NEW YORK STATE
TECHNICAL & ECONOMIC MAGLEV EVALUATION

New York State Energy Research and Development Authority

The New York State Energy Research and Development Authority (Energy Authority) is responsible for the development and use of safe, dependable, renewable and economic energy sources and conservation technologies. It sponsors energy research, development and demonstration (RD&D) projects and financing programs designed to help utilities and other private companies fund certain energy-related projects. The Energy Authority is a public benefit corporation which was created in 1975 by the New York State Legislature.

In working toward these goals, the Energy Authority sponsors research, development and demonstration projects in two major program areas: Energy Efficiency and Economic Development, and Energy Resources and Environmental Research.

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The Energy Authority derives its basic RD&D revenues from an assessment levied on the intrastate sales of New York State's investor-owned electric and gas utilities. Additional RD&D funds come from the investment of retained earnings, as well as from an annual contribution from the New York Power Authority.

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NEW YORK STATE
TECHNICAL & ECONOMIC
MAGLEV EVALUATION

Final Report

Prepared for

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NOTICE

ACKNOWLEDGEMENT

This report describes the results of a MAGLEV applications study for New York State. The study was a combined effort of a New York State task team and a team of subcontractors led by the Grumman Corporation. The following persons participated in the study:

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EXECUTIVE SUMMARY

INTRODUCTION

The New York State Energy Research and Development Authority, with the assistance of the Departments of Transportation, Economic Development, Environmental Conservation, and the New York State Thruway Authority, is undertaking a comprehensive, systematic evaluation of High-Speed Surface Transit options for the State. This study represents the first phase of that effort. It is a preliminary evaluation of technical and economic characteristics of magnetically levitated ground transportation systems (MAGLEV). The evaluation focuses on two major questions:

1) Does MAGLEV offer potential to meet future New York State transportation needs in a cost-effective manner?

2) What benefits could New York State expect from participation in MAGLEV technology development and MAGLEV system implementation?

This preliminary three-month study was intended to identify key issues and provide recommendations for subsequent phases of the comprehensive evaluation. The study was cosponsored by the New York State Energy Research and Development Authority and the New York State Thruway Authority. Following a competitive solicitation, a contract was awarded to a team headed by the Grumman Corporation that included staff from Parsons Brinckerhoff Quade & Douglas, Inc.; General Electric Company; Intermagnetics General Corporation; and Brookhaven National Laboratories. The New York State Department of Transportation provided marketing information and economic analysis.

MAGLEV TECHNOLOGY

MAGLEV is a transportation technology that uses magnetic field forces to levitate a vehicle up to four inches above a guideway surface. Physical contact between the

MAGLEV vehicle and guideway is avoided, which minimizes many of the maintenance requirements of other means of transportation.

MAGLEV cars carry from 50 to 100 passengers. The vehicles run on elevated concrete guideways that may be sited within existing interstate highway rights-of-way.

MAGLEV can be operated at speeds up to 300 miles per hour. However, varying grades and curves will reduce operating speed.

MAGLEV may absorb current transportation system capacity overloads in the intermediate, 100- to 600-mile range, reducing highway and airline traffic. Commuter routes in urban areas may be able to use a reduced-speed MAGLEV system.

HISTORICAL PERSPECTIVE

New York State has led the nation in developing and implementing innovative transportation technologies and facilities such as the Erie Canal and railroads in the 1800s, the New York City subway system and airports in the 1900s, and, most recently, the New York State Thruway. These projects represented immense investments that were accompanied by considerable political and economic risk. Yet, in retrospect, each venture provided the impetus for commerce and industry to expand and prosper throughout the State.

The Federal Government is supporting the development of a new MAGLEV program. The Department of Transportation's Federal Railroad Administration, the Army Corps of Engineers, the Department of Energy, and NASA have formed a National MAGLEV Initiative. This program will consider the possibilities of either adopting existing technology options or developing a new, domestically designed system. The future of this program is expected to be resolved in late 1992.

Senator Daniel Patrick Moynihan (NY) introduced a bill in 1989 that recommended using the interstate highway system as a dual-use right-of-way with MAGLEV. He later proposed including a MAGLEV demonstration project in the 1991 Surface Transportation Act.

In March 1990, at the request of State Assemblyman William Hoyt, an Ad Hoc Technical Committee was formed that included representatives of the Departments of Transportation, Economic Development, and Environmental Conservation; the New York State Thruway Authority, and the Energy Authority. This ad hoc group formulated the statement of work for this study, evaluated proposals, and selected a team led by Grumman Corporation of Bethpage, New York to undertake the study.

In his 1991 State-of-the-State message, Governor Cuomo appointed Lieutenant Governor Stanley Lundine to spearhead an effort on High-Speed Transportation. Under his direction, a High-Speed Ground Transportation Advisory Committee that includes agency, legislative, and educational representatives was formed in 1991. This Committee is chaired by Commissioner William D. Cotter of the State Energy Office and is chartered to provide oversight and advice on subsequent phases of this study.

THE MAGLEV STUDY

The goal of this study was to quantify the technological requirements and potential benefits of MAGLEV with specific objectives:

- Assessing the best technological approach;
- Quantifying the market for ridership and freight in primary corridors; and
- Quantifying the environmental impact as well as the potential for energy conservation.

The study identified performance guidelines for a MAGLEV system tailored to the climatological and geographical characteristics of New York State. This evaluation considered available interstate highways for dual use and is based on the use of the

New York State Thruway as the right-of-way corridor.

The state-of-the-art technologies currently being developed and tested in Germany and Japan were reviewed. The design and performance characteristics of these systems and a domestically designed concept were compared. System cost projections were developed for each alternative. The energy and environmental impacts of system implementation were projected.

Market and economic analysis concentrated on a potential MAGLEV route along the New York State Thruway. The market analysis was undertaken using an existing passenger forecast model. Data availability limited the market focus to intrastate travel estimates. The results, therefore, must be considered a preliminary estimate of the potential for MAGLEV.

CONCLUSIONS

The principal conclusions of the MAGLEV study are:

- Technical Feasibility: There are no insurmountable engineering or technological barriers to developing and implementing a MAGLEV system in New York State. The New York State Thruway right-of-way could accommodate an average speed of 240 mph from New York City to Buffalo, assuming vehicle and guideway banking of 24 degrees and crossing medians wherever appropriate;

- Estimated Cost: Several MAGLEV systems were reviewed. The costs of the guideway structure and electrical system averaged $19 million (1990 dollars*) per mile. At a vehicle cost of $9 million, the total system cost would be $21.4 million per mile, or $10.6 billion for a 495-mile system extending from New York City to Buffalo;

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* Except where noted, the economics in this report are based on 1990 dollars.

- Estimated Ridership: The passenger market was forecast solely for intrastate trips based on a 240-mph average speed, 20-minute headways and fares at twice current intercity rail fares. Intrastate ridership was estimated at about five million after 10 years of operation, based on diverting 2.1 million trips from airplane and automobile transportation. This estimated ridership is approximately four times the current intrastate Amtrak total;

- Estimated Revenue/Amortization: Farebox revenue based on an estimated five million intrastate trips would be approximately $340 million annually after 10 years of operation. The revenue would cover estimated operating and maintenance costs of $157 million annually, but would not amortize capital costs within the usual bonding period;

- Environmental Issues/Energy Conservation: An interstate MAGLEV system would reduce air pollution and fossil-fuel use. After 10 years of operation, it is estimated that the MAGLEV system annually would reduce carbon monoxide emissions some 11,600 tons and hydrocarbons some 1,500 tons, in the process conserving 7.8 million gallons of fuel. These estimated emission level and fuel usage reductions equal approximately 300 million car miles per year; and

- Economic Potential: MAGLEV could provide considerable economic benefits to the State. For example, constructing a system connecting New York City and Buffalo would create 70,000 person-years of labor and $5.1 billion in construction wages. Approximately 132,000 construction-related jobs would be generated. Operating, maintenance, and other related activities would generate more than 1,000 new jobs with annual wages of approximately $79 million. MAGLEV stations would stimulate residential and commercial development and encourage the extension of commuter networks.

RECOMMENDATIONS

This is a preliminary study; its most important function is to identify the issues and future tasks required to comprehensively analyze the potential of MAGLEV as a high-speed transit option in New York State. A number of recommendations have been developed:

- One of the competitive advantages of MAGLEV is its 200 to 300 mph speed. The capability to sustain a high operating speed will be critical in determining if a MAGLEV system should be developed. Therefore, a thorough analysis of potential routes must be an integral part of MAGLEV research programs;

- Market demand and passenger projections for an intercity MAGLEV system are decisive in estimating revenue, total system costs, and financing. A detailed market assessment, including a forecast demand model based on appropriate origin and destination data, should be undertaken in future studies;

- Comprehensive analysis should be done to accurately estimate the economic benefits associated with a MAGLEV system compared to other means of transportation. Station development as a source of potential revenue should be part of the financial analysis; additional and more detailed financial evaluations should be undertaken in future studies;

- Due to complex issues related to real estate development, market demand, and integration with existing transportation systems, station location must be thoroughly investigated, including the impact of low-speed MAGLEV system development in suburban and urban areas;

- Additional research in vehicle and guideway design and their interaction is necessary. This research should include an analysis of vehicle banking requirements and ride comfort criteria for vehicles and guideways. Technical research should investigate passive coil and flat-plate guideway design including the null-flux design and high-speed switching methods;

- MAGLEV may provide a high-speed, relatively cost-effective alternative to carrying freight in terms of operation and maintenance; however, potential freight markets need to be examined; and

- The effects of electromagnetic fields (EMF) need to be monitored because safety is an important issue. All MAGLEV research should emphasize vehicle design that shields the induced magnetic fields. The Federal Government must set standards for EMF exposure. MAGLEV system safety and operational standards to minimize potential hazards including guideway misalignments, power deficiencies, and levitation failures need to be investigated.

SUMMARY

The study concluded that MAGLEV systems can potentially provide all-weather, quiet, high-speed, energy-efficient, environmentally safe transportation in New York State.

MAGLEV technology may provide alternative transportation using existing right-of-way corridors within the State. Cost, however, is an issue.

There is a need to better quantify potential refinancing alternatives, system cost, benefits, and technical feasibility. There is, however, sufficient merit in the MAGLEV option to warrant more detailed study of this technology and its potential to meet New York State's future transportation requirements.

1 – TECHNICAL SUMMARY

1.1 INTRODUCTION

The New York State Energy Research and Development Authority (The Energy Authority) issued a contract on June 25, 1990, for a Technical and Economic MAGLEV Evaluation for New York State. The goal was to quantify the technology requirements and potential benefits of MAGLEV so the State's industries could respond to opportunities associated with this technology on a national level. To accomplish this goal, the project had specific objectives:

- To assess the best technological approach to MAGLEV;
- To quantify the market and potential benefits of MAGLEV technology for ridership in statewide and regional travel corridors, and for freight applications;
- To quantify energy-environmental impacts; and
- To identify State industries with the capability to develop a New York MAGLEV consortium and a strategy for implementing this technology.

To achieve these objectives, four major New York State-based companies along with the Brookhaven National Laboratory formed a team headed by the Grumman Corporation that included Parsons Brinckerhoff Quade & Douglas, Inc., General Electric Company, and Intermagnetics General Corporation. This team worked directly with The Energy Authority, the New York State Departments of Transportation, Environmental Conservation, Economic Development, and the New York State Thruway Authority.

1.2 THE NEED FOR IMPROVED TRANSPORTATION

The economic development of New York State has historically been linked to its leadership and innovation in developing and constructing transportation systems. In the early 1800s, the Erie Canal more efficiently moved people and goods within the State, which led to economic expansion and competitive advantages for industry. Development of the rail system in the late 1800s again improved the economic position of New York State and the Northeast region, eventually leading to accelerated development of the entire country. Finally, the construction of the Interstate Highway System just completed in 1990 provided easy access to almost all regions of the State and country, while increasing the efficiency and mobility of automobiles and trucks. In addition, these transportation systems dramatically affected urban development, as most urbanized areas were at one time or another major transportation centers. Implementing extensive transportation systems requires initial public consensus.

Transportation professionals in the Northeast have described a serious situation. Congestion on the highways and in the air, particularly in the Northeast, is growing. Forecasts by the Federal Highway Administration (FHWA) predict that vehicle miles travelled on all highways will increase from 1.6 trillion (1985) to 2.6 trillion in 2005. Vehicle delay will correspondingly increase from 2.7 billion vehicle hours in 1985 to more than 11.9 billion vehicle hours in the year 2005. A report by the American Public Transit Association estimates this loss in time and fuel to be approximately $41 billion/year. In 1983 approximately 54 percent of peak-hour travel was congested, and increased to 65 percent in 1987. If this trend continues, nearly all peak-hour travel will be done under congested conditions by 2005.

Air travel has similar congestion and delay problems. In the Northeast, the four major airports (LaGuardia, JFK, Newark and Logan) recorded 16.3 million hours of delay in 1986, according to data supplied by the Federal Aviation Administration. This number will increase to an estimated 22.5 million hours by 1996. All four airports are among the 10 most congested in the country to access from the ground.

Other problems are directly related to increased highway and air congestion added to documented increases in motor vehicle and aircraft use, plus predicted growth for both. Pollution emissions will increase, adding to the degradation of the environment. The relatively inefficient use of fossil fuels by automobiles and airplanes will increase, additionally complicating unstable oil supplies. Based on problematic oil supplies, depending on fossil fuel as the major source of energy for transportation is not prudent.

There are few options available to solve these problems. Building more highway lanes and airports will consume vast resources, aside from environmental and community issues. The responsibility to maintain these facilities would attach future economic resources. Constructing more facilities or infrastructure, the current approach, ignores the related issues of pollution and fossil fuel reliance. Despite the inherent difficulties, a comprehensive, energy-efficient, environmentally acceptable program is needed.

Two new transportation systems currently being reviewed in the United States are very high speed rail (VHSR) and magnetic levitation (MAGLEV). Successful VHSR systems in France (TGV) and Japan (Shinkansen bullet train) have generated interest in other countries and throughout the United States. VHSR has been successfully tested at speeds exceeding 300 mph; revenue operation is limited to 200 mph or less. Constructing VHSR corridors for passenger-only operation due to track degradation caused by heavier freight loadings requires rights-of-way similar to modern interstate highways that are relatively straight with limited grades. Implementation of VHSR poses substantial obstacles in the Northeast, where land for development is limited and where existing railroad rights-of-way are unsuitable.

MAGLEV, with its elevated guideways, relatively small footprint, and the possibility of using interstate highway rights-of-way, is more practical than other options. The lack of physical contact between the MAGLEV vehicle and guideway (3/8 to 4 inches clearance depending on the design) minimizes the major maintenance requirements of other transportation systems. MAGLEV's major speed limitation is air drag; consequently, vehicles can technically be operated at speeds of 250 to 300 mph in revenue service. Compared to airline travel, MAGLEV is a high-speed transit mode that is relatively tolerant of inclement weather.

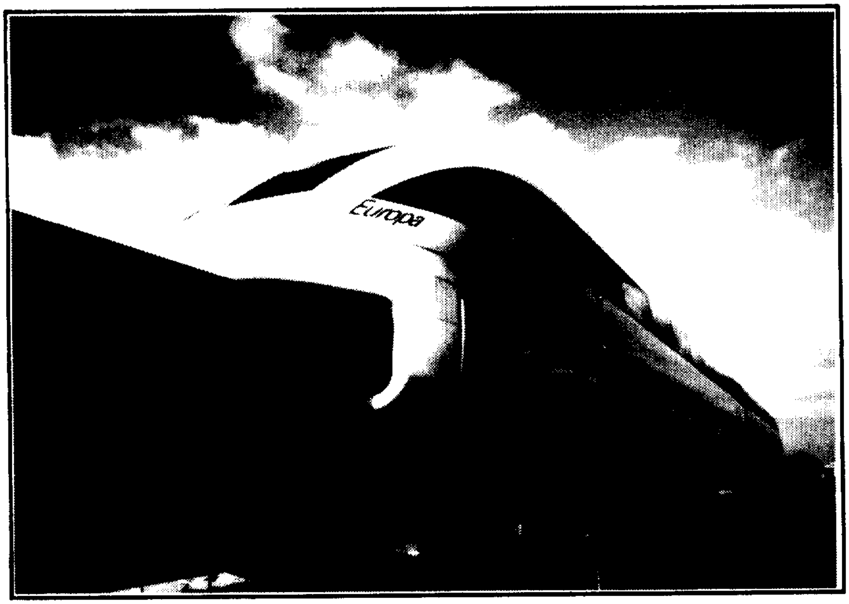
1.3 CURRENT STATUS OF MAGLEV IN THE UNITED STATES

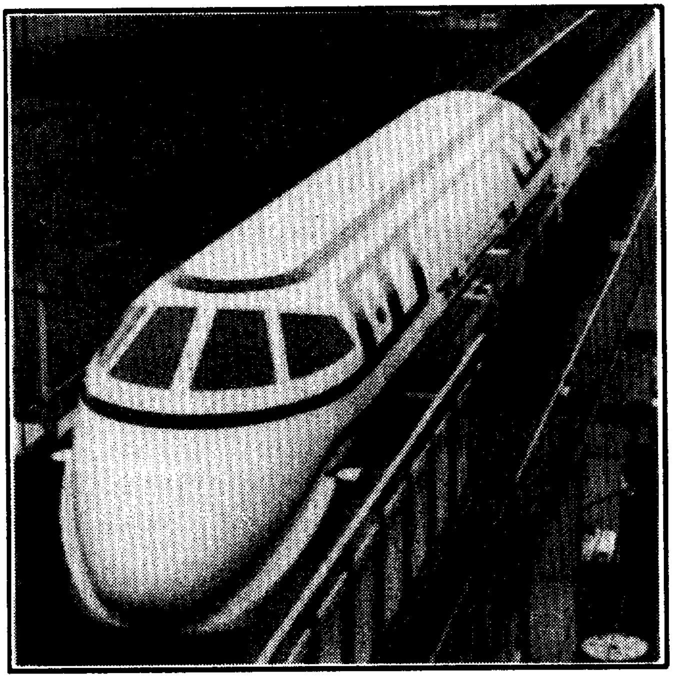
Superconducting MAGLEV technology was initiated in the U.S. in the late 1960s and early 1970s when Drs. James Powell and Gordon Danby of New York's Brookhaven National Laboratory invented the concept of a repulsive magnetic suspension using superconducting magnets. In the mid-1970s the U.S. stopped MAGLEV and other high-speed ground transportation research. Other countries, however, continued to develop MAGLEV and today have viable systems. Germany's Transrapid vehicle has been extensively tested and has been proposed for use on several projects in this country. Japan is developing a system that uses superconducting magnetic suspension and is currently starting construction of a major test route that could ultimately be incorporated into a revenue-producing system. The German and Japanese systems are shown in Fig. 1-1.

The United States is reviving its MAGLEV program. The Department of Transportation (Federal Railroad Administration) along with the U.S. Army Corps of Engineers, the Department of Energy, and NASA have formed a MAGLEV Test Team to create a national program for developing a MAGLEV system that will either adopt the foreign-developed systems or leapfrog them with a U.S design that would offer superior technology optimal for U.S. applications. This program is targeted for a major federal decision in late 1992. The available foreign systems and domestic designs must both be considered to analyze MAGLEV applications in New York State.

A number of U.S. Senators and Congressmen have actively promoted MAGLEV development. Senator Daniel Patrick Moynihan (D-NY) restarted the U.S. initiative by introducing a bill (S524) in January 1989 that promoted the interstate highway system as a dual-use right-of-way with MAGLEV. Representatives Robert Torricelli (D-NJ) and Robert Mrazek (D-NY) introduced a bill (HR5535) in 1990 to provide up to 75 percent of the cost of a demonstration project.

GERMANY





JAPAN

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Fig. 1-1 Foreign MAGLEV Systems

1.4 ALTERNATE MAGLEV SYSTEMS

The five different MAGLEV designs selected for this study are described in the following paragraphs and their general configurations are shown in Fig. 1-2. Table 1-1 lists some quantitative parameters for the competing designs.

Transrapid 07

The German Transrapid is the most advanced MAGLEV system in the world. Development started in 1978 and to date more than $1.25 billion has been spent, most of which was supplied by the German federal government.

The Transrapid design is based on electromagnetic suspension (EMS) in which normal or non-superconducting magnets suspend the vehicle through attractive forces between the vehicle magnets that are wrapped around the underside of the guideway and the laminated steel guideway. While this system requires no cryogenic cooling for the magnets, it is heavier than other designs and has weaker suspension magnetic fields, making this payload freight operation less attractive and requiring a small (10 mm) gap between the magnets and the guideway. Although the gap is considerably smaller than with other MAGLEV concepts, the developers report no need for guideway realignment. The Transrapid is propelled by a linear synchronous motor (LSM) with active coils in the guideway. Only minor housekeeping and suspension power is transferred inductively to the vehicle when traveling at high speed; batteries supply the power at low speed. The guideway, however, must be equipped with variable-frequency, variable-voltage power conditioning units approximately every 20 miles.

The Transrapid system has been tested for seven years on a 31.5-km closed-loop test track in Elmsland, Germany, and recently was proposed for a 14-mile demonstration line between the Orlando, Florida, International Airport and International Drive as well as a 265-mile route between Los Angeles and Las Vegas. The $5.1-billion Las Vegas project was proposed by a consortium headed by the Bechtel Corporation.

MLU002

The MLU002, the most advanced test vehicle produced by the Japanese, uses superconducting magnets in the repulsive electrodynamic suspension (EDS). This system uses a powerful magnetic field to induce currents in passive aluminum coils in the guideway that repel the magnets in the vehicle. These systems require cryogenic systems to maintain the vehicle magnets at 4.2 degrees Kelvin but use no power for suspension and have a large (100 mm) gap between the vehicle and the guideway. Propulsion is provided by a LSM similar to the Transrapid's. These vehicles are lighter in weight and can accommodate heavier payloads than Transrapid over comparable guideways.

