Report Number FTA-MD-26-7029-2003.1

Applicability of CHSST Maglev Technology for U.S. Urban Transportation

U. S. Department
of Transportation

Federal Transit
Administration

June 2003

FTA
Federal Transit

OFFICE OF RESEARCH, DEMONSTRATION, AND INNOVATION

REPORT DOCUMENTATION PAGE

Form Approved

OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)* Report Number FTA-MD-26-7029-2003.1	2. REPORT DATE June 2003	3. REPORT TYPE AND DATES COVERED Final Report

4. TITLE AND SUBTITLE Applicability of CHSST Technology for U.S. Urban Transportation	5. FUNDING NUMBERS
6. AUTHOR(S) G. Samavedam[1], F. Raposa[2], R. Feder[3]	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) [1]Foster-Miller, Waltham, MA [2]FL Raposa Services, Cape Cod, MA [3]Port Authority of Allegheny County, PA	8. PERFORMING ORGANIZATION REPORT NUMBER DSAI.020226
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Transit Administration Office of Technology 400 Seventh Street, SW Washington, DC 20590	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

COTR: Venkat Pindiprolu, FTA

12a. DISTRIBUTION/AVAILABILITY STATEMENT Limited Distribution	12b. DISTRIBUTION CODE N/A

13. ABSTRACT *(Maximum 200 words)*

This report discusses the Chubu HSST technology applicability to U.S. urban transportation. This low speed system based on the principle of electromagnetic levitation by attractive suspension and propulsion by vehicle mounted linear induction motors is being deployed in Japan. This report was prepared based on the FTA team findings and experience with the system during a recent visit to Japan that observed the progress of the system deployment. The report discusses the performance characteristics of the CHSST vehicle and compares them with the FTA goals. For wider applicability of the CHSST in the U.S., the report describes a higher speed vehicle design under consideration in Japan. U.S. mandatory requirements on the vehicle for use in the United States are also discussed.

A CHSST Maglev comparison with conventional Light Rail for urban transportation is presented. The report identifies two types of example corridors in the U.S. where there may be potential for application of the CHSST technology.

14. SUBJECT TERMS Maglev, Magnetic Levitation, Propulsion, Urban, CHSST, Transportation	15. NUMBER OF PAGES 57
	16. PRICE CODE N/A

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

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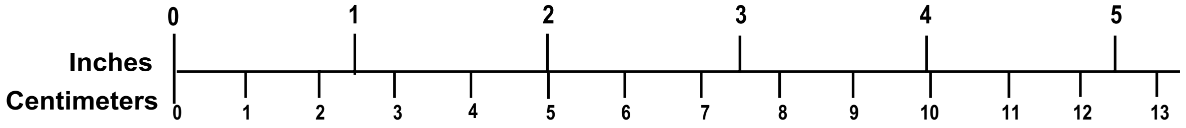

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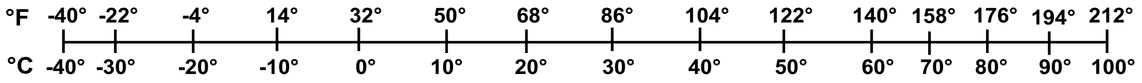

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Updated 6/17/98

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Acronyms

ADA	Americans with Disabilities Act
ASTM	American Society of Testing Materials
ATC	Automated Train Control
ATO	Automated Train Operations
DLIT	Department of Land, Infrastructure and Transportation
EIS	Environmental Impact Statement
FTA	Federal Transit Administration
LIM	Linear Induction Motor
LRT	Light Rail Transit
MUSA	Maglev Urban System Associates
NFPA	National Fire Protection Association
TKL	Tobu Kyuryo Line

Acknowledgments

This work was performed under the overall technical and program direction of Mr. Venkat Pindiprolu, who is the Contracting Officer's Technical Representative (COTR) from the Federal Transit Administration. The authors are grateful to him for his inputs and arrangements for the execution of the visit to CHSST and other facilities in Japan.

The authors are grateful to the Chubu HSST team, in particular Messrs. Masaaki Fujino, Michio Takahashi and Junro Kato who put in hours of work to respond to the FTA team's questions during the visit to Japan.

The authors wish to thank Dr. John Harding of the Federal Railroad Administration for his technical input and guidance during this project. The other members of the visiting team provided input to this work that was central to its completion.

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The funding for the work came from the FTA. Foster-Miller and FL Raposa Services are subcontractors to the SAIC. Special thanks are due to Dr. David Keever of SAIC for his help in the project management.

Executive Summary

The Federal Transit Administration (FTA) is examining the possibility of introducing magnetically levitated low speed vehicles for urban transportation in the United States to reduce road traffic congestion. For this purpose, the FTA is evaluating existing technologies and also developing alternate technologies within the realm of Maglev. One of the existing technologies currently under deployment is the Chubu HSST in Japan. To assess its technical merits and applicability to U.S. scenarios, in February, 2003 the FTA sent a team of experts to Japan, including a select group of representatives from U.S. transit agencies.

This report is based on the FTA team visit to CHSST in the Nagoya facility where the Maglev vehicles are being tested on a special test track, and also to facilities elsewhere in Japan where the vehicles and linear motors are being manufactured. The visit involved discussions with the CHSST technical staff and representatives of Aichi Prefecture (similar to state government) in Nagoya, Japan and the national Department of Land, Infrastructure, and Transportation (DLIT), which assisted in funding the project.

A previous delegation to Japan in 2002 focused on the HSST 100L Series vehicle and prepared a report that compared the HSST performance characteristics with FTA goals. A major conclusion of the report is that although the vehicle does not satisfy all the FTA goals, the vehicle and Maglev technology are applicable for certain scenarios in the U.S. For many other scenarios it is desirable to upgrade the vehicle, particularly to achieve higher peak speeds (to 200 km/h from the existing 100km/h). The existing vehicle should also be examined and modified, if necessary, for improved egress, crashworthiness, fire safety, and ADA requirements, which are mandatory in the U.S.

The focus of the recent visit was on the 200 km/h speed vehicles, for which the CHSST has specifications and preliminary design concepts. In addition, clarifications were sought on the mandatory requirements referred to above. The vehicle and motor manufacturing infrastructure for the CHSST was also examined. The current construction for a deployment on a 9 km track in Nagoya, to be operational in 2005, was also monitored by the FTA team during the one week stay in Japan.

The following conclusions are drawn in this report:

- The current CHSST Maglev technology has potential application in U.S. urban transportation, particularly for short distance routes with close station spacings. For long distance routes with long station spacings, the CHSST Maglev vehicle needs technical enhancements requiring developmental work.
- The CHSST technology has been demonstrated and is mature, with the necessary manufacturing support. It is in a state of readiness for deployment in the U.S. on short station spacing scenarios of less than two miles, typical of today’s urban application, for efficient trip times.
- The advantages of CHSST Maglev over traditional transit systems such as Light Rail include public acceptance due to low noise, low vibration, superior ride quality, superior grade climbing, and low energy consumption.

- The U.S. need to examine methods of cost reduction on the CHSST guideway for adoption in urban transportation scenarios, and may consider joint projects with CHSST for technology improvements and implementation in U.S. urban scenarios.

1. Introduction

The FTA sent a delegation to Japan in March 2002 to evaluate the Chubu HSST technology for potential application to U.S. urban transportation. The evaluation is presented in a technical report [1] which covers the performance and operational characteristics of the CHSST, including the guideway system, vehicle system, levitation, guidance and propulsion systems, braking system, automated train operations, and component and system level safety.

The costs as given by the CHSST are also presented in the report. The FTA team concluded that the CHSST system is a viable Maglev system for low speed urban transportation and has advantages such as grade negotiating capability, low noise and pollution.

The CHSST system design characteristics are compared with the FTA performance requirements, (speed, acceleration, etc.), and with U.S. mandatory requirements such as emergency egress, crashworthiness, and those stipulated in the Americans with Disabilities Act (ADA).

The assessment of the CHSST for U.S. applications [1] showed that the CHSST does not satisfy some of the FTA goals, particularly for maximum speed, acceleration, deceleration, and grade climbing capability. Additionally, some of the U.S. mandatory requirements are also not fully satisfied in the current design. These issues were communicated to the CHSST staff with the intent of obtaining their comments on enhancements to their system for potential use in the United States.

The FTA team made a follow-on trip to Japan in February, 2003, this time including several experienced managers from U.S. transit agencies. The names of the team members and the trip agenda are presented in Appendix A. The specific aims of this trip were:

- For the Transit User Group to experience the CHSST and assess its potential for U.S. transit use.
- To witness the CHSST deployment on Tobu Kyuryo Line (TKL) in Nagoya and to observe in-progress guideway construction and vehicle fabrication.
- To obtain feedback from CHSST designers on previous FTA evaluations and recommendations.
- To review technical data with CHSST on the 200 Series (120 mph) vehicle design under consideration.
- To obtain input on CHSST costs if deployed in the U.S.

The purpose of this report is to present the findings of the team as a result of the visit. Section 2 of the report presents further technical assessment of the Series 100L vehicle, which has a maximum speed of 100 km/h (60 mph) and is being deployed by the CHSST on a revenue line in Nagoya. This assessment is made on the basis of the CHSST answers to the questions raised by the FTA team [1]. Section 2 also contains an evaluation of the conceptual 200 Series vehicle, which has operational speed capability up to 200 km/h. The FTA is interested in this vehicle because it meets the maximum speed goal for U.S. urban Maglev transportation. The issues around upgrading the existing 100L vehicle to the 200 Series are also discussed in this section.

Section 3 presents an assessment of the usability of the CHSST Maglev system in the U.S. and identifies issues and comparison with conventional systems such as LRT. The issues cover environmental and deployment aspects of Maglev.

Section 4 describes the deployment progress made in Japan on the 9.2 km Tobu Kyuryo Line in Nagoya. Construction progress on the infrastructure (guideway, pylons, and foundation) and vehicle manufacturing progress are presented. Cost and financing issues are also covered in this section.

In Section 5, the applicability of the CHSST to U.S. urban transportation is discussed using example scenarios.

Conclusions of practical interest, with recommendations, are presented in Section 6.

2. Technical Background

The assessment of Chubu HSST was performed by the FTA team which visited Japan in March 2002 and February 2003. During these visits, the team collected HSST performance and safety test data which was compared against the FTA system requirements. From the 2002 visit, a technical report [1] was prepared to identify the design changes needed to the 100 series vehicle to satisfy the FTA requirements and also U.S. mandatory requirements for consideration of potential deployment of the CHSST technology in U.S. urban areas. The technical background of the 100L vehicle, the desired improvements, and the status of the 200 Series vehicles are presented in the following sections.

2.1 HSST 100L Vehicle

The HSST vehicles have had significant development history as shown in Table 1. The 100L series vehicle testing started in 1995 to support deployment on the Tobu Kyuryo Line in Nagoya, which is discussed later in this report.

Table 1. HSST Development History

Date	Development
1972	Studies for High Speed Access to Airports (Japan Air Lines)
1975-1981	Kawasaki 1.3/1.6 km Test Track • HSST-01 Subscale Vehicle -- 307km/h • HSST-02 Full Scale Vehicle
1985-1989	HSST-03, -04, -05 Vehicles • Low speed demonstrations at several expositions
1991-Present	Nagoya 1.6 km Test Track • 100-S (8 m "short") Vehicles in 2-car consist
1991-1993	Aichi Prefecture/Ministry of Transport Evaluation of HSST Maglev for Commercial Suitability
1995	Testing of 100-L (14 m "long") cars
1995-2003	Testing to support development of Tobu Kyuryo system and vehicles (based on 100-L)
2003	Start construction of 9.2 km Tobu Kyuryo (Tobukyu) Line in Aichi Prefecture
2005	Commercial Operation of Tobukyu Line at Aichi Exposition

The 100L vehicle carbody, which is about 14 m long, is of aluminum alloy. Levitation and guidance are from Electromagnetic Suspension (EMS). The propulsion is derived from the reaction force of the aluminum plate on the guideway to the electromagnetic force generated by an onboard Linear Induction Motor (LIM). The aluminum reaction plate is attached to a continuous steel rail mounted on steel sleepers, which are supported on hollow rectangular concrete girders as shown in Figure 1. The vehicle electromagnets are attracted to the steel rail when energized, and the gap (typically 8 mm) is continuously monitored by sensors to control the current in the vehicle magnet coils.

