 Communication and Control Systems	0.11	0.11
Total	10.49	11.37

21

M2000 O&M Costs Per Vehicle and Passenger Mile

2-Digit Account Category	20 Metric Ton Vehicle @ 60 MPH 50 passengers	40 Metric Ton Vehicle @ 100 mph 100 passengers
Operating personnel	$0.55	$0.33
Energy	0.40	0.36
Maintenance personnel	2.02	2.29
Materials & Equipment		
Total	$2.97	$2.98
Cost per passenger mile (100% capacity factor)	$0.05	$0.03

22

Attachment 3: System Characteristics Data Sheet

I. Operational Characteristics	Compact Urban /// Urban/Suburban
Max. Operation Speed	
Max. Initial Acceleration	0.2G /// 0.2G
Max. Deceleration	0.2G /// 0.2G
Service Brake	0.2G /// 0.2G
Emergency Brake	0.4G /// 0.4G
Max. Gradient	15 Degrees /// 15 Degrees
Min. Horizontal Curve Radius	1000 feet /// 2000 feet (Low Speed)
Min. Vertical Curve Radius	1000 feet /// 2000 feet (Low Speed)
Max. Super Elevation Angle	10 Degrees /// 10 Degrees
Passenger Capacity for One-Car Train	Seated 50///100 Standing 0///0 Total 50///100
Temperature	-40˚ to +40˚ C /// -40˚ to +40˚ C
Max. Wind Velocity (operational)	75 mph /// 75 mph

23

II. Vehicle Configuration	
Train Type and Formation	
(1) Vehicle Type (2) Train Formation	Magnetically Levitated and Propelled Vehicles can operate individually or coupled together
Vehicle Dimensions	
(1) Car Body Length (2) Width (3) Height (4) Rail Gauge	(1) 66 feet /// 100 feet (2) 11 feet /// 11 feet (3) 10 feet /// 10 feet (4) NA
Vehicle Weight	
(1) Empty (2) 75% Loaded (AW2)	(1) 43,000 lbs /// 60,000 lbs (2) 52,000 lbs /// 80,000 lbs
Car Body Structure	
(1) Material (2) Construction	Aluminum Undercarriage with attached fuselage

24

III. Levitation and Guidance System	
(1) Magnet (2) Levitation Gap	(1) Superconducting (2) 4 Inches
IV. Propulsion System	
(1) LSM (Linear Synchronous Motor)	(1) 300 foot energized block
(2) Power Supply Inverter Type	(2) 60 Hz Power Cable 60 Hz AC/DC /Variable Frequency AC
V. Suspension System	
(1) Suspension (2) Module Frame (3) Secondary Suspension	(1) Induct8ive 2/superconducting magnets (2) Aluminum undercarriage (3) Pressurized air
VI. Brake System	
(1) Service Brake (2) Emergency brake (3) Parking Brake	(1) LSM Brakes (Vehicle) (2) Guideway resistive loops (3) Locked wheels

25

Achievements

- Full size prototype guideway beam fabricated at acceptable cost –design is practical
- Full size prototype aluminum guideway loops fabricated and encapsulated in polymer concrete at acceptable cost—design is practical
- 4 full-size prototype SC quadrupole magnets and cryostats were fabricated—design is practical
- Full size vehicle aluminum undercarriage and wooden fuselage were fabricated

26

Achievements

- 2 full-size SC Magnets were successfully operated.
- Force measurements between SC magnets and powered guideway loops agreed with 3D computer predictions.
- Guideway loop tests demonstrated electrical and weather operability (2-year outside exposure).
- Fabrication of full size prototype Maglev 2000 components has validated projected ~ 15 million dollars per 2-way mile.

27

Achievements

- Fabrication of full size prototype Maglev 2000 12. Common Maglev 2000 technology enables seamless system for urban, urban/suburban, and intercity service
- Large clearance, heavy lift, inherently levitated, highly stable Maglev 2000 system is practical

28

Lessons Learned

- Levitation test of front end of Florida vehicle postponed due to magnet damage in transit. Small air leak into cryostat prevented reaching SC state. As a result, more robust cooling system designed and fabricated.

- New cryocoolers enable much simpler cryostat plumbing and refrigeration for thermal shields – second set of 2 SC magnets has been redesigned to use cryocoolers.

29

Lessons Learned

- New high temperature SC are becoming available at acceptable cost – eliminates liquid helium cooling and enables much simpler and cheaper magnet.
- Levitation demonstration of Florida vehicle prevented by unexpected de-obligation of State funding for program
- Maglev 2000 development presently being self-funded
- Seeking new funding sources, private and/or public, seems to be difficult in the present climate in the U.S.

30

Future Plans

- New funding sources will enable
  - Levitation demonstration of full vehicle at zero speed
  - Fabrication of Maglev 2000 magnets using high temperature superconductor
- Maglev 2000 is currently seeking additional funding for facility for vehicle running tests – first step is 1-mile guideway

31

MUSA Maglev Project

Pierre Brunet
Earthtech

MUSA Maglev Project

Pierre Brunet
Earthtech

An Application of the Chubu-HSST Maglev System

FTA Urban Maglev Transit Technology Development Program

Objective

- To develop a cost effective, reliable and environmentally sound transit option for urban mass transit

Chubu HSST System

- Tested and Ready for Commercial Use

MUSA's Project Objectives

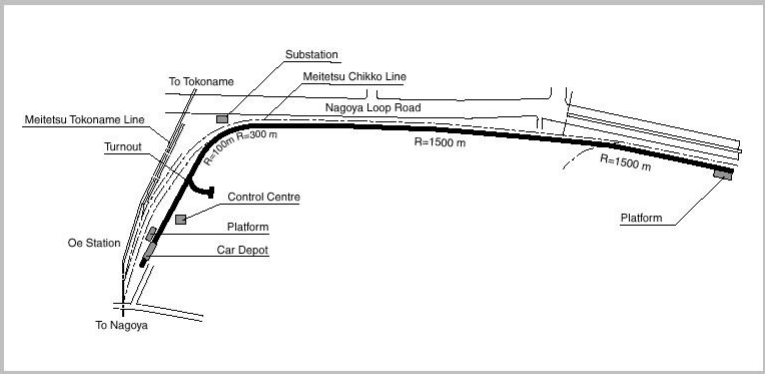
- Investigate the Adaptability of Japanese Low Speed Maglev Technology for a US application
- Comparison of Technical Specifications and Performance Criteria
- Modification and Recommendations to Meet American Standards
- Commercialization Plan

Chubu HSST Development Corporation

- 1972: High Speed Access to Airport
- 1978: HSST-01, 307.8 km/hr (190 mph)
- 1985-1989: Demonstration at Expos
- 1991: Nagoya Test Track
- 1993: Ministry of Transport
- 2005: Tobu Kyuryo Line in Aichi Prefecture

1991: Nagoya Test Track

Figure 4 HSST-100 Test Track



Total Length 1.5 km

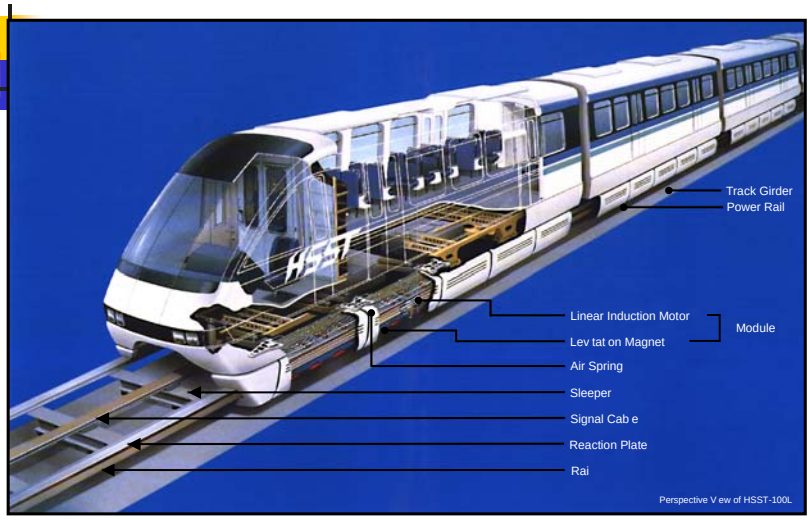
Minimum Radius 100 m

Maximum Grade 7%

1 - Guideway Switch

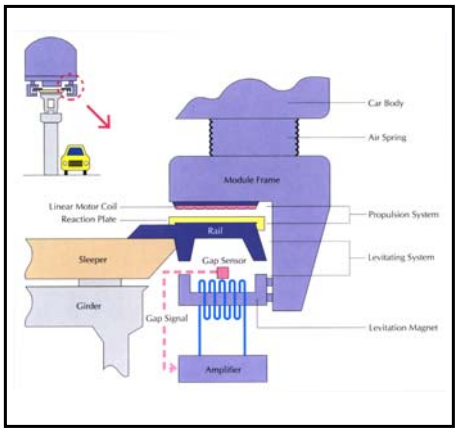
Photos by Masatoshi Sakamoto

HSST-100L



Chubu-HSST MAGLEV

How Does it Work?