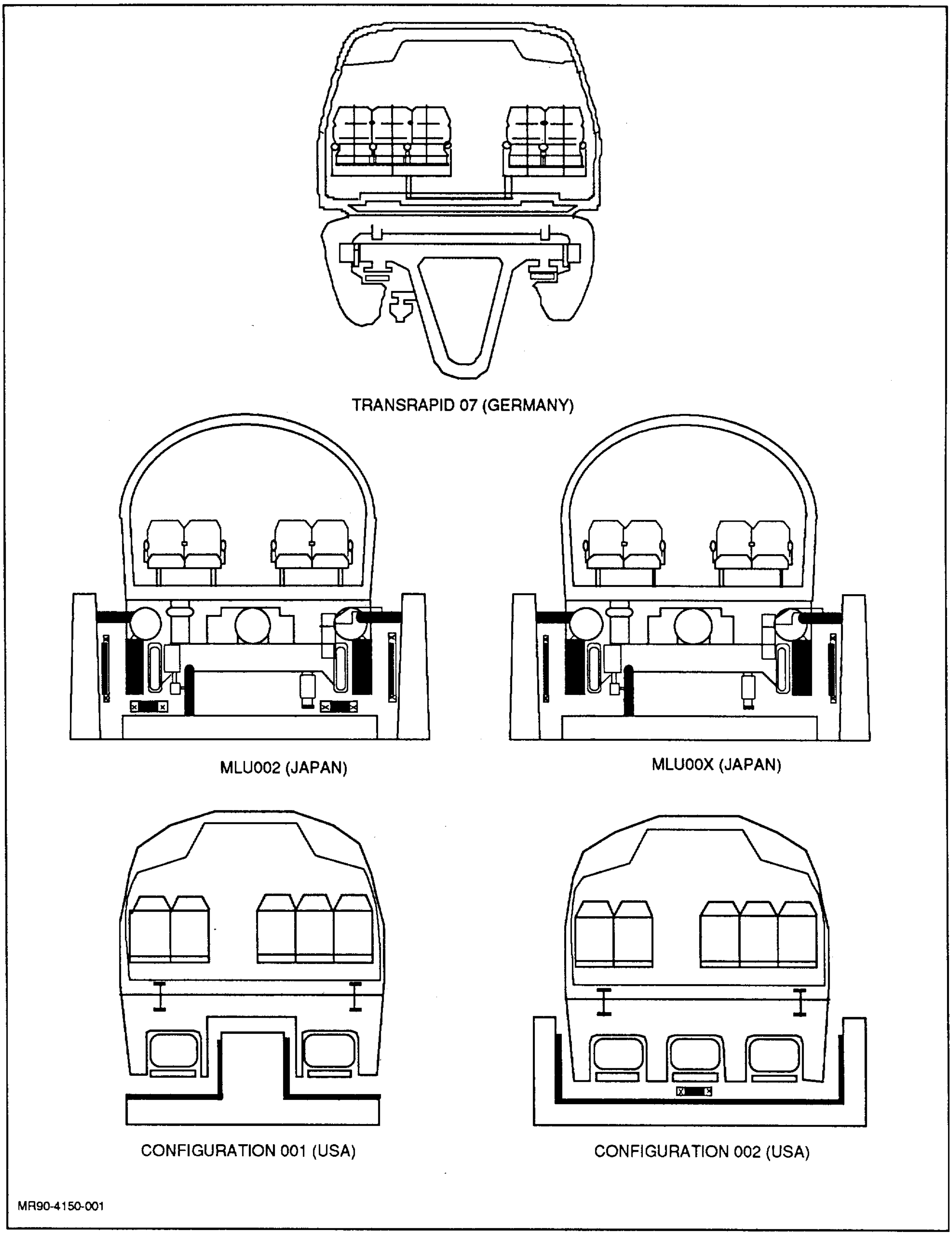

Fig. 1-2 Selected MAGLEV Configurations

Table 1-1 MAGLEV Configuration Comparison Summary

Item	Configuration				
	Transrapid 07	MLU002	MLU00X	Config 001	Config 002
Suspension	EMS	EDS	EDS	EDS	EDS
Propulsion	LSM	LSM	LSM	LIM	LSM
Max speed, kph (mph)	500(311)	420(261)	500(311)	483(300)	483(300)
Seats/car	160–200 (1)	44	68	100	100
Max cars/train	10	1	14	TBD	TBD
Min headway at max speed (2), sec	92	33	38	50	50
Max capacity, passengers/hr (3)	7826	4800	6440	7200	7200
Max car wt, MT	100	17	27	39	30
Car wt/seat, lb	1103	851	875	860	660
Power at max speed, MW/car	7.7 (1)	3.4 (4)	2.5 (4)	10.3	7.4
Normalized power, MW/car (5)	5.8	5.6 (4)	5.6 (4)	11.4	7.8
Specific energy consumption at max speed, kwh/passenger-mile	0.12–0.15	0.30 (4)	0.12 (4)	0.38	0.25
Estimated guideway cost, M$/mile (6)	21.9	N/A	20	15.5	18.6

1. Transrapid is operated as a 2-car set
2. Assumes max speed, max deceleration, 5 sec reaction time
3. Full cars, max speed, min headway
4. Power data not available on Japanese systems, numbers shown are estimates
5. Normalized to 500 kph, 12 m^2 frontal area, 30 m length
6. Normalized to 35 ft guideway height

MR90-4150-002

MLU00X

The MLU00X is the vehicle that the Japanese describe as their "proposed commercial train." It uses technology similar to the MLU002 with a smaller cross section because the Japanese believe that 70 percent of their commercial routes will be underground. The magnetic suspension bogies are located between the cars. The position of these bogies is an attempt to lower the magnetic fields in the passenger compartments. The magnetic suspension invented by Powell and Danby at Brookhaven Laboratory will use guideway magnets arranged in a "null-flux" configuration that lowers the magnetic drag of the suspension system. Propulsion is provided by a LSM.

Configuration 001

This, a new design produced by the Grumman team, is based on earlier work by Philco-Ford published in 1975. It uses superconducting magnetic suspension interacting with a flat-plate aluminum guideway and a linear induction motor (LIM) for propulsion. The LIM uses no active components in the guideway, but must have a high-power, high-speed power pickup to supply the on-board power conditioning unit. This configuration was examined primarily to minimize guideway cost since the guideway is the costliest element in a MAGLEV system.

Configuration 002

This design is similar to Configuration 001 except that the LIM propulsion system is replaced with a LSM, reflecting the fact that developing the appropriate power pick-up needed by the LIM (10 megawatts at 300 mph) may be impossible in the short term.

1.5 SYSTEM REQUIREMENTS AND CHARACTERISTICS

A priority in defining MAGLEV's place in New York State's transportation network was to establish a consistent set of requirements for evaluating current technology that could be used to design new MAGLEV systems consistent with the environment, available rights-of-way, and transport needs of New York State.

A maximum speed of 300 mph was selected as realistic, one which would balance energy usage and trip time. Other system requirements, including weather and terrain parameters, were dictated based on conditions expected in New York State. A critical parameter was the payload capacity to allow freight-carrying capability. A payload for a 100-seat passenger service would be about 16,000 lbs. Light freight could be carried up to this load limit with no penalty, but a loaded shipping container or truck trailer of dimensions comparable to the MAGLEV passenger vehicle, a 48-foot trailer, has a gross weight of almost 62,000 lbs. Since a MAGLEV system can be designed to carry this load, this limit was chosen for freight.

Right-of-way profiles have a direct effect on MAGLEV design because highways in the Northeast section of the country usually have curves designed for speeds of about 60 mph through hilly terrain and populated areas. To design a MAGLEV system capable of operating over these routes at high speeds is a challenge. Since land acquisition is expensive, it was decided to limit rights-of-way to existing corridors without specifying a maximum allowable curve radius. The analysis, which determined speeds consistent with existing alignments, required high bank in the turns. A guideway bank limit of 12 deg was chosen since it is estimated to be the maximum banking over which a person can walk. In addition to the guideway bank, an additional 12 deg carriage bank was incorporated in the vehicle suspension. Although this complicates the vehicle design, a total bank angle of 24 deg is provided which corresponds to the 0.1 g vertical acceleration limit, the only way in which high-speed operation is possible given the turns on highways. By dividing the total bank angle between the guideway and the vehicle, reduced speed is possible in the turns, and the vehicle can stop in a maximum banked turn with the carriage remaining level.

A serious question concerns requirements for vehicle speed and banking. Operation in regions like New York State will require banking every few miles, accompanied by vehicle roll acceleration. There are real concerns about what motions passengers will tolerate. Use of vehicle simulators (as used by the aircraft industry) will be necessary to determine what constitutes a comfortable ride.

Integration with Existing Transportation Systems

Any MAGLEV system must interface with the existing transportation network. The system must be able to relieve, or at least minimize, capacity problems. Its ability to directly or indirectly connect with other transportation systems will be a major issue near large urban centers such as the New York City metropolitan area.

Additional investigation may include development of low-speed suburban and urban MAGLEV systems that could directly interface with the intercity system, and provide access to major urban centers. The systems that use the EDS suspension (all but the Transrapid design) must have some type of retractable wheels or landing gear for use at low speeds since these designs require a minimum speed of approximately 120 kph or 75 mph for complete levitation. It might be possible to use properly designed wheels to travel along conventional and existing rail or transit lines.

Freight-Carrying Potential

MAGLEV should have the capability to carry freight to generate additional revenue. The potential to divert air freight could reduce traffic in some heavily congested air corridors. Although the Transrapid could be modified for this freight service, its EMS suspension system may be more limiting than the EDS concepts. Any of the EDS systems could be designed for freight service, but not without some penalty.

The basic vehicle configuration could be modified to accommodate freight containers or even piggyback service (Fig. 1-3). An economic analysis was performed for Configuration 002 to compare MAGLEV to existing truck freight transport. The additional system cost associated with designing the vehicle and guideway for the heavier payloads, up to 62,000 lbs corresponding to a typical 48-foot trailer of a tractor-trailer combination, was estimated at about 20 percent. This cost increment was then annualized and compared to existing typical freight costs. It was found that high-value or time-critical freight, e.g. air freight, could justify the added cost at shipping costs comparable to today's truck values if sufficient freight traffic were available. The crossover point was about 50,000 trips per year.

There is no technical barrier to hauling freight. Special freight vehicles could be constructed, for operation at slower speeds, and operated primarily at night when there is less passenger traffic. The basic issue is to establish present State freight traffic statistics that can be used to project the system's cost and revenue potential.

Ability to Use Existing Rights-of-Way

A basic tenet of the national MAGLEV program is using the interstate highway system as a dual-purpose right-of-way. This is critical since the cost to acquire large amounts of land would probably stop MAGLEV development. Even using a right-of-way designed for a vehicle travelling 60 mph at speeds up to 300 mph presents a problem, particularly in the Northeast where terrain and high population density would force deviations in right-of-way alignment. High speeds over circuitous routes require high bank angles. Passenger comfort requirements dictate a maximum bank angle of 24 deg which, coupled with the right-of-way geometry, determines the allowable speed. At this time, the best solution to the bank angle problem would be to provide independent carriage-banking capability in the vehicle secondary suspension. Neither the Transrapid nor the Japanese systems provide this, and both would be severely speed-restricted with New York State's present highway configurations.

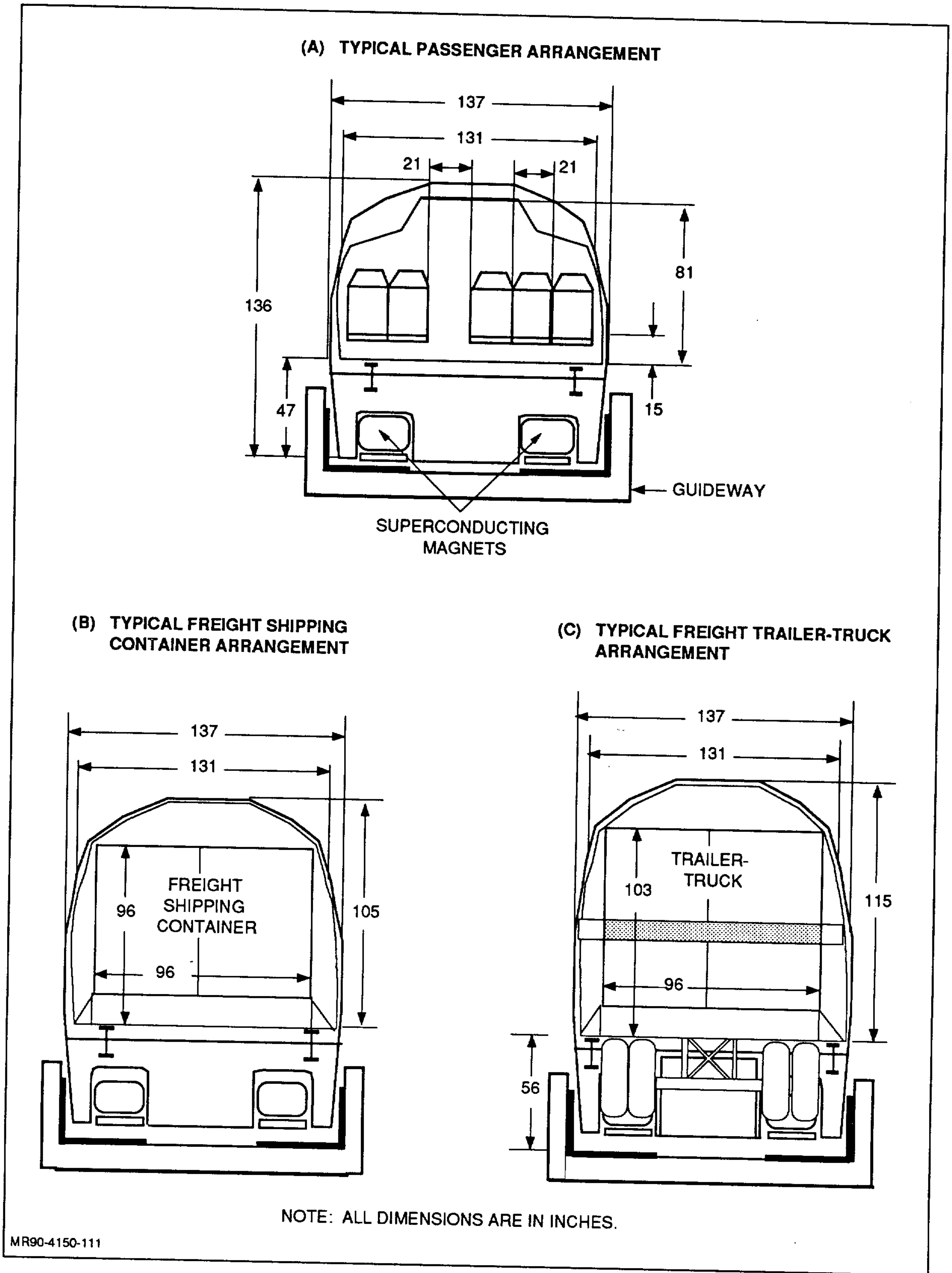

Fig. 1-3 Basic Vehicle Configuration – Passenger & Freight Arrangements

Guideway Alignment Requirements

The low gap of the EMS system will require more stringent track alignment than the large gap EDS system, which may mean higher guideway costs for the Transrapid system. However, Transrapid representatives say the Elmsland test track has never required realignment. Compared to the fine alignment required for high-speed rail, all of the MAGLEV systems offer a significant maintenance advantage.

System Safety

Safety standards established for rail and air systems, to which MAGLEV is sometimes compared, are inappropriate.

Due to MAGLEV's extremely high speeds, virtually all the vehicle and network operations will be controlled through a centralized control system. This control system should incorporate safeguards that will promote safe operating conditions including alignment and detection of foreign objects in or along the guideway. The control system should also ensure safe minimum vehicle headways (distance between vehicles on same guideway) and should monitor vehicle speed and location for emergency braking. Aspects of the control system affecting safety should be failsafe in design with multiple redundancy. The use of linear synchronous motors (LSM) for propulsion would ease incorporation of this type of system since the LSM design controls both the speed and braking of the vehicle. Because the LSM design is a ground-based system, transmittal of information to and from the vehicle is unnecessary to control the vehicle speed. Vehicle personnel will probably be necessary, however, for passenger oversight, amenities, information, emergency conditions or other situations.

Some aspects of MAGLEV design are inherently safe. For example, the Transrapid design vehicle wraps around the guideway, minimizing the possibility of leaving the guideway. With the EDS design, the guideway could be shaped in a number of ways, such as a trough, which also would impede separation from the guideway.

In the event of power loss, the vehicle in the Transrapid design uses an on-board battery supply to maintain levitation above the guideway with back-up braking systems to stop the vehicle. If the on-board battery supply fails, in all likelihood a rare occurrence as there are four independent battery systems, the vehicle would drop down onto skids that stop the forward motion. With the EDS design, the vehicle maintains levitation as long as a supply of cryogenic helium is available, but a back-up emergency system is required to provide aerodynamic or mechanical braking.

The Orlando MAGLEV project proposed by MAGLEV Transit, Inc. will be a Federal Railroad Administration pilot safety project to develop and test safety standards for high-speed MAGLEV.

One important safety issue that requires additional investigation is induced magnetic fields and their effects since MAGLEV systems use magnetic fields for both levitation and propulsion. Two components are involved in this issue, alternating (ac) and steady (dc) magnetic fields.

Low-level dc fields are less hazardous because life evolved in the steady magnetic field of the earth. A dc level of 5 gauss, 10 times the earth's magnetic field strength, is considered an upper limit for people who have pacemakers.

Most health questions about induced magnetic fields involve ac fields. Some epidemiological studies find a link between exposure to electromagnetic fields involving 60 Hz ac and cancer. Concentrated studies are presently being conducted; however, based on the potential danger, it seems prudent to limit ac field strengths to much lower levels than dc fields. One figure proposed for power line exposure is 0.2 gauss for 60 Hz ac fields.

The Transrapid system can meet these standards because it uses weaker levitation magnets that are set below the guideway and because its iron core magnet structure has a confined field.

Since the EDS designs incorporate powerful superconducting air-core magnets, their unshielded field strength is higher than the Transrapid design. Levels of up to 200 gauss have been measured in some Japanese test vehicles. The EDS designs have to incorporate some type of magnetic shielding into the vehicle design. To effectively shield dc fields, "bucking" coils are used that oppose the offending fields with coils of opposite polarity. Ferromagnetic materials such as mu-metal can also be used to shield dc fields. AC fields can be blocked by using any conductor, including the vehicle's aluminum structure. Positioning the magnetic assemblies at either end of the vehicle as planned for the MLU00X will also reduce magnetic field exposure.

There is no inherent technological problem designing a MAGLEV system to meet a reasonable magnetic field standard; however, federal standards are needed so designs to accommodate them can be developed.

System Cost

The capital cost of MAGLEV systems may be calculated as cost-per-mile of system. Estimates have ranged from $10 million to $50 million. The Transrapid system recently proposed for the Los Angeles to Las Vegas corridor was estimated at $20 million per mile for a two-way guideway which included at-grade and elevated guideway structures with minimal land acquisition costs. This figure was changed to $22 million to reflect the cost of a continuous 35-ft elevated guideway. The Japanese Yamanashi test track is estimated to cost $33 million per mile, with much of the guideway in tunnels. It is estimated that this system design would cost $20 million per mile if built above ground, without tunnels. Estimates for Grumman's designs are just under $20 million per mile. This figure does not include the cost of land acquisition. Future studies should refine these estimates and minimize guideway construction costs by exploring new, innovative designs and manufacturing processes.

Developing a new MAGLEV system design will cost an estimated $1 billion. Development costs were not factored into the estimates, since this amount may be provided by the Federal Government and private industry. Research and development costs are justified by economic benefits.

System Characteristics Summary

No present MAGLEV system design is clearly superior to the others; however, some design characteristics are better than others. For example, the larger levitation gap and lighter weight favor the EDS; however, a superior system may be designed that combines the best of the present MAGLEV systems. Design parameters for the new-generation MAGLEV design should maximize the levitation gap; minimize vehicle weight and guideway design loads; develop freight-carrying capability, maximum banking capabilities, non-mechanical guideway switching, and efficient energy usage; and comply with established magnetic field standards.

1.6 MAGLEV ENERGY USE AND AIR POLLUTION IMPACTS

Energy Usage

The energy use of MAGLEV systems compared to other modes of transportation is shown in Fig. 1-4. These values represent the energy that must be expended at the source (i.e., at the powerplant for electric systems) for each passenger mile. MAGLEV energy use is somewhat higher than the HSR systems, primarily due to its higher operating speeds. Compared to automobiles and short-haul aircraft, it requires only about one-third and one-fourth the energy expenditure respectively.

MAGLEV uses central station power that can be generated by energy sources such as hydroelectric, oil, coal, gas, or nuclear. The selection is open, unlike the restriction to petroleum products that characterizes autos, trucks, or airplanes. Unlike all present systems, long-term changes in power sources need not affect the transportation technology.

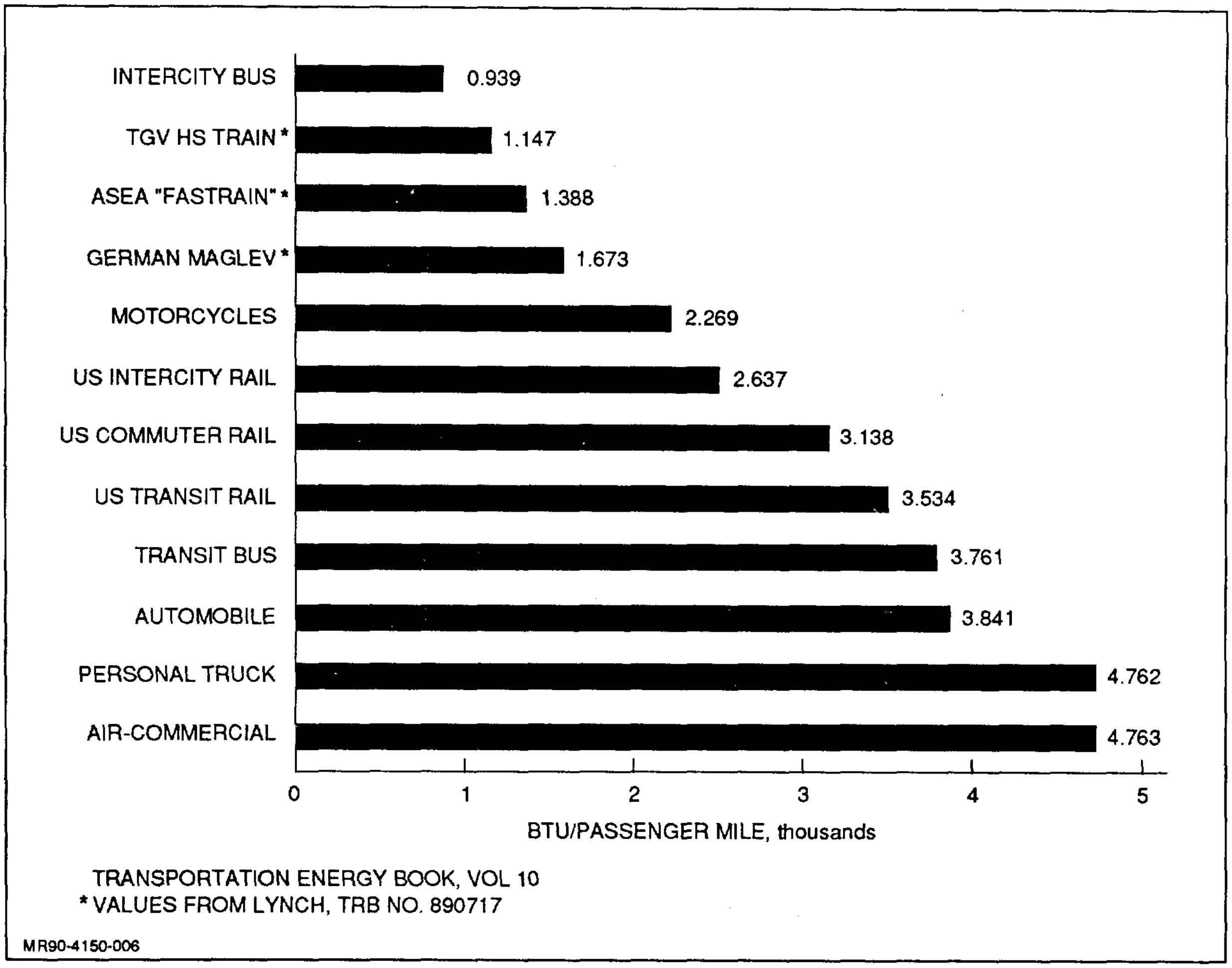

Fig. 1-4 Transport Mode Energy Consumption Comparison

In comparing vehicle concepts, there are significant differences in energy consumption. The EMS suspension system used by Transrapid has low magnetic drag which results in the lowest specific energy consumption of 0.15 kWh per passenger mile. Configurations 001 and 002 have higher values because the flat-plate guideway has magnetic drag equal to about one-third of the aerodynamic drag. Detailed performance figures for the Japanese configurations are unavailable, but the Powell/Danby configuration of null-flux suspension which uses discrete coils in the guideway wired in a figure-eight fashion that produces a low drag is used. It is presumed that the Japanese MAGLEV would have specific energy consumptions similar to those of Transrapid.