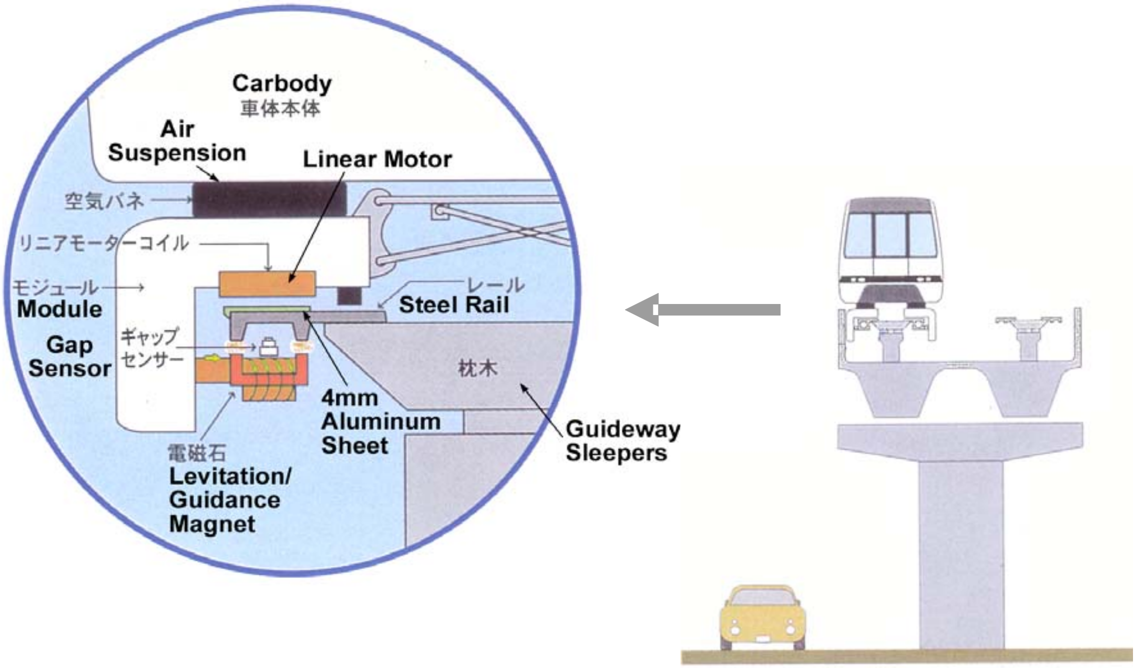


Figure 1. CHSST Maglev Module and Rail Cross-Section

There are five modules on each side of the vehicle. Each module can be independently articulated as indicated by its connection with the "slide tables" between the carbody and modules. There is one motor in each of the modules, totaling 10 motors per vehicle. The single-sided motor makes use of an aluminum winding for light weight and economy.

The primary brakes are electrical. The secondary are hydraulically controlled caliper brakes. Automated Train Control (ATC) and Automated Train Operations (ATO) are to be deployed in revenue service.

2.1.1 Technical Attributes Identified from the Assessment

The technology is mature, with significant research and development since 1972. The noise and vibration levels are very low so the vehicle is likely to receive public acceptance. The vehicle has superior grade climbing capability when compared to LRT. The system is suitable for urban area applications on routes with close station spacings typical for today's urban applications.

2.1.2 Mandatory Design Changes for U.S. Requirements

For applications in the U.S., the CHSST Maglev should satisfy the mandatory requirements described below.

ADA Requirements

The 100L vehicle needs to be modified by a) increasing the width of the side door openings from 80 cm to 81.5 cm, b) increasing the width of the aisle between seats, stanchions and handrails on the vehicle from 60 cm to 82 cm, and c) providing door chimes/buzzers for visually impaired people. These are discussed in the final report by MUSA [2].

This proposed approach to satisfy the ADA requirements reduces the seating capacity of the vehicle, requires significant body structural changes, and adds to the cost of the 100L vehicle.

Emergency Evacuation

The procedure being considered in Japan consists of opening the end doors on the end cars of the train and deploying a plank on the sleeper surfaces, from where the passengers can use a ladder to climb down one by one. Figure 2 shows the end doors on the vehicle for egress.

This procedure may not be rapid enough in an emergency with fire and smoke. Eliminating sleepers by directly fastening the steel rail to the guideway girder may provide a surface for passengers to distance themselves from the cars in a timely manner during an emergency, but this is not considered in the existing CHSST guideway design.

Figure 2. End Door on 100L Vehicle

Crashworthiness

Sufficient vehicle crashworthiness is necessary to reduce injuries to passengers in collisions with other vehicles or objects on the guideway. The MUSA report [2] dismisses this issue, stating that collisions are not possible because of the Automated Train Operation. However, collisions may occur because of objects (trees, rocks thrown by vandals) falling onto the guideway. Slow speed collisions can take place in yards and maintenance depots.

The only response received from the CHSST is that the 100L vehicle body is designed to withstand a buff load of 34 tons. It is clear that this issue needs further evaluation for the usability of the system in the U.S.

2.1.3 Desirable Changes to Meet FTA Performance Goals

Some changes in the vehicle are desirable for wider applicability to U.S. scenarios. At present the CHSST 100L vehicle does not satisfy the FTA performance goals. Current 100L performance is contrasted with the FTA goals in Table 2. The significant differences in the CHSST performance and the FTA goals are in the speed, emergency deceleration, and minimum horizontal turning radius. The most important of these is probably the maximum speed. The 160 km/h speed cannot be achieved by the current 100L design, which according to HSST staff is designed for and can be operated at 130 km/h. There is still a need for a higher speed vehicle as discussed in the following subsection.

Table 2. CHSST 100L Vehicle Performance versus FTA Goals

	CHSST Performance	**FTA Goals***
Maximum Speed:	100 km/h (60 mph)	160 km/h (100 mph)
Maximum Acceleration:	0.11 g (2.5 mph/s)	0.15 g (3.4 mph/s)
Maximum Deceleration:	0.11 g (2.5 mph/s)	0.15 g (3.4 mph/s)
Emergency Deceleration:	0.13 g (2.8 mph/s)	0.15 g (5.4 mph/s)
Minimum Curve Radius:		
Horizontal	50 m (250 ft)	18.3 m (60 ft)
Vertical	1500 m (6000 ft)	1500 m (6000 ft)
Grade Climbing Capability:	7 percent (reduced speed)	7 percent (full speed capability)

*Note: These goals are tentative and are being finalized by the FTA

The FTA requirement for vehicle maximum speed is 160 km/h (Table 2). The increased speed will reduce trip time over long distances with stations spaced far apart (> 2 miles). Increased acceleration capability will reduce trip time over short distances with close station spacings (< 2 miles). The difference between FTA goals and the 100L acceleration/deceleration capabilities typically reduce trip times by about 13 percent. To achieve increased speed, increased acceleration, and improved grade climbing capability, the 100L motor needs to be more powerful, or a larger number of motors per vehicle will be required. A reduction in vehicle weight will also contribute to increased vehicle performance.

The HSST recommends the 200 Series vehicle for improved performance. The 200 Series vehicle, as described in the following subsection, is only in the conceptual design stage at this time.

2.2 HSST 200 Series Vehicle

The HSST 200 series vehicle was originally developed in 1975 and was designated as the HSST-05. In the development history of the CHSST, this was the first modular design evolution of HSST and unlike its predecessors incorporated both LIM propulsion and EMS levitation. It was also the first magnetically levitated train to be authorized to carry passengers, and it did so at the Yokohama Exposition in 1989.

Although the LIM for the HSST-05 (see Table 1) was originally designed to operate at 200 km/h, the Yokohama exposition consisted of only a 570 m track which thus limited vehicle speeds to 42 km/h. Because of this known limitation, Chubu has stated that the onboard power electronics controls for the LIM were not designed for the maximum speed capability, but designed specifically for the Yokohama demonstration. Further, there were some propulsion design configuration issues on how the 3.6 m LIM modules were to be connected in order to achieve an optimum design and as of the time period of 1989 were still to be resolved.

Following the Yokohama testing, Chubu planned to take an upgraded version of this vehicle to Las Vegas and test it to 200 km/h. However, the Las Vegas program did not materialize and high-speed testing was not performed. In the early 1990s, Chubu studied a 50 km route between Hiroshima airport and downtown Hiroshima that would require a speed capability of up to 200 km/h. Because of a downturn in the Japanese economy, the Hiroshima line was never realized.

Upon conclusion of the Yokohama testing, the high speed capability of the HSST-05 was unproven and remains so at the present time. Testing on a laboratory-scaled wheel with a full scale LIM module, however, had been successfully accomplished during its early development history. As such, the present version of the HSST 200 must be considered as a design concept and for purposes of this report we will designate it as the HSST 200P (prototype) vehicle.

2.2.1 Current Development Status

1. Vehicle Configuration

The following information is based on data provided by Chubu and appears to be derived from the HSST-05 vehicle. Figure 3 shows a conceptual view of a two vehicle consist HSST 200P. Each section is 18.25 m long, 3.6 m high and 3.0 m wide. The seating arrangement shown of 80 seats per section would appear to be representative of high-density seating. The track gauge, from LIM center to LIM center, is 2.0 m wide. For comparison, the track gauge for the 100 series and TKL vehicles is 1.7 m. Chubu has stated two reasons for this difference. One reason is to add some lateral stability with the wider gauge. The other equally important reason is to provide the needed increased space for equipment installation between modules, principally for the higher powered inverter required for the 200-km/h speed capability. For comparison, Figure 4 shows a comparable view of the HSST-Hiroshima concept vehicle which was based on the Yokohama HSST-05.