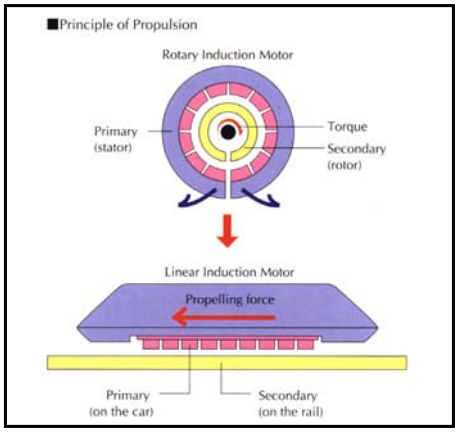
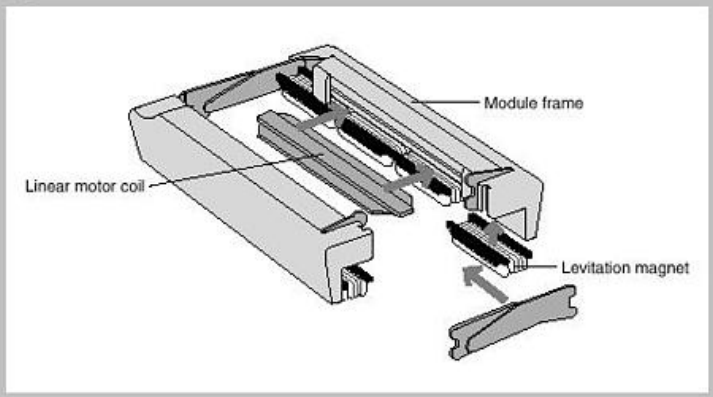


Figure 3 HSST Module Construction



Advantages of the Low Speed Maglev System

- Route Adaptable

  7% Grades with No Power Loss
- Environmentally Friendly

  Reduced Noise and Vibration

  No Emissions
- Economically Competitive

  Construction Cost

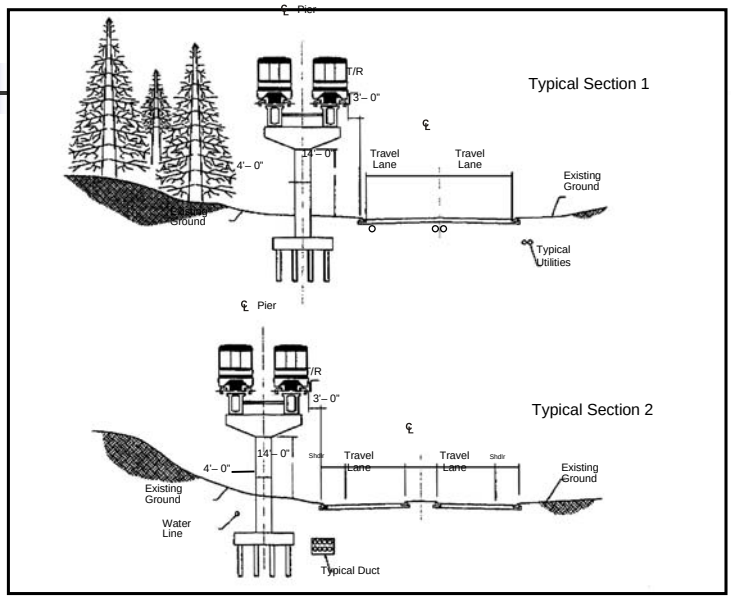
  Maintenance Cost

Vehicle Performance

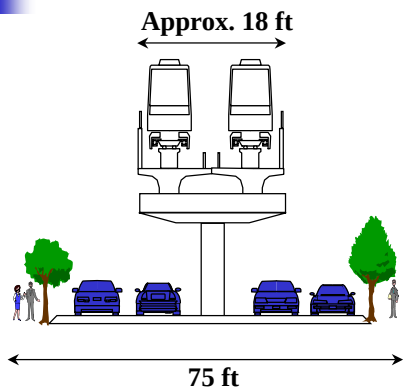
Maximum Speed:	60 mph (100 km/h)
Maximum Acceleration:	2.5 mph/sec (4.0 km/h/sec)
Maximum Deceleration:	2.5 mph/sec (4.0 km/h/sec)
Emergency Deceleration:	2.8 mph/sec (4.5 km/h/sec)
Minimum Curve Radius (Horizontal):	250 ft (75 m)
Minimum Curve Radius (Vertical):	6,000 ft (1,500 m)
Maximum Gradient:	7 %
Maximum Superelevation:	8 degrees

Vehicle Sub-Systems

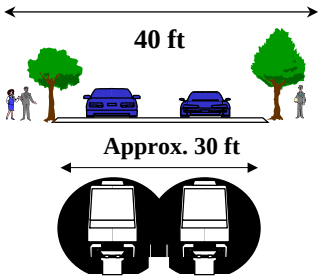
Car Body Structure:	Aluminum Alloy
Suspension:	"Module" System Air Spring as Secondary
Levitation & Guidance:	EMS (Electro-Magnetic Suspension)
Propulsion:	LIM VVVF Inverter (IGBT)
Braking:	Electrical Brake (as primary) Hydraulic Brake (as back up)
Train Control:	ATC
Operation:	ATO



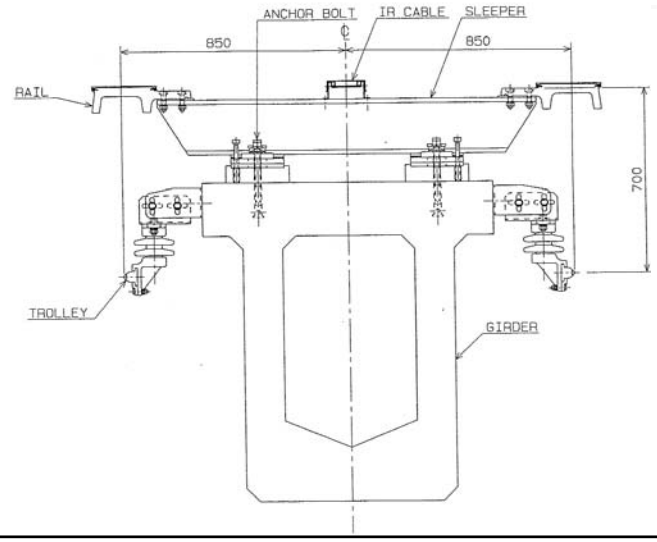
Guideway Cross Section



Typical Elevated Section



Tunnel Section



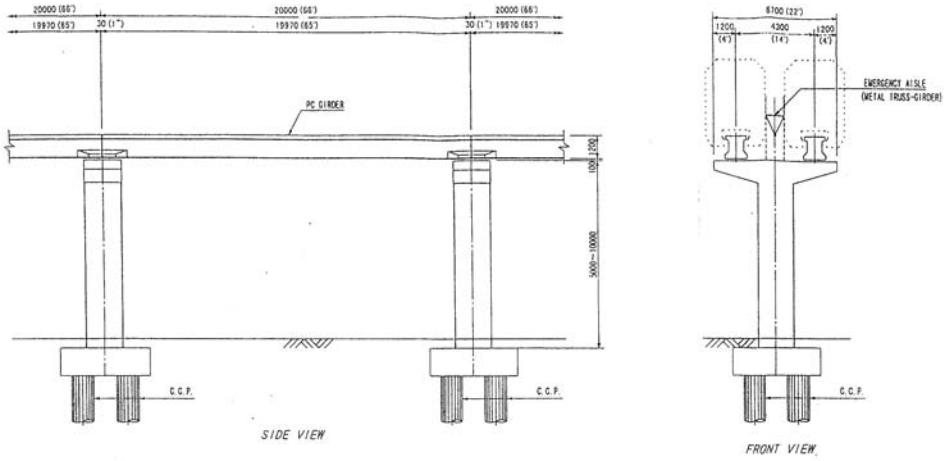


FIGURE 2-5
TYPICAL GUIDEWAY ELEVATION AND CROSS-SECTION

LIMITING FACTORS TO CURVE RADII

- Horizontal Curve Radii
  - Lateral module linkages
  - Clearance between mechanical brakes and rail
  - Construction tolerances to which reaction rail installed and maintained
- Vertical Curve Radii
  - Vehicle length
  - LIM module length
  - Speed of train through curve

SWITCH DESIGN

- Current CHSST Design
  - Segmented Switch
  - Crossover/Scissors Switch
- Alternative Switch Design
  - Beam Replacement Switch

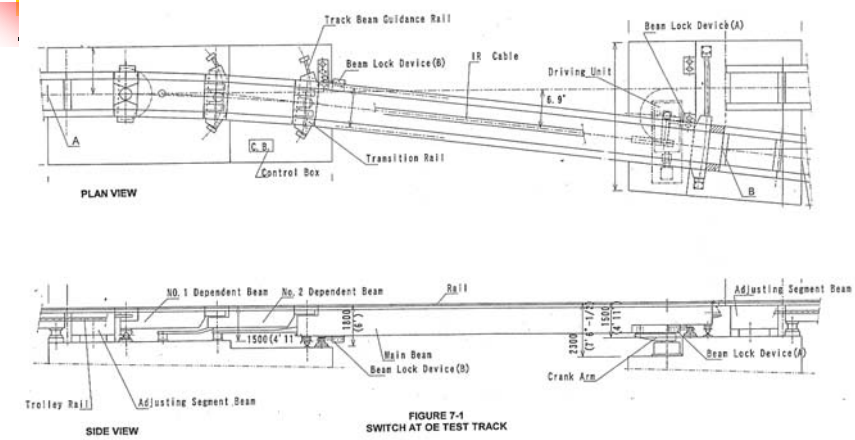


FIGURE 7-1
SWITCH AT OE TEST TRACK

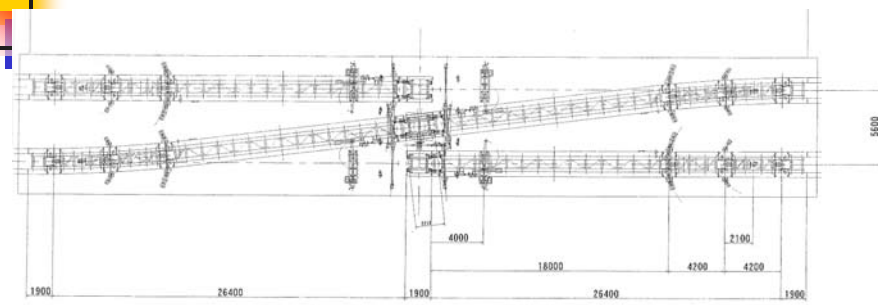


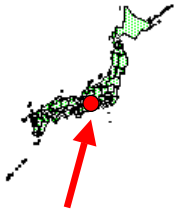
FIGURE 7-4
CROSSOVER / SCISSORS SWITCH

POTENTIAL GUIDEWAY IMPROVEMENTS

- Rail Fixation Method
- Foundation Design
- Design and Construction Approach
- Efficiency of Construction
- Fabrication and Construction Tolerances
- Vehicle Weight
- Value Design