Although the energy consumptions vary by a significant amount, the annual electricity costs would vary from only $7 million to $17 million for the 892 million passenger miles projected for this study, which is a minor part of the annual estimated $70 million operating cost.

Air Pollution

Because MAGLEV uses a central station power source, there are significant advantages compared to mobile power sources when considering air pollution. Fig. 1-5 shows pollution from electric utilities and highway vehicles in the New York City metropolitan area. Only in the area of sulfur oxides do the stationary sources produce more effluents. An additional advantage is that the utility mix in New York is divided equally between generating sources that do and do not create air pollution. With the exception of electrically powered vehicles, all mobile power sources pollute.

MAGLEV will offer substantial pollution relief compared to present means of transportation. Since the power source is similar for all MAGLEV concepts, the pollution impact reflects their energy consumption. Thus, the Transrapid and perhaps the newer null-flux vehicles will have an advantage over the other concepts.

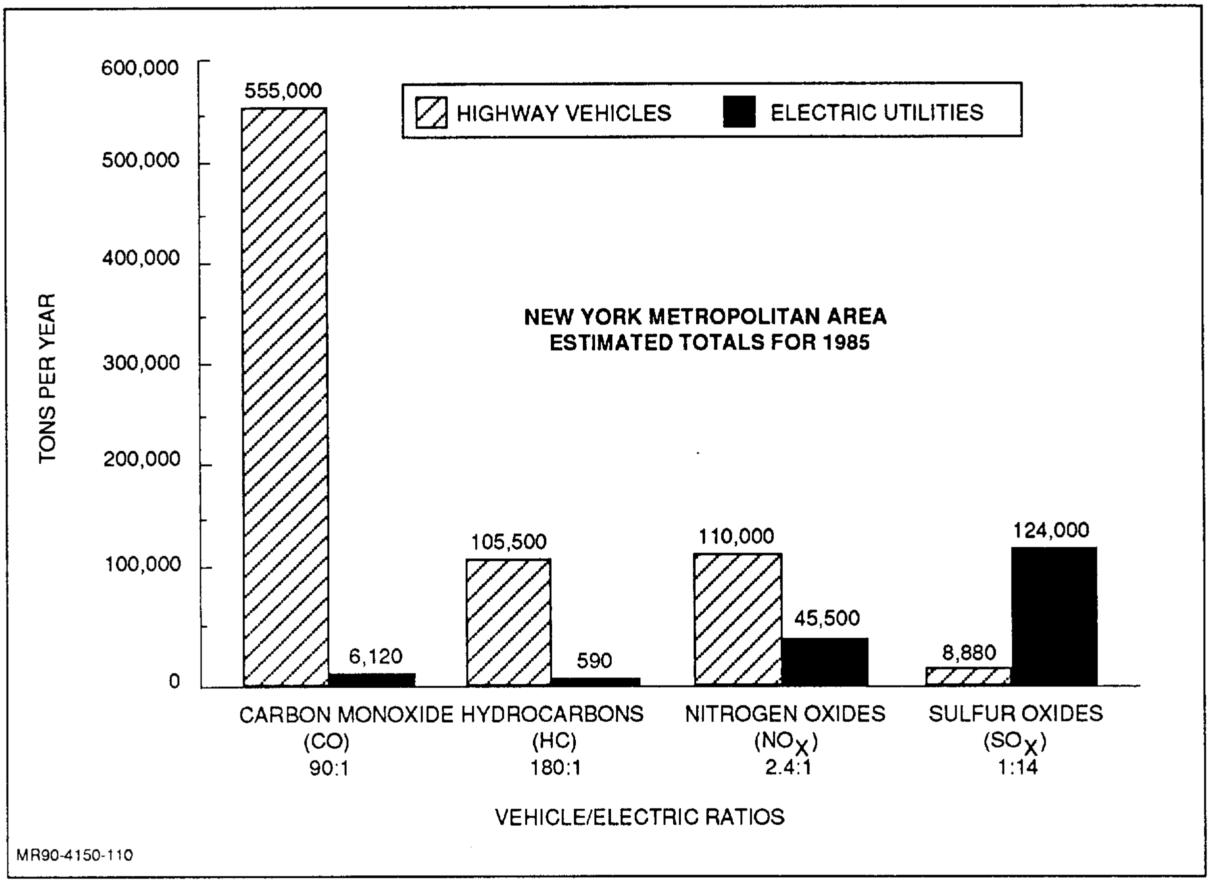

Fig. 1-5 Highway Vehicle & Electric Utility Pollution Burden

1.7 NEW YORK STATE ROUTE EVALUATIONS

Route evaluations for this study were restricted to major highways to avoid prohibitive land acquisition costs. Corridors that were not evaluated included power line rights-of-way and the Erie Canal. The primary alignment considered was the New York State Thruway, shown in Fig. 1-6. All of the technical and traffic demand analysis concentrated on the Thruway from New York City to Buffalo. A qualitative evaluation of the Thruway and the Long Island Expressway is presented in Table 1-2. There are generally no major impediments to implementing MAGLEV along these routes. The route and the distribution of curves and the curve radii were, however, designed for relatively low-speed travel, which means that vehicle design and guideways need to be designed to allow high-speed travel within these limits.

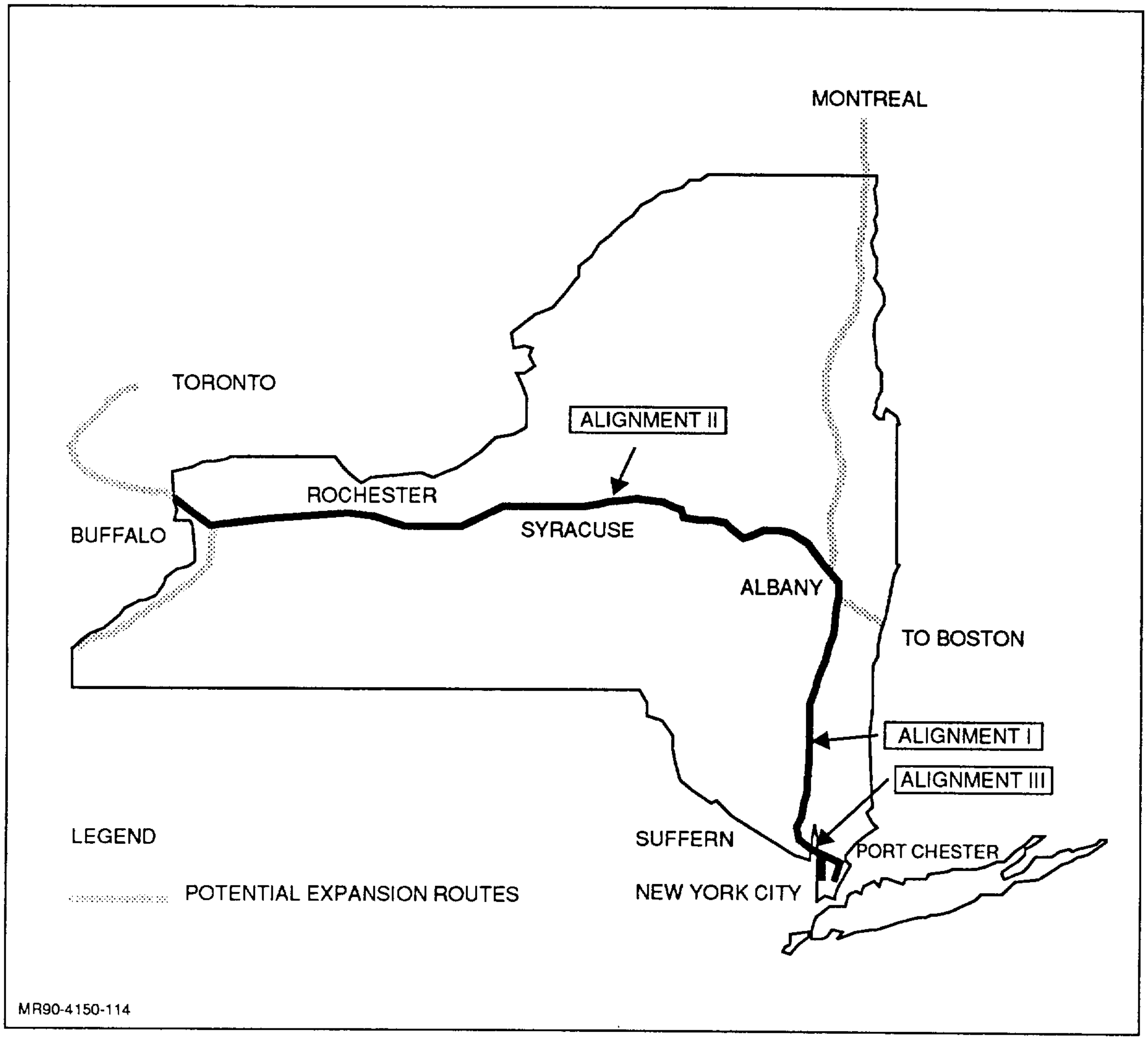

Fig. 1-6 New York State Primary Alignments

Table 1-2 New York State Route Evaluation Summary (Sheet 1 of 2)

Design guidelines	New York City to Albany	Albany to Buffalo	LIE to Sunnyside
Grade characteristics: number of instances and locations where a grade of 4.0% occurs and/or would be exceeded.	There is no instance where a grade larger than 4.0% exists along this corridor.	There is no instance where a grade larger than 4.0% exists along this corridor.	Not available.
Major utility crossings.	The NYS Thruway Authority reserves the right to relocate any utility lines which cross the Thruway.	The NYS Thruway Authority reserves the right to relocate any utility lines which cross the Thruway.	Not available.
Right-of-way: number of instances where right-of-way constraints exist.	Between Interchanges 1-9 there are serious right-of-way constraints due to service roads and residential and non-residential urban development.	Interchange 24 is a complex interchange, right-of-way constraints would exist. Service road constraints would exist in the urban areas of Buffalo. In Syracuse the right-of-way is limited and adjacent areas are developed.	The potential for serious right-of-way constraints would exist in Queens County and western Nassau County. This is primarily due to service roads and heavy residential and non-residential urban developments.
Water body crossings: number of locations of water body crossings that do not have the ability to support a MAGLEV structure.	The Tappan Zee Bridge crosses the Hudson River at Interchanges 9-10. The ability of this water body crossing to support a MAGLEV system segment must be evaluated. There may be a need to construct a separate MAGLEV river crossing structure.	The Mohawk River crossing located near Interchange 30 must also be evaluated to determine its ability to support a MAGLEV system segment.	Not available.

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Table 1-2 New York State Route Evaluation Summary (Sheet 2 of 2)

Design guidelines	New York City to Albany	Albany to Buffalo	LIE to Sunnyside
Interchanges: number of interchanges and average distance apart.	There are 30 interchanges along this alignment with an average distance between them of 5 miles. Between Interchanges 1 and 17, the spacing between interchanges averages 0.9 miles due to the urban nature of the area.	There are 32 interchanges along this alignment if the MAGLEV system were terminated at Interchange 50, with an average distance between them of 7.5 miles. In the areas of Syracuse and Buffalo, spacing between Interchanges averages one mile due to the urban nature of these areas.	There are 27 interchanges along the LIE between MacArthur Airport and the Nassau/Queens County line. The spacing of interchanges along this potential MAGLEV alignment is approximately 1.6 miles. There are primarily service roads from the Nassau/Queens line to Sunnyside.
Conclusions and recommendations.	The New York City – Albany alignment could prove to be a viable MAGLEV corridor; however, there are a number of issues which must be addressed if this corridor is considered. These issues include: the crossing of the Hudson River, handling the deep rock cuts along this alignment, limited right-of-way due to service roads and urban development, and the issue of continuing service from Interchange 1 to the Manhattan central business district.	The Albany – Buffalo corridor could prove to be a viable intrastate transportation system. A MAGLEV corridor spanning from Albany to Buffalo could offer travelers a true alternative to short-haul air travel and mid-to-long-range auto and truck trips. This corridor could also be extended into Canada which could prove valuable in the transporting of high-value goods between the U.S. and Canada.	A MAGLEV system along this corridor would give daily commuters an opportunity to travel to and from New York City in a short amount of time. This corridor would have the potential to carry large numbers of passengers and could help alleviate traffic congestion on Long Island. However, there is limited right-of-way access between the Nassau/Queens County line continuing into Long Island City, Queens. There is also freight potential along this alignment.
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The Thruway Authority supplied data on bend radii and grade for the length of the Thruway that consisted of minimum radii and typical radii for each section between interchanges. An analysis determined the MAGLEV speed potential along this route. The assumption was made that all turns would be coordinated and the vehicle banked so that the passengers would feel no side force. Comfort criteria specifications dictated a maximum downward g loading of no more than 10 percent which corresponds to a maximum bank angle of 24 deg. This establishes a simple relationship between the allowable velocity in a turn and the turn radius. The Thruway data was analyzed for possible speed profiles along its length. Assuming that the speed between interchanges is held constant corresponding to the smallest turn radius, the average speed between New York City and Buffalo was 169 mph, significantly less than the MAGLEV potential (See Fig. 1-7). The average speed can increase to 192 mph if the speed varies to correspond to the average turn radii.

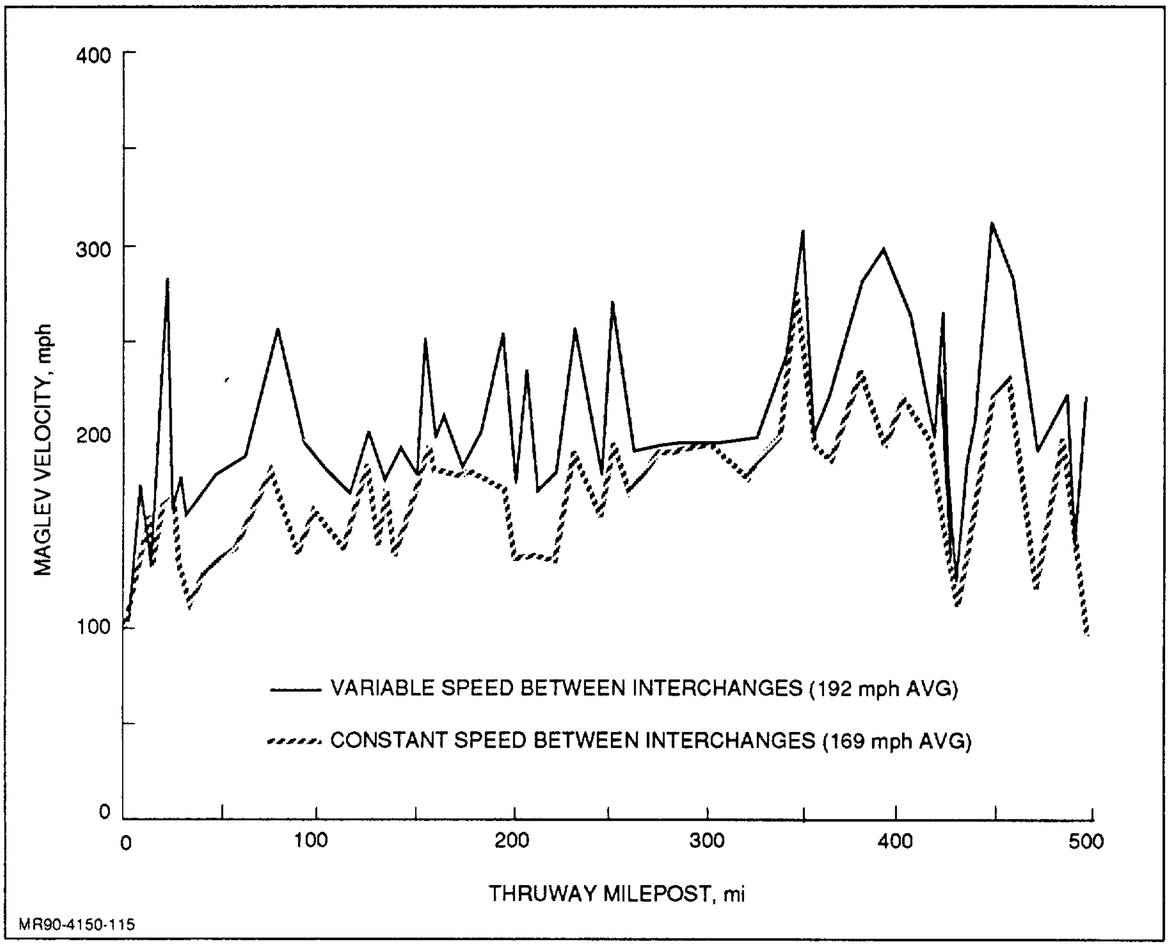

Fig. 1-7 NYS Thruway Speed Profiles

The previous results assume that the MAGLEV guideway parallels the highway, always on the same side of the road. If the guideway support structure were built to accommodate transition from one side of the road to the other, then the turn radii could be softened and the speed increased which is referred to as enhancing the turns, and which improves the average speed to as much as 240 mph as shown in Fig. 1-8.

More detailed Thruway geometry data was analyzed for a 20-mile segment in the vicinity of Exit 15, which confirmed the possibility of speeds in the 240-mph range.

A guideway that transitions back and forth over the highway would have an adverse effect on guideway cost and perhaps the highway user. An alternative technique would be to deviate from the highway right-of-way where necessary to increase the bend radius which would involve some land acquisition cost. Clearly the route evaluation issue must be given considerably more attention in ensuing studies to confirm the speeds possible on existing rights-of-way.

Ride quality was not analyzed for this study. Using relatively high bank angles and high speeds will subject passengers to motions that could be uncomfortable. In some sections of the route, the vehicle will have to negotiate maximum bank turns that occur in rapid succession. Practical standards for roll rate have not been fully established but they may have to be limited to a few deg per second. Ride quality must be examined in greater depth to verify the tentative conclusions that MAGLEV can operate in the Northeast at high speeds.

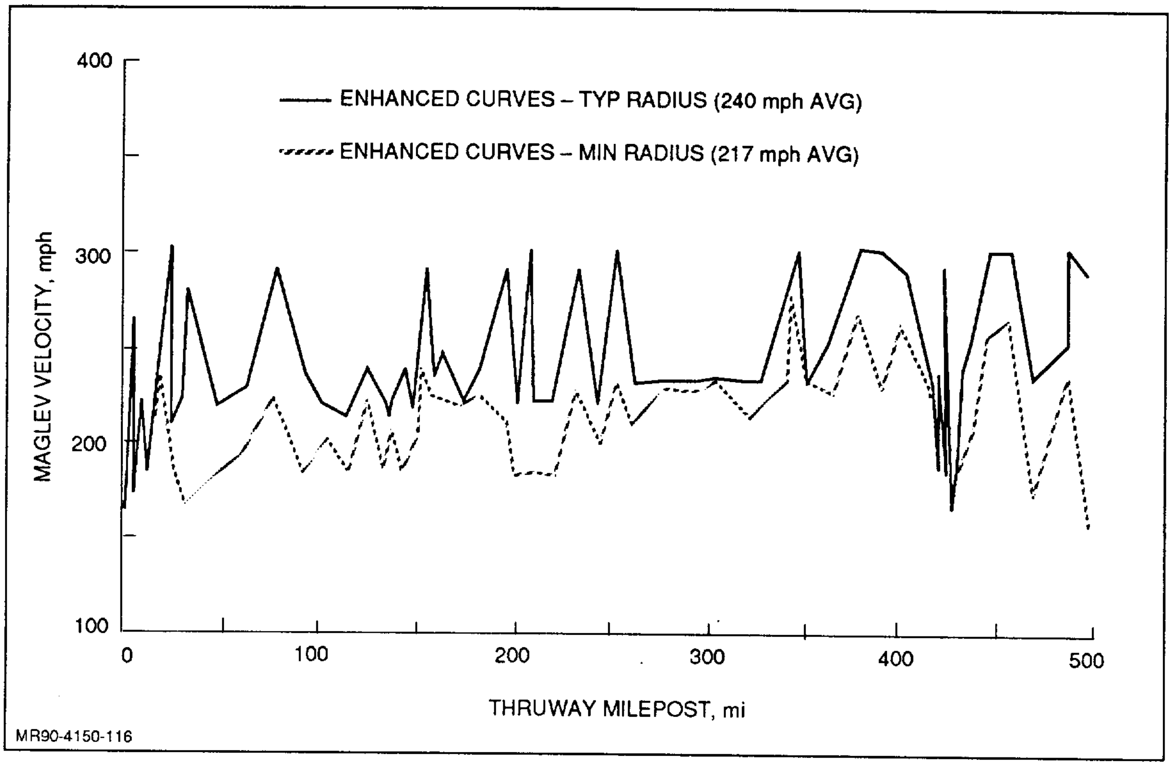

Fig. 1-8 NYS Thruway Speed Profiles – with Enhanced Turns

1.8 MARKET DEMAND ANALYSIS

As part of the conceptual analysis various technical variables from the study were used to estimate potential ridership for an in-state MAGLEV system. The analysis was done by the New York State Department of Transportation using an intercity travel demand forecasting model, a microcomputer-based, multimodal demand forecasting tool incorporating time series and trade-off analyses.