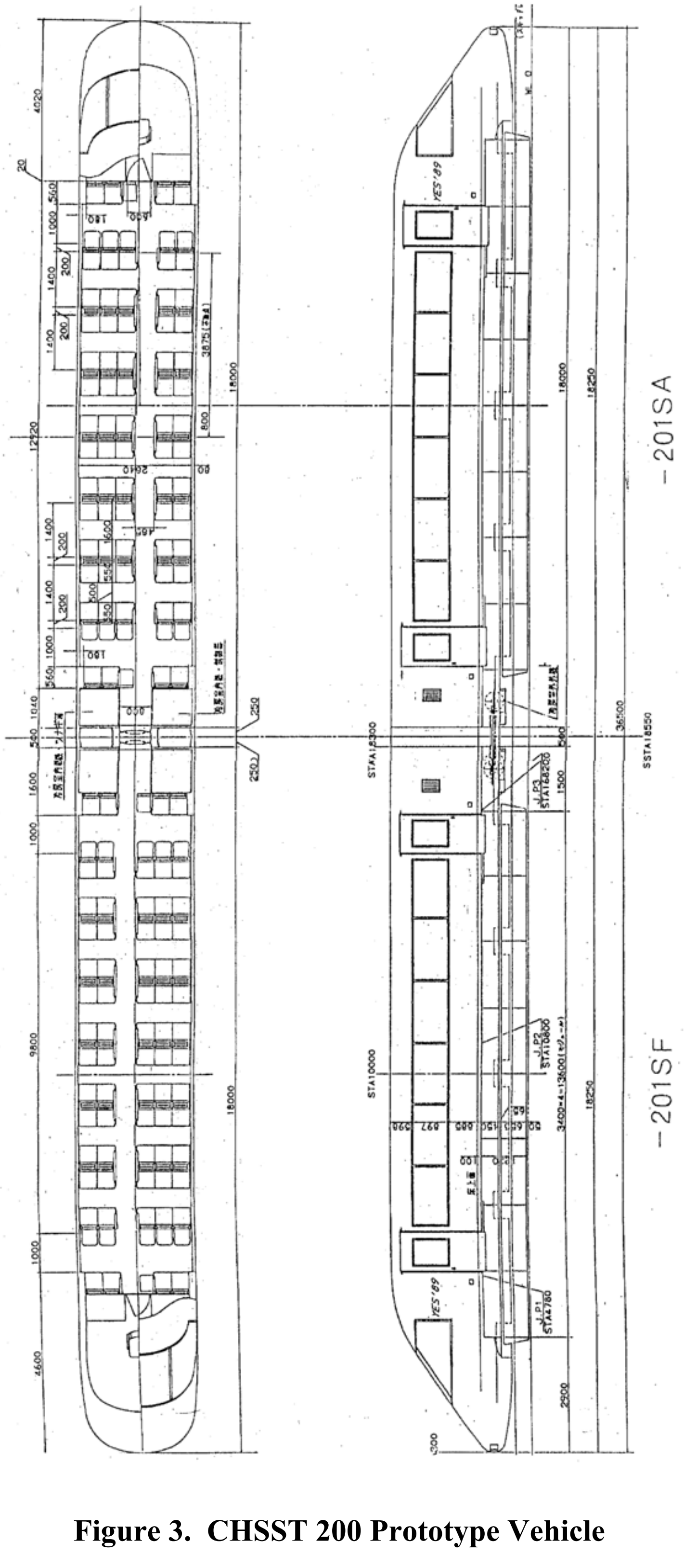


Figure 3. CHSST 200 Prototype Vehicle

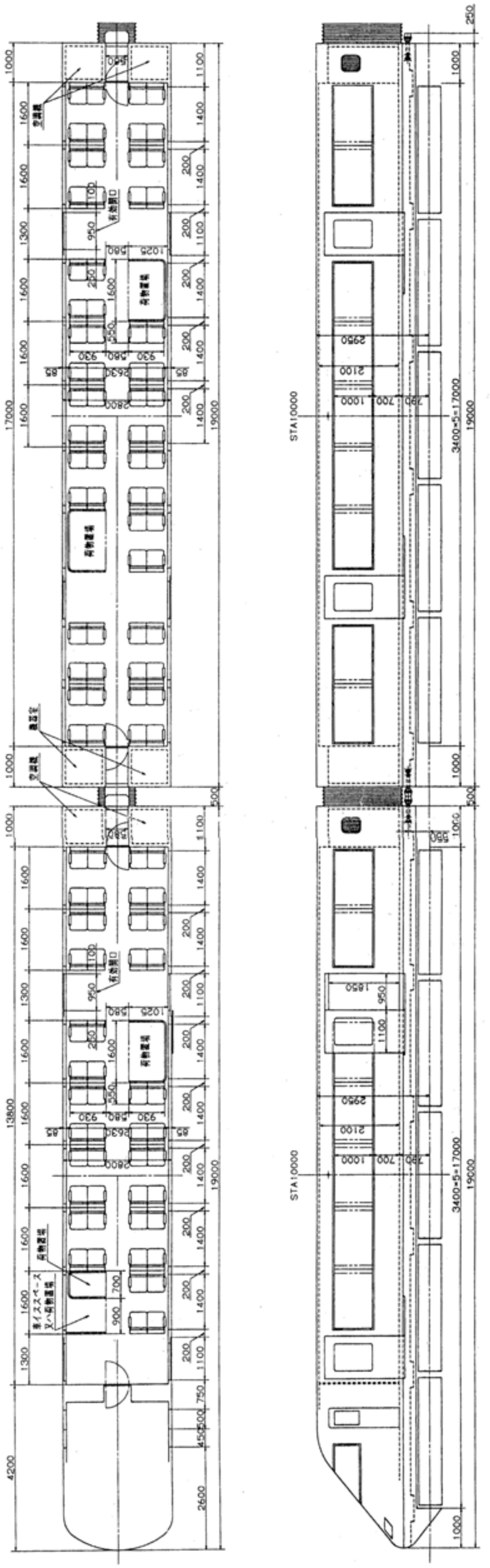


Figure 4. CHSST Hiroshima 200 km/h Vehicle

One of the salient differences between the two concept vehicles is the more aerodynamically shaped nose of the 200P. As seen in Figure 3, another apparent difference is the lack of definition of the modules for the 200P. The Hiroshima concept apparently was based on the use of five modules per side, similarly to the 100L vehicle resulting, in a LIM configuration of five modules in series and two sets in parallel (5s-2p). As stated by Chubu for the 200P, one of the design configurations requiring further definition is the series parallel configurations of the modules. Chubu stated that they will need to investigate the optimum series-parallel LIM configuration further. They stated that this could vary from the standard 5s-2p configuration to a 2s-5p, and possibly to a lesser number of LIM powered modules such as the 3s-2p configuration. The User Group was provided performance characteristics for the 3s-2p configuration and this will be discussed in another section of the report.

At this time, the number of levitation magnets—two per module with ten modules—is thought to be the same as the 100L. This may be subject to change as the final weight of the 200P becomes better defined and the LIM configuration is chosen. The weight goal for the 200P is similar to the 100L at approximately 28 tonnes. Pending a more complete definition of the power electronics, the ultimate passenger payload weight is yet to be determined.

Estimated Performance

LIM performance sample design data for a four car train was provided by Chubu and is shown in Figure 5. These curves, which were developed on a per car basis, show the estimated vehicle drag resistance for both a zero and six percent gradient for a 33 tonne car. The data shown is for the two-series three-parallel (2s-3p) LIM configuration. Also shown in Figure 5 are the thrust capability and corresponding electrical characteristics of the LIM. The electrical characteristics are LIM current, inverter output voltage (voltage per LIM pair), and DC input current. The DC input conditions are for a 1500 VDC power supply.

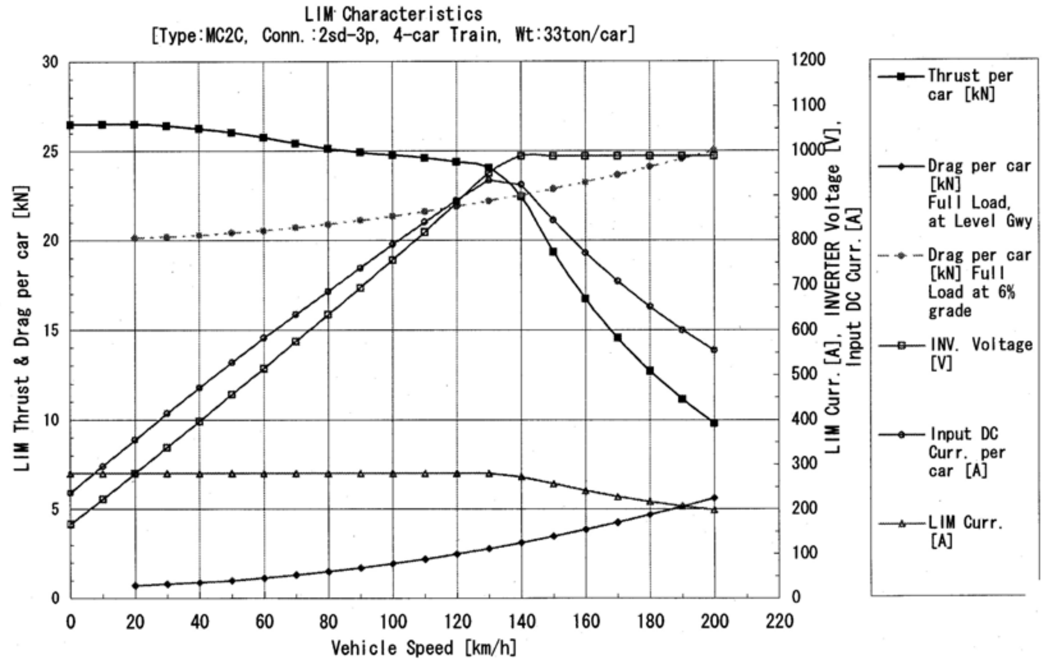


Figure 5. 200P LIM Performance Design Sample

From a cursory review of the zero gradient drag resistance curve, it was found that the estimated aggregate drag of the 200P vehicle closely follows that for the 100S vehicle as reported in our July 2002 CHSST assessment report [1]. This was based on the reported Chubu 1993 test results. Accordingly, the drag component equations developed by Chubu for the two car 100S configuration can be used to approximate the drag components for the 200P when appropriately adjusted for the 200P configuration. The drag resistance components, in SI units (force in Newtons (N), speed in m/s and weight in kg), as reported in the July 2002 CHSST assessment report are:

$$D_c = 41.68*n \text{ N} \qquad (1)$$

$$D_{m1} = 3.354* v*(n*W) \text{ N} \qquad v < 5.56 \text{ m/s} \qquad (2)$$

$$D_{m2} = (18.221+0.0741* v)(n *W) \text{ N} \qquad v \geq 5.56 \text{ m/s} \qquad (3)$$

$$D_a=(1.6522+0.572*n) v^2 \text{ N} \qquad (4)$$

In these equations, D_c is the power collector drag, D_m is the magnetic drag, which has two parts depending on speed, and D_a is the aerodynamic drag. The term W represents the weight (mass) of a single car in kg and n represents the number of cars in a train.

For purposes of any analysis in this report the following are the assumed pertinent characteristics:

Vehicle	Weight (Mass)	Cross Section
100S	16,000 kg	8.58 m^2
100L	26,000	8.32
200P	33,000	8.26

Also, unless otherwise specified, it will be assumed that a two vehicle consist will be analyzed (that is n=2).

The weights given above are used here because these are the weights specified for Chubu supplied data and do not necessarily reflect maximum capable weights. For example, the 100L specifications provided list 28,000 kg as the maximum capable weight for that sized vehicle. Further, unless the levitation system for the 200P concept is upgraded, the likely maximum weight for that vehicle will also be limited to about 28,000 kg.

Using Equations (1) through (4), the estimated drag resistance components and aggregate drag for a 200P two-car train is shown in Figure 6. The magnetic drag equations have been further adjusted to reflect the planned increase in air gap from a nominal size of 8 mm to 9 mm. As seen, the aerodynamic drag is the dominant component and peaks to nearly 9 kN at a speed of 56 m/s (202 km/h). At this speed the output mechanical power requirement is nearly 600 kW. Using the equations, the calculated total thrust value is about three percent more than the value shown in Figure 3 and probably reflects a slightly pessimistic value for the aerodynamic drag component. Note that these equations were derived from the 100S vehicle tests, and the 200 series vehicle should be more aerodynamically shaped. Of the nearly 600 kW of output power, about 16 percent is required to satisfy the magnetic drag component.

Figure 7 shows the maximum thrust capability and corresponding LIM power characteristics on a per car basis. The data shown here was derived directly from the Chubu data shown in Figure

5. A single car develops a maximum thrust of about 26.5 kN and maintains a nearly constant thrust out to about eight m/s (29 km/h). From this point on the thrust begins to decay slightly, and at the 38 m/s corner point the available thrust is 23.4 kN. At near the 56 m/s (202 km/h) point, about 10 kN of available thrust remains.

The lower chart in Figure 7, derived from the Chubu data in Figure 5, portrays both the mechanical output power and corresponding electrical input power. From this data one can estimate the overall efficiency, which is also shown. The overall efficiency peaks at about 65 percent in the speed range of 40-48 m/s, and is still above 64 percent at the maximum speed point of 56 m/s. Note that these are maximum capability estimates and would be expected to be less for cruise speed conditions. Note also, that the power characteristics of the 200P vehicle are similar in shape to the characteristics reported for the 100L in the July 2002 report [1], where the peak power occurs at the speed point associated with the end of the maximum thrust profile and then falls off for higher speeds.

The acceleration performance and maximum power characteristics for the CHSST 200P two car train are shown in Figure 8. The data shown are for zero gradient and zero headwind conditions. The maximum acceleration is about 0.08g and occurs over the speed range from zero to about 16 m/s (58 km/h). For higher speeds, the acceleration drops off and finally gets to a point near 56 m/s where there is no residual acceleration available. The plot shown here is for a slightly pessimistic aerodynamic drag resistance condition and may not be fully representative of an aerodynamically shaped 200P vehicle.

The bottom curve in Figure 8 shows the electrical power characteristics (in kVA) from the output of the inverter to the mechanical output power of the vehicle. From these two points the power factor of the LIM can be estimated as shown. The power factor peaks at about 64 percent (0.64 pu) at 40 m/s (144 km/h), which is also the peak power point for the propulsion system. The power factor then falls off to about 53 percent at the end of the acceleration profile. As expected for cruise speed conditions, the power factor would be less than that shown for maximum capability performance.