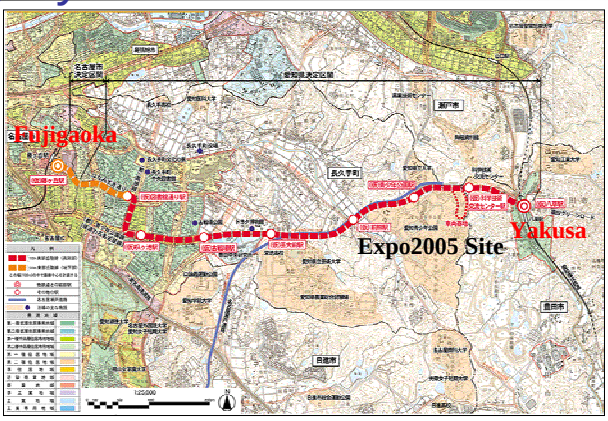
UPCOMING OPERATING SYSTEM

Tobu Kyuryo Line



City of NAGOYA,

Aichi Prefecture



Linimo Route Plan

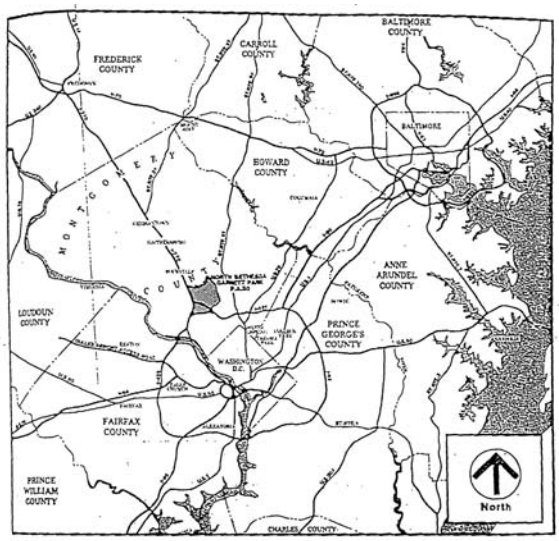
Route Length:	5.6mile (Double track) (From Fujigaoka to Yakusa)
Guideway Type:	Tunnel: 1 mile, Elevated: 4.6mile
Number of Trains:	8+1 trains (3 car train)
Train Capacity:	402 pass/train, 1.5 ft2/pass
Number of Stations:	9
Trip Time (One way):	Approximately 15 min.
Headway:	6 min. peak, 10 min. off pk
Demand:	30,000 passengers/day
Peak Demand:	3,500 passenger/hour/way

Commercialization Plan

North Bethesda Transitway
Corridor

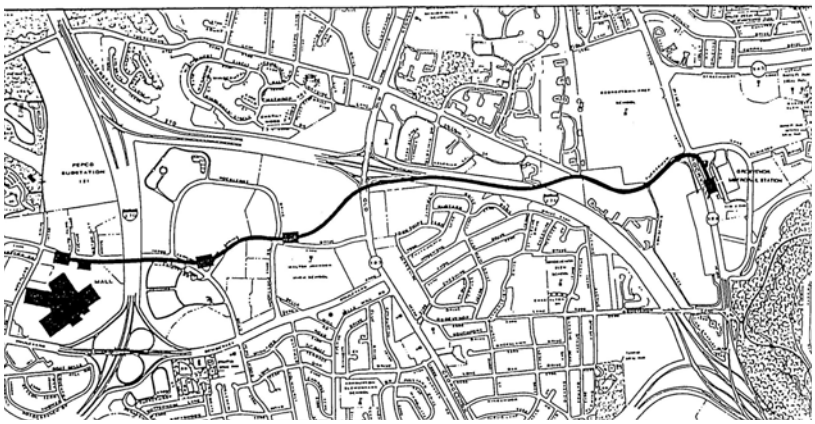
Based on the Final North Bethesda Transit Study

Chapter Dated December 1992
Prepared by Douglas & Douglas
FTA Report No. MD-03-4500



REGIONAL LOCATION MAP Figure 6-1 Regional Location Map

Integration of the Chubu HSST Urban Maglev to link the Montgomery Mall to the WMATA Grosvenor Metrorail Station with two intermediate stations for local employment centers.



Capacity

From 1992 forecasts of 15,447 passengers per day, 70% are peak am and pm periods or 10,819 total or 5,406 passengers per peak period. Peak period would last 2 hours.

5,406 over 2 hours or 2,700 pphpd. Service level of 4 2-car vehicles would provide 2,900 pphpd at 3.3 minutes headway. A fleet of 5 2-car vehicles.

Passengers per 2-car is estimated at 165 passengers total, at 0.3 sqm/standee

Train Operation Estimates

Station	Length	(Link Speed) Avg. Speed	Link Time) Total Time
1-2	1,310 ft.	18.2 mph	49 sec.
2-5	1,300 ft	18.3 mph	48 sec.
3-4	1,430 ft	21.7 mph	45 sec.
4-5	8,370 ft	34.8 mph	164 sec.
1-5	**12,540 ft**	**17.5 mph**	**351 sec. + dwell 6.61 min.**
			Total Round Trip 13.23 Min.

Note: *Average Dwell Time at Stations 2 & 4 => 20 seconds*
Average Dwell Time at Stations 1 & 5 => 30 seconds

Headway Estimates

# of 2-Car Sets	Headway	pphpd
1	13.23 min.	726
2	6.61 min.	1,453
3	4.40 min.	2,179
4	3.30 min.	2,906
5	2.6 min.	3,632
6	2.2 min.	4,358
7	1.89 min.	5,085

Estimated cost, direct and indirect

$142,408,339 for 2.4 miles, as outlined in the MUSA Report FTA-MD-26-7029-03.8

$51,550,411 per mile

Chubu-HSST System: What's Still Needs To Be Done

- Adaptation of Needed Changes to Meet U.S. Requirements
- Provide a Revenue Generating Environment (U.S. End User!)
- Verification of Capital and Operating Cost Estimates
- Analysis of Tobu Kuyro operation!

The 1st Commercial Application of HSST for FTA Urban Maglev Workshop

By
Michio Takahashi
Chubu HSST Development Corporation
HSST Systems International Inc.

The 1st Commercial Application of HSST

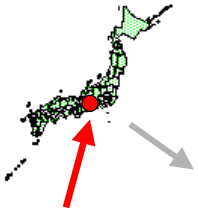
for FTA Urban Maglev Workshop

By
Michio Takahashi

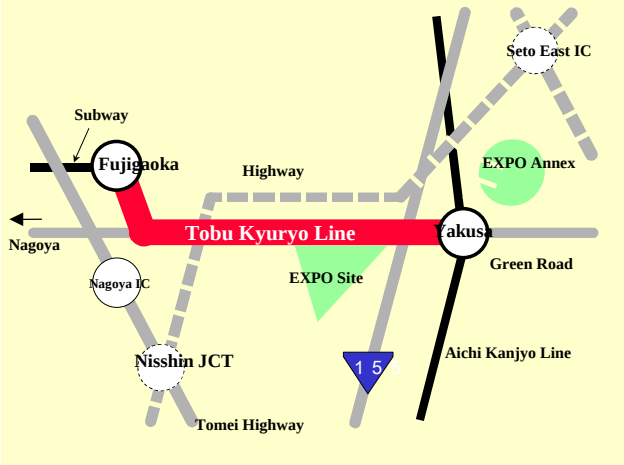
Chubu HSST Development Corporation
HSST Systems International Inc.