These demand estimates are conservative due to the limits the forecast demand model imposes. As currently designed, the model includes only four means of travel – air, auto, bus, and rail. Implementation of a MAGLEV system would create a five-mode competitive system which the model cannot reflect. For this study, a MAGLEV system hypothetically replaced existing in-state rail passenger mode with many of its attributes. Therefore, all in-state rail trips with an origin and destination within New York State were assigned to MAGLEV. The rail mode was assigned trips involving one or both trip ends outside New York State for which the MAGLEV mode was unavailable.

The model used the following parameters:

Route Alignment – Alignments I and II (New York City to Albany and Albany to Buffalo) were selected for examination.

Speeds – Two speed scenarios were investigated that corresponded to the estimated speed capabilities of the system depending on the guideway geometry. These average trip speeds were estimated at 217 and 240 mph. In addition, an average speed of 280 mph was examined, the potential maximum speed capability if the route alignment were unrestricted. These speed scenarios would provide trip times from New York City to Buffalo of 125, 112, and 95 minutes, respectively.

Service Frequency – Three service patterns were investigated reflecting the frequencies of two vehicles per hour at 30-minute headways, three vehicles per hour at 20-minute headways, and four vehicles at 15-minute headways. It was assumed that direct express service would be provided between each station along the route.

Stations – Stations were assumed to be located in the general areas of New York City, Croton-Harmon/Tarrytown, Newburgh/Poughkeepsie, Kingston/Rhinecliff, Catskill/Hudson, Albany, Schenectady, Amsterdam, Utica/Rome, Syracuse, Rochester, Buffalo, and Niagara Falls.

Fares – Three different fare structures were examined that reflected one, two or three times the 1989 intercity rail fares.

Results of the Ridership Demand Analysis

Figure 1-9 shows the estimated sensitivity of ridership demand to vehicle speed; for the 29 percent difference in average speed, there is a four percent change in ridership demand.

Examination of the three fare structures established that the fare that was two times the 1989 intercity rail fare generated the highest revenues.

The effect of service frequency is shown in Fig. 1-10. As expected, the greater the number of frequencies, the higher the ridership totals; however, the greater the number of frequencies, the greater the cost of operating the service since more vehicles, personnel, and power are needed. Future studies should investigate these relationships to optimize the operational variables including frequency, revenue, operating costs and number of vehicles required.

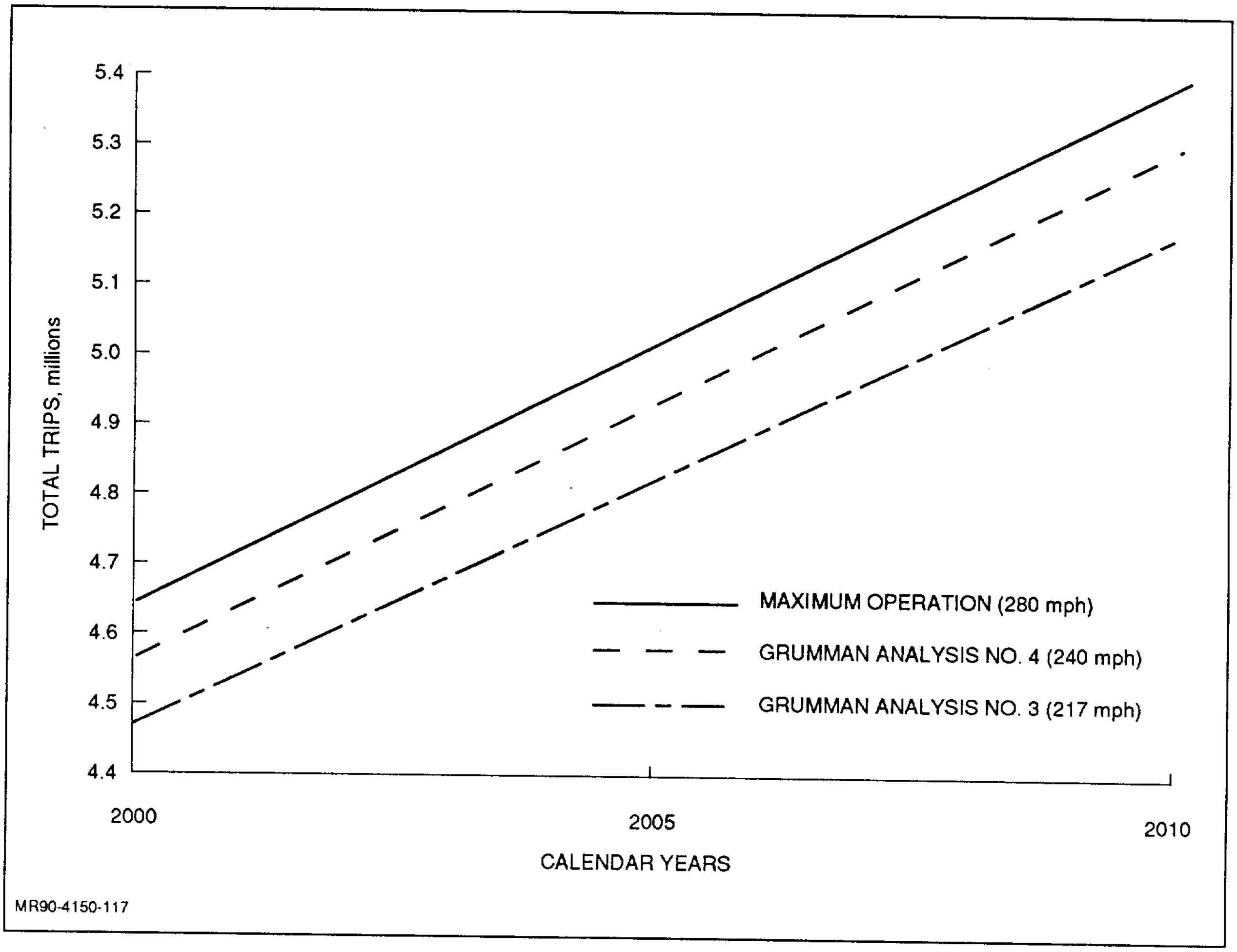

Fig. 1-9 Relationship of Ridership Demand to Vehicle Speed

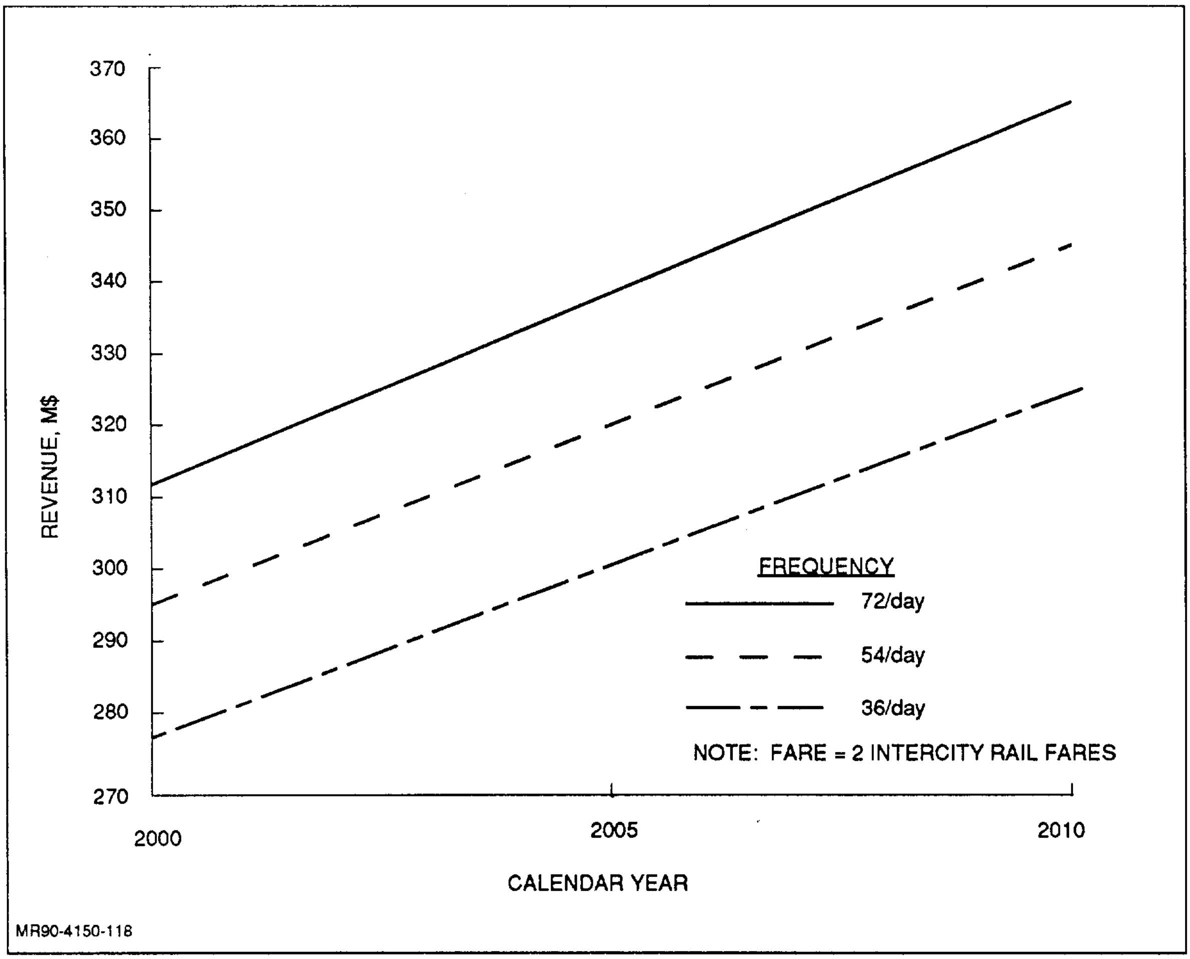

Fig. 1-10 Relationship of Ridership Revenue to Service Frequency

The maximum revenues for the best-case scenario were approximately $340 million in 2010, 10 years after initiating the system. This analysis estimated that by 2010, in-state MAGLEV ridership would be approximately 5.34 million trips each year. This total includes approximately 2.1 million trips diverted from the air, bus, and auto modes and 1.3 million induced trips, or trips that would not be made if the MAGLEV alternative were unavailable.

Restricting the analysis to in-state trips produces a conservative estimate of its potential. If a MAGLEV system were expanded to a regional system the percentage of the trips that could be diverted to MAGLEV from the Boston-New York City combination is 50 percent of the total, or approximately 1.5 million; the total number of air trips between Boston and New York City in 1989 was about 3.0 million.

1.9 FINANCIAL ANALYSIS AND ECONOMIC IMPACTS

One of the most critical areas in assessing MAGLEV, or any high-speed ground transportation-system, is type of financing and the economic effects associated with development and construction. Insights and answers to questions concerning capital and operating costs and economic development are crucial for federal, state, and local officials, as well as potential private investors, in determining whether the relatively high costs of construction and operation of such systems are worthwhile.

Because of the importance and the large-scale nature of the impacts of these financial and economic issues, particularly those that may be publicly oriented, it is imperative that New York State evaluate the financial and economic impacts of these systems. While detailed investigation of these areas is beyond the scope of this study, a preliminary assessment of these impacts is discussed and, where possible, quantified.

System Cost

Extensive studies were made of the guideway structure and the electrical systems, both primary system cost components. A ground-up structural design was conducted by Parsons Brinckerhoff and verified by Grumman's parametric computer program. The electrical systems cost was estimated by General Electric. The results shown in Table 1-3 for several candidate MAGLEV configurations indicate an average cost of $19 million per mile. This figure should be used for planning until more accurate estimates are available.

Analysis has shown that typical MAGLEV vehicles should cost about $9 million each. Assuming a vehicle base of 150, the total vehicle cost would be $1.35 billion. This yields a total system cost of about $21.4 million per mile.

Considering the electric energy cost, the station and guideway maintenance costs, and personnel costs, the estimated total operating and maintenance costs for the MAGLEV system is about $88 million per year which compares favorably with figures developed for the Los Angeles – Las Vegas project and the Pennsylvania study.

With revenues projected at $360 million and O&M projected at $88 million, the net revenues will be $272 million per year. At $21.4 million per mile and a 495-mile system (New York City – Albany – Buffalo), the total capital cost is estimated at $10.6 billion. The excess farebox revenues are obviously insufficient to amortize the capital investment; however, these results, based only on intrastate ridership figures, significantly underestimate the farebox revenue per mile that would be generated by a regional MAGLEV network. Consequently, the inability of the excess farebox revenue to cover capital costs was expected. New transportation systems do not usually pay for themselves from farebox or user revenues, but are implemented based on social and economic benefits, some of which are discussed below.

Table 1-3 MAGLEV Cost Estimates by Subsystem[1]

Subsystem	Transrapid German[3]	Config. 001 USA	Config. 002 USA	MLU00X Japan[6]
Guideway structure[2]	15.00[4]	11.40	11.40	11.40
Levitation	0.00[5]	1.60	1.60	1.50
Propulsion	2.80	0.80	1.70	3.00
PCU	2.40	0.00	2.50	2.50
Power distribution	0.75	1.00	0.75	0.75
Switches	0.22	0.10	0.10	0.10
Signal & communication	0.66	0.66	0.66	0.66
Totals, M$/mile	21.93	15.56	18.71	19.91

1. Values are in terms of M$/mile
2. Includes 35 ft elevated guideway, excavation & backfill
3. Data based on Transrapid information
4. Adjusted for 35 ft column height
5. Included in propulsion coil
6. Based on Grumman data developed for USA Configurations 001 and 002

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Environmental Benefits

It was estimated that the MAGLEV system, by diverting other means of transport, will reduce the annual air pollution load in New York State by 11,600 tons of carbon monoxide, 1500 tons of hydrocarbons, and 800 tons of nitrous oxide by 2010.

Energy Savings

It is estimated that by 2010, 7.8 million gallons of fuel will be saved annually due to trips diverted to the MAGLEV system.

Construction-Related Economic Impacts

The construction-related economic impacts associated with building a MAGLEV system are direct, short-term benefits that extend throughout the construction time period and end when the system is completed. The estimated economic benefits are directly related to the total dollar amount spent on construction; New York State's share of these benefits varies with the type of expenditure. The economic benefits would probably come mainly from construction labor, MAGLEV supply and associated industries such as guideways, electronic components, and vehicle construction. A reasonable estimate of the percentage of the direct construction impacts that may be captured by New York State is 80 percent.

For a New York City to Buffalo MAGLEV system, it is estimated that a total of 90,600 construction jobs with $4.24 billion in construction wages would be created. In addition, approximately 132,000 construction-related jobs with over $6.75 billion in construction-related wages would be generated.

In addition to the direct construction-related impacts, additional economic activity is generated. The short-term construction-generated economic activity output is estimated at approximately $6.3 billion from direct construction jobs and $9.7 billion from construction-related jobs.

Operating and Maintenance-Related Economic Impacts

Unlike the economic impacts from construction which only extend over the project's construction period, the economic impacts associated with the operation and maintenance (O & M) are generated every year the system operates. Additionally, the share of these impacts captured by New York State would probably be greater than 80 percent of the construction costs captured since O & M activities are predominantly local. Of these O & M-related economic impacts, the urban areas of New York State would probably capture a larger share of the total. Economic impacts would expand in proportion to ridership growth.

While detailed analysis cannot be done at this stage, some generalities may be useful. For example, every $85,000 direct expense should create one permanent new job in O & M, including technicians, station and vehicle personnel, and personnel in supporting industries such as food and beverage suppliers. Using a New York City to Buffalo MAGLEV system as an example, the annual O & M cost is estimated at approximately $88 million; therefore, more than 1000 new jobs would be created, of which approximately 300 would be directly involved in the O & M of the system. Using salary estimates of $50,000 for employees directly involved in the O & M of the system and $30,000 for O & M-related jobs, the total wages for direct and indirect O & M employees is $37 million.

Based on these estimates of jobs and wages relating to the O & M of the MAGLEV system, an additional $53 million would be generated from the multiplier effects of new jobs and salaries.

Travel-related expenditures would have substantial economic impact. It is estimated that approximately 30 percent of the projected travel would reflect trips made, or created, only with access to a MAGLEV system. The travelers would spend money for local transportation, lodging, food, entertainment and incidentals.

Economic Impacts of Structural Changes/Ancillary Development

In addition to the economic impacts generated by the construction, operation and maintenance of the MAGLEV system, other benefits would be generated within the region due to structural changes and ancillary development caused by an efficient, high-speed transportation network.

Although these economic impacts would be substantial, it is premature to estimate their potential impact. However, such changes would improve New York State's competitive position and status compared to regional and national economies. For example, with a MAGLEV system that provides high-speed, superior service, New York State industries may become more competitive. New York State may also become a premier location for industrial development due to the improved transportation provided by the MAGLEV system. By improving accessibility, the MAGLEV service would expand the tourism market, which could in turn increase investment potential for new tourist attractions. Initially the MAGLEV system could be a tourist attraction in its own right.

Economic impacts would also include land development. Although difficult to quantify at this time, the historical effect of transportation systems including railroad stations, interstate highways and airports and, recently, rail rapid transit systems on the economy suggests that development will probably include commercial, retail, office, lodging and restaurant components.

The land around station locations would be among the first areas to economically benefit from the MAGLEV system. Development at station locations should be capable of generating a substantial revenue stream; however, public policy may be needed to capitalize on the potential secondary investment opportunities offered by a MAGLEV system. In a favorable economic climate, development in station areas could generate (a return on investment) benefits that could pay for part of the system's construction costs.

State Government Revenues and Benefits

Implementing a MAGLEV system would contribute to State revenues. For example, income tax revenues would increase due to the creation of jobs and salaries. Sales tax revenues would increase due to expenditures for materials to build and operate the MAGLEV system.

There is also a potential to reduce State expenditures since increase in employment and income would reduce the State's unemployment and associated public costs. Some reduction in transportation costs may be expected due to the reduced need to maintain or construct new facilities. Since the potential safety benefits of MAGLEV are greater than other modes, some travel-related accidents and their corresponding cost may also be reduced.

Industrial Outreach Efforts

The preceding discussion highlights MAGLEV-related development, construction and implementation opportunities. New York State is fortunate in having a substantial presence in the various aspects of MAGLEV development. Although a number of these firms are already involved in MAGLEV, others undoubtedly have the potential to get involved. Outreach to industry could include direct mailings, advertisements in professional periodicals, and conferences.

1.10 CONCLUSIONS

While this study was conceptual and limited in scope, it provides a useful perspective for identifying issues associated with developing a MAGLEV system in New York State. The current transportation problems in the Northeast make various aspects of magnetic levitation systems extremely attractive and desirable. This study has led to the following conclusions:

- There appear to be no insurmountable engineering or technological obstacles to developing and constructing MAGLEV systems in New York State;
- Since the guideway is the most expensive component of a MAGLEV system, innovative and refined designs and manufacturing techniques are needed to minimize system costs;
- A high-speed intercity MAGLEV system should attract a substantial level of ridership, with the associated farebox revenue covering the operating and maintenance costs of the system;
- MAGLEV systems could alleviate the airport congestion attributed to short- and medium-haul air trips;
- Benefits can be realized from the MAGLEV system by using it to carry high-value or time-critical freight as well as passengers, which may reduce some truck-related highway maintenance costs;

- Considerable economic benefits could be generated through the research and development, construction, operation and maintenance of a MAGLEV system in New York State. In addition to these direct economic benefits the improved transportation system will help stimulate economic growth in the State;

- Development in the proximity of station locations could enhance the economic viability of a MAGLEV system;

- Integration of high-speed MAGLEV with the existing transportation network is extremely important; however, this will require future consideration of intermodal concepts;

- There is potential to develop a new-design MAGLEV system that would incorporate various aspects of current systems to optimize its application in the Northeast;

- Implementation of MAGLEV systems would help solve some transportation-related problems such as air pollution and reliance on fossil fuels;

- MAGLEV systems can potentially be operated at very high degrees of safety and the technology exists to minimize potential health issues involving induced magnetic fields; and

- New York State has a substantial presence in research, manufacturing and service firms related to MAGLEV development and implementation. Considerable economic benefits would accrue to New York State business from the various phases of MAGLEV.

1.11 RECOMMENDATIONS

Based on this study, the following recommendations are made regarding the development of MAGLEV systems in New York State:

- One of the competitive advantages of MAGLEV as a transportation mode is its ability to operate at speeds approaching 300 mph. The ability of the vehicle to sustain as high an operating speed as possible is critical to implementation. Therefore, it is recommended that further, refined analysis of potential routes and their application as MAGLEV rights-of-way is critical and should be investigated;

- Market demand and ridership forecasts for an intercity MAGLEV system are critical in estimating the potential farebox revenue and its relation to total system costs and financing. A detailed market assessment, including a forecast demand model, with appropriate origin and destination data as its foundation, should be made as soon as possible;

- Since the potential economic benefits associated with the development, construction, operation and maintenance of a MAGLEV system are substantial, it is recommended that additional economic analysis be conducted to refine these estimates. Detailed economic evaluation will be crucial in determining the overall benefits and advantages of a MAGLEV system compared to major investments in other transport modes. Station development may offer the potential for providing non-farebox revenues and should be analyzed;

- Station location must consider real estate development, market demand, and integration with existing transportation systems. A thorough analysis of low-speed MAGLEV system development in suburban and urban areas is recommended;

- Additional research should be conducted in vehicle and guideway design and their interaction. This work should include analysis of banking requirements and ride comfort criteria for vehicles and guideways. Other areas of research should include study of passive coil and flat-plate guideway design including the null-flux design;

- Freight-carrying capability requires further study; and

- Due to the importance of transportation safety, the ongoing research into the effects of magnetic fields should be monitored. All MAGLEV design research should address this issue. Designs should be developed that can effectively shield the induced magnetic fields generated. Further investigation of MAGLEV systems also should be used to develop system safety standards and operational standards that can minimize all potential safety situations that may be encountered, such as guideway misalignments, power failures, and levitation failures.

1.12 REFERENCES

1. Conceptual Design and Analysis of the Tracked Magnetically Levitated Vehicle Technology Program (TMLV). Vol. 1 Technical Studies, by Philco-Ford Corp., Feb 1975, Final Report DOT-FR-4002M PB-247-931.