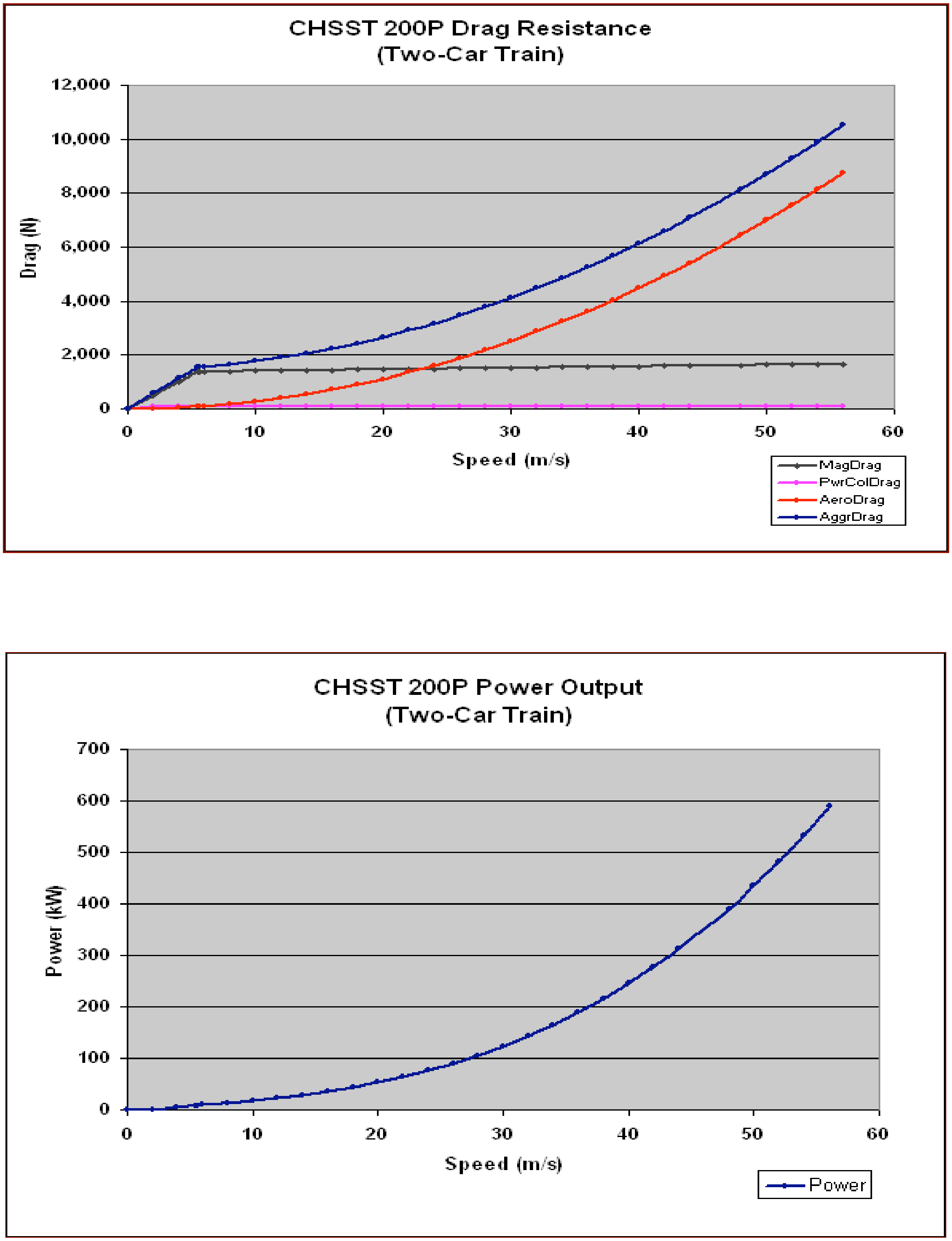
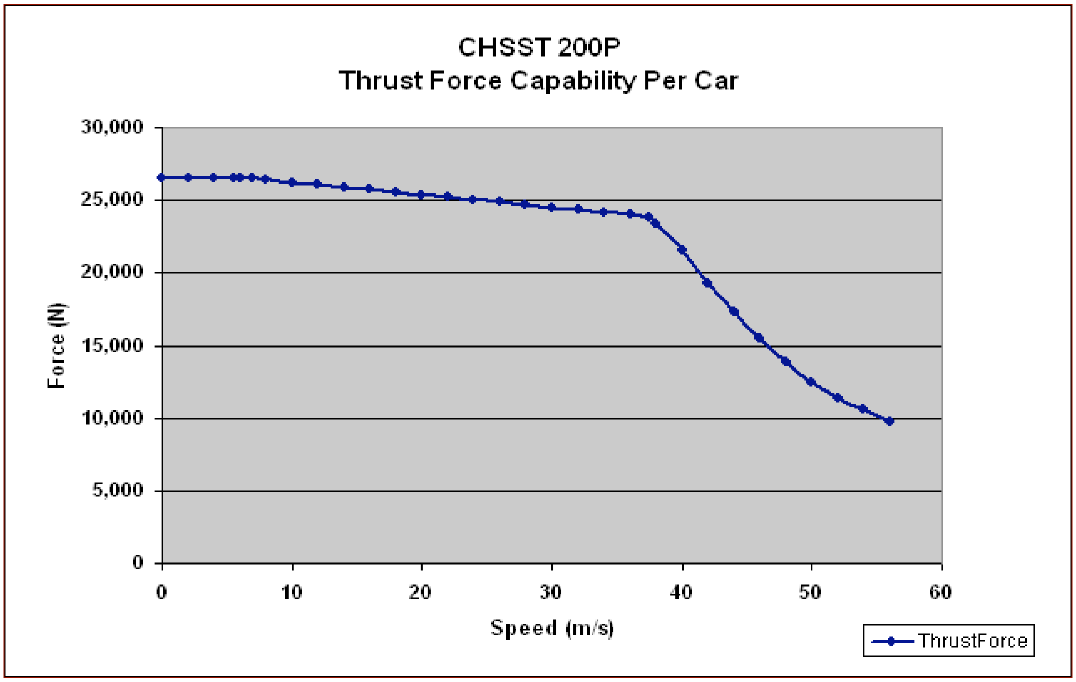


Figure 6. Drag Resistance Characteristics of the CHSST 200P Two Car Train



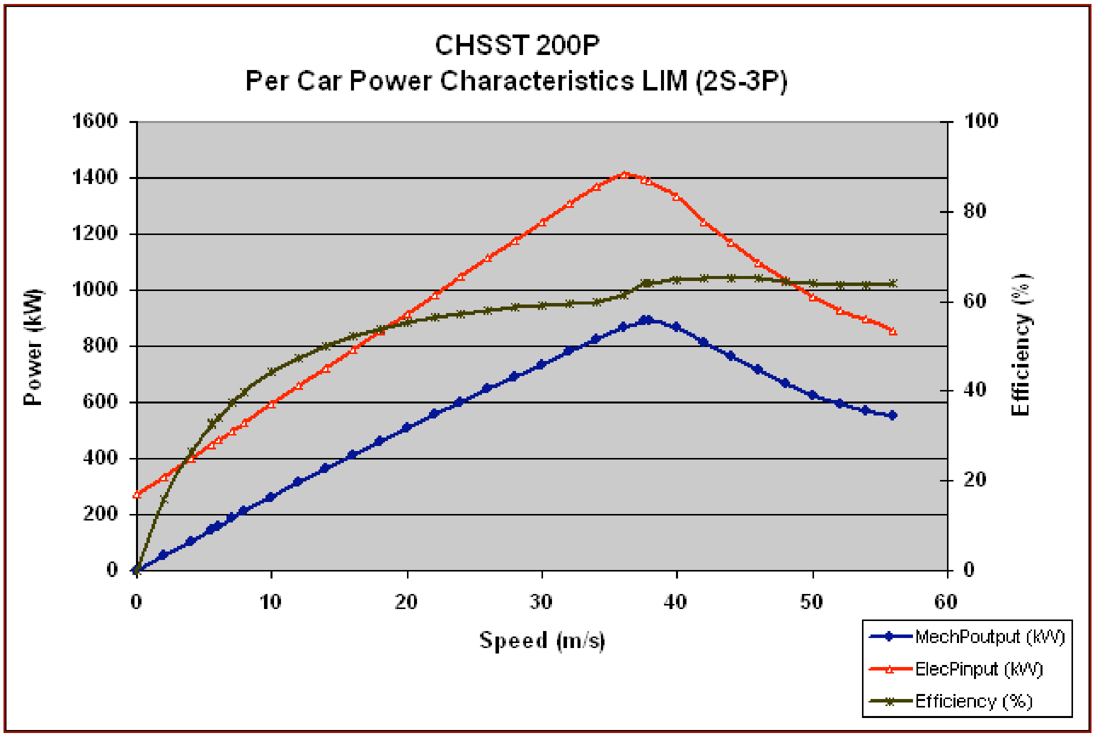
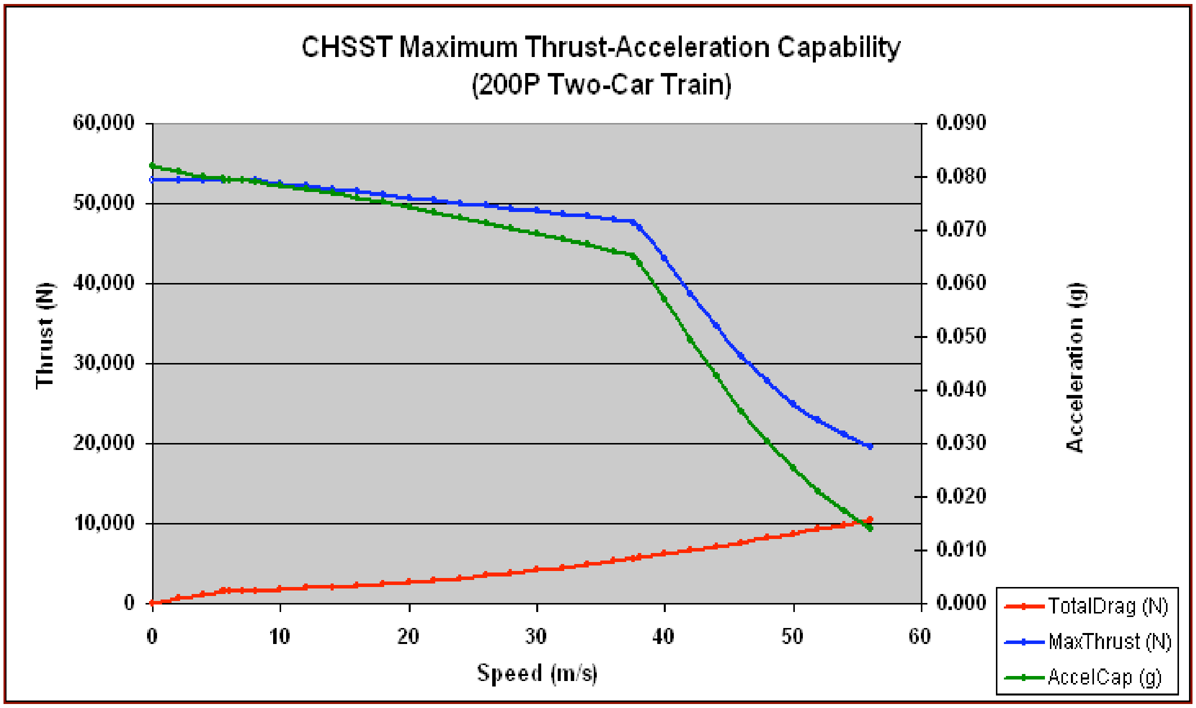


Figure 7. CHSST 200P Maximum Thrust Capability Per Car



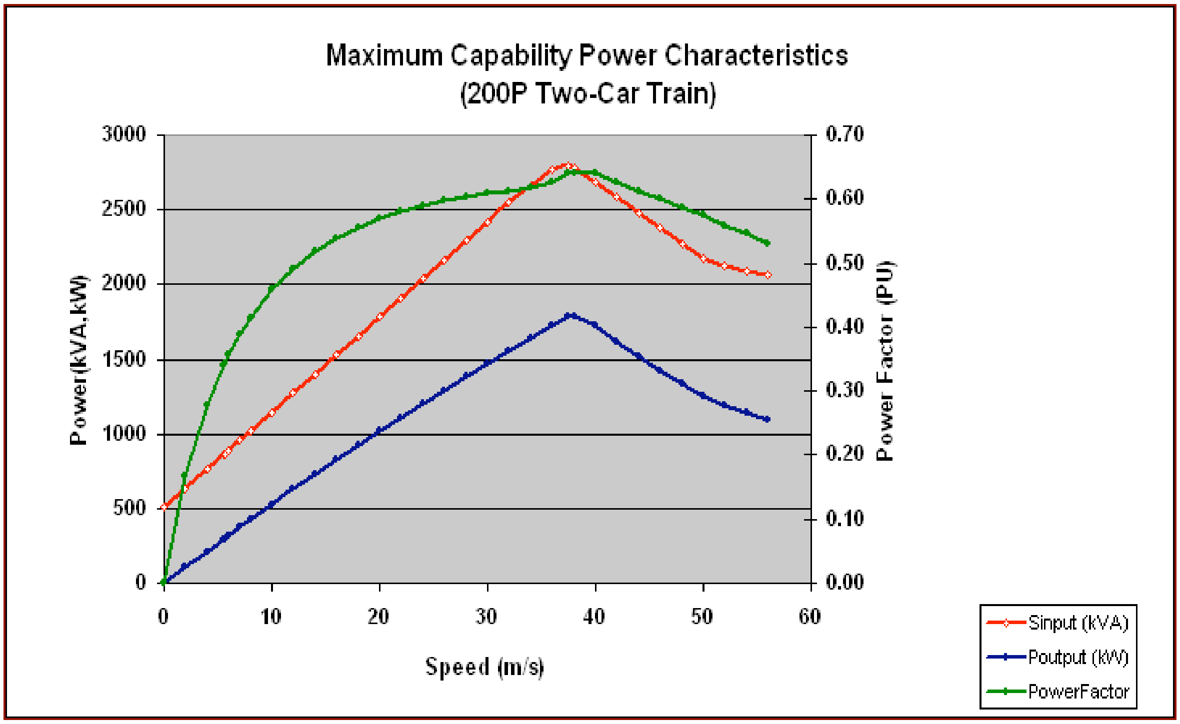


Figure 8. CHSST 200P Acceleration Performance and Maximum Power Capability

2.2.2 Preliminary Specifications for the Colorado Corridor Project

The Colorado Corridor project has a requirement for sustained operations at a minimum speed of 160 km/h. The current version of the CHSST 100 series as applied in the TKL design has a speed capability of 100 km/h with the possibility that with minor modifications its maximum speed could be extended to 130 km/h. For the Colorado application, Chubu has stated that it will be considering two approaches for meeting the desired performance of achieving 160-200 km/h operation.