Tobu Kyuryo Line [Linimo]

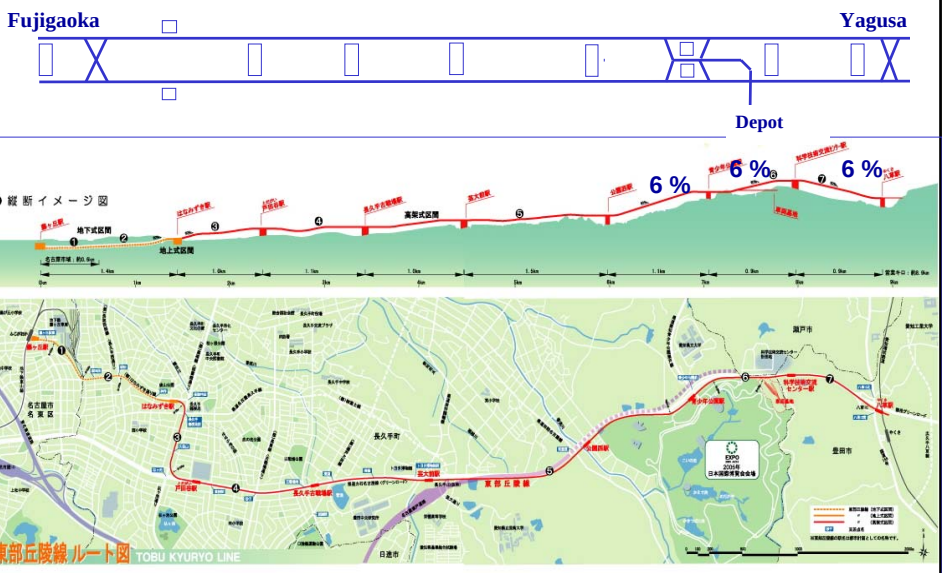
Linimo Route Location



Nagoya, Aichi



Linimo Route Outline



Linimo Route Plan

Route Length:	**5.6mile (Double track)**
	(From Fujigaoka to Yakusa)
Tunnel Section:	**1.0mile**
Elevated Section:	**4.6mile**
Number of Station:	**9**
Demand:	**30,000 passengers/day**
Peak Demand:	**3,500 passenger/hour/way**

4

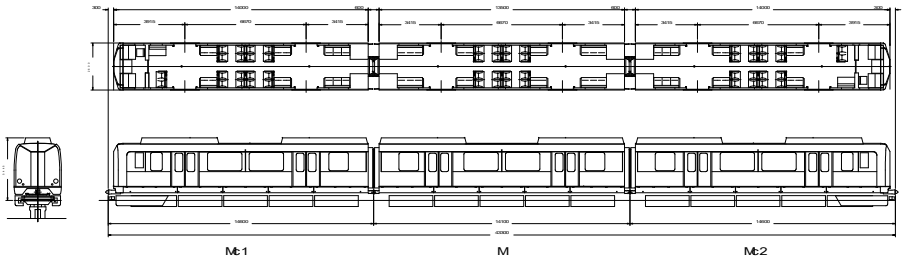
Linimo System Outline

Trip Time (One way):	Approximately 15 min.
Maximum Operating Speed:	65 mile/h
Number of Trains:	8+1 trains (3 car train)
Train Capacity:	402 persons/train (1.5 ft2/person)
	244 persons/train (3.2 ft2/person)
Headway:	6 min. in peak time
	10 min. in off peak time
Operation:	Driverless with ATO
Trolley rail voltage:	1,500 VDC

5

Linimo Vehicle

	Mc	M	Train
No. of Seats	32+2	36	100+4
Standee (3.2 ft2/person)	47	46	140
Standee (1.5 ft2/person)	100	98	298
Capacity (3.2 ft2/person)	81	82	244
Capacity (1.5 ft2/person)	134	134	402



6

Cabin & Driver's Console--Linimo

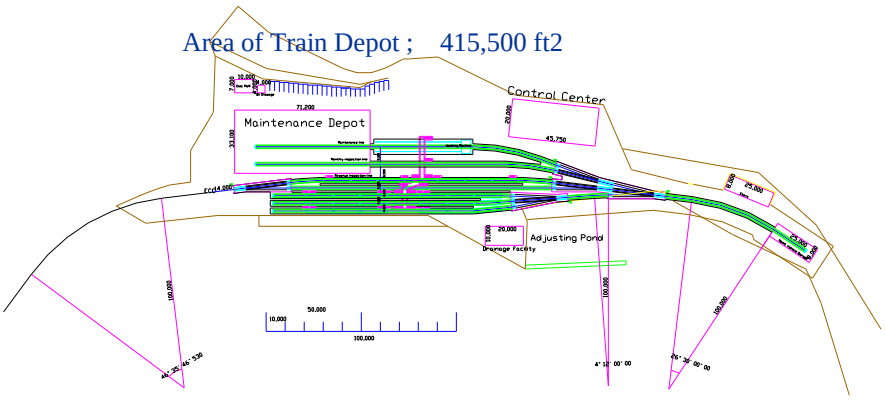
Cabin

Driver's Console

7

Linimo -- Train Depot

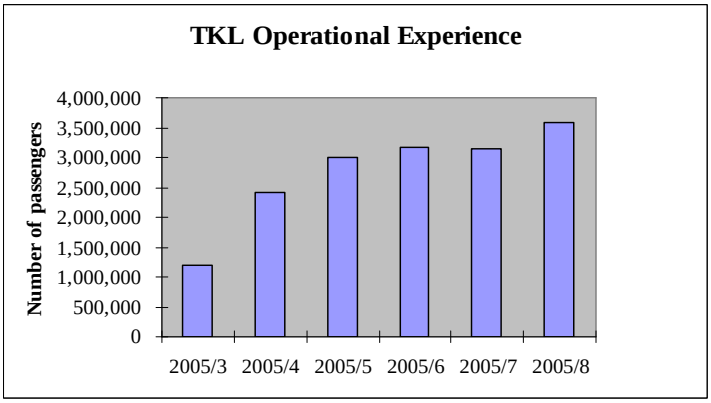
Area of Train Depot ; 415,500 ft2



Plan View of Train Depot

8

Linimo Operational Experience



Total Passengers (2005/3/6 ~ 2005/8/31) : More than 16.5 million persons

Korean Maglev
FTA Low Speed Urban Maglev Workshop

September 8-9, 2005

Korean Maglev

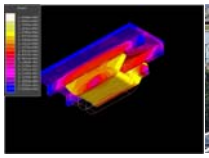
FTA Low Speed
Urban Maglev Workshop

September 8 and 9, 2005

Development Status of Korean Maglev System

Urban Transit Type – 110 km/h level

Development of basic technology	○ '85, Start of development of Maglev system ○ '85 ~ '90, Development of main components and equipment.
Development of complete vehicle	○ '91 ~ '93, the Maglev system(HML-03) for service operation at Daejeon EXPO'93 ○ '94 ~ '02, the Urban Transit Maglev(UTM-01) system and test track(1.3km) by the national R&D project
Development of commercial model	○ '03 ~'06, the Commercial Model Maglev system and Signaling system(ATP/ATO), supported by the government



Main component (Electro-Magnet)

Exposition Model (HML-03)

Urban Transit Model (UTM-01)

Commercial Model (in progress)

I Principles of Korean Maglev

- **Levitation and Guidance**
  Controlled Electro-magnets (U-shaped)
  Attracted to U-shaped track-sided rails
  Combined Levitation and Guidance by same set of Magnets

- **Electrical propulsion**
  Single-sided asynchronous Linear motors,
  Supplied by VVVF Inverters (IGBT Technology)

Model

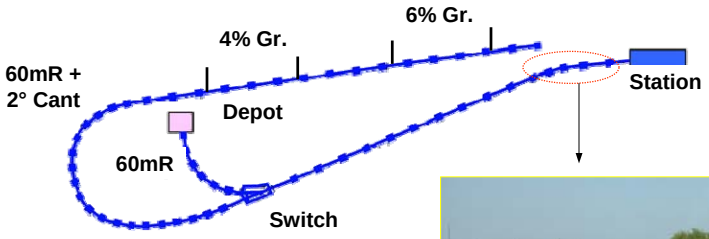
- Service operation for the EXPO'93, Daejeon
- Development Period : Jan. 1991 ~ Nov. 1993
- Result of public operation during the EXPO'93
  - Operating period : 93 days
  - Running distance : 3,010 km
  - Boarding : 120 thousand passengers
- Donated to the government after the EXPO'93 exhibition

ansit Model

- Supporter :
  the Ministry of Science & Technology
  of Korean Government (MOST)
- Development Period :
  - Development : May 1994 ~ Oct. 1999
  - Remodeling : Mar. 2000 ~ Dec. 2002
- Running Distance : 35,000km (July, 2005)

ck for Maglev Development

- Track layout (located in KIMM)



- Specifications :
  - Track length : 1.3 km
  - Min. curve radius : 60 m
  - Max. gradient : 6 %
  - Switching type : Sliding

Next Steps

Vehicle of the MOCIE Project

(Ministry of Commerce, Industry and Energy)

- Specification :

Train Formation	2 cars (Mc1-Mc2)
Vehicle Dimensions	13.5 m (L) x 2.85 m (W) x 3.50 m (H)
Vehicle Weight	Laden : 28.5 t
Passenger capacity	100 Persons / car
Max. Design Speed	110 km/h
Supply Voltage	1,500 VDC

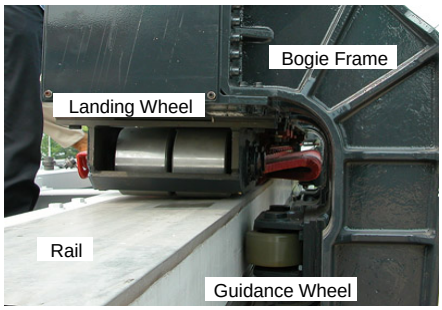
BEING READIED FOR INNOTRANS 04

ommercial Model

- Supporter : the Ministry of Commerce, Industry & Energy of Korean Government (MOCIE)
- Project Period : Oct., 2003 ~ March, 2007
- Operating Start : April, 2007 ~
- Objective : Commercial Application as a driverless system
- Key development Items :
  - 2 vehicles with high performance
  - Signaling(ATP/ATO) system
  - Track / Power Supply

Emergency Door and Ladder

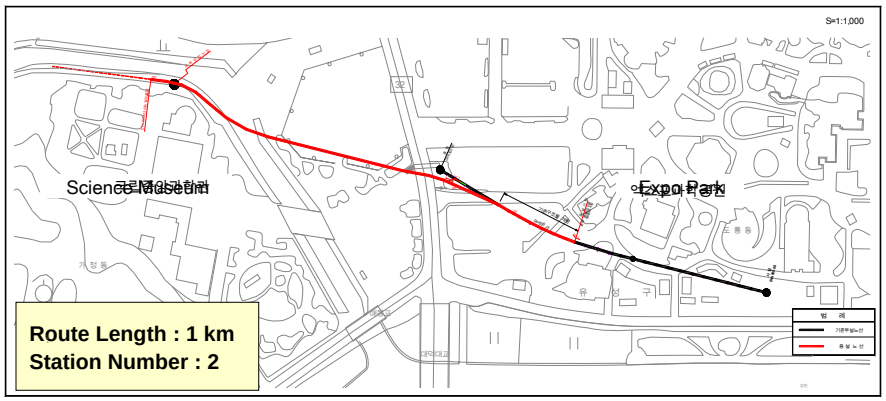
r ncy Landing & Guidance Wheel



The interior has been designed to concentrate upon the urban commuters' convenience and safety. Whole interior fittings such as panel, floor and seats are made of non-combustible material complies with international fire and safety standards.