2 – SYSTEM REQUIREMENTS

2.1 INTRODUCTION

Basic MAGLEV speed and passenger-carrying capacity requirements were established to provide transportation to supplement short-haul aircraft, rail, or automobile. This section presents additional MAGLEV vehicle performance requirements to assure passenger safety and comfort. These performance requirements, based on information developed in Ref. 2.1, and updated to include recent information, should be considered preliminary. The environmental impact of noise, air pollution, magnetic fields, and induced winds on the surrounding area and on passengers is discussed in Subsection 2.3. Based on the requirements discussed in this section, a detailed MAGLEV performance specification was developed and is presented in Appendix B. Particular aspects of these requirements are discussed below.

2.2 PERFORMANCE REQUIREMENTS

2.2.1 Ride Quality

Under any normal operating condition and at all speeds below 300 mph, sustained or steady-state acceleration and rate-of-change of acceleration (jerk) shall not exceed the levels specified in Table 2-1 at any time. According to Ref. 2.2, these limits do not apply to cabin vibrations, but apply to vehicle maneuvers that exceed one to two seconds. A maximum roll rate of 3 deg/sec, a value typical of aircraft in coordinated turns, is an additional constraint.

The spectral composition of acceleration/time histories over any sample collected over a 1 km (0.621 mile) length of guideway or greater, over the frequency ranges of 0.1 to 50 Hz, shall not exceed the limits shown in Fig. 2-1. Comparison with Fig. 2-1 shall be made on the basis of a power spectral density analysis with a frequency resolution of 0.1 Hz intervals in the passband.

Table 2-1 Allowable Acceleration and Jerk Levels – *Forces resulting from accelerations as well as rate-of-change of acceleration (jerk) will affect passenger comfort.*

Direction	Sustained acceleration, +g	Jerk, +g/sec
Longitudinal	0.15	0.03
Lateral	0.08	0.03
Vertical	0.10	0.04

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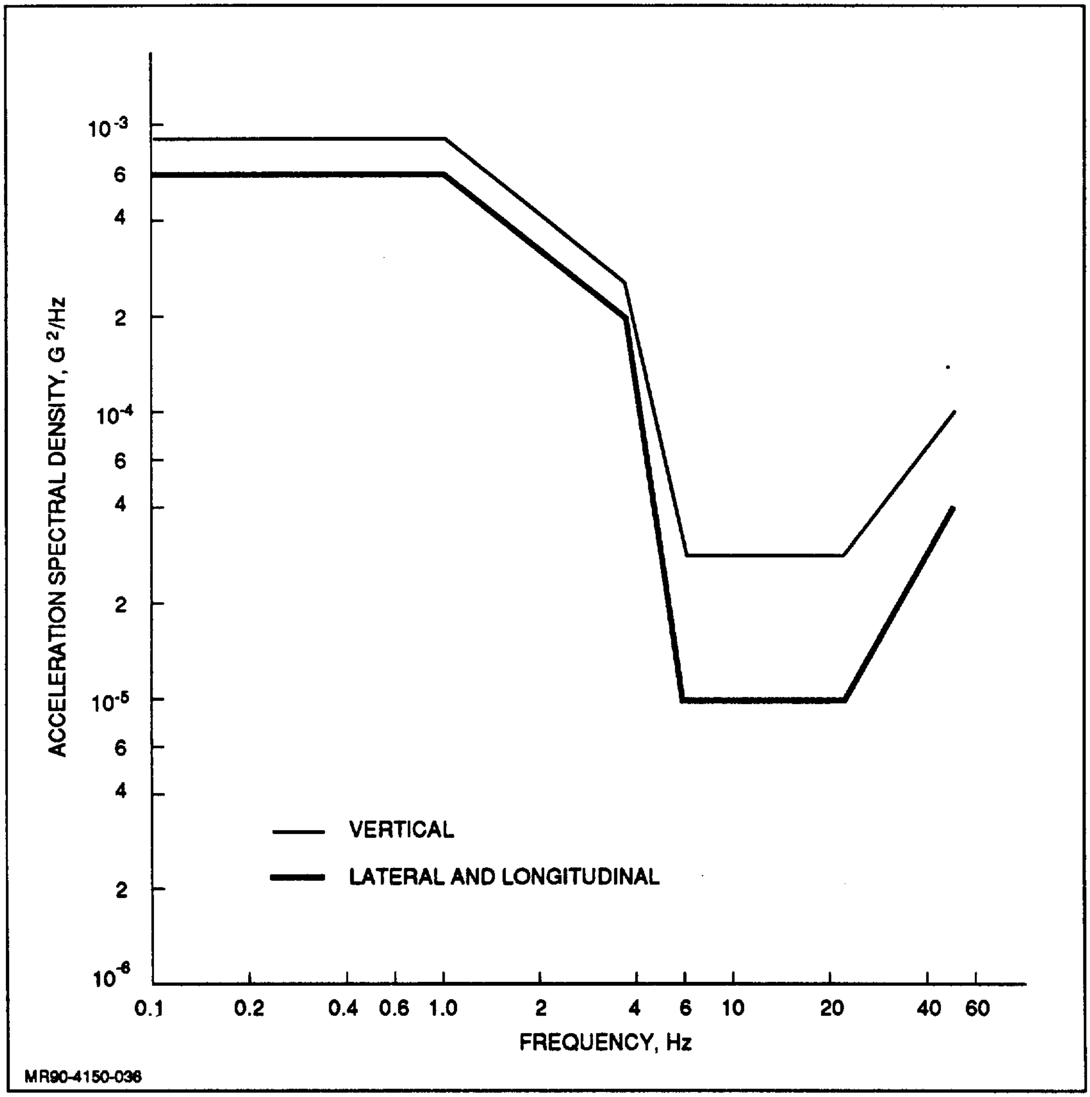

Fig. 2-1 DOT Specification for Spectral Composition of Acceleration in Passenger Compartment – *Vibration levels in the vehicle cabin can affect the comfort of the passengers. This graph shows the allowable power spectral density levels of acceleration as a function of the frequency of the vibration.*

Passengers are also affected by combinations of vehicle banking rate, accelerations, and noise levels. An empirical equation established for ride quality in Ref. 2.3 for new transportation systems such as MAGLEV is stated below:

$$C = 1+.5W_R+.1[dB(A)-65]+17(a_T+a_V)$$

where:

C = Comfort level, which should rarely exceed a value of 4 without some warning to passengers. A value of 1 for C is considered very comfortable, 2 is comfortable, 3 is somewhat comfortable, 4 is neutral, 5 is somewhat uncomfortable, 6 is uncomfortable, and 7 is very uncomfortable.

W_R = RMS roll rate in deg/sec;

dB(A) = Cabin absolute noise level in dBs;

a_T = RMS transverse acceleration in gs; and

a_V = RMS vertical acceleration in gs.

This relationship is based on limited data from testing train, bus, and aircraft. There is no direct relationship to a MAGLEV application that would operate mostly on existing interstate rights-of-way on elevated guideways 35-ft high negotiating numerous curves designed for 60 mph traffic (see Subsection 6.5). Therefore, development of an extensive MAGLEV simulation program, using passengers and aircraft flight simulators, is recommended to establish acceptable values for the above-stated parameters.

2.2.2 Guideway and Vehicle Bank Limits

The radii or guideway curvature required to satisfy the ride quality described can obviously be reduced by using guideway banking (superelevation) and/or vehicle cabin bank. The guideway superelevation for a vehicle that does not have the capability of rolling the cabin independently of the undercarriage is usually limited to approximately 12 deg because greater angles are uncomfortable for passengers if the vehicle stops or negotiates curves considerably below the design speed of the curve (Ref. 2.1). It may also be difficult for guideway maintenance workers to negotiate bank angles greater than 12 deg. The maximum combined guideway and vehicle bank angle is 24.6 deg, the point at which the 0.1g vertical acceleration limit is reached. For any speed, a 24.6 deg bank angle and the specified 0.08 g lateral acceleration limit define the minimum radius turn. Typical results are shown in Fig. 2-2 for speeds of 300, 200, and 100 mph. The curves labeled COORDINATED TURN indicate a turn with no lateral acceleration. For this study only coordinated turns have been considered; as noted, this requires bend radii of about 4.5 km at 300 mph.

2.2.3 Guideway Vertical Radius of Curvature

The minimum vertical radius of curvature for a transition to a grade at a nominal cruise velocity of 300 mph is 60,000 ft. At 200 mph, this value is reduced to approximately 27,000 ft. In general, combined horizontal and vertical curves require larger radii of curvature and must be calculated for the parameters of interest. The acceleration limits at the beginning or end of the transition sections are dictated by the ride comfort values previously described.

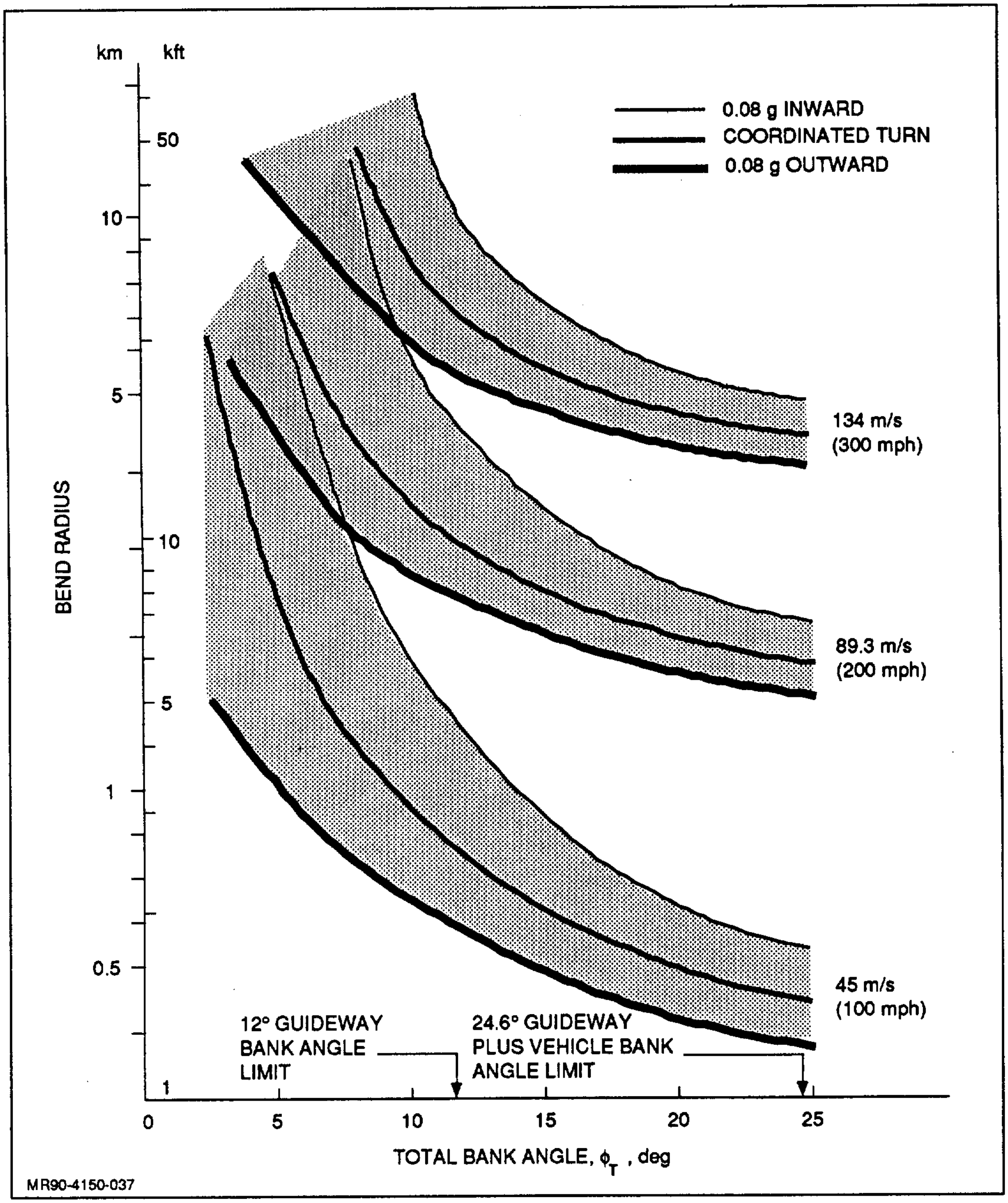

Fig. 2-2 Turn Radii Requirements vs Total Bank Angle – *For the comfort of passengers, maneuvers required to negotiate curves on the right-of-way must be performed with coordinated turns (guideway and/or vehicle banking). This graph shows the bend radius required to meet bank angle limits (guideway and vehicle) at different speeds.*

2.2.4 Guideway Safety

The guideway structure will be designed to withstand normal loads. The design wind loads will be 100 mph without vehicles operating, and 50 mph steady winds and gusts up to 70 mph with the vehicles operating. For electrodynamic suspension (EDS) systems, the normal height of the vehicle above the guideway (four to eight inches) allows it to pass over relatively large objects, as well as considerable ice, snow or sand. Low-speed areas may require clearance of ice and snow, due to the reduced clearance and the use of wheels. A system for detecting objects on the guideway is required either onboard the vehicle and/or on the guideway. A MAGLEV vehicle needs several miles to stop from high speed, so this system must be automatic and part of the central control system. At this time, systems are unavailable to satisfy this requirement; they should be the subject of further research.

Sufficient side clearance must be allowed between vehicles to reduce the passing loads to reasonable levels (see discussion on Vehicle Flow Field Effects in Subsection 2.3.3). The right-of-way must be completely dedicated; i.e., there are no grade crossings. Fencing must be provided at the edges of any at-grade rights-of-way to prevent people or animals from approaching the track or throwing objects directly at the vehicles or track. The number of overpasses above the MAGLEV guideway should be minimized. The overpasses must be fenced to reduce the possibility of objects being dropped on the vehicles or onto the track. Elevated guideways will be mandatory in most urban areas to ensure the safety of the vehicles and to reduce the amount of right-of-way required in these areas.

If electrical power is picked up from the guideway, the usual provisions of protecting people or other objects from contacting the power rails must be provided. The electrical system must be properly grounded and protected from overloads. Communication links and the system for detecting vehicles or other objects on the track must be redundant.

2.2.5 Maintenance, Reliability and Life Cycle

Low maintenance, safety and durability, important aspects of the MAGLEV system, if improperly integrated in the early phases of the program, could cause such operational problems that the entire program could be abandoned.

2.2.6 Standardized System Specifications

Detailed nationwide system design specifications for the vehicles, guideways, passenger stations, central control stations, operating procedures, and maintenance procedures must be developed before building demonstration models or the final transportation system. One purpose of these specifications is to assure that a common design exists among all systems built in the United States.

2.2.7 Qualification and Acceptance Testing

Detailed qualification, acceptance, and safety testing of any demonstration system or the final transportation system shall be established to assure that standard procedures are established for qualifying a United States MAGLEV system.

2.3 ENVIRONMENTAL IMPACT REQUIREMENTS

This subsection discusses issues associated with environmental impacts and limits on the passengers riding in a MAGLEV vehicle.

2.3.1 Vehicle Noise

The primary noise sources at cruise speed radiate from the vehicle boundary layer and wake or are generated by the on-board propulsion system. The latter source will emit negligible noise for any of the systems considered in this study; however, the noise of the electrical pickup must be included. The noise limits specified by the Federal Railway Administration in its 1970s studies in high-speed transportation systems are developed in Ref. 2.2 and are summarized in Table 2-2.

Table 2-2 Specified Noise Limits for High-Speed Transportation Systems per 1970s Studies – *Noise levels imposed by MAGLEV on the passengers and the surrounding area present an important issue. This table indicates the allowable noise levels established by the FRA in 1970 for high-speed transportation systems.*

Item	Noise limit, dBA
Exterior noise:	
Cruise speed	73(1)
Braking, idling, or in terminals	63(2)
Interior noise:	
Passenger compartment	65
Crew compartment	75

1. Measured 50 ft from vehicle centerline at 90 deg to guideway & includes specified tone corrections
2. Measured 50 ft in front of and behind the nearest noise source on the vehicle & includes specified tone corrections

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More recent studies indicate that acceptable noise levels should be based on relative background noise rather than the absolute values specified in Table 2-2. Fig. 2-3, which is based on information presented in Ref. 2.3, identifies impact regions of acceptable and unacceptable levels of noise depending on the ambient background levels.

2.3.2 Passenger Comfort Requirements

Abrupt cabin pressure changes upon entry and exit from tunnels and pressure changes on grades must be avoided. The obvious solution is to use a sealed, pressurized cabin. The discomfort experienced by a person due to a reduction in pressure depends on the rate of change of pressure, and when the middle ear can adjust to it. Pressure changes due to the cabin conditioning system should be limited to less than 0.005 psi/sec, and the pressure change from the initial ambient must be limited to a few tenths of a psi.

The environmental impact of the elevated or at-grade guideway, passenger terminals, parking lots, and other facilities should be minimal. In general, environmental impact is highly route-specific and requires careful planning and design.

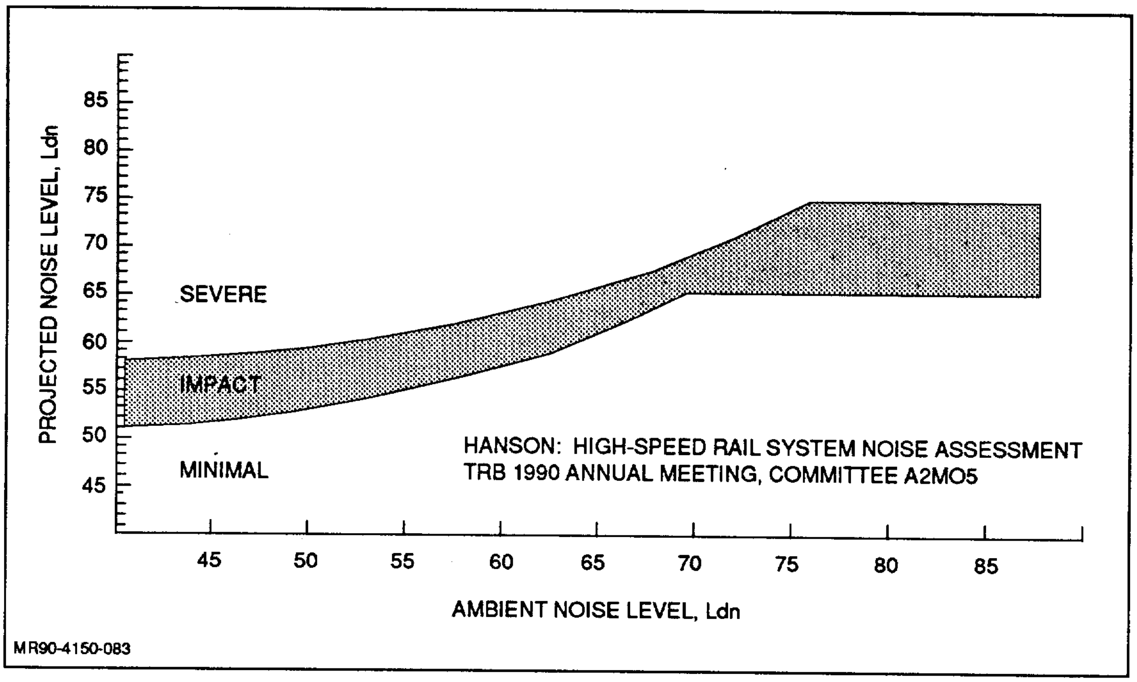

Fig. 2-3 Noise Impact Criteria Based on Projected Ldn vs Ambient Ldn – *Recent studies have indicated that noise levels are better specified on the basis of the surrounding noise levels. This graph shows the impact of the noise source as a function of the ambient noise levels.*

The visual effects of close objects passing the vehicle at high speeds has an unsettling effect on people. Optokinetic (train) nystagmus and intermittent photic (flicker) stimuli can be maintained within acceptable levels by eliminating large vertical objects that are close to the track and/or by restricting the passengers' visual field. The latter may be done by limiting the location, size, and number of side windows or by making the windows partially opaque when high speeds are reached.

2.3.3 Vehicle Flow Field Effects

The aerodynamic flow field produced by a high-speed vehicle will be felt by objects close to the guideway in the form of a wind gust of short duration (<1 sec). The magnitude of the gust will be influenced by the distance from the passing vehicle, the vehicle characteristics, i.e., shape, speed, method of propulsion, and the magnitude of any crosswind.

The principal aerodynamic phenomena, caused by the vehicle body, results from the pressure field created by the vehicle nose and the wake aft of the vehicle base. Hammitt, in Ref. 2.4, presents graphical estimates of these phenomena in parametric form for a representative vehicle configuration. The results have been used to determine the approximate magnitude of the wind gusts that would be experienced from passage of a single vehicle traveling at 300 mph with no crosswind. Figure 2-4 shows the estimated maximum induced gust velocity as a function of side distance from the vehicle centerline. The results indicate the wake is more important than the nose effect. Figure 2-4 also demonstrates that the induced velocity for an aerodynamically smooth body representative of MAGLEV is hardly noticeable at distances greater than about 30 ft from the vehicle centerline. Therefore, a distance of 50 ft to the edge of the right-of-way and 10 ft between passing cars should provide sufficient distance to eliminate gust effects at the edge, even with crosswinds. Additional test data are needed to confirm these conclusions.

2.3.4 Health Risk and Electromagnetic Fields

The introduction of MAGLEV technology to the U.S. transportation system initiates a need to shield the passenger compartment, right-of-way boundaries, employees, and loading/unloading platforms against stray magnetic fields. The following three general questions arise with any shielding problem:

- The level and type of field to be shielded;
- The level to which the field has to be shielded; and
- The overall geometry of the system — i.e., location of sources relative to position of a shield.