One approach for higher speed capability is to extend the performance of the 1700 mm gauge 100-series type vehicle. The existing TKL vehicle would need to be increased in length from approximately 14 m to about 16 m, have a reduced height of less than 3 m and be more aerodynamically shaped. It would need a corresponding weight increase from about 17 metric tonnes per car to about 18 tonnes. Seating capacity, depending upon whether the car is an end-car or mid-car configuration, would be about 79 to 88 seats. The propulsion-levitation modules would need to be expanded from the current 2.5 m length, 10 modules per car configuration, to an estimated 3.4 m module length to accommodate a 2.5 m long higher-speed LIM design. Because of car length constraints, the number of modules per car would need to be reduced from 10 to 8 modules.

The alternate approach being considered is to modify the design of the 2000 mm gauge Yokohama 200P type vehicle. Such a vehicle would have a car length of 18 to 20 m or possibly more, have an estimated weight of about 24 tonnes for both end and mid cars, and improve its aerodynamic shape. The seating capacity per car, depending upon the car configuration, would vary from about 108 to 119 seats. The propulsion-levitation modules also would be about 3.4 m in length to accommodate the 2.5-m LIMs and would use a 10 module per car configuration. The levitation magnet design would need to be modified to accommodate a 33 tonne/car design criteria as compared to the 26 tonne/car design of the current 100 series vehicles.

As previously discussed, acceleration performance would be slightly reduced from the present 4.0 km/h/s performance of the 100 series down to about 3.8 km/h/s. The longer modules are almost certain to have an impact on vehicle performance on curves. Low speed turn out curves would likely have to increase from the present 50 m design of the 100 series to 100 m or more for the longer modules. Chubu has stated that main-line high speed curving performance both in the horizontal and vertical directions would also need to be determined.

Table 3 contains selected data provided by Chubu on these concepts. The data shown here should be considered as preliminary and tentative only, as the design definition effort for this corridor is in its early stages of development.

At this time, it would appear that the preferred configuration for the Colorado Corridor is an extension of the 200P series.

Table 3. Chubu Selected Data on Vehicle Upgrades for the Colorado Corridor Project

	100L (TKL)	Extended 100 Series	Modified 200P Series
Maximum Speed (km/h)	100	200	200
Gauge (mm)	1700	1700	2000
Vehicle Capacity (Seated)			
End Car	81	79	108
Mid Car	82	88	119
Car Length (m)			
End Car	14.0	16.2	19.6
Mid Car	13.5	14.8	18.2
Empty Car Weight (tonne)			
End Car	17.1	18.0	24.0
Mid Car	16.6		24.0
LIM (motor length, m)	1.8	2.5	2.5
Levitation Design Criteria (tonne/car)	26	26	33
Guideway Horizontal Radius			
Side Track (low speed)	50	110	100
Main Line (line speed)	100	TBD	TBD

2.2.3 Compliance With FTA Performance Requirements

As stated above, the 200P is a conceptual design whose design performance has not yet been fully defined or specified. Therefore, a full description of the 200P system in the context of FTA requirements cannot be provided. Some of the key attributes of estimated propulsion system performance are known and enable a brief comparison to other CHSST systems. Table 4 summarizes these attributes for two vehicle trains and compares them to what is known of the 100L two vehicle train.

Table 4. FTA System Requirements for Propulsion Sensitive Parameters

Parameter	FTA Requirement	CHSST 200P	CHSST 100L
Maximum Speed	160km/h	200km/h	100km/h
Longitudinal Acceleration	0.16 g	0.08 g	0.11 g
Longitudinal Jerk	0.10 g/s	TBD	0.08 g/s
Grade Climbing	7% Full Performance 10% Degraded Performance	7% @ 86km/h 8% Creeping	7% @ 56km/h 10% @ 44km/h
Horizontal Curves	18.3 m	100 m	50 m
Vertical Curves	1000 m	TBD	1500 m
Headwind	50km/h Full Performance 80km/h Ride Comfort Threshold	TBD	90km/h

As seen from the table, at this point in the definition of the 200P vehicle only its maximum speed capability of 200km/h meets or exceeds the FTA desired performance requirement. The TBDs listed are To Be Determined data. All other data should be considered as provisional pending a more complete definition of the 200P vehicle.

With respect to the CHSST 100L, the longitudinal acceleration capability of the 200P is only 0.08 g compared to 0.11 g for the 100L vehicle, both of which are well below the FTA desired performance goal of 0.16 g. Note that according to the maximum thrust data for both vehicles published here as well as in the previous assessment [1], the regime for constant acceleration for the 200P vehicle is from zero speed to about 30km/h, compared to zero speed to about 46km/h for the 100L vehicle. Hence, for the same vehicle weight, the 100L would have superior acceleration performance in the low speed operating regime and potentially shorter trip times for short station-to-station distances.

Although neither vehicle will meet the FTA requirement of full performance on grades of up to and including the seven percent gradient, the 200P vehicle has a higher balance speed (steady-state speed) of 86km/h compared to a balance speed of about 56km/h for the 100L on that particular gradient. However, the 100L could be expected to negotiate ten percent grades at speeds of up to 44 km/h (with no headwind) whereas the 200P, with its significantly reduced acceleration capability, could operate only at creeping speeds.

A 200P vehicle with its weight limited to 28,000 kg would have improved grade climbing capability. With the seven percent gradient and 50 km/h headwind condition, the balanced speed increases to about 136km/h with the reduced weight. However, the system could not operate at any creeping speeds on the ten percent gradient because the initial acceleration is still not adequate. Improving the initial acceleration is also necessary in order to meet that FTA goal.

As seen in this brief discussion, in addition to known needed improvements, the 200P requires a more comprehensive definition than what is currently known. Therefore, at this time it is not possible to evaluate the degree of compliance of this conceptual vehicle with the whole spectrum of FTA requirements.

2.3 Summary

The 100L vehicle with a maximum operational speed of 100 km/h is suitable for routes with short station spacings. The vehicle needs modifications in order to satisfy U.S. mandatory requirements. The modifications have been addressed to a certain extent, and need to be further examined prior to 100L introduction on short routes in the U.S. For long routes, the vehicle performance characteristics should be improved to reduce trip times. The CHSST has conceptual designs with preliminary specifications for a vehicle that can be operated at a peak speed of 200 km/h. Further examination of such higher speed vehicle designs will be required for potential application in the U.S.

3. Usability Assessment

3.1 Objectives

As stated in Section 1, the CHSST assessment was performed by a selected group of specialists from transit operations in the U.S. The overall objectives of this assessment are:

- Acquire first hand experience and knowledge of a running low speed Maglev system,
- Assess the applicability of the CHSST for U.S. urban transit needs, and
- Make recommendations on deployability and U.S. acceptance of the technology for urban transit.

3.2 Assessment Method

The group performed a review of the existing materials including the first report [1] prepared by the FTA team. A set of pre-trip questions for the CHSST was prepared to facilitate the discussions with CHSST staff in Japan. Discussions and briefings with CHSST staff were held to understand the operational and deployability issues. The FTA team took rides on the new 100L three vehicle consist at the test track in Nagoya. Ride quality, ability of the vehicle to negotiate curves and seven percent gradients, and wayside noise were subjectively evaluated by the User Group. The User Group took a tour along the TKL Maglev guideway now under construction, and had discussions with the prefecture (state government) officials and planners on cost and environmental issues.

In addition to the foregoing, the User Group made the following stops during the CHSST evaluation:

- Visited the Maglev vehicle manufacturer, Nippon Sharyo.
- Visited the Linear Motor manufacturer, ToyoDenki.
- Rode in a Linear Rail Car in the Tokyo Metro.
- Met with Macquarie, a financing organization, for discussions on financing Maglev vehicles, etc.
- Met with the staff of the Department of Land, Infrastructure, and Transportation for discussions on safety issues, safety certification, and project financing by the Japanese Federal Government.

3.3 Observations and Remarks

- The Chubu HSST has more than two decades of developmental and testing activities including demonstrations at several exhibitions with over 60,000 vehicle miles of experience. The most remarkable aspect of this is that no accidents or loss of levitation occurred at these demonstrations, showing the reliability of the CHSST vehicles.
- The vehicle ride was very comfortable with low noise and vibration. The vehicle was capable of stopping and starting on a seven percent grade. Wayside observations by the

group showed that the vehicle produced very low noise at full vehicle speed (60 mph) running at grade as compared to nearby automobiles and trucks.

- The TKL route and construction site was visited by the group. The TKL is a 5.6 mile double track, mostly elevated line, that includes about a one mile tunnel. It is expected to provide a revenue based service in eastern Nagoya, Japan, that is scheduled for operation in March 2005. There will be nine stations. The train headway is to be 6-10 minutes, with expected ridership of 31,000 passengers per day. The construction operations through the city center are being performed as planned. The construction requires large columns (6 ft diameter) and deep foundations (> 60 ft) due to the potential for seismic activity.
- Public acceptance for Maglev seems to be based on:
  - Low noise and vibration,
  - Traffic free operation,
  - No apparent electric or magnetic field problems,
  - Good ride quality, and
  - Minimal concern about visual impact of the elevated construction.
- The cost of construction as presented by the Japanese is high. The construction cost for the U.S. needs to be worked out. The guideway design appears to be very conservative, which may be required for seismic conditions in Japan.
- The maximum speed of 60 mph may be adequate for short station spacings. This will need enhancement to 100 mph for applications with longer station spacings (> 2 miles). The acceleration/deceleration levels of .11g may contribute to higher trip time, as compared to FTA desirable acceleration of .16g.

3.4 Comparison with LRT

3.4.1 CHSST Advantages over LRT

The following are identified as the advantages of Maglev over the LRT.

- Low noise and vibration
- Grade climbing capability (sustained headway 7 percent grade, no headwind vs. 3-5 percent for LRT)
- Smaller car width requiring narrower tunnels and guideways
- Low maintenance and operation costs
- Increased public acceptance
- Higher speeds due to grade separation, leading to higher ridership

3.4.2 CHSST Disadvantages Compared to LRT

The following are considered to be potential disadvantages of CHSST compared with LRT.

- Stringent guideway tolerances
- Lower acceleration/deceleration and speed capabilities requiring longer trip times (~ 13% more for short station spacings)
- Probable high initial cost
- No prior experience in the U.S.
- Requires smaller headways to meet capacity
- Visual impacts; inability to provide integrated at-grade operation

3.5 Environmental Considerations

Maglev is generally an elevated system. Any sections that would be at grade would be fenced off, similar to the way an interstate highway would be separated from cross traffic. Operation of Maglev would benefit from the grade separation, as there is no cross traffic or traffic signals, thus improving the speed of operation. Capital costs per mile would be more expensive due to the elevated aspect, but being elevated would contribute to lowering annual operating costs due to the higher speed of operation. Station spacing would likely be in the higher range of typical _-1 mile spacing, which contributes to its higher average operating speed and resulting in lower operating and maintenance costs. With stations elevated and not in easy view of the street, there would be additional security costs for the stations that would partially offset the lower operating and maintenance costs.

Light Rail Transit could be completely grade separated like Maglev, but is generally not entirely grade separated. There would likely be a mix of alignment, for example, 25 percent elevated, 65 percent at grade on its own right-of-way (with traffic signals at cross streets), and ten percent in street. As a result of doing some portions at grade and in street rather than elevated, capital costs would be less but operating speeds would be lower and operating costs would increase. Station spacing is on the order of _ mile, thus contributing to lower operating speeds and higher operating costs.

There are 20 environmental areas that are reviewed in a typical EIS, and by which various transit alternatives are compared and assessed. The following identifies the 20 areas, describes them, and reviews the two modal alternatives, Maglev and LRT, from the perspective of these areas. Where appropriate, the discussion suggests where a particular mode, HSST or LRT would seem to have an advantage based on the qualitative discussion.

1. **Land Use and Development Activity**

   Impact on existing land use, and ability to either facilitate or detract from development.

   Being elevated over adjacent land uses, Maglev could pass over development and avoid the need to acquire property in certain instances. However, there are visual impacts, which could negatively impact development, although improved accessibility due to higher operating speeds could counterbalance this. Maglev cannot be easily integrated within the street network, even when such integration would positively impact development.

   With on street operation where appropriate, LRT could be well integrated with development. When elevated construction is warranted, LRT could be elevated, as Maglev would be. LRT is more flexible in these regards. Due to its flexibility, LRT would appear to have an advantage in regard to land use and development.

2. Neighborhoods and Environmental Justice

Impacts on neighborhoods and neighborhood populations, including low income and minority groups.

Either mode would be sited to provide maximum benefits to neighborhoods and populations, through increased accessibility, while attempting to minimize negative impacts caused by property acquisition. Thus both modes would have equal levels of advantage.

3. Visual and Aesthetic

Impact on visual and aesthetic aspects of the neighborhoods through which the system operates and the cultural resources therein.

Maglev, when elevated, could be perceived by some to have negative impacts. To mitigate these impacts, Maglev in some cases could be designed to be built close to the ground, albeit not completely at grade. Where there are cross streets, Maglev would have to be elevated, whereas LRT could be at grade with grade crossings. Grade crossings, however, have their negative aspects, such as diminution of speed and exposure to potential accidents.