Route Layout for Commercial Operation

(EXPO park ~ Science Museum in DaeJeon)



Project Schedule for Commercial Model

Items		2005				2006				2007		Remark
		1/4	2/4	3/4	4/4	1/4	2/4	3/4	4/4	1/4	2/4	
Vehicle	Manufacturing											
	Test & Commissioning											at KIMM
Civil	Design											for Daejeon
	Construction											
E&M Works												Signaling Power Supply
Operating Test												at the extended Daejeon Expo track
Operating Start												

Projects under Discussion

Domestic Projects

- Korean Government announced in Dec. 2004 to commercialize Maglev in Korea
- National Project pursued and funded by Korean Government with construction cost amounting up to US$ 450 millions
- Competition between Regional authorities of Kyungnam province, Daejeon city, Incheon, Gwangju. Kyungnam Province schedule : Completion in 2007

Project for Jakarta

- Requirement

- Ridership	10,000 ~ 30,000 pphpd
- Routing	2 Lines, Route Length 14.3 km / 13.5 km
- No. of Stations	28 (Both Lines)
- Track	Elevated, Typical Span Width 30 m
- Schedule	Track Construction to be finished at the end of 2006, Delivery of the 1st Trainset : Beginning of 2007

Summary of System Characteristics for Commercialization

I. Operational Characteristics		
Max. Design Speed		110 km/h
Max. Initial Acceleration		1.0 ㎧
Max. Deceleration	Service Brake	1.0 ㎧
	Emergency brake	1.25 ㎧
Max. Gradient		6 %
Min. Horizontal Curve Radius		60 m
Min. Vertical Curve Radius		800 m
Passenger Capacity for One-car Train	Seated	33 persons
	Standing	67 persons (4 persons/㎡)
	Total	100 persons
Temperature		-25 ℃ ~ 40 ℃
Max. Wind Velocity (Operational)		30 m/s
II. Vehicle Configuration		
Train Formation		Mc1 - Mc2 or Mc1 - M2 - M1 - Mc2
Vehicle Dimension	Carbody Length	13,500 mm
	Width	2,850 mm
	Height	3,530 mm (above the rail)
	Rail Gauge	2,000 mm

II. Vehicle Configuration (Continued)		
Vehicle Weight	Tare	21 ton
	75% Loaded	27.5 ton
Carbody Structure	Material	Aluminum Extrusion and Plate
	Construction	Fabricated by welding
III. Levitation and Guidance System		
Magnet		Electro Magnets, providing combined Levitation & Guidance
Levitation Gap		10 mm
IV. Propulsion System		
Type of Propulsion Motor		Single-sided Asynchronous Linear Induction Motor
Type of Power Supply		VVVF Inverter (IGBT Technology)
V. Suspension System		
Suspension		Electro-Magnetic Suspension
Module Frame		Aluminum Extrusion and Casting / Fabricated by Rivets
Secondary Suspension		Air Suspension System
VI. Brake System		
Service Brake		Regenerative + Pneumatic - Friction Brake
Emergency Brake		Pneumatic / Friction Brake
Parking Brake		Spring / Friction Brake

Frequently Asked Questions

- **Magnetic field inside car**
  The level of the stray Magnetic field caused by the levitation system is low and does not reach the passenger compartment (Proven by measurements, pacemaker tested).

- **Power Failure Effects**
  If power supply fails, then electrical back-up system takes over for 10 minutes. Finally, vehicle will be supported by landing wheels.

- **Energy Consumption for Levitation & Guidance System**
  Typically the power needed to operate the electro magnets is around 1kW/t, means a 30t heavy car requires 30kW (A house hold iron needs approx. 1kW). But max. power needed for propulsion is around 20 times higher.

Frequently Asked Questions

- **Investment Costs**
  An answer by number cannot be given in general. Investment costs depend significantly on the specifications of each project, such as
  - Costs for Land Acquisition
  - Route Alignment, No. of Stations, Ridership
  - Topography, Ground Quality
  - Necessity for Earthquake Proven Track Design
  - Local Labor Costs
  - Localization Requirements
  - Financing Costs, Insurance

Old Dominion University Maglev Efforts: Progress and Goals

FTA Low Speed Urban Maglev Workshop
Washington, DC

September 8, 2005

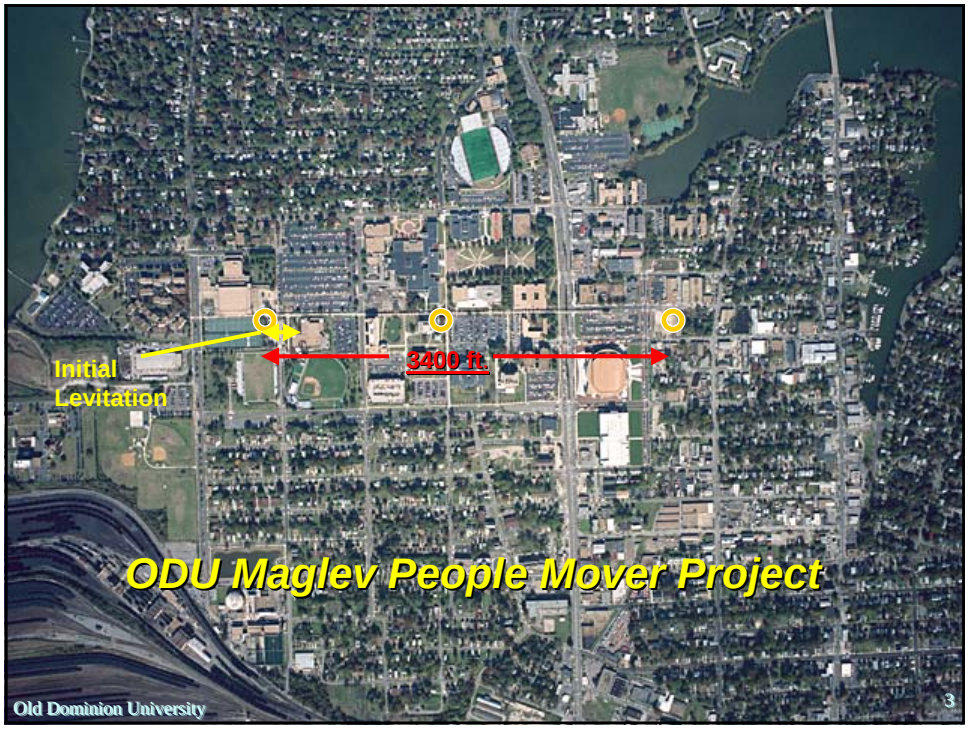
Old Dominion University Maglev Efforts: Progress and Goals

FTA Lowspeed Urban Maglev Workshop
Washington DC
September 8, 2005

Dr. Thomas E. Alberts
Aerospace Engineering Department
Old Dominion University
Norfolk VA
talberts@odu.edu

ODU Maglev Objectives

- Acquire A Functional Transportation System For Old Dominion University
- Establish Old Dominion University As Research University In Maglev Technology
- Establish Maglev Systems As Economical and Practical for Public Transportation



ODU Maglev Funding and Partners

- Participants
  - American Maglev Transportation Inc.
  - Dominion Resources
  - Lockheed Martin
  - Commonwealth of Virginia
- Initial Project funding: VA State Loan to AMT
  - $21-million overall estimated project cost
  - Initial Private-State participation @ $14M
    - $ 7M loan from Commonwealth to AMT
    - $ 7M Million in-kind matching (primarily LMCO and Dominion)
- Old Dominion University initially acted as the host for the project

- 2004: $2M Congressional Earmark to ODU, administered by FRA – "Demonstrable Engineering Prototype"

Old Dominion University 4

Views of the ODU Maglev

Project Purpose: A matter of perspective

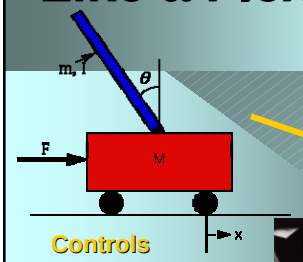
- University:
  - –Student Transportation System
  - –Recognition
  - –Research
- Partners
  - –Demonstration Project

Technical Project Status- Fall 2002

- Guideway Construction Completed
- Station Designs Approved
- Station Construction Started
- Vehicle "Ground" Tested in Florida
- Vehicle Delivered to ODU / Mounted on Guideway
- About 1000ft of Laminated Track Installed
- Vehicle and Guideway Testing Started
- November: "Save the Maglev Meeting"

Old Dominion University 6

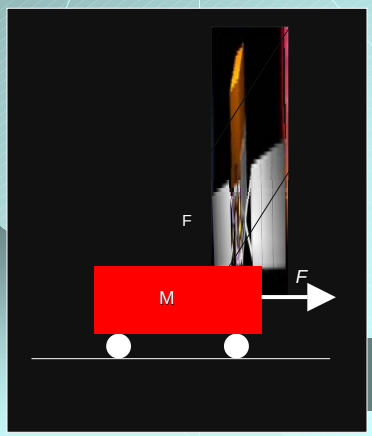
Like a Flexible Inverted Pendulum?