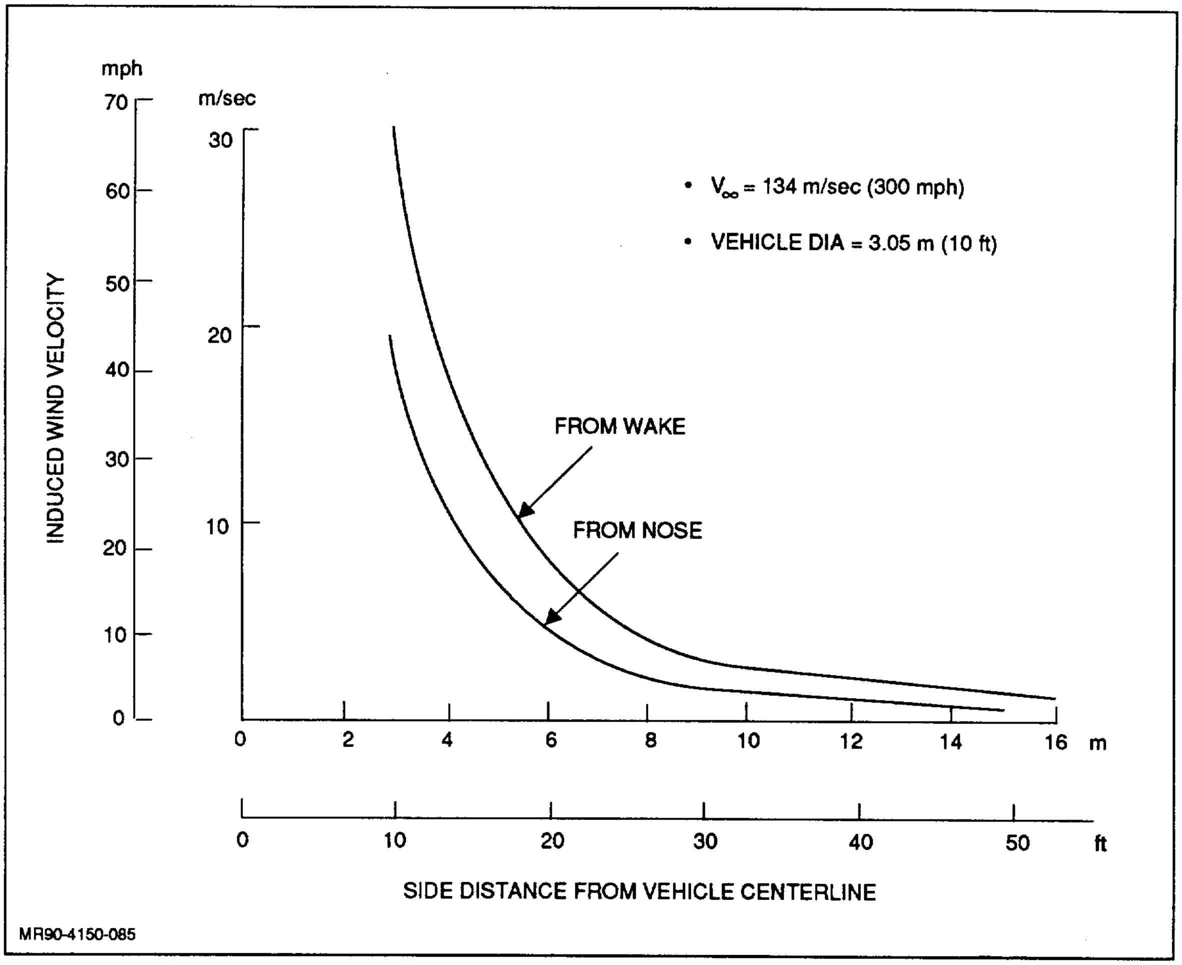

Fig. 2-4 Induced Wind Velocity Resulting from Passage of High-Speed Vehicle – *This curve indicates that a separation of 20 ft between vehicle centerlines (10 ft clearance between vehicle sidewalls) will induce small wind gust velocity (less than 15 mph) when vehicles pass each other at 300 mph.*

For MAGLEV systems, only partial answers are currently available. This subsection reviews the current status of exposure limits, and the health risks associated with both static and alternating magnetic fields as a first step in answering the question of the stray field effects of MAGLEV. Magnetic shielding techniques and effectiveness are discussed in Subsection 4.5. Since public acceptance of a particular MAGLEV system will depend on factors like the mitigation of stray fields, the proper handling of the field effect problem will affect selection of a next-generation MAGLEV system.

Recent epidemiological studies seem to show a link between exposure to electromagnetic fields resulting from 60 Hz alternating current (ac) and cancer. The evidence for health risk with low-level exposure is inconclusive at this time; however, public concern has already had a pronounced impact on such diverse technologies as electric transmission lines and computer monitors. This public concern has stimulated, in the last year, two scientific reviews on the subject, as well as numerous special reports and articles (Ref. 2.5 through Ref. 2.9). The topic is controversial because the available evidence suggests a complex and non-linear exposure-response relationship. Federal agencies such as the National Institute of Health (NIH), U. S. Department of Energy (DOE), and the U.S. Environmental Protection Agency (EPA), along with the Electric Power Research Institute are conducting studies. The National MAGLEV Initiative has called upon the EPA to provide information about the effects of exposure to electromagnetic fields on the public.

There are several salient points in the controversy about the health risks associated with electromagnetic fields. Low-frequency (50 to 200 Hz) magnetic fields are apparently the most problematic. Several epidemiological studies indicated that exposure to 50 to 60 Hz magnetic fields as small as 250 microteslas correlated with a rise in cancer rates. In comparison, exposure tolerances to static electric fields and magnetic fields are placed at much higher levels. The normal earth magnetic field where human life evolved is steady-state and around 50 microteslas or 0.5 gauss.

One way to measure the ac magnetic exposure level problem is to consider exposure levels from 60 Hz household appliances. Refrigerators, washers, and dryers have electric motors near the back of the unit so that 60 Hz magnetic fields around these appliances are low (0.1 to 1.0 microteslas). Heating elements in electric blankets have caused some concern because they are close to the body, with long exposure times (eight hr/day). However, their magnetic flux densities are low (1.0 to 5.0 microteslas), and as yet no risk correlation has been attributed to their use. Television and some computer monitors with levels between two to 50 microteslas have attracted considerable attention. Electric ranges have fields of six to 200 microteslas; mixers, blenders, and can openers have field levels of 50 to 600 microteslas. Since daily 60 Hz exposure levels are at the several hundred microteslas levels without a corresponding correlation in a rise in health risk, more rigid standards may not be warranted. The answer to "what is an acceptable exposure level?" depends on further studies; however, attempts at establishing standards are under way. Although the IEEE SCC28 committee so far has been unable to agree on how to treat low-frequency fields, the International Radiation Protection Association (IRPA) has set 100 microteslas (1 gauss) as the limit for maximum ac field exposure; for occupational exposure to a low-frequency magnetic field, a five-gauss limit or 500 microteslas is suggested over an eight-hour working day. This limit was set due to the effect on heart pacemakers, not for biological cause, reflecting an ability to understand electronics rather than the human body. The utilities, however, have adopted a strategy of product avoidance by lowering 60 Hz magnetic fields at the borders of power line rights-of-way to levels of around 20 microteslas (0.2 gauss). In conclusion, current trends place the allowable limits for MAGLEV systems in the range of one to 100 microteslas (0.01 to 1.0 gauss) for low-frequency magnetic fields. Electric fields, both ac and dc, do not appear to be a problem for MAGLEV, and the static (dc) magnetic field allowable limit may be around 200 microteslas (2 gauss).

2.4 TOP-LEVEL SPECIFICATION

A preliminary Top-Level Requirements and Performance Specification for a MAGLEV System, which incorporates the requirements outlined in this section, has been developed and is presented in Appendix B.

2.5 REFERENCES

2.1 " Conceptual Design and Analysis of the Tracked Magnetically Levitated Vehicle Technology Program (TMLV). Repulsion Scheme. Volume I Technical Studies." Feb. 1975, Final Report DOT-FR-40024, PB24793.

2.2 "High Speed Rail Systems." FRA Report No. FRA-RT-70-36, PB192506, Feb. 1970.

2.3 Hanson. "High Speed Rail System Noise Assessment." TRB 1990 Annual Meeting, Committee A2M05.

2.4 Hammitt, A. G., "The Aerodynamics of High Speed Ground Transportation," Western Periodicals Co., 1973.

2.5 "Extremely low frequency electric and magnetic fields and cancer." EPRI, EN-66784, July 1990.

2.6 "Evaluation of the potential carcinogenicity of electromagnetic fields." EPA/600/690/005A, July 1990.

2.7 Fitzgerald, K. "Electromagnetic Fields: The jury's still out." *IEEE Spectrum*, Aug. 1990, p. 22.

2.8 Brodeur, P. "The magnetic-field menace." *MacWorld*, July 1990, p. 136.

2.9 Pool, R. "Electromagnetic fields: The biological evidence." *Science*, Vol. 249, 1990, p. 1378.

3 – COMPARISON OF ALTERNATE MAGLEV SYSTEMS

3.1 INTRODUCTION

The objective of this section is to establish a data base on a spectrum of five MAGLEV concepts (Fig. 3-1):

- Transrapid 07 (Germany);
- MLU002 (Japan);
- MLU00X (Japan);
- Configuration 001 (USA); and
- Configuration 002 (USA).

Each of the above configurations is described in detail followed by an evaluation based on various criteria important to the development of a MAGLEV system. The criteria included:

- System cost;
- Ability to carry freight;
- Ability to interface with low-speed systems;
- Ability to use existing rights-of-way;
- Ability to accommodate passive track switching;
- Guideway alignment requirements;
- Power to drive the system;
- Electromagnetic environments; and
- Safety issues.

3.2 DESCRIPTION OF ALTERNATE MAGLEV SYSTEMS

3.2.1 General Description

The Transrapid was selected as representative of the most highly developed MAGLEV system in the world, with probable application in the near future. The MLU002, a research vehicle not necessarily representative of a revenue system, was included to provide comparative data on the electrodynamic suspension system. The MLU00X (our designation) represents the Japanese concept designed for revenue service based on the MLU002 technology. Configurations 001 and 002 are domestic designs developed by Grumman, and are included to provide what we believe to be the system with the lowest possible capital costs. The systems differ in that the 001 is driven with a Linear Induction Motor (LIM) and 002 with a Linear Synchronous Motor (LSM).

A fairly extensive data base is available for each of these systems. Table 3-1 provides a summary of comparative characteristics of these systems. Additional information on each configuration is presented in Appendix A.

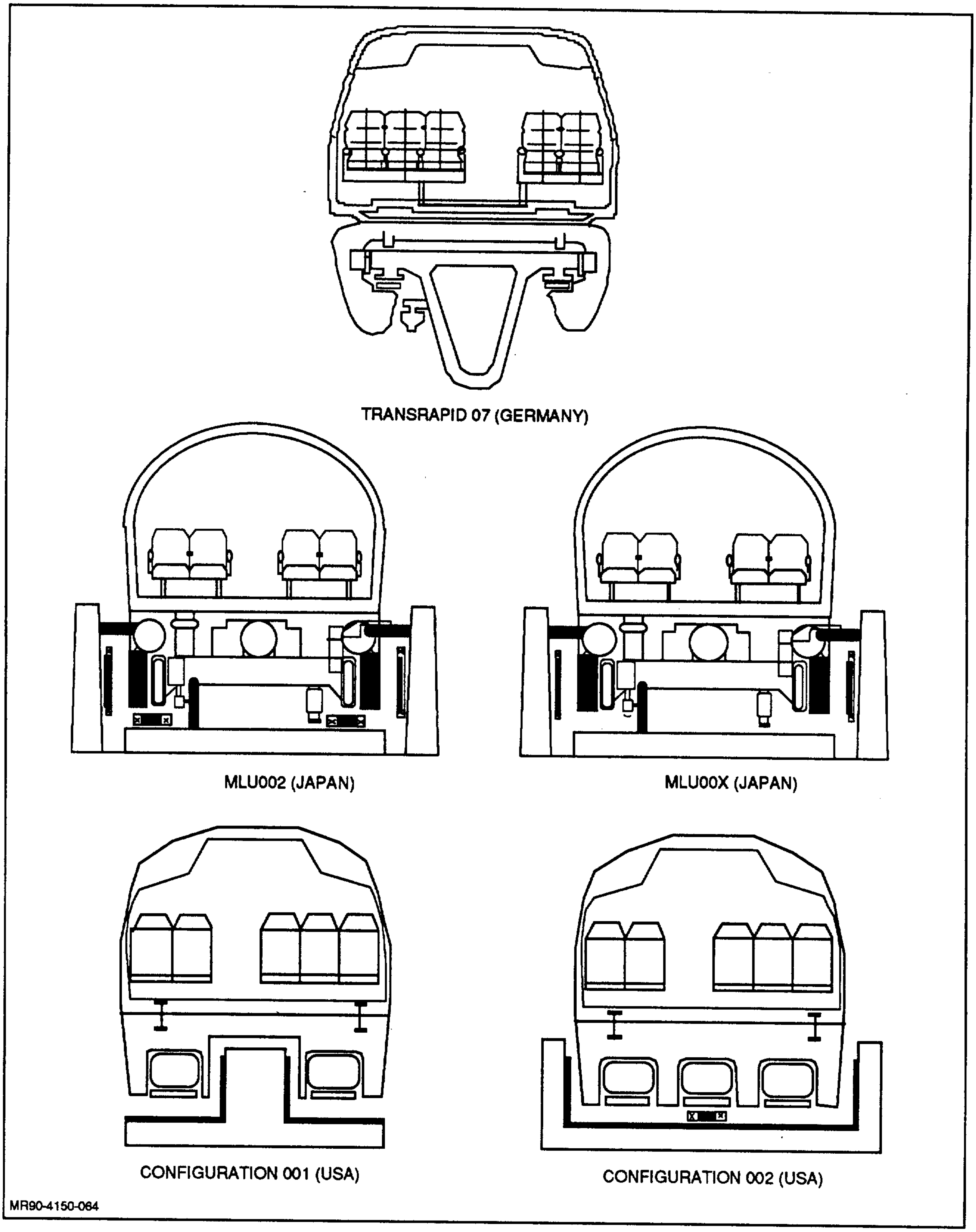

Fig. 3-1 Alternate MAGLEV Configurations – *These five configurations evaluated for the study are generally representative of most systems currently being considered.*

Table 3-1 Alternate MAGLEV Systems Comparison Summary

Item	Configuration				
	Transrapid 07	MLU002	MLU00X	Config 001	Config 002
Suspension	EMS	EDS	EDS	EDS	EDS
Propulsion	LSM	LSD	LSM	LIM	LSM
Max speed, kph (mph)	500(311)	420(261)	500(311)	483(300)	483(300)
Seats/car	160–200 (1)	44	68	100	100
Max cars/train	10	1	14	TBD	TBD
Min headway at max speed (2), sec	92	33	38	50	50
Max capacity, passengers/hr (3)	7826	4800	6440	7200	7200
Max car wt, MT	100	17	27	39	30
Car wt/seat, lb	1103	851	875	860	660
Power at max speed, MW/car	7.7	3.4 (4)	2.5 (4)	10.3	7.4
Normalized power, MW/car (5)	5.8	5.6 (4)	5.6 (4)	11.4	7.8
Specific energy consumption at max speed, kwh/passenger-mile	0.12–0.15	0.30 (4)	0.12 (4)	0.38	0.25

1. Transrapid is operated as a 2-car set
2. Assumes max speed, max deceleration, 5 sec reaction time
3. Full cars, max speed, min headway
4. Power data not available on Japanese systems, numbers shown are estimates
5. Normalized to 500 kph, 12 m^2 frontal area, 30 m length

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3.2.2 Transrapid

The Transrapid currently represents the most advanced MAGLEV system in the world. Initiated two decades ago by the German Minister of Transport, the companies of Messerschmitt-Boelkow-Blohm (MBB), Krauss Maffei, and Thyssen Henschel built progressively more advanced MAGLEV vehicles. In 1978 the German government decided to concentrate on the electromagnetic (attractive) MAGLEV with a LSM (active guideway) for propulsion; this forms the basis for subsequent developments.

The above-noted companies, joined by others, have formed the Transrapid International consortium (TRI) supported by the German Federal Railroad Administration and the Federal Research and Technology Administration. To date the German government has invested more than $1 billion in MAGLEV research. Additional investments by private industry are estimated at 25 percent.

The Transrapid is not presently employed in revenue service anywhere in the world. A facility at Elmsland, in the north of Germany, is used to test and certify MAGLEV systems. The test track is 31.5 km long consisting of a straightaway section with return loops and high-speed switches at each end providing cruising speeds of 300 kph with brief bursts to 400 kph.

The Transrapid was recently proposed for revenue service between Los Angeles and Las Vegas. If this project continues, it could be operational by 1996. A similar system has been proposed to link the Orlando, Florida, International Airport with International Drive, which could be operational at the same time.

A primary consideration in designing the Transrapid system was to minimize energy consumption. As a result, the levitation magnetic drag is almost negligible; the drag of the power pickup induction generator is higher than the levitation coils at full speed.

Since the prime discriminator in cost comparisons among the different MAGLEV systems is the electrical equipment embodied in the guideway and its associated power systems, some discussion of this area is necessary. The Transrapid system uses laminated iron-inverted "rails" against which the vehicle magnets are attracted. Because of the field strengths achievable with normal magnets, the gap between the vehicle and guideway coils is limited to about 10 mm, which will require maintaining consistent guideway tolerances.

Propulsion is provided by traveling magnetic waves produced by coils in these armatures. The coils are iron core, with serpentine 3-phase aluminum windings in the slots of the laminated iron guideway and aluminum windings around iron poles on the vehicle bogies.

The power conditioning equipment at the Elmsland Test Track includes a 110/20 kV, 31.5 MVA HV transformer, two 20/1.2 kV, 5.6 MVA rectifier transformers, two 3300 A, 1300 V rectifiers, rectifier circuit breakers, eight 2 MVA, 0 – 2027 V, 680 A, 0 – 215 Hz inverters, four 1.8 MVA, 55 – 215 Hz output transformers, output circuit breakers, and a controller. This hardware would be typical of that required at each substation located at approximately 30 km intervals.

3.2.3 MLU002

The MLU002 is a research vehicle using superconducting magnets that react against wound coils in the guideway to provide levitation by repulsion. With the higher field strengths that superconducting coils provide, the gap between the vehicle and the guideway can be about 100 mm, or ten times that of the Transrapid, an important feature of this concept. The Japanese may have favored the superconducting EDS suspension system to get an earthquake-tolerant design.

The vehicle weight per seat is only about 60 percent that of the Transrapid, reflecting the reduced weight of the superconducting systems; this helps achieve large gaps, and lowers guideway costs.

3.2.4 MLU00X

The MLU00X is our designation for the Japanese proposed commercial train. It includes a multicar configuration with the magnetic levitation bogies between the cars to control passenger exposure to high magnetic fields. The vehicle is designed with a lower frontal area than the MLU002 because the Japanese believe up to 70 percent of their route will be underground, and this design will reduce tunnelling costs. Data on this system are limited; some of the critical performance parameters, such as power demand, were unavailable but were estimated for purposes of this study.

3.2.5 Configuration 001

This vehicle, a domestic design produced by Grumman, is based on the technology presented in the Ford Report (Ref. 3.1). It uses superconducting coils in a repulsion (electrodynamic suspension - EDS) scheme, along with a LIM for propulsion. This system was chosen because it has the lowest guideway and overall system cost.

The guideway system will consist of a reinforced concrete elevated structure with aluminum plates to react against the levitation magnets, and an iron plate backed with two aluminum plates on each side as the armature of the LIM. There will be power pickup rails to supply the vehicle. The power supply system will be distributed along the guideway at intervals similar to that of the other systems, but will be simpler and less expensive because the supply will be dc. The switchgear and power-conditioning equipment will be on the vehicle and will not have to be replicated along the guideway. A drawback of this system is the need for high-speed power-pickup brushgear. While designs have been presented for this equipment, additional development is required.

Configuration 001 has the highest energy consumption of all of the systems reviewed. The figure presented, 10.3 MW for the 86 klb car, is a result of the reduced efficiency of the LIM at high speed.

3.2.6 Configuration 002

This configuration, identical to Configuration 001, uses a LSM rather than a LIM. This concept, included to provide a low-cost guideway, offers an alternative if the LIM efficiency is too low at the desired speeds or the cost of developing high-speed brushgear is too high. The vehicle weight is reduced by 20 klb compared to Configuration 001 because the motor and switchgear are removed; however, a wayside power system will be needed to use variable-voltage and variable-frequency systems.

3.3 EVALUATION OF ALTERNATE MAGLEV SYSTEMS

A discussion of several qualitative factors that apply to the selected system concepts follows.

3.3.1 System Costs

For the typical MAGLEV system, the guideway cost dominates the total cost. A wide range of per-mile costs have been quoted ($5 million to $35 million) for the various systems in different parts of the world and in a variety of situations. The costs quoted in this section are based on data developed by Grumman for each system using a common baseline (see Section 9). The Transrapid system was recently proposed for the Los Angeles–Las Vegas route with a total system cost (mostly guideway) of $20 million per mile which included limited land acquisition costs. This estimate was adjusted to $22 million for a continuous elevated guideway 35 ft above ground. A $27 million per mile figure for the Japanese system was taken from the cost estimates for the new 43 km Yamanashi test track that could form part of a commercial route between Tokyo and Osaka. Although many of the details of this cost estimate are unknown, 70 percent of the line will be underground. The system cost estimate, using the same baseline as the other systems, is $20 million per mile.

The U.S. Configurations 001 and 002 were estimated at $15.5 and $18.6 million per mile respectively, leading to the conclusion that while differences exist, they are not significant enough to force a final choice.

3.3.2 Integration with Low-Speed Transportation Systems

It may be possible that MAGLEV vehicles could be configured with wheels and interface directly with conventional rail systems or even paved surfaces. The MAGLEV concepts that use EDS suspension technology would have landing gear for low-speed travel.

3.3.3 Ability to Carry Freight

The Transrapid is described as having light freight-carrying capability unlike the Japanese systems that only carry passengers. Any of the systems could be configured to carry freight up to the capacity of the passenger and accommodations load; beyond this weight, the vehicles must be designed to carry heavier loads which implies larger vehicle size and aerodynamic drag, larger magnetic systems and, in the case of the EMS system, more levitation power, and increased magnetic drag. There is an advantage of the EDS MAGLEV concept as a freight carrier, and there is a clear advantage of MAGLEV compared to high-speed rail in terms of track alignment and maintenance.

3.3.4 Ability to Use Existing Rights-of-Way

There is a strong advantage, especially in the Northeast, in using existing rights-of-way. This is primarily a speed-dependent issue. Existing rights-of-way have curves, and each curve will have a maximum allowable speed when bank angle and passenger comfort guidelines are established.

The analysis presented in Subsection 6.5 on the speed and banking limits of the NYS Thruway indicates the need for vehicle as well as guideway banking at an average speed of 240 mph. Neither the German nor the Japanese MAGLEVs provide this capability. The Transrapid test track is banked at up to 12 deg. It is unknown if this is a physical limit; corresponding limits for the Japanese systems are unknown. In hilly terrain, a 12 deg bank allows only 70 percent of the speed of a 24 deg bank.