The overhead catenary of LRT provides an "elevated" visual element in a community. In many cases, such impact is perceived as neutral or positive. With its ability to be at grade, LRT would tend to minimize visual and aesthetic impacts compared with Maglev, and thus could be perceived to have an advantage. If the LRT is also elevated, its visual impact can be considered to be increased due to the appearance of relatively bulky vehicles and overhead power.

4. Cultural, Historic and Archaeological Resources Impacts

Impacts on cultural, historic and archaeological resources.

The alignment of either mode would be selected and designed to minimize or eliminate impacts on these resources. There would appear to be no advantages to either mode in regard to the extent to which they might be able to avoid encountering cultural, historic and archaeological resources.

5. Parklands

Impacts on parklands

The alignment of either mode would be selected and designed to minimize or eliminate impacts on parklands. There would appear to be no advantages to either mode in regard to the extent to which they might be able to avoid impacting parklands.

6. Utilities

Impacts on utilities due to construction of the transit system. An impact could be mitigated through relocation and/or reconstruction of the impacted utilities.

In an urban environment, an at grade or elevated alignment is likely to encounter utilities such as telephone, power or cable lines that would have to be relocated along the way. There should not be much difference between Maglev and LRT in this regard. Likewise, when the two modes are in subway, their impacts would be similar. In regard to underground utilities such as water, sewer or electrical, there might be some need for elevated Maglev to relocate utilities due to the below-ground support for the elevated structure. However, this may not be a significant impact (unlike subway alignments that could have significant utility impacts). The two modes are relatively even.

7. Safety and Security

Ability to construct and operate the system safely, and to provide for the security of users of the transit system.

CHSST has logged significant miles on test tracks carrying passengers [1]. The report suggests that a number of additional tests be conducted:

- Safety certification for operation in U.S.,
- Testing of adequacy of structural design,
- Refinement of design for emergency egress from the vehicles,
- Americanization of the technology,
- Passenger interior injury assessment,
- Vertical control system test,
- Crashworthiness tests,
- Egress tests,
- Flammability test; and
- Test demonstration of the automatic train operation.

Assuming these and other tests yield positive safety results, Maglev transportation can be considered safe. The LRT vehicle can experience unsafe dynamic behavior such as wheel climb, lift, hunting, and poor curve negotiation leading into derailments in some rare instances. The possibility of a Maglev vehicle leaving the guideway is very small, although levitation failure can occur. Maglev can also experience dynamic instability modes, such as yaw and sway. At grade operation can introduce the possibility of accidents.

Similarly, a security plan for any transit system is needed upon implementing any mode. This security plan would provide for security of the system and its users, and it would account for the differences in alignment of the projects (elevated, at grade or subway).

It can be concluded that Maglev vehicles are as safe as LRT, if not better.

8. Transportation Impacts and Effectiveness

Impact on existing transit modes; and effectiveness of the transportation system with the proposed modal alternative in place.

The primary function of a transit system is to carry passengers. The more people who ride transit vehicles rather than their personal automobiles, the more benefits there are such as congestion and air quality reduction in addition to direct mobility benefits. The two main factors that contribute to increased ridership are improved travel time and accessibility to transit stops.

Maglev will likely have faster travel time due to fewer stations, however, fewer stations means access to the stations would be, in general, more difficult. With park and ride available at stations, however, this mitigates the relative difficulty of getting to a Maglev station. Faster operating speeds should provide higher ridership potential for Maglev that should slightly offset increased accessibility to LRT stations.

Note: Because of its need to be grade separated, Maglev would be appropriate for fewer situations, at least in the typical urban commuting corridor. (On the other hand, Maglev would likely be considered more readily as a candidate for people mover type applications.) Thus, the ridership advantage identified herein accrues only in those corridors or applications where Maglev could be applied.

9. Air Quality

Impact that operating the proposed system would have on regional air quality and air quality in the immediate vicinity of the alternative; and air quality impact of constructing the alternative.

Both modes utilize electric propulsion energy, and thus there are no air emissions in the vicinity of the guideway due to the operation of the system.

The ability to improve regional air quality is based upon the ability to attract automobile users out of their cars. It has been identified in item 8 above that Maglev should be able to attract higher ridership than LRT.

Emission of carbon dioxide that contributes to global warming is based upon energy efficiency. The greater the efficiency, the less energy and carbon dioxide produced per passenger. Relative energy efficiency of Maglev is required for energy-based comparisons.

Because Maglev has potential air emissions advantage due to somewhat increased ridership potential, and impact on carbon dioxide emissions and energy comparison are unknown, Maglev has the advantage at this time.

10. Noise and Vibration

Noise and vibration impact of operating the modal alternative.

Maglev produces less noise and vibration due to the fact that it does not contact the guideway when in motion. This may be offset in whole or in part by the fact that Maglev is elevated, since noise from an at-grade alignment might be partially mitigated due to ground effect and intervening structures. On the other hand, LRT can also be elevated, at least in portions. Noise and vibration would need to be analyzed as part of any deployment.

Maglev has potential advantage in this category, pending results of future field tests.

11. Ecology

Impact of constructing the alternative on terrestrial and aquatic habitats.

The ability to site the alignment in order to minimize impacts to terrestrial and aquatic habitats is independent of mode.

12. Water Resources

Impact on regional and local water quality.

The ability to site the alignment in order to minimize impacts to water resources is independent of mode.

13. Soils/Geotechnical

Ability of the soils and geotechnical system to accept placement of the alternative.

Soils/geotechnical considerations need to be dealt with in laying out a linear right-of-way, regardless of whether there is at grade or elevated guideway involved. Therefore, this category would be even for the two modes.

14. Contamination/Hazardous Materials

Contamination and hazardous materials that would have to be dealt with as the alternative is constructed.

Similar to soils/geotechnical, contamination/hazardous materials are a consideration for any type of linear right-of-way.

15. Energy

Amount of energy required for constructing and operating the proposed transit system.

Maglev operation without touching to the guideway could lead to energy efficiencies. Determination of the amount of energy required for constructing and operating Maglev would be made as part of evaluation of a deployment of the technology. Thus, an energy analysis and comparison are needed to evaluate this issue.

16. Construction Impacts

Collective impact, during the construction period, of construction of the alternative on land use, visual, historic/archaeological, parklands, safety and security, transportation, air quality, noise and vibration, ecology, water resources and contamination.

Determination of construction impacts of Maglev would be made as part of evaluation of a deployment of the technology. In addition, determination of construction impacts would be assessed for specific alignments during the environmental process.

17. Secondary and Cumulative Impacts

Indirect impacts related to the implementation of the alternative.

This area is a function of impacts in other areas, and thus is not a distinguishing area for this comparison.

18. Financial Impacts

Ability of the implementing entity(ies) to finance the construction of the alternative, and to absorb operating and maintenance costs of the alternative.

This category should be broken up into two elements: financial wherewithal to construct the alternative and the financial impacts of operating and maintaining the alternative.

There is correlation between financing and costs. Generally speaking, the higher the costs, the more difficult it is to come up with the money to finance such costs, unless there are offsetting revenues that can contribute to the financing of costs.

It is intended that TKL's fare box revenue cover operating and maintenance costs plus a portion (related to the vehicle and systems element) of capital costs. The capital costs of TKL seem to be high relative to U.S. costs for subway and elevated construction. Even if it is assumed that capital costs in the U.S. will be lower than in Japan, elevated construction in either country is significantly more expensive than constructing at grade. In addition, there is no experience with an urban transit system being able to cover its costs for operating and maintaining the system.

A. Financing of Construction Costs

Because Maglev would be for the most part elevated, construction costs of Maglev would be more expensive than LRT, which would have portions at grade. Thus the advantage of least cost would, in most cases, go to LRT. In some cases there might be exceptions, wherein LRT that is constructed at grade for the most part would have to be placed in subway in the Downtown area due to local constraints, whereas Maglev could potentially find a location within Downtown that allows elevated construction. This determination would be made during AA/EIS.

Due to its lower construction costs, LRT would have the advantage.

B. Financing of Operating and Maintenance Costs

As discussed in item 8, Transportation Impacts and Effectiveness, Maglev should be able to attract more riders than LRT. However, since the CHSST vehicle at 2.7 meters wide is ten percent narrower than a light rail vehicle at three meters wide, Maglev would carry fewer passengers per car, thus is less efficient at carrying passengers. (This is based upon use of the 100L vehicle, currently intended for use on TKL. The proposed 200L vehicle, which is currently under consideration for development design, would rectify this by providing a wider vehicle.) Other aspects of Maglev could potentially be less expensive to operate than LRT. For example, due to its lack of moving parts, there should be less propulsion energy needed, and its automated operation would reduce labor costs.

19. Public Involvement

Involvement of the public in the decision to implement an alternative, and on the design of the alternative that is the collective decision to implement.

The public is likely to accept Maglev due to its noise-and-vibration free environment as well as higher travel speeds, although the issue of elevated versus at-grade operations may also impact public opinion.

20. Section 4(f) Evaluation

In the case where parklands or cultural, historic and archaeological resources are affected, the analysis required to determine whether there is a feasible and prudent alternative to such action.

Section 4(f) evaluation is a result of impacts in two areas previously reviewed: parklands and cultural, historic and archaeological resources. Although an important area of environmental analysis, it provides nothing new in this modal comparison than already discussed in the two sections.

3.6 Deployment Issues

Candidate locations for deployment of CHSST Maglev in the U.S. include

- Grade requirements greater than five percent,
- Alternative to tunneling due to smaller cross-section and grade climbing capabilities, and
- Noise sensitive areas.

Other possible applications include: airport people mover, downtown circulator, or other activity center transportation system, and where elevated system is the desired option. Technology transfer and “Americanization” or adaptation of the CHSST technology will be required. The ability to operate at higher speeds (130kph) may be required for U.S. applications. Safety certification for operation in the U.S. will be required by the FRA. Inclusion of an Urban Maglev alternative in an AA/EIS at one or more major U.S. cities will be needed for the agencies to consider Maglev seriously.

3.7 Summary

The usability of the CHSST for U.S. urban transportation scenarios has been addressed in this section, based on the experience of the FTA user group team. The intense observations of the CHSST Maglev vehicle leads to the conclusion that urban Maglev transportation is viable in the U.S. and indeed, the CHSST may have direct applications with several advantages over traditional Light Rail Transit. Such applications include terrains with severe grades (> five percent), with tunnels, and within noise sensitive areas, as well as people-mover type applications. Safety certification and “Americanization” of the CHSST technology will be required. Increased vehicle performance including speed higher than 100 km/h may also be required. Inclusion of the Maglev alternative in AA/EIS is recommended.

4. Deployment Progress of HSST

As per plan, the HSST technology is being deployed in a 9.2 km nine station two-way revenue line, to be known as the "Tobukyu Line", in Aichi Prefecture for an Exposition in 2005. The planned location of this new line will connect with and comprise a component of the Nagoya area rail network. A layout of the planned line is shown in Figure 9, including projected station locations and use of street rights-of-way. It is intended to become a permanent mass transit line. Approximately 7.4 km will use an elevated guideway, with 1.8 km in a tunnel at the western end.

Figure 9. Detailed Layout of Tobukyu HSST Line, Aichi Expo 2005

An evaluation and verification/test program for that project was conducted in the 1990-93 time frame leading to approval by Japanese authorities for construction, financing and revenue operation for the public. A detailed report supporting this process [3] gives a description of the evolution, testing, and economic analyses of the systems performed over that period.

On the basis of the report, the Aichi Prefecture proceeded with several intermediate steps which resulted in the start of project construction. Major steps were procurement of safety certification from the federal government (DLIT), identification of required contractors, and development of a financial plan for finance contributors including banks, the federal government and industry partners.

4.1 Guideway Construction Progress

At the time of the first visit by the FTA team members in March 2002, there was no HSST construction activity. In February, 2003, when the team made a follow-on visit, there was significant activity in regard to the foundation and completion of the erection of the pylons along the TKL alignment (except in tunnels). Reinforced concrete guideway beams (girders) were also completed over some spans. Figure 10 is a photo of columns and stations integrally made with columns and beams. The columns are hexagonal in shape with a maximum cross section dimension of about six feet. The span length is typically 30 m, but varies depending on the location. The foundation depth is approximately 30 m and varies from location to location. The whole guideway structure is being cast in situ with reinforcement in place. Figure 11 shows the earthworks for the maintenance depot being built. No superstructure (steel sleepers, rails, aluminum reaction plates, etc.) was seen at the time, nor was a power supply seen.

The construction work to-date was impressive to the User Group, particularly in its clean execution. The group, however, questioned whether this project is too large to be completed in time for operation in 2005, especially since no progress has been made on the excavation of the 1.5 km tunnel.