Controls

Flexible Robots

Flexible Spacecraft Control



ODU Maglev Technical Details

- Single vehicle, 45 ft long, 100 passenger standing capacity
- Size similar to Orlando Airport People Mover
- Maximum speed 40 mph, 3400 foot track
- Elevated guideway, 80-90 foot Pre-stressed Concrete Spans
- Potential of 100 to 150 mph on longer track (undocumented)
- Direct route along "46th" street, 3 stops
- EMS (Attractive) Levitation – 1cm Gap
- Linear Induction Motors
- Empty weight: ~25,000 lbs

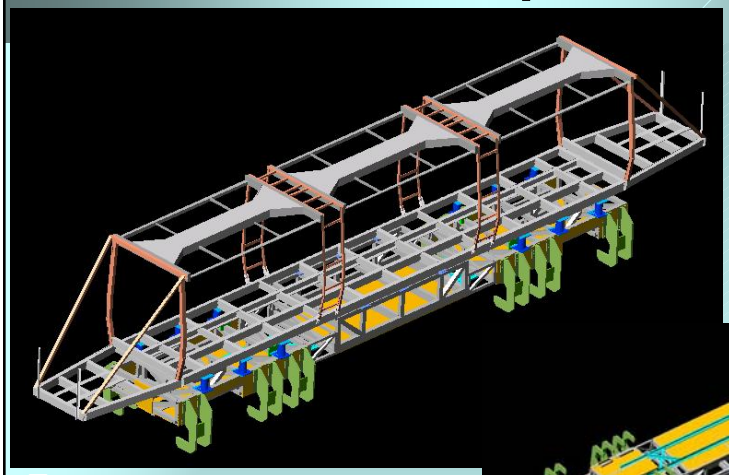
Design Concept of the ODU Maglev

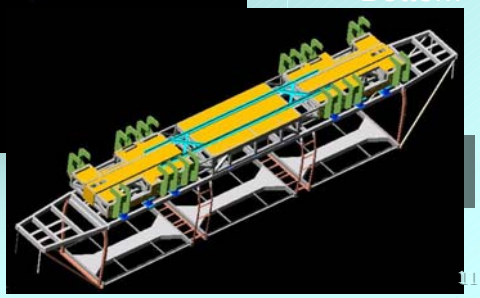
- Magnetic Bogie Concept
- EML Levitation "Short Stator" LIMs
- 12 Lift Magnets – 6 Per Bogie
- No Dedicated "Guidance" Magnets
- Regenerative Braking Maintains Levitation in the Event of Power Outage
- Low Cost Guideway, Laminated Steel Track
- Initial Controller Design Centralized

System Issues

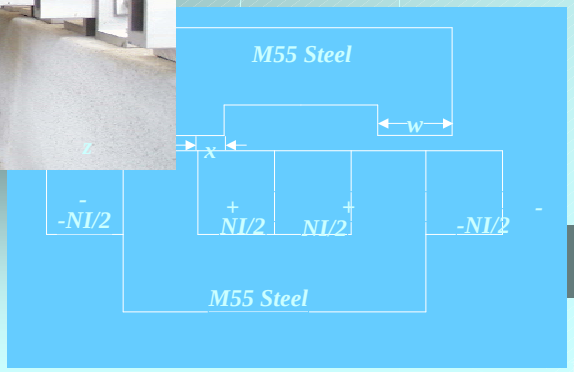
- Lack of Lev-Control Stability Robustness
  - Guideway Flexibility
  - Stability Varied with Location on Track
  - No Secondary Suspension
  - Centralized Control Possibly not Suited to Vehicle
- Ride Quality
  - Acceleration levels not comfortable to passengers

AutoCAD: “Complete” Frame

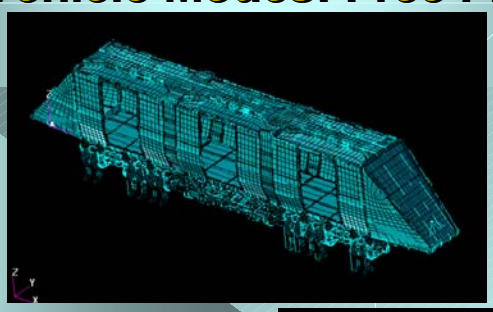


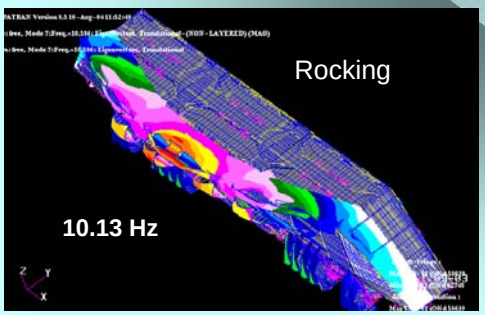


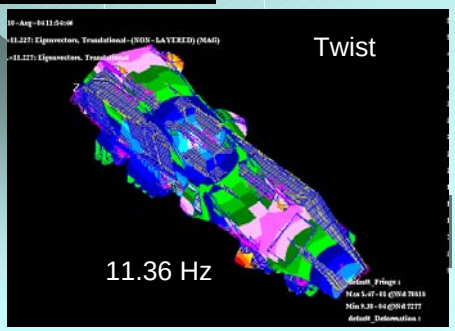
Magnet and Rail



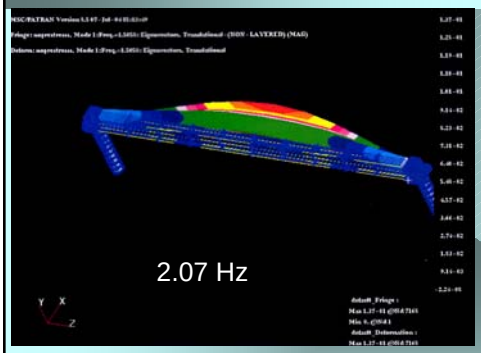
FEM Vehicle Modes: Free Floating







Finite Element: Guideway



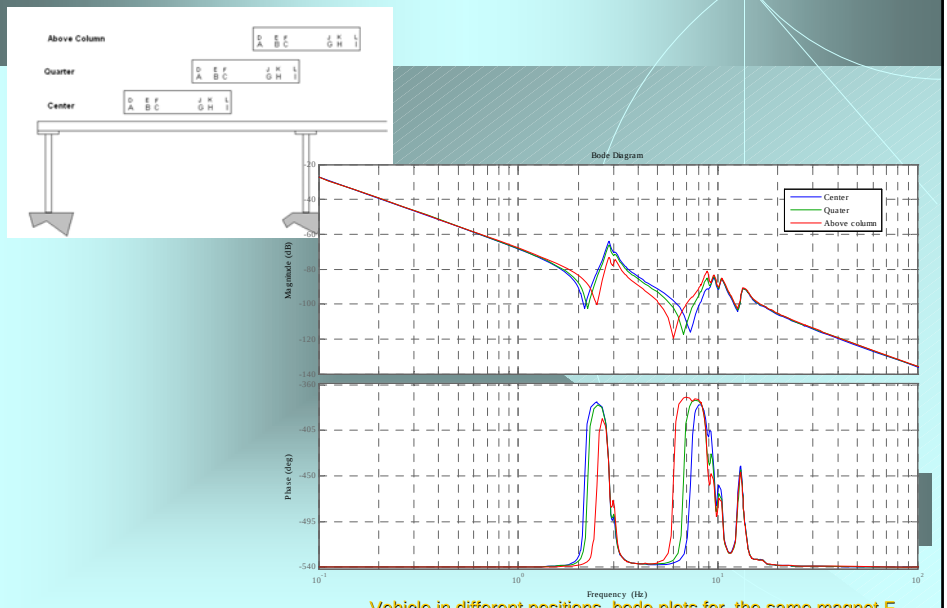
Horizontal Bending

Vertical Bending

Guideway: Prestressed Concrete w/ Rubber Pads

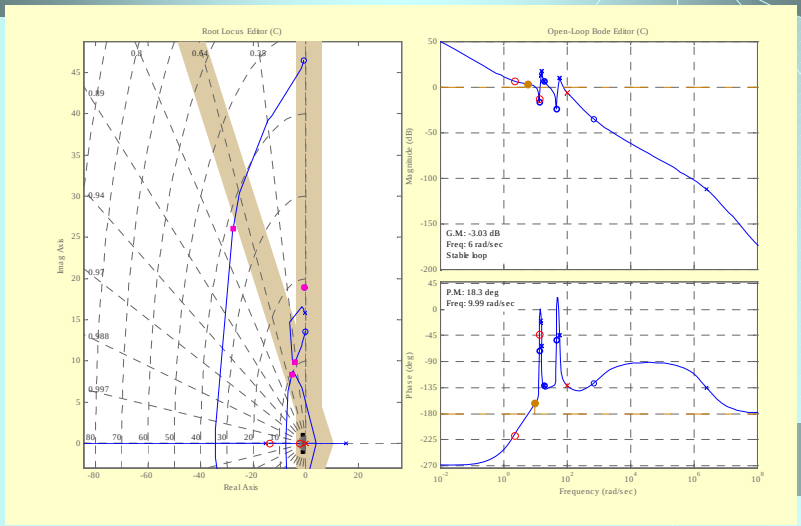
Track (steel) also analyzed separately: 70 Hz