3.3.5 Ability to Use Passive Track Switching

According to the Grumman team, from a reliability and cost aspect, a non-movable switch mechanism would be preferable, especially if many off-line stations are used along a particular run. Extremely high reliability and low failure rate are required to minimize the possibility of a switch hang-up in an intermediate position.

Transrapid's wrap-around design prevents the use of passive track-switching techniques described in Subsection 4.7 and this is a disadvantage. The Japanese could use passive switching, but have decided to use a mechanical approach.

3.3.6 Guideway Alignment Requirements

Because of the low 3/8-inch guideway clearance requirements for the EMS Transrapid 07, it is estimated that the guideway tolerances are four times more stringent than the EDS system, which represents another disadvantage for the EMS system.

3.3.7 System Safety

There are special safety concerns of MAGLEV systems compared to conventional or high-speed rail that are generally applicable to MAGLEV vehicles as a class.

The higher speeds possible with MAGLEV, about twice that of any existing means of ground transportation, present several safety concerns. The stopping distance with normal braking varies between 4 km and 14 km, considerably beyond the visual range of an operator, which necessitates automatic control of vehicle functions. The lightweight structures coupled with higher speeds will present safety considerations similar to aircraft; however, a significant advantage compared to aircraft will be the complete absence of flammable fuels.

The Transrapid design, which wraps around the guideway, is inherently resistant to derailing. The other designs could easily incorporate similar restraints to prevent derailing.

All systems maintain levitation despite a loss of power. The Transrapid reverts to onboard battery supply, and the superconducting systems can withstand a loss in refrigerator power for some time. The Transrapid reverts to wheels at low speeds. All systems, however, lose their primary means of braking, which makes it necessary to use several redundant brakes that do not require extensive power. Aerodynamic and friction brakes are likely candidates.

Guideway surveillance will be required, probably over the entire guideway length. This system must have the capability of sensing (and/or removing) ice, snow or foreign objects on the track that could damage the vehicle. Safety systems this specialized do not presently exist and should be the focus of technology research.

The magnetic passenger environment is a critical safety concern. At the present time, definitive safety levels for widely accepted magnetic field strengths do not exist. A level of 5 gauss has been established for people working around Magnetic Resonance Imaging (MRI) equipment. This level was determined by the electronic sensitivity of heart pacemakers and not by a biological concern. People may be much more sensitive to ac fields than dc fields, but much more research is needed. Transrapid reports that their field levels are within the 5 gauss limit. The MLU002 reports 200 gauss at floor level, which reflects the higher fields of the high clearance superconducting systems. The MLU00X design places the magnetic bogies between the cars to provide separation from the passengers. In addition, the superconducting designs, or perhaps all designs, will require a combination of active and passive shielding. Additional information is given in Section 4.

The Orlando MAGLEV project proposed by MAGLEV Transit, Inc. will be used as a pilot safety project by the Federal Railroad Administration to test and develop safety standards specifically for high-speed MAGLEV technology.

3.4 EVALUATION SUMMARY

The issues previously described are summarized in Table 3-2, with qualitative comparisons presented in Table 3-3. Configuration 002 would apparently meet all of the criteria important for the New York State MAGLEV application. The present German and Japanese MAGLEV systems were considered too speed-restricted due to bank angle limits, which may be sufficient reason to develop a new American MAGLEV system designed to meet U.S. conditions.

3-5 REFERENCES

3.1 Conceptual Design and Analysis of the Tracked Magnetically Levitated Vehicle Technology Program (TMLV). Vol. 1 Technical Studies, by Philco-Ford Corp., Feb. 1975, Final Report DOT-FR-4002M PB-247-931.

Table 3-2 Alternate MAGLEV Configuration – Criteria Evaluation Summary – *This table summarizes the comparative characteristics of the five MAGLEV configurations using each of the major criteria. The USA Configuration 002 best satisfies all of the criteria, but would require a major development effort.*

Criteria	Configuration				
	Transrapid 07	MLU002	MLU00X	Config 001	Config 002
Guideway cost-$M/mile (1)	21.9 (3)	N/A	20 (3)	15.5 (3)	18.6 (3)
Ability to carry freight (2)	No	No	No	No	Yes
Tilting of passenger compartment	No	No	No	No	Yes
Uses passive track switching	No	No	No	Yes	Yes
Guideway alignment accuracy	1 in 4K	1 in 1K	1 in 1K	1 in 1K	1 in 1K
Power to drive at max speed (4)	7.7	N/A	N/A	10.3	7.4
DC electromagnetic levels, gauss	<1	>50	<10	<50	<5
AC electromagnetic levels, gauss	<.05	N/A	N/A	N/A	N/A

1. Dual guideway; includes cost of levitation, propulsion & electrification
2. Ability to adapt to freight in excess of normal passenger loads
3. Based on Grumman team data assuming 35 ft column height
4. Single vehicle at max speed (2-car for Transrapid)

Shaded: Recommended configuration

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Table 3-3 MAGLEV Systems – Relative Advantages & Disadvantages

System	Type	Advantages	Disadvantages
Transrapid (Germany)	EMS & LSM	• Highly developed system • Uses room temperature magnets • Low power requirements • Always levitated with smooth low- and high-speed operation	• Small 3/8 in. clearance • Tight tolerances required on guideway • Requires mechanical track switch • High weight and cost penalty to carry freight • Complex levitation control system
MLU002 (Japan)	EDS & LSM	• Developed thru testing phase • Large clearance (6-8 in.) • Moderate power requirements	• Requires use of superconducting magnet, with high magnetic fields perceived as problem • High guideway costs • Rough ride at lower speeds • Requires wheels for liftoff • Uses mechanical track switch
MLU00X (Japan)	EDS & LSM, null flux	• Scheduled for advanced development & testing by 1993 • Large clearance (6-8 in.) • Moderate power requirements	• Requires use of superconducting magnet, with high magnetic fields perceived as problem • High guideway costs • Rough ride at lower speeds • Requires wheels for liftoff • Uses mechanical track switch
Config 001 (U.S.,Ford/ Philco, Grumman)	EDS & LIM, aluminum sheet	• Lowest guideway cost system • Smooth operation at all speeds	• Requires development • Requires use of superconducting magnet, with high magnetic fields perceived as problem • Requires wheels for liftoff • LIM requires a separate suspension system to accommodate small air gap and transfer of power to vehicle
Config 002 (U.S., Grumman)	EDS & LSM, aluminum sheet	• Low guideway cost system • Smooth operation at all speeds • Can use passive track switch • Will be designed to provide vehicle body tilting • Large clearance (6-8 in.)	• Requires development • Requires use of superconducting magnet, with high magnetic fields perceived as problem • Requires wheels for liftoff

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4 – MAGLEV SYSTEMS DESIGN AND CONSTRUCTION

4.1 INTRODUCTION

This section discusses many of the technical issues related to designing a MAGLEV system. Configuration 001 was chosen as a baseline vehicle to review alternate concepts. A tradeoff analysis by the Ford Motor Company in the early 1970s (Ref. 4.1) developed a baseline which they felt was a cost-effective MAGLEV configuration. It used superconducting coils for repulsion levitation riding on an aluminum guideway and two, ducted air-fan turbine drives for propulsion. This configuration was later modified to use a LIM propulsion system. The resulting 100-passenger baseline configuration shown in Fig. 4-1, was further improved as discussed in Subsection 4.2.3. A detailed weight breakdown of the modified baseline MAGLEV vehicle is given in Table 4-1.

A discussion of candidate guideway design concepts studied by TRW in Ref. 4.2 is also included, followed by a tradeoff analysis that evaluates the guideway and system costs as a function of guideway span length and the number of passengers per vehicle. An independent Parsons Brinckerhoff guideway cost estimate for a point design guideway structure indicated good correlation with TRW data.

4.2 VEHICLE DESIGN CONSIDERATIONS

A MAGLEV vehicle operating at 300 mph is analogous to an aircraft fuselage flying without wing or tail surfaces. The design was based on traditional aluminum aircraft. The optimum design for a MAGLEV vehicle is predicated on a structural system that is made up of numerous components, each designed to satisfy a specific function, including static strength, fatigue strength, stiffness, damage tolerance, durability, supportability, repairability, and maintainability. Factors associated with thermal, moisture and acoustic environmental requirements also were considered.

4.2.1 Aircraft Aluminum Structures

The traditional structural material for aircraft, aluminum, forms the basis for the following design discussion.

4.2.1.1 Passenger Cabin Configuration – A minimum cabin area with large seats, similar to DC-10 seats, was designed. The internal dimensions are: a height (headroom) of 81 inches, a width of 131 inches, and a cabin length of 64 feet. A five-seat row with center aisle (2 x 3) was used, with an aisle width of 21 inches. A seat pitch of 36 inches was used to ensure adequate leg room. The magnets, propulsion system, and landing/switching gear are located in channels or "sponsons" on either side of the vehicle. The distance between the floor of the cabin and the bottom of the vehicle is primarily dictated by the diameter of the landing/switching wheels.

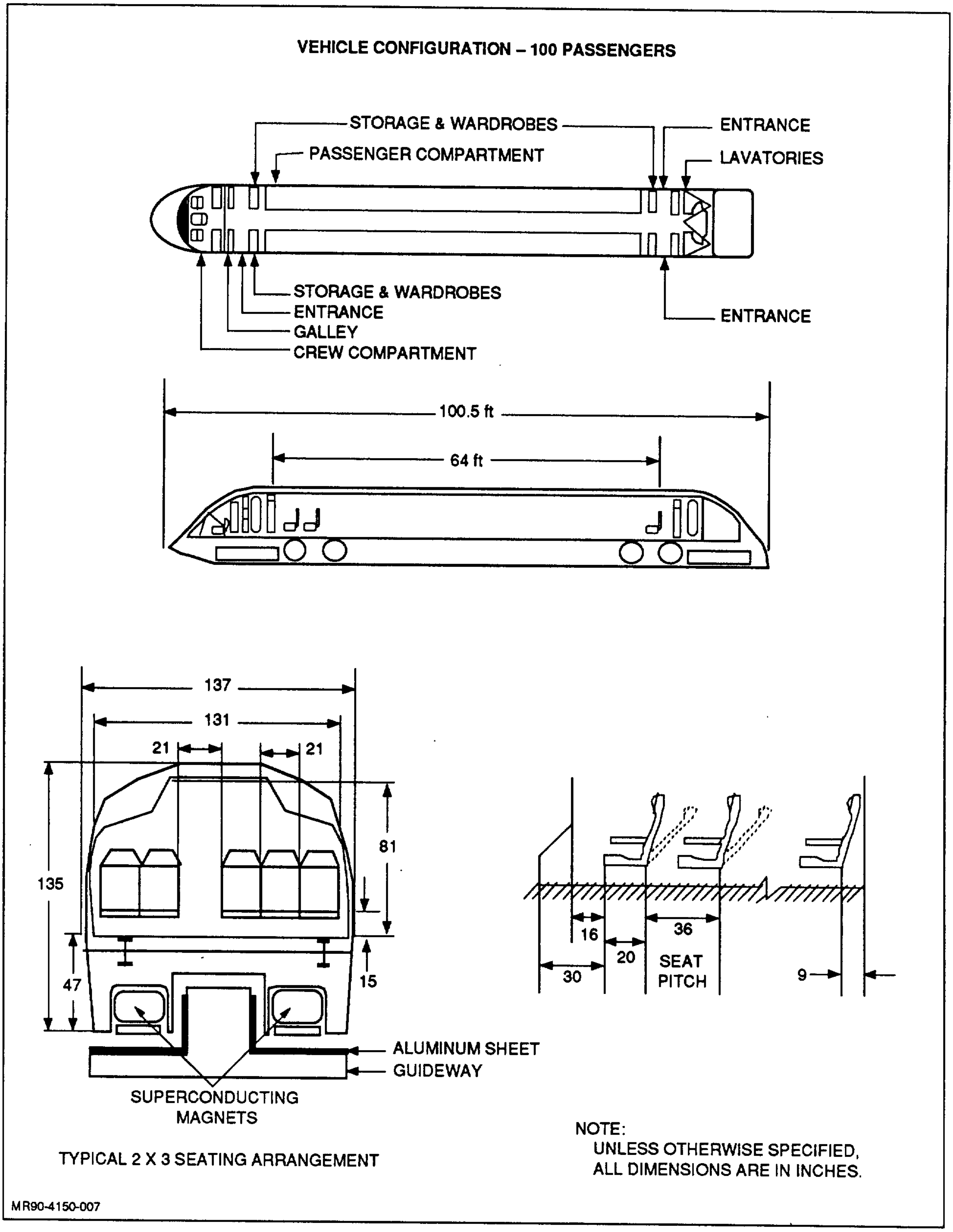

Fig. 4-1 MAGLEV Vehicle Baseline Configuration – *This baseline configuration (USA Configuration 001) is based on the Ref. 4.1 baseline system modified for 100 passengers instead of 80, and using a linear induction motor instead of a turbofan for propulsion.*

Table 4-1 Detailed Weight Breakdown Summary for Configuration 001 MAGLEV Vehicle[1],[2]

Item	Weight, K lb	
Suspension		15.0
Lift/guidance magnet modules[3] (4 sets)	5.0	
Cryogenic refrigeration[4]	1.6	
Landing/switching wheels, bogies & brakes (4 sets)	4.4	
Cryogenic piping, insulation, attachments, etc.	1.0	
Electronic control for lift/guidance magnets	3.0	
Structure		12.6
Primary structure	9.6	
Secondary structure	3.0	
Furnishings		6.6
Seats (100)	3.0	
Carpeting & lining	2.2	
Windows & exterior doors	1.4	
Auxiliaries		4.7
Air conditioning (air cycle machines plus ducting)	1.4	
Auxiliary power unit & lighting	0.8	
Partitions & baggage racks	1.7	
Lavatories (two), potable water & tank	0.8	
Brakes (aerodynamic panels & emergency parachute)		4.5
Crew compartment		3.5
Communications	0.5	
Electrical distribution	2.0	
Galley	0.6	
Console instruments & furnishings	0.4	
Propulsion		24.5
Linear induction motor	14.5	
Speed and power controller	10.0	
Contingency – 10% of total	7.1	3.0
Empty vehicle weight		78.5
Payload (100% load factor) Passengers – 100 plus 2 crew members (average passenger & crew weight plus luggage = 195 lb)		19.9
Gross vehicle weight		98.4

1. Source: Ref. 4.1 modified for 100 passengers and a linear induction motor in place of ducted fan for propulsion
2. Evaluated for baseline trip profile of 750 km (300 mile) length with five equidistant intermediate stops
3. Includes levitation/guidance coils, shielding coils, dewars & control coils
4. Includes basic system consisting of one compressor & two refrigerators plus one back-up compressor

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The seats for the 100-passenger car shown in Fig. 4-1 would face forward to take advantage of the higher allowable longitudinal accelerations. Two single-passage door openings for passenger ingress/egress are shown on each side of the vehicle. At any time, it is likely that only the two doors on one side will be used. The door opening will be approximately 30 inches wide, with a loading/unloading capacity of one passenger per second. For 100 passengers, the minimum loading/unloading time is 50 seconds or 25 seconds for an emergency exit from all four doors. It may be economical to add a door near the center of the vehicle to improve the load/unload time, and the average speed, particularly if the passenger capacity per vehicle is expanded.

4.2.1.2 Structural Design – A preliminary structural analysis of the aluminum design concept was conducted which defines the structural elements and estimates the structural weight (Ref. 4.3). The calculations are based on the initial estimates for a 100-klb vehicle. Scaling relationships were developed to estimate the structural weight for the baseline vehicle. Since vehicle ride requirements limit allowable vehicle accelerations, dynamic loading during cruise conditions was assumed to be low. The most severe bending loads occur at low speeds when the vehicle drops down on the landing wheels. Normally, the transition from magnetic levitation to wheeled support will be smooth; however, a conservative 2g vertical acceleration was assumed for adverse landing conditions.

Since the vehicle structure is lightly loaded, stiffness is a primary structural design constraint. To simplify the vehicle dynamic control problem, the fundamental natural frequencies of the vehicle structure should be high relative to the estimated vehicle/suspension system rigid-body heave-motion natural frequency of 0.6 Hz. Calculations were made to predict the value of the bending stiffness required to give a fundamental vehicle bending frequency of 5 Hz or eight times the heave-motion frequency. Various structural configurations were adopted to meet this stiffness requirement.

Aluminum aircraft-type sheet-stringer construction, used for the basic structure, was modified in the forward and aft vehicle sections to support the levitation and guidance magnets, landing wheels, and propulsion system. In the passenger section, sheet-stringer construction is used in the external perimeter of the vehicle. In the forward and aft sections, where massive vehicle subsystems must be supported, an I-beam frame replaces the sheet-stringer construction below floor level. Nonstructural fairings enclose the lower level in the forward and aft sections.

The vehicle cross section uses two stringer designs; the stringers along the top and bottom of the vehicle are considerably larger than the side stringers to support the higher vertical loads through the vehicle, and to compensate for reduced vertical height in the forward and aft sections. The lateral stiffness provided by the side stringers is reinforced by floor panels and support beams.

To prevent buckling during compressive loads, a two-inch aluminum Z-section frame was specified to support the outer structure every 18 inches. Aluminum honeycomb-core floor panels, supported by transverse beams tied to the frames on each side of the vehicle, were designed to support 100 lb/ft^2 maximum load.

Fundamental bending natural frequencies of 6.9 Hz and 5.8 Hz were calculated for the vehicle structure. This assumes that the structure is simply supported at the ends with suspension magnets. These two frequencies were calculated for the motion in the vertical and transverse planes, respectively. The fundamental torsional mode was calculated to occur at approximately 6 Hz.

The 2g landing induces maximum stress in the vehicle. Calculations of the structural margins of safety during landing assumed that the outer sheet is fully effective in tension and partially effective in compression, common practice in aircraft fuselage stress analysis. Margins of 480 percent to local buckling of the assumed 2024-T3 aluminum alloy sheet-stringer structure between frames on the top of the vehicle, and 390 percent to tensile yield along the bottom of the vehicle, were calculated.

4.2.2 Composite Materials

To achieve a lighter structural weight relative to aluminum structures, advanced polymer matrix composites, advanced metallics, and hybrid material systems were considered.

Advanced polymer matrix composites offer great potential to achieve significant weight reductions since using them to make aircraft components has produced weight reductions between 15 percent to 30 percent compared to conventional aluminum structures. Polymer matrix composites are also attractive because they do not corrode and are fatigue-resistant under repeated tension-dominated loading conditions.

Studies described in Section 8 on the ability of MAGLEV to carry freight as well as passengers indicate that halving the weight of the MAGLEV vehicle produced a two-percent reduction in guideway cost. A 25-percent weight reduction, about the best that can be expected with the use of composites, will reduce the price of the guideway system by less than one percent. Vehicle cost also will not be significantly reduced with composites when lightning strike control is included in the design. The general conclusion, therefore, is that although composites affect aircraft performance, they have a marginal effect on the MAGLEV systems because the high initial cost of the guideway and vehicles is not significantly lowered.

4.2.3 Vehicle Weight and Power Optimization

In Ref. 4.1, a matrix of 80- to 140-seat vehicle designs was synthesized to assess seating arrangements. A 2+1 seating arrangement is two seats on one side of an aisle and one on the other; 2+2 is two seats on each side of an aisle, with the objective to determine the minimum weight and power configurations for the systems analysis in Section 5 of Ref. 4.1 which may be used to analyze changes in the weight of individual vehicle components.

The vehicle design assumes a cruise speed of 300 mph and a linear induction motor for propulsion. Four 0.5 x 3 m (or eight 0.5 x 1.5 m) superconducting magnet modules separated by one foot (horizontal and vertical) from L-shaped aluminum guideway elements of 0.5-inch thickness arranged in a hat-shaped configuration provided levitation and guidance. The magnetic lift-drag ratio is estimated at 45 at 300 mph.

The major tradeoffs were:

- The seating arrangement, together with the number of seats, which determines the basic vehicle dimensions;

- Aerodynamic drag power increases with vehicle cross-sectional area and length; long, slender shapes are preferred for fixed payload volume; and

- Magnetic drag power increases with vehicle gross weight, along with the energy expended during acceleration; gross weight is in turn influenced by the structure and other component weights; structure weight is adversely affected by vehicle length.

Figure 4-2 plots how the vehicle's structural weight (frame, skins, support, and structure) varies as a function of vehicle length, seating arrangement, and number of seats per vehicle.

A simplified aerodynamic drag analysis was used, based on the data given in Ref. 4.4. The aerodynamic drag coefficient for this general configuration class derives from various sources. Vehicle surfaces were assumed to be smooth, conforming to aircraft design; doors and windows are flush. The protuberance and nose drag were estimated for a streamlined vehicle. The base drag was computed on the assumption of partial boat-tailing (i.e., Db/D = 0.5). The resulting total aerodynamic drag coefficient values are given in Table 4-2.

Based on these results and empirical expressions used to estimate the vehicle's total gross weight, including suspension, structure, furnishings, auxiliaries, brakes, crew compartment, payload, propulsion and contingency, the power required to drive the vehicle was calculated. The results, shown in Fig. 4-3, indicate that a five-seat-across vehicle provides the minimum weight and power configuration; this seat arrangement was used for the remainder of the study.