Figure 10. Columns Under Construction

Figure 11. Maintenance Depot Under Construction

The arrangement of the basic guideway beam, rails, sleepers, and support is shown in Figure 12. The specially designed steel rail section provides both the levitating two-pole lower section and the upper LIM surface, covered with aluminum (insulated from steel), with the outer vertical flange also used for mechanical brakes. Guideway rail alignment can be done via adjustments in the seating of the sleepers on the beams, as shown in the figure. Lines in the tunnel are also anticipated, using the sleepers on slab foundation. Little or no at-grade operation is projected in the urban-type infrastructure.

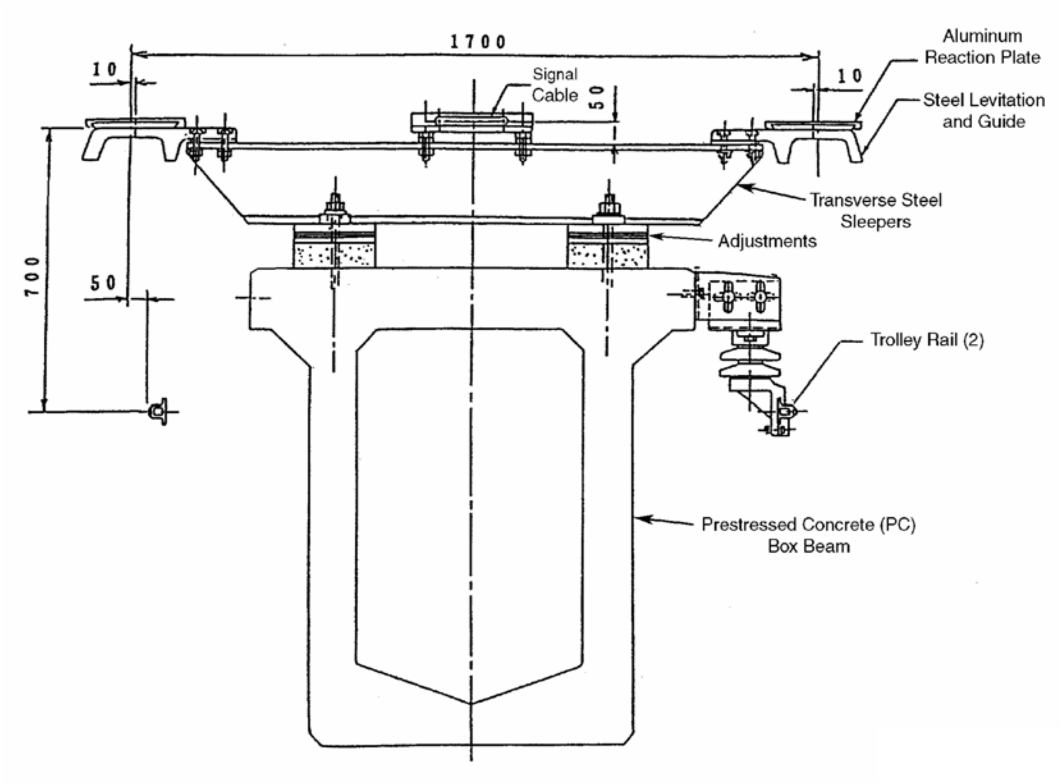
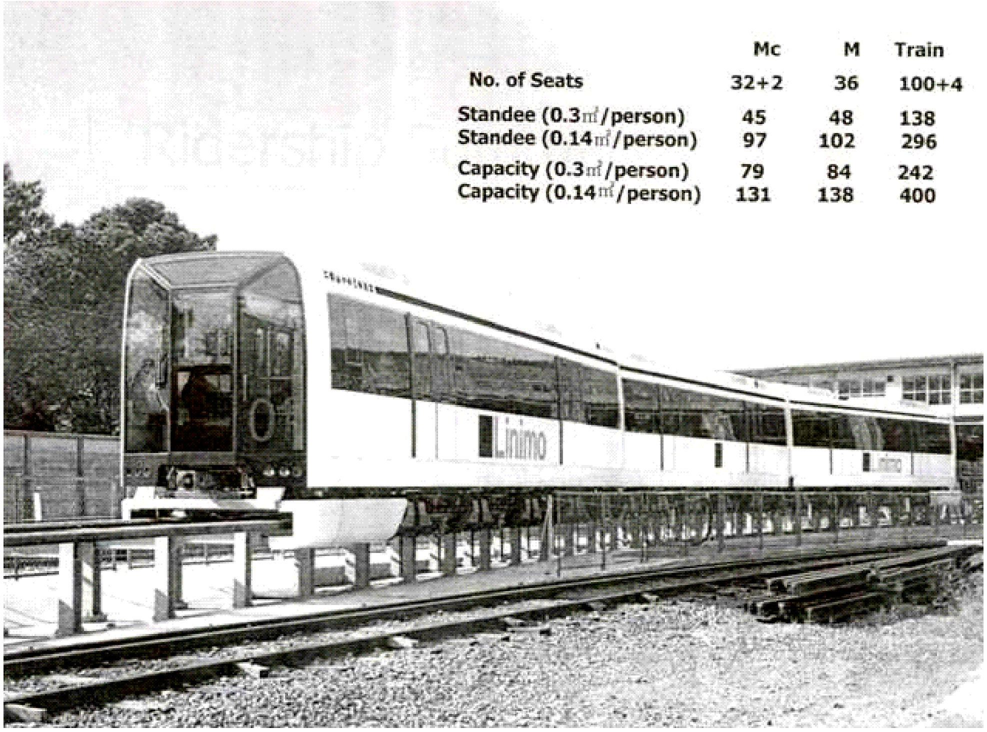


Figure 12. Cross Section of Standard CHSST Single Guideway

4.2 Vehicle and Manufacturing

Vehicles are being manufactured at Nippon Sharyo, which also makes Shinkansen vehicle chassis and other rail vehicles. At least one train set of three cars (Figure 13) was delivered to the Nagoya test track in October, 2002. Each vehicle has five modules on each side, with each module accommodating one Linear Induction Motor. The cars were produced more or less to the same specifications of the 100L as discussed in the previous report [1]. Eight trainsets with a total of 24 cars will be manufactured for deployment on the TKL.



	Mc	M	Train
No. of Seats	32+2	36	100+4
Standee (0.3㎡/person)	45	48	138
Standee (0.14㎡/person)	97	102	296
Capacity (0.3㎡/person)	79	84	242
Capacity (0.14㎡/person)	131	138	400

Figure 13. Three Car Trainset
(Mc = Middle Car, M = End Car)

The following is a list of specific safety features of the vehicle.

- Egress. An emergency escape door in the ends of the trainset allow for rapid egress of passengers onto the guideway, whose top surface has sleepers so is not suitable for walking. Passengers would be lowered from the guideway using an escape ladder or other means. The HSST is aware of U.S. egress requirements and will be able to provide adequate solutions when required. For deployment in Japan, this is not considered to be a serious issue.
- Braking. The vehicles are fitted with mechanical caliper brakes, hydraulic brakes, and electrical regenerative brakes as per the specifications.
- Fire and Safety. Fire safety flammability requirements for the HSST 100L vehicle are based on Japanese standards. (A-A standards as they are called in Japan). These standards and methods of testing are apparently different from that of the NFPA followed in the U.S. According to Japanese practices, the materials in the vehicle are classifiable as Non-flammable, Highly Resistant to Flame, or Resistant to Flame. Non-flammable materials are required for the vehicle body, skin, floor, underfloors, etc. The High Resistance materials are the electrical wiring. The Resistant Materials are adequate for upholstery, seat cushions, etc. The NFPA fire safety requirements are defined in terms of satisfying specific ASTM tests for the materials. The Japanese test procedures are different from those in ASTM. Hence, if the vehicles are imported, testing of the materials according to ASTM will be required to ensure fire safety.
- Vehicle Crashworthiness. Apparently, no design changes have been made for improvements to vehicle crashworthiness.

4.3 Linear Induction Motor

The LIMs are being manufactured as per the specifications by ToyoDenki, which is under contract to produce 240 LIM units (10 per car). The steps in their manufacturing process are:

1. Steel laminate core plates are punched out.
2. Steel laminates are assembled (layered) to form the core.
3. Aluminum bar windings are bent into shape.
4. Aluminum bar windings are wrapped with a glass fiber woven mat and worked around the core in a largely manual operation.
5. The entire unit is soaked in a varnish bath.
6. The stator is then placed in a vacuum which aids in pulling the varnish into the glass fiber material, around the coils, and into the gaps between the core laminates.
7. The varnished stator is oven cured.
8. The stator is then painted black and connectors are attached.

Photographs of the stator at different stages of the manufacturing process are shown in Figure 14 through Figure 16.

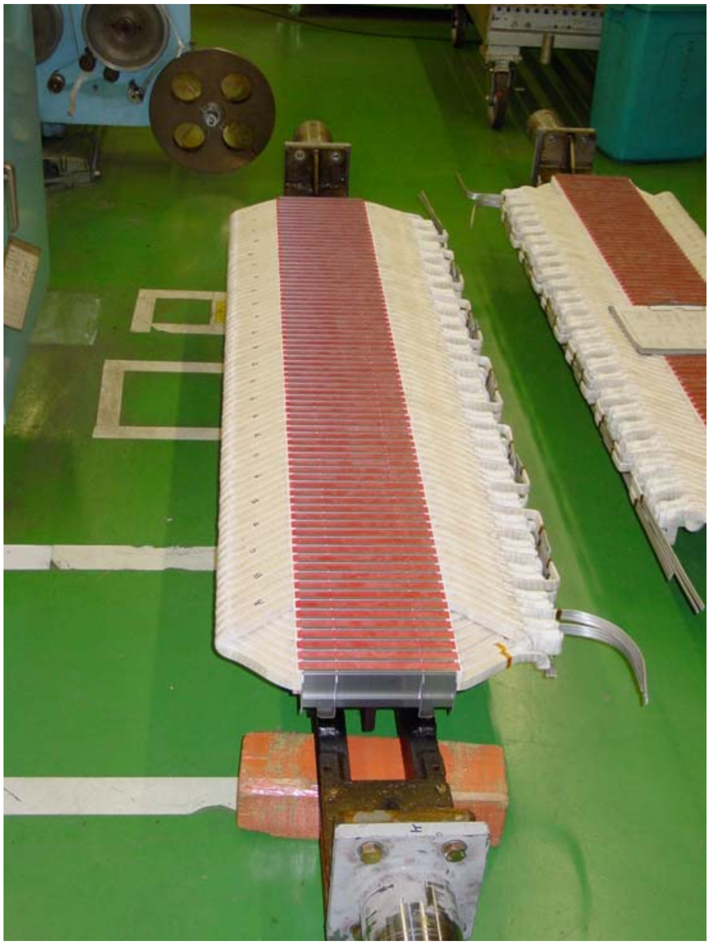


Figure 14. The LIM in Assembly at the ToyoDenki Plant in Yokohama

Figure 15. The 100 Series LIM After the Varnishing Process

Figure 16. The 100 Series LIM After Painting and Attaching Connectors

4.4 Financing and Costs of Deployment

The FTA team had discussions with the HSST and the Aichi Prefecture in Nagoya on project financing and costs. Although these issues are specific to Japanese conditions and rates (labor and materials, and Japanese business practices), they are discussed here in some detail and may be useful to the U.S. Government and investors.

The financing of the TKL project has apparently been done through a combination of interest bearing and interest free loans, plus grants from the Aichi Prefecture Department of Land, Infrastructure and Transportation, the Japanese Central Government, and private banks and industry. The breakdowns are presented in Table 5, Table 6, and Table 7.

Table 5. Breakdown of Costs and Estimated Revenues

Civil Work ▪ Guideway Beam ▪ Columns, Foundations ▪ Stations	62% ≅ $558M*
Systems Work ▪ Vehicles ▪ Electrical ▪ All Others	38% ≅ $338M
Estimated Revenues	$23.3M/year
Estimated O & M Costs	$21M/year

*The costs are deduced from the information stated by the Japanese and converted into $ at the exchange rate current in late 2002.

Table 6. Financing Breakdown of Civil Work

Aichi Prefecture	$360M
City of Nagoya	$108M
Federal Government	$ 92M
	$558M

Table 7. Financing Breakdown of Systems Work

Private Sector Grant	$33M
Aichi Prefecture Grant	$21M
Aichi Prefecture Interest Free Loan	$54M
Aichi Prefecture Interest Bearing Loan	$27M
Municipalities Grant	$14M
Municipalities Interest Free Loan	$36M
Municipalities Interest Bearing Loan	$18M
Bank of Japan Interest Bearing Loan	$135M
	$338M

4.5 Summary

- The work on the deployment of the HSST Maglev guideway infrastructure for the TKL is progressing well as per the plan. There is a significant portion of the civil works, including the tunneling of approximately 1.5 km, remaining to be completed for the 2005 Expo in Nagoya.
- Vehicle and Linear Induction Motor manufacturing seem to be progressing on schedule and without any technical problems. The manufacturing processes apparently need fairly sophisticated technologies, which may not be readily available from U.S. firms.
- The Japanese costs of the Maglev guideway infrastructure are much higher than the FTA system level requirements. The visiting User Group shares the same concern, recommending that the infrastructure costs be evaluated for U.S. conditions by U.S. firms with basic technical input from the HSST. This approach will lead to a more realistic cost of Maglev for U.S. applications.