Model Variation With Vehicle Position



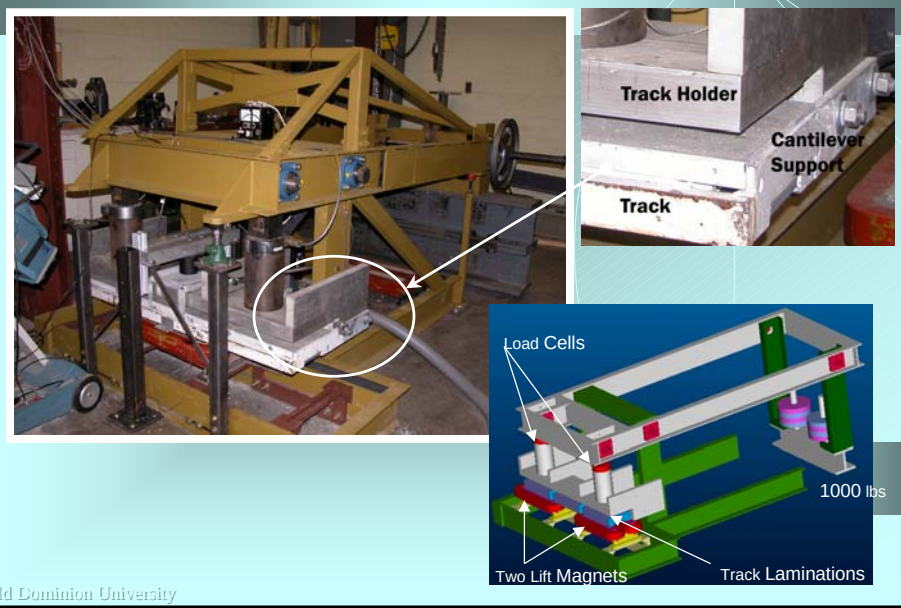
Vehicle in different positions, bode plots for the same magnet F

Decentralized Design Example



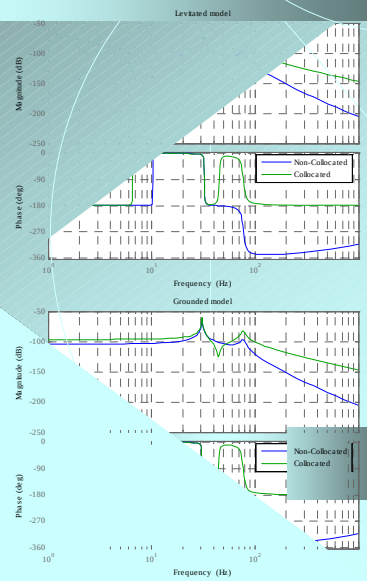
Positive Feedback, Lead Compensators

1 DOF Levitation Test Rig

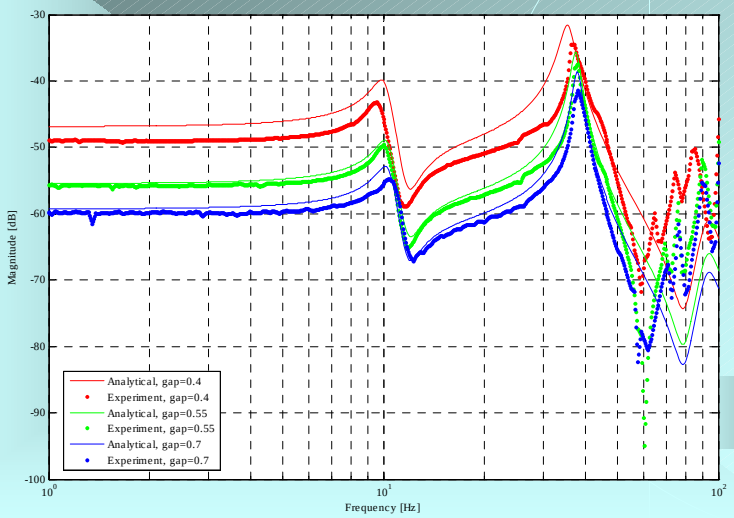


Test Rig Structural Model

Grounded System



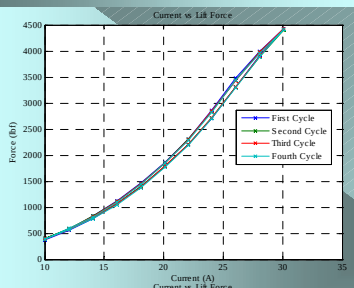
Test Rig Model Verification

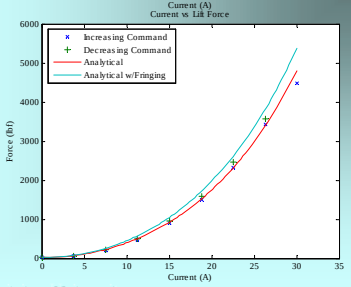


Old Dominion University 19

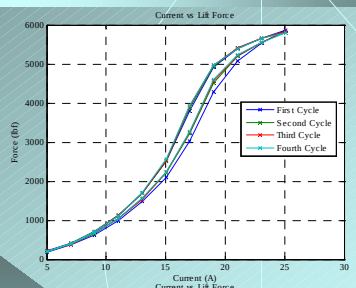
Magnet Testing

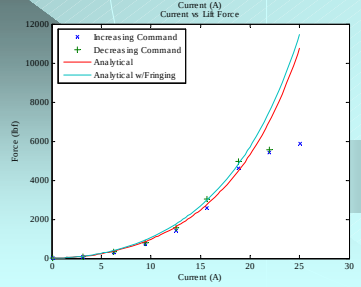
0.7 Inch Gap





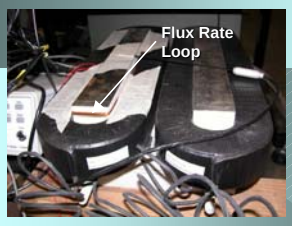
0.4 Inch Gap

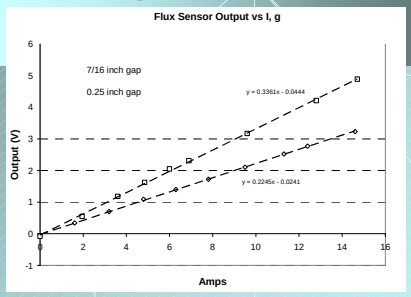


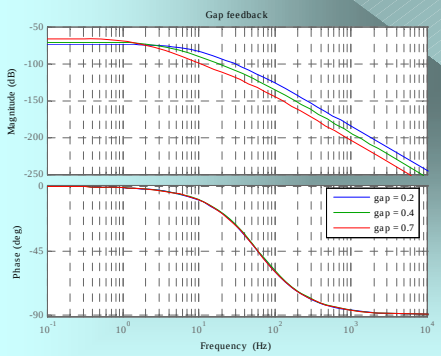


Old Dominion University 20

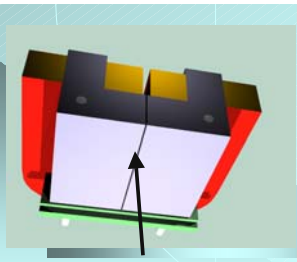
Flux Sensing







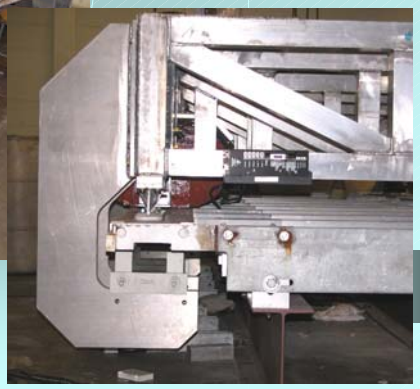
Gap Feedback: 12dB DC Gain Variation
(rigid case shown)



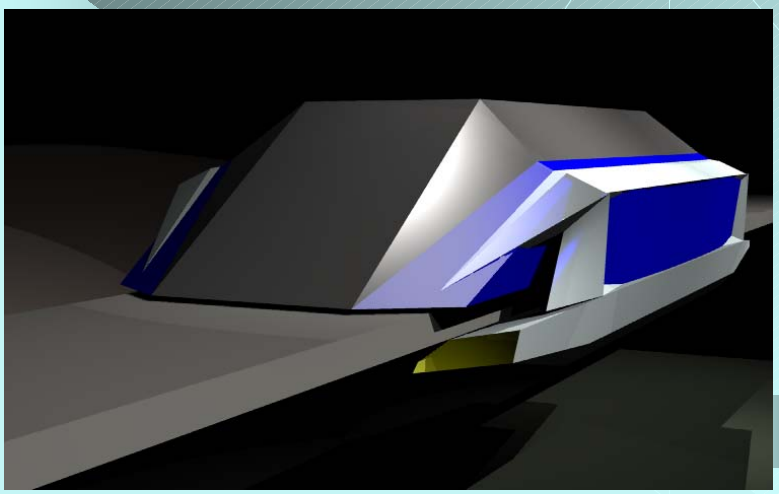
Hall Effect Sensors Inserted
Split Backplane

Test Bogie

- 6 Lift Magnets
- Gramme LIMS
- About 3000 lbs (as shown)
- 3800 lbf Thrust



Test Bogie Body Concept



Old Dominion University 23

Summary: DEP Technical Objectives

Do the best we can with current configuration.