5. Applicability to U.S. Scenarios

The low speed CHSST Maglev technology, with certain upgrades, may be applicable to several FTA urban transportation scenarios in the United States, especially some of the congested downtown centers where several stops with close spacings are required. In addition, the technology may be used for long distance travel if the Maglev vehicle speed can be upgraded to, say, 200 km/h. The User Group identified two examples of Maglev applications which are presented here. These are examples only. The FTA does not intend to specifically recommend these sites over other possible routes, nor is it the intent to propose the CHSST technology exclusive of other possible Maglev technologies. The CHSST technology, however, is matured, commercially available, and attractive compared with other traditional systems such as Light Rail Transit.

5.1 North Bethesda Transitway Corridor

The material in this section is based on a presentation by Gary Erenrich [4]. The proposed corridor is shown in Figure 17. The corridor has the following characteristics:

- It is approximately 2.3 miles long.
- The guideway will be fully elevated.
- The alignment follows public rights of way.
- It connects a major shopping center, corporate headquarters & other offices, over the Interstate to an existing Metrorail Red Line.
- It abuts residential, institutional, and recreational centers.
- It will have three to five stations on the route

Figure 17. North Bethesda Corridor

5.1.1 History of the Corridor

The transit way is in the Land Use Master Plan with dedicated land. The 1992 study examined alternative modes: Monorail, People Mover, Automated Light Rail. The corridor was studied by MUSA for a low speed Maglev application. The corridor is expandable into Virginia.

5.1.2 System Characteristics

The expected ridership exceeds 15,000 passengers per day. This requires vehicles with a capacity of 3000 passengers per peak hour in each direction. Four 2-Car consists running at 3.3 minute headways (8 cars for operation and 2 spares) will be adequate to meet the capacity requirements. The estimated cost of the system is on the order of $50M per two-way mile.

5.1.3 Preliminary Assessment

- Alignment: Chubu HSST, LRT, and Monorail all can achieve grades and curvature. The entire corridor is aerial.
- Noise: The HSST can meet the FTA prescribed noise limit of 70 dBA at 50 ft. The LRT may not meet this due to the wheel-rail friction.
- Ridership: There is a potential for higher ridership on HSST because of reduced headways and travel time.
- Construction Costs: The HSST appears to be very competitive
- Aesthetics: The HSST is less obtrusive than aerial LRT. No overhead wires and poles are required.

5.2 Colorado I-70 Maglev Project

The material in this section is based on a presentation by Vladimir Anisimow and Mark Ashley [4]. The I-70 Corridor experiences significant congestion with automobile traffic on the weekends. The roads cannot be widened due to proximity to people's dwellings. Steep gradients exist that will not be suitable to LRT. The weather conditions are harsh. Low speed Maglev technology such as the CHSST seems to offer many advantages, including low noise and pollution.

5.2.1 Route Characteristics

The length of the corridor from Denver International Airport (DIA) to Glenwood Springs is about 156 miles. The initial portion of the route, from DIA to Golden, is only 35 miles and does not pose problems for any mode of transportation. The mountain portion of the corridor (Figure 18) has harsh terrain with maximum gradients of 12 percent. Full speed without degradation should be maintainable on grades of at least 10 percent. The peak speed of 200 km/h is required in order to have a trip time reasonably comparable to that of an automobile in the absence of traffic congestion. The ambient temperature along the route can range from 100° F in summer to about -50° F in winter, when there can be snowfalls of as much as 34 inches in a single day. The corridor also experiences gusty winds, lightning, and the potential for avalanches.

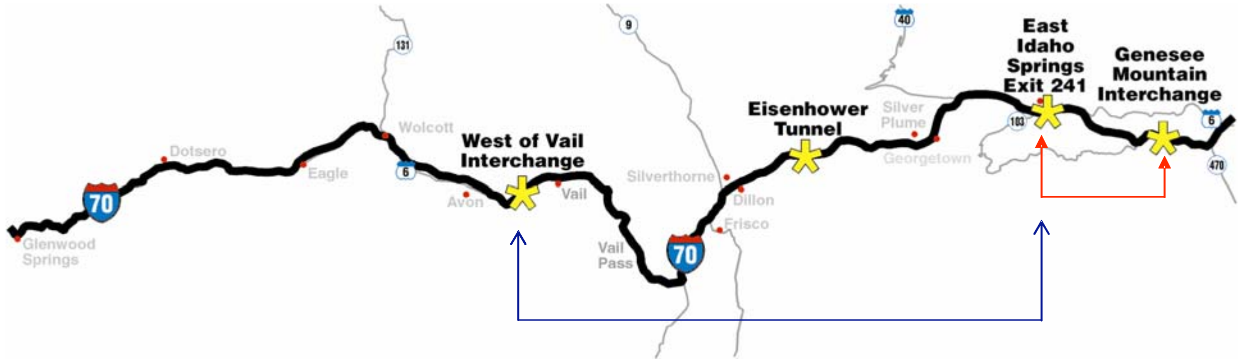


Figure 18. I-70 Mountain Alignment

5.2.2 Current Studies

The Colorado Department of Transportation (CDOT) Maglev Team is currently evaluating the advantages of Maglev over other conventional transportation modes such as LRT or buses on an elevated guideway. The team is also studying the feasibility of the CHSST Maglev with enhanced speeds up to 200 km/h for application to the corridor. Preliminary findings show that the cost of the infrastructure (guideway, foundation and pylons) plus the system costs (power supply, vehicles, etc.) are reasonably low and the total system could be build in the range of $50 million/two-way mile.

5.3 Summary

- The CHSST technology is applicable to scenarios on some short and long distance routes in the United States. Whereas for short distances the technology can be applied as is, for long distances upgrades are required, particularly for speed. The 200 Series vehicle will be required on long routes to achieve reasonable trip times.
- The North Bethesda Corridor in Montgomery County Maryland can benefit from the CHSST technology using the 100L vehicle with a maximum speed of 100 km/h.
- The CDOT I-70 route will require the 200 Series vehicle, which can achieve a maximum speed of 200 km/h. The CHSST has background in the technology required to upgrade the 100L vehicle to a 200 Series vehicle, but it will take some effort and funding to accomplish this.

6. Conclusions and Recommendations

6.1 Conclusions

1. The CHSST Maglev technology has potential for application in U.S. urban transportation if certain enhancements are made to the vehicle design. The 100L vehicle, with a maximum speed of 100 km/h, has already been designed and tested, and may be adequate for short distance routes with close station spacings. This vehicle needs modifications for improved egress in order to satisfy the ADA requirements. For long distance station spacings, use of the 200 Series vehicle, with a maximum speed of 200 km/h will be appropriate to reduce trip time. This vehicle has only a conceptual design. Therefore, developmental work will be required prior to its deployment in the U.S.
2. The CHSST low speed Maglev seems to have several advantages over traditional transit systems such as Light Rail. These include 1) public acceptability due to low noise, low vibration, potential for low energy consumption, and low visual impact, 2) superior and sustainable ride quality, 3) superior grade climbing capability for hilly terrain, and 4) high reliability.
3. There are several urban sites in the U.S. where the CHSST Maglev has the potential to reduce automobile traffic congestion. Two examples, one in the North Bethesda Corridor in Maryland and the other in the I-70 Colorado corridor, seem to have the required features which make Maglev transportation advantageous over other modes..
4. There are deployment issues for CHSST Maglev. These include safety certification, technology transfer, and reasonable estimates of costs to be incurred. The Maglev costs to date are those experienced or quoted by the Japanese for its deployment in Japan. The U.S. costs will be different and need to be evaluated on the basis of U.S. labor and material costs. Reliable estimates for the operational and maintenance costs of the Maglev are also needed.
5. Maglev deployment on the TKL in Nagoya is proceeding as per the Japanese plan with funding from the Aichi Prefecture, the Federal Department of Land, Infrastructure and Transportation, and banks. Although there is a 1.5 km tunnel yet to be started, the CHSST is confident that the project will be ready for the 2005 Expo in Nagoya.

6.2 Recommendations

1. The FTA should continue monitoring the CHSST Maglev deployment in Nagoya and be aware of any changes in vehicle, guideway, and component design.
2. The FTA should obtain independent cost estimates for construction of the CHSST guideway and other components in the United States.
3. The FTA should procure finalized designs and parameters for the 200 Series vehicles for potential application in the U.S.
4. The FTA should encourage making low speed Maglev one of the alternatives to be considered by transit planners in their AA/EIS studies.

7. References

1. *Assessment of CHSST Maglev for U.S. Urban Transportation*, G. Samavedam et. al., Final Report, July 2002.
2. *Urban Magnetic Levitation Transit Technology Development Program*, Report #8, Chubu HSST Maglev System Evaluation and Adaptability to American Standards, MUSA Draft Report No. FTA-MD-26-7029-8, October 2002.
3. *Report on Economic Feasibility Study of Magnetic Levitation Linear Motor Car for Urban Transportation"*, Japan Transportation Economics Research Center, Aichi Prefecture, March 1993.
4. *Chubu HSST User and Technical Evaluation Team Briefing,* presented to Federal Transit Administration, Washington DC, March 26, 2003.

Appendix A. February 2003 Trip Agenda

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February 2nd	(Sun)	PM	Arrive at Narita in the afternoon from various gateway in US			
(2Œ2“ú?j	(“ú)		Stay at the Hotel Nikko narita (81-476-32-0032)			
February 3rd	(Mon)	AM	Fly to Nagoya (Leaving at 0855 Narita and arriving at 1015 Nagoya)	ANA3201		
	(Œ)					
		PM	Visit the HSST Test Center and view of the TKL new train	Item-1: Overview Briefing by CHSST.....	A,B	CHSST
			Discussion with Chubu HSST	Item-2: US User Group Presentation.....	A,B	CHSST
				Item-3: Maglev Capital Cost Estimation.....	A,B	CHSST
			Stay at the Meitetsu Grand Hotel (81-52-582-2211)	Item-4: Demo ride on the TKL new train	A,B	CHSST
February 4th	(Tue)	AM	Visit the TKL Construction Site	Item-8: Construction practice and issues	A,B	CHSST
		13:30-15:00	Survey the Guideway-bus system	Item-6: System selection, funding etc	A	Subsidiary of Nagoya city
		15:30-17:00	Meeing with Aichi Prefectural Gov. (Planning&Promotion Dept.)	Ditto	A	Aichi prefectural Gov.
		PM	Discussion with CHSST at the HSST Test Center	Item-5: on the planned 200 series	B	CHSST
			Stay at the Meitetsu Grand Hotel (81-52-582-2211)	Item-7: on the open items	B	CHSST
February 5th	(Wed)	AM	Discussion with Chubu HSST at the HSST Test Center	Discussion on any pending issue	A,B	CHSST
		13:00-16:00	Visit Nippon Sharyo (Car Manufacture)	Item-9: Tour of vehicle manufacture	A,B	Nippon Sharyo
			Move to Tokyo (Bullet train)			
			Stay at the Akasaka Prince Hotel (81-3-3234-1111)			
February 6th	(Thu)	09:30-11:00	Visit Toyo Electric Yokohama Work(Inverter, LIMs)	Item-10: Tour of major equipment supplier	A,B	Toyo Elec. (Yokohama Works)
		13:00-15:00	Visit Tokyo Metropolitan Gov. and ride on Linear Metro	Item-12: LIM Application to subway car	A,B	Tokyo Metropolitan Gov.
		15:30-17:00	Meeting with MLIT (Ministry of Land, Infra. And Transportation)	Item-14: Public-Private partnership	A	MLIT
		17:30	Meeting with Professor Masada	Item-13: Discussion on LSM and LIM	(A) B	Prof. Masada
			Stay at the Akasaka Prince Hotel (81-3-3234-1111)			
February 7th	(Fri)	09:30-11:00	Meeting with Macquarie (Macquarie Tokyo office)	Item-11: Japanese operating lease	A	Macquarie (Investment Bank)
		PM	Leave for USA			

US team participants	Gopal Samavedam, Foster Miller, Team Leader, FTA Technical Consultant	MA(	B
	Frank Raposa, FTA Technical Consultant	MA(	B
	Richard Feder, Director of Planning, Port Authority of Allegheny County, PA	PA	A
	Denis Cournoyer, Hampton Roads Transit, VA	VA	A
	Gary Erenrich, Montgomery County, MD	MD	A
	David Munoz, CDOT project team	CO	A
	Clark Roberts, CDOT project team	CO	A
	David Keever, SAIC	Washington DC	A
	Suhair Alkhatib, MTA's Maglev Project Manager	MD	A
	John Harding, FRA	Washington DC	B
	Yoav Arkin, Earth Tech, MUSA Team	MD	B

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