- **1 DOF Test Rig**
  - **Stable Levitation Using Decentralized Approach**
  - **Noise Reduction**
  - **Validate Models, Evaluate Flux Feedback**
- **Test Bogie**
  - **Multi-Magnet Laboratory Demonstration of Decentralized Control w/ Flux Feedback**
- **Vehicle**
  - **Levitate and Propel on Guideway**

Old Dominion University 24

Our Future?

- Depends on DEP Results / Disposition of University Administration
- Development Partnerships Possible
- What We Have to Offer:
  - Laboratory
  - 3400ft Guideway
  - 1000ft Useable Laminated, 160 ft Solid Track
  - 1 MWatt DC Power Supply
  - Full Scale Test Bogie
  - Full Scale Vehicle (fixer upper special)

Summary, Lessons Learned and Benefits to the Transit Industry

Dr. Gopal Samavedam
Group Director
Foster-Miller, Inc.

September 9, 2005

Summary, Lessons Learned and Benefits to the Transit Industry

Dr. Gopal Samavedam

Group Director

Foster-Miller, Inc.

September 9, 2005

Summary – General Atomics

Status: On-going

1. Operational Principle
   - Electro Dynamic Suspension (EDS)
   - Permanent magnets on vehicle in a Hallbach arrangement
   - Propulsion by Linear Synchronous Motor
   - Levitation by electrodynamic principle, i.e. moving vehicle magnets interacting with Litz wire track to get lift

Summary – General Atomics

Status: On-going

- **Operational Principle**
  - **Electro Dynamic Suspension (EDS)**
  - **Permanent magnets on vehicle in a Hallbach arrangement**
  - **Propulsion by Linear Synchronous Motor**
  - **Levitation by electrodynamic principle, i.e. moving vehicle magnets interacting with Litz wire track to get lift**

FTA Low Speed Urban Maglev Workshop

Summary – General Atomics

- **Accomplishments to Date**
  - **Laboratory demonstration of levitation usin rotating wheel**
  - **Built 120m long track at San Diego with a Linear Synchronous Motor**
  - **Built one vehicle chassis with levitation magnets and propulsion coils**
  - **Carried out a limited demonstration of propulsion and levitation**

Summary – General Atomics

- Contractor Estimated Cost of the System: $35M/two way mile
- System Deployment Readiness: Under evaluation. More testing planned to demonstrate vehicle dynamic control and stability. California University in Pennsylvania (CUP) is the proposed deployment site.
- System Attributes: Large levitation gap

FTA Low Speed Urban Maglev Workshop

Summary – General Atomics

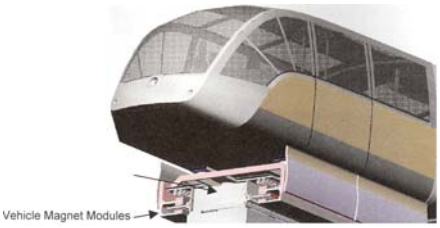


Figure 1. Vehicle on guideway (conceptual)

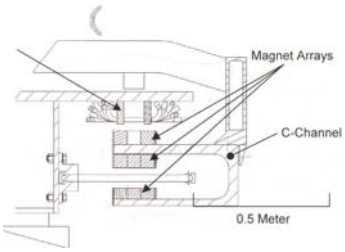


Figure 2. Cross-section of maglev guideway magnet system

Summary – MagneMotion

Status: Final Reports Completed

- Operational Principle
  - Electro Magnetic Suspension
  - Levitation by attraction of vehicle electromagnets and permanent magnets to th steel guideway. Gap control by electromagnets
  - Propulsion by Linear Synchronous Motor
- Accomplishments to Date
  - 1/7 scale successful laboratory demonstration of levitation, propulsion and gap control

FTA Low Speed Urban Maglev Workshop

Summary – MagneMotion

- Contractor Estimated Cost of the System: $19.2M/two way mile
- System Deployment Readiness: Not ready. Requires demonstration at full speed on full scale guideway. Deployment site to be finalized
- System Attributes:
  - Small vehicles (bus size) that can operate at small headways (< 30 sec)
  - Large levitation gap
  - Good levitation gap control

Summary – MagneMotion

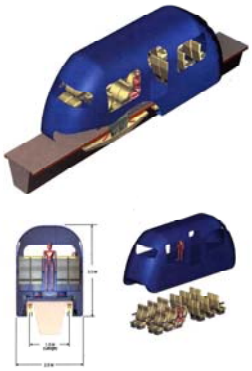


Figure 3. Cutaway views of preliminary vehicle design (conceptual)

Figure 4. Photograph of the low speed prototype showing vehicle, guideway, and propulsion coils (laboratory demonstration)

Summary – Maglev 2000

Status: Final Report Under Completion

- **Operational Principle**
  - **Electro Dynamic Suspension**
  - **Levitation is due to moving vehicle superconducting magnets that provide lift interacting with guideway coils**
  - **Propulsion by Linear Synchronous Motors**
- **Accomplishments to Date**
  - **Partial fabrication of a superconducting magnet in the laboratory for a levitation demonstration**

Summary – Maglev 2000

- Contractor Estimated Cost of the System: $11-37M/two way mile
- System Deployment Readiness: No. The system needs laboratory demonstration.
- System Attributes: Application of superconducting magnet

Summary – Maglev 2000

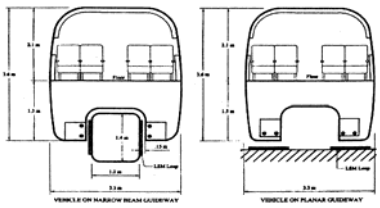


Figure 6. Maglev 2000 117 foot vehicle (conceptual)

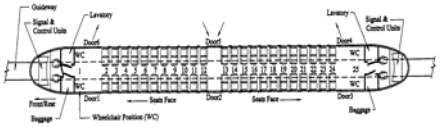


Figure 7. Maglev 2000 vehicle internal layout

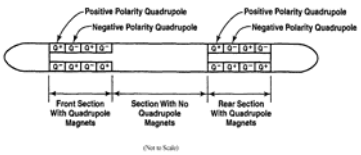


Figure 8. Arrangement of multiple quadrupole magnets on Maglev 2000 vehicle

Summary – MUSA

Status: Final Report Completed

- Operational Principle
  - Electro Magnetic Suspension
  - Levitation by attraction between vehicle electromagnets and the steel rails on the guideway
  - Propulsion by Linear Induction Motor
- Accomplishments to Date
  - Evaluated and adapted CHSST system
  - No laboratory or field demonstrations in the U.S.

Summary – MUSA

- Contractor Estimated Cost of the System: Over $100M/two way mile in the U.S.
- System Deployment Readiness: Yes.
  - Maximum speed is limited to 60 mph
  - Requires CHSST involvement
  - Deployment site not finalized
- System Attributes
  - Only system available for low speed urban applications
  - Technology has been proven and very matured
  - Deployment history in Japan

Summary – MUSA

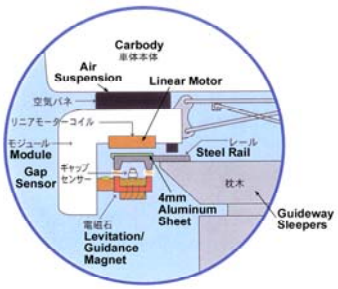


Figure 9. CHSST Maglev rail and module cross-section

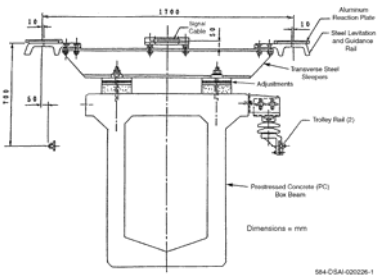


Figure 10. CHSST Maglev guideway

Summary – MUSA

Status: Final Report Completed

- **Operational Principle**
  - **Electro Magnetic Suspension (EMS) as in CHSST**
  - **Propulsion, advanced Linear Induction Motor reacting with aluminum rail**
  - **Levitation as in CHSST using electromagnets attracted to steel rail of the guideway**
- **Accomplishments to Date**
  - **Cost effective guideway concepts**
  - **Advanced Linear Induction Motor concept**

Summary – MUSA

- Contractor Estimated Cost of the System: $40M/two way mile
- System Deployment Readiness: No. System requires validation for higher speed (~ 100 mph), higher gradients (10%) and harsh weather conditions. Deployment site is supposed to be along I-70 corridor
- System Attributes
  - Higher speed (100 mph) than CHSST
  - Specifically designed for Colorado winter conditions

Summary – MUSA

Figure 11. Precast concrete U-girder (conceptual)

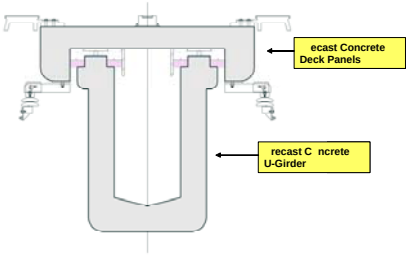


Figure 12. Proposed U-girder for Colorado