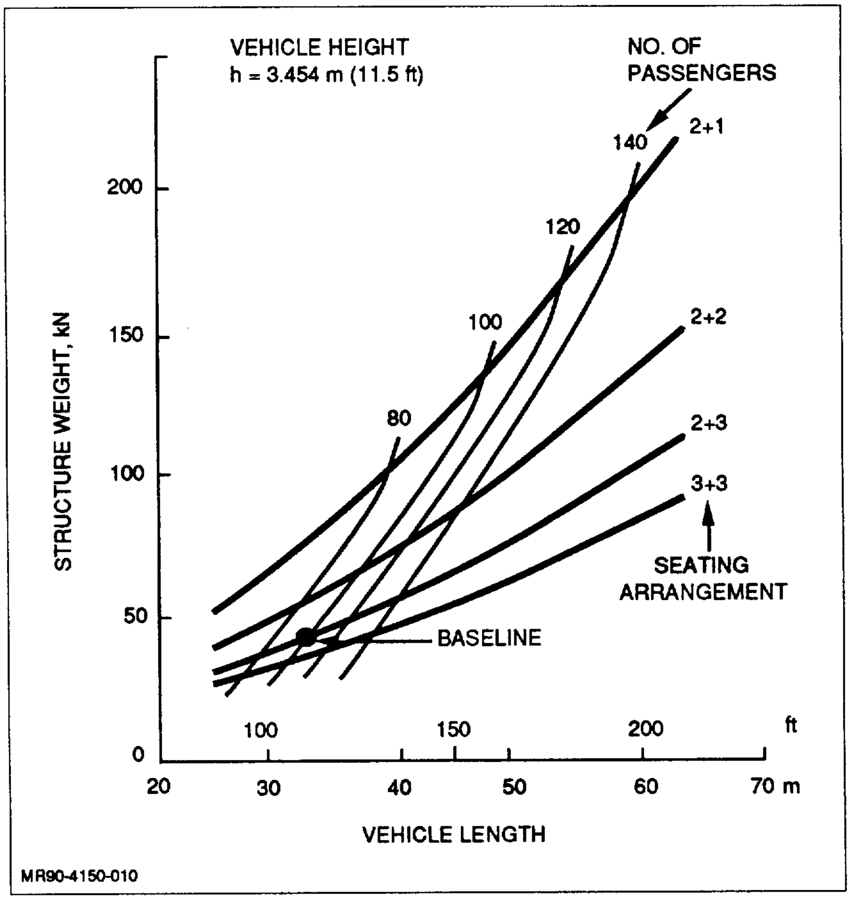

Fig. 4-2 Structural Weight Sensitivity – *Parametric data show vehicle length and structural weight as a function of seating arrangement and number of passenger seats.*

Table 4-2 Aerodynamic Drag Coefficients – *Parametric data show aerodynamic drag coefficient as a function of seating arrangement and number of passenger seats.*

No. of passenger seats	Seating arrangement			
	2+1	2+2	2+3	3+3
80	0.244	0.213	0.197	0.188
100	0.263	0.255	0.206	0.195
120	0.284	0.242	0.219	0.204
140	0.303	0.254	0.228	0.213

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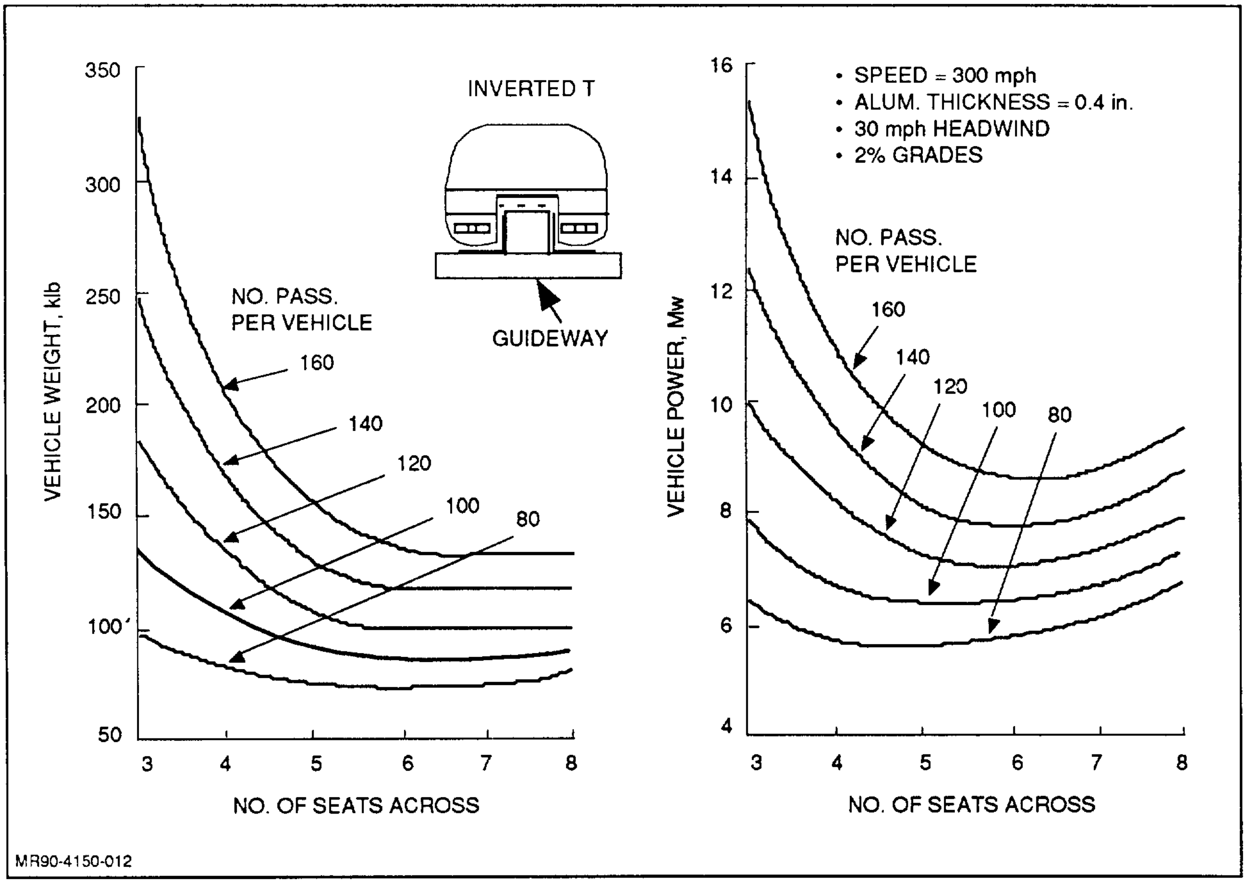

Fig. 4-3 Vehicle Weight & Power Tradeoff – *The results of this tradeoff analysis, using parametric data, indicate that minimum weight and power requirements result from a seating arrangement five to six across. A five-across seating arrangement was used for the remainder of this study.*

4.3 MAGLEV SUSPENSION TECHNOLOGY

MAGLEV suspension systems have been categorized as either attractive or repulsive. Attractive means electronically controlled electromagnets suspended below an iron rail with positional feedback are used to achieve stability; repulsive means magnets moving above a conducting media induce currents to repel the moving magnet. These schemes can be reversed; for example, an array of magnets in the guideway can repel a conductor on the lower side of the vehicle. Permanent magnets may also repel permanent magnets, as Polgren and Knolle demonstrated. There are a host of other combinations.

The acronyms EMS (Electromagnetic Suspension) and EDS (Electrodynamic Suspension) mean attractive suspension using electromagnets, and repulsive suspension using induced currents. EMS has been implemented by the Germans in the Transrapid 06 and 07 designs; EDS is used by the Japanese in the MLU series.

To discuss guideway design, narrow gap and wide gap may be preferable. There is no accepted definition of wide and narrow; however, anything below 1 cm (0.4 inch) may be called narrow gap, and anything above 10 cm (4 inches) may be called wide gap. With the materials available today, a narrow gap designation means that an electromagnet or permanent magnet approach is viable, and an EMS or attractive system is practical. A wide gap or EDS system cannot be constructed without using superconductors.

The ultimate challenge is constructing a cost-effective solution that meets MAGLEV transportation requirements. A detailed description of these requirements is given in Sections 2 and 8; a comparison of the various systems is presented in Section 3.

4.3.1 Electromagnetic Suspension (EMS)

Electromagnetic suspension systems are typified by the German Transrapid system which uses a series of conventional non-superconducting electromagnets arrayed along carriages below the vehicle. These magnets create an attractive force to a laminated iron armature that is attached, facing down, under either side of the guideway. The limited field strengths available with normal coils require a limited gap distance of about one centimeter. This is a naturally unstable system because without control, the magnets would either drop free or attach themselves to the iron armature. A gap sensor is used to measure the instantaneous gap and to control the coil current to maintain a hovering position at the desired gap. The power required to levitate the 100 mt two-car train sets is only about 130 kW, mainly due to the flux concentration provided by iron core devices, and is supplied by on-board batteries. As the speed rises, the batteries are recharged by an induction generator receiving power from the guideway.

The EMS system has an additional advantage in that the iron core magnetics and lower field strengths reduce the magnetic field strengths in the vehicle passenger compartments, so the Transrapid vehicles will likely meet proposed environmental requirements.

4.3.2 Electrodynamic Suspension (EDS)

Electrodynamic suspension generally uses superconducting magnets on the vehicle. As the vehicle moves forward, electrical currents flow in guideway conductors (specially shaped coils or aluminum sheets).

The interaction between the currents in the guideway and the currents in the superconducting magnet on the vehicle produces forces that can levitate and guide the vehicle. Figure 4-4 shows the cross section of a U.S. conceptual design in which a superconducting horizontal levitation coil is used with an L-shaped aluminum guideway. This shape of guideway provides vertical repulsion forces (suspension, levitation) using currents flowing in the horizontal section of guideway. Similarly, repulsion forces from currents in the vertical section of guideway guide the vehicle. At high vehicle speeds, currents flow in the aluminum surface only. Discrete coils with appropriately small conductors have been used by the Japanese for levitation and guidance.

There are several economic tradeoffs between the simple aluminum sheets and wound coils. The resistive losses that appear as magnetic drag on the vehicle must be supplied by the propulsion system. For example, reducing the conductor weight of the guideway coils by 50 percent results in an increase in the magnetic drag by a factor of two. The propulsion system power is then increased to make up for this drag. Increasing another important parameter, the ampere turns in the vehicle, will decrease the ampere turns required in the guideway and reduce the conductor weight in the guideway coils.

As previously discussed, the early Ford concept used horizontal superconducting coils for levitation with gas turbines for propulsion. The early Japanese configurations also used horizontal superconducting coils with levitation and guidance coils in a configuration essentially similar to the L-shaped aluminum guideway. Separate propulsion used a linear induction motor acting on an aluminum reaction rail.

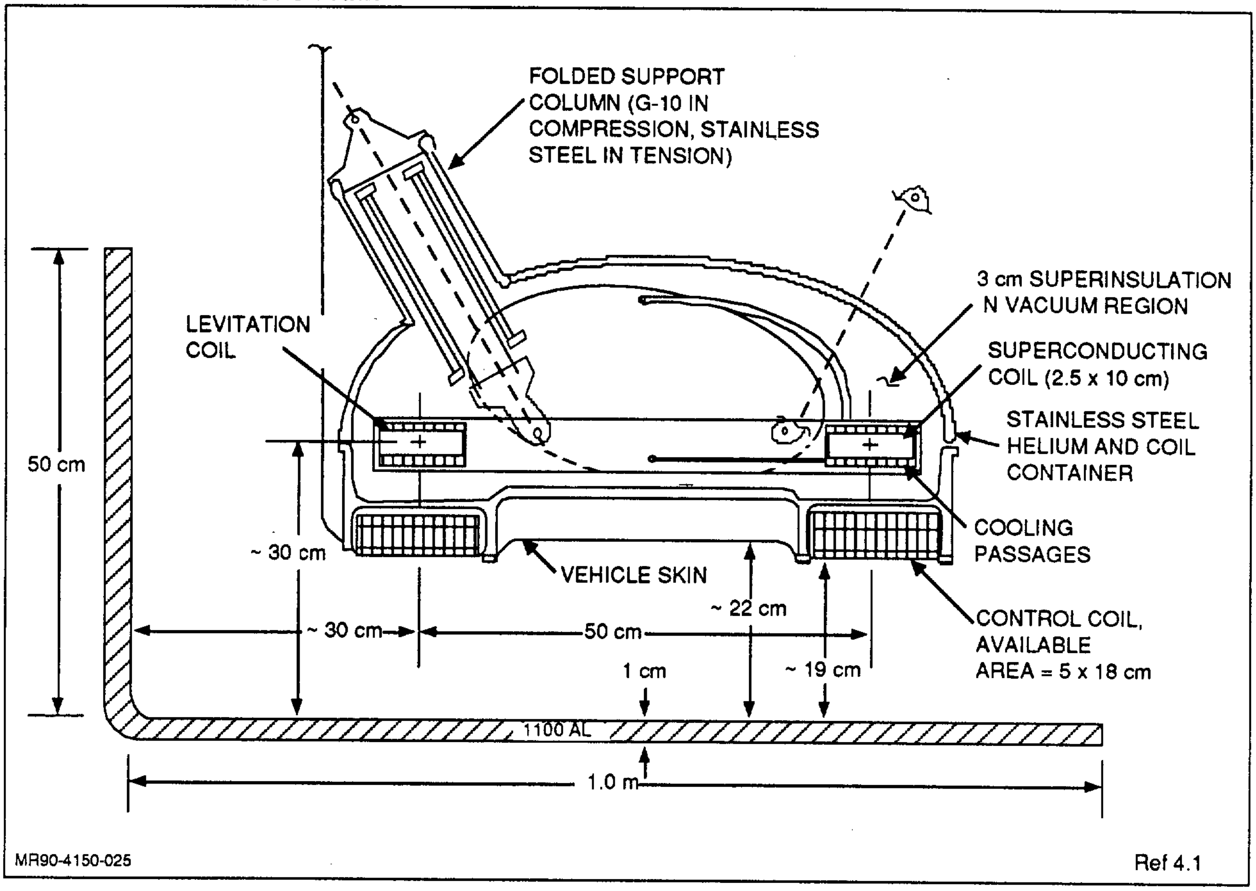

Fig. 4-4 Cross Section of Magnet Assembly without Shielding Coil – *Basic cross section of a superconducting magnet shown with an aluminum sheet guideway. This configuration can also be used in a horizontal or vertical orientation with aluminum sheets or individual guideway coils.*

The Japanese configurations progressed from using the separate linear induction motor to using a separate linear synchronous motor with additional superconducting propulsion coils on the vehicle. They continued to use suspension from the bottom with vertical superconducting coils on the side of the vehicle, suspension guideway coils under the vehicle for levitation, and guideway guidance coils for lateral forces.

The latest Japanese configuration uses vertical superconducting coils on the side of the vehicle that are used for suspension, propulsion and guidance. These coils provide forces in both the vertical (suspension) and horizontal (guidance) directions.

4.3.3 Magnetic Forces

The magnetic forces on the vehicle's coil are produced by currents perpendicular to the direction of current flowing in the guideway. No propulsion or braking forces can be exerted along the segments of the coil parallel to the direction of travel. Propulsion and braking forces are exerted on the coil segments that are transverse to the direction of travel. This is true for both horizontal and vertical configurations.

In the horizontal configuration, guidance forces cannot be generated in the coil segments transverse to the direction of motion; consequently, guidance forces are applied in the parallel segments. Lift can be achieved in all segments.

In the vertical configuration, lift is achieved in the coil segments parallel to the direction of motion, while guidance forces are possible in all coil segments. To achieve the desired forces, appropriate track currents must flow either in metal sheets (usually aluminum) or in specially shaped and positioned coils in the guideway.

4.3.4 Superconducting Magnet Design

The EDS technology described depends on superconducting magnets for levitation. Superconducting magnets are used by Magnetic Resonance Imagery (MRI) manufacturers throughout the world. Two of these manufacturers, GE and IGC, are in fact contributors to this report. This technology corresponds to the superconducting magnets required for MAGLEV.

4.3.4.1 Superconducting Magnet Configuration – The basic vehicle magnet module configuration is shown in Fig. 4-5 and its specifications are presented in Table 4-3. Additional technical features of the magnet module include:

- Redundant magnets for safety and reliability;

- High current density, intrinsically stabilized, superconducting winding (300 A/mm^2);
- Twisted, multifilament, large-core braid for low ac losses;
- Separable current leads for low heat loss;
- 3-cm superinsulation for radiation shielding;
- 16-liter liquid helium emergency storage container in each dewar, gravity feed;
- Aluminum outer cryostat;
- Magnetic field and liquid helium level instrumentation; and
- Magnet cool-down time – 16 hrs (approx).

The basic configuration consists of coils with 3.5 x 10^5 ampere turns. The forces exerted on the coil due to track currents are transmitted through the cryostat to the vehicle structure using low thermal conductivity support columns. The Nb-Ti superconductor operates at 4.2K which requires using reflecting multilayer insulation in vacuum to achieve efficient thermal insulation. To minimize refrigeration requirements, removable electrical leads are used along with a persistent superconducting switch to initially energize and short-circuit the superconducting windings.

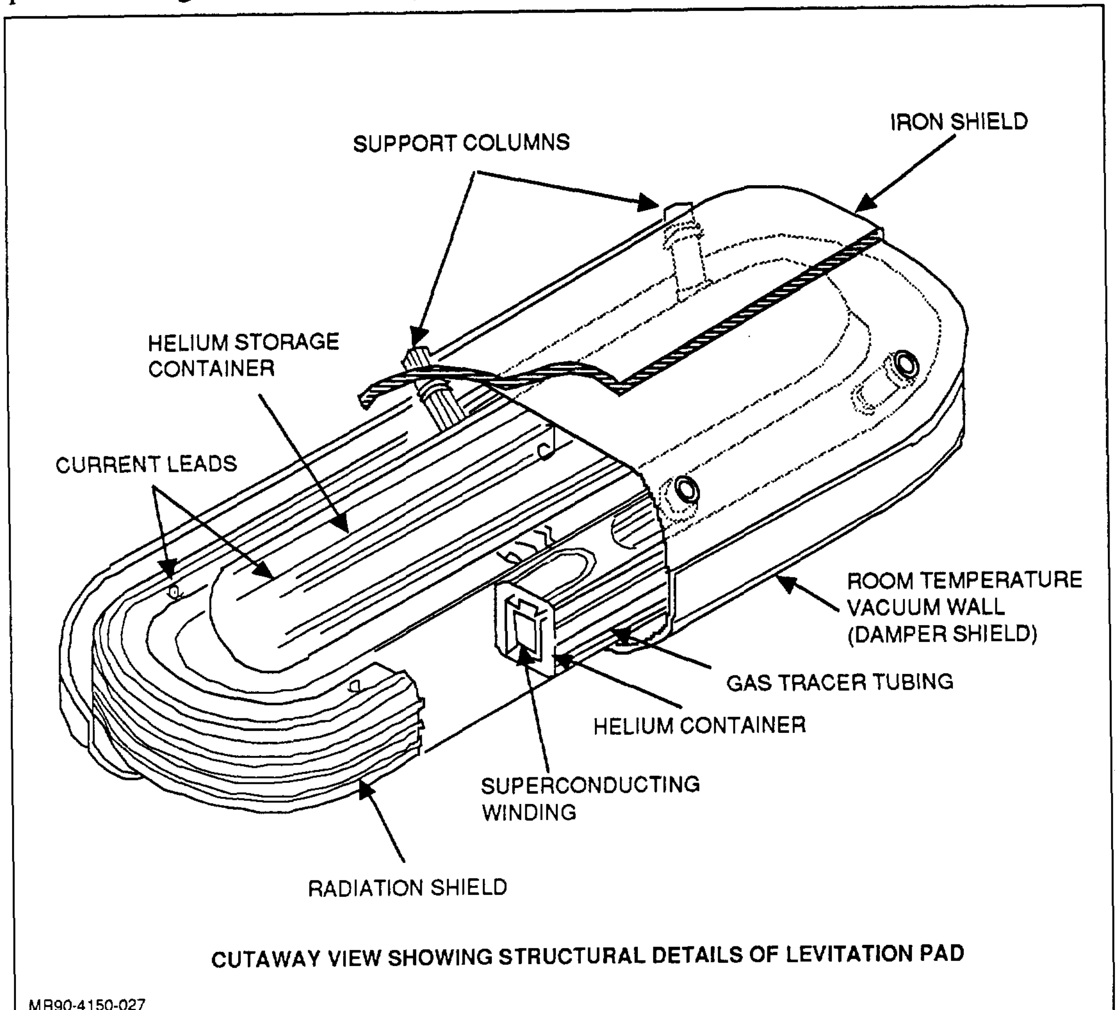

Fig. 4-5 Superconducting Magnet Configuration without Coil for Shielding Magnetic Fields – *This figure is an isometric cutaway view of the magnet shown in Fig. 4-4.*

Table 4-3 Basic Vehicle Magnet Module Specifications

Characteristic	Specification
Number required	4 modules
Coil size	0.5 x 3 m; two 0.5 x 1.5 m magnetic end-to-end
Suspension height	~30 cm
Lateral guidance distance	~30 cm
Ampere turns	~3.5×10^5 A-turns (normal operation)
Lift-to-drag ratio for 1100 H14 aluminum at 134 m/s:	
Infinite flat plate	61.7
Corner (guidance force = 0.36 F_L)	45.5
Lift-to-weight ratio:	
Without shielding coil	20.5
With shielding coil	16.8
Current density	300 A/mm^2
Operating current	1310 A
Type of superconductor	NbTi multifilament, twisted, large – core braid
Persistent switch resistance	~$10^{-7} \Omega$
Helium cooling system	Gravity feed with 16 liter container
Magnet coil support	Low heat loss folded epoxy-fiberglass columns
Control coil	Aluminum with ~2 A/mm^2; forced air cooling can be provided, if required

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The basic magnet configuration, while shown with an aluminum sheet, is generally suitable for operation with a guideway using coils, and can be adapted for vertical operation. The coil design ampere turns can be varied to match the particular system configuration and the larger values of 7×10^5 AT characteristics of the coils used to provide propulsion, suspension and guidance in the latest Japanese configuration.

4.3.4.2 Shielded Configurations – The configuration discussed above produces an undesirable, stray magnetic field. While this is discussed in Subsection 4.5, some discussion on how shielding affects the design is appropriate. Figure 4-5 shows a design using iron at room temperature to reduce the external magnetic field. The weight of iron required for any configuration is directly proportional to the coil ampere turns. In general, iron shielding is heavy and unattractive. While beyond the scope of this study, the use of iron should be considered if an integral shielding approach is used, and the iron is used to shield as well as increase coupling with the guideway. Another approach is to use superconducting shield windings (shielding coils) as shown in Fig. 4-6. This, however, increases the overall size of the cryostat.

Both iron and shield windings have been successfully used in MRI systems. For magnetic levitation, shielding is complicated by superconducting coils that are energized when the vehicle is stationary.

The track currents vary with velocity and vehicle oscillations relative to the guideway levitation coils or sheet, which results in the need to account for the changing magnitude of the magnetic field. Winding the shielding coils in series with the main coil should help minimize this effect since current changes in the main coil will produce corresponding opposite changes in the shielding coil.

4.3.4.3 Magnet Failure – A serious problem may be loss of the magnetic field at one of the vehicle's corners. The likelihood of failure, although minor for a well-designed magnet, is a function of magnet and cryogenic design (i.e., the choice of superconducting current density, the stability of the coil in response to changes in the magnetic field, the loss of refrigerant, and/or loss of vacuum). While the magnets can be designed with excess copper and superconductors to minimize the possibility of failure, the amount of excess must be experimentally determined in a magnet development program. Further, the use of monofilament wire to minimize heat generated by ac losses must be balanced against the stability obtained with multifilament twisted superconducting composites.

Magnet failure can be caused by loss of vacuum and/or loss of refrigeration. Loss of vacuum will cause rapid loss of superconductivity due to the sudden large heat inputs; for this reason, each of the redundant magnets has a separate cryostat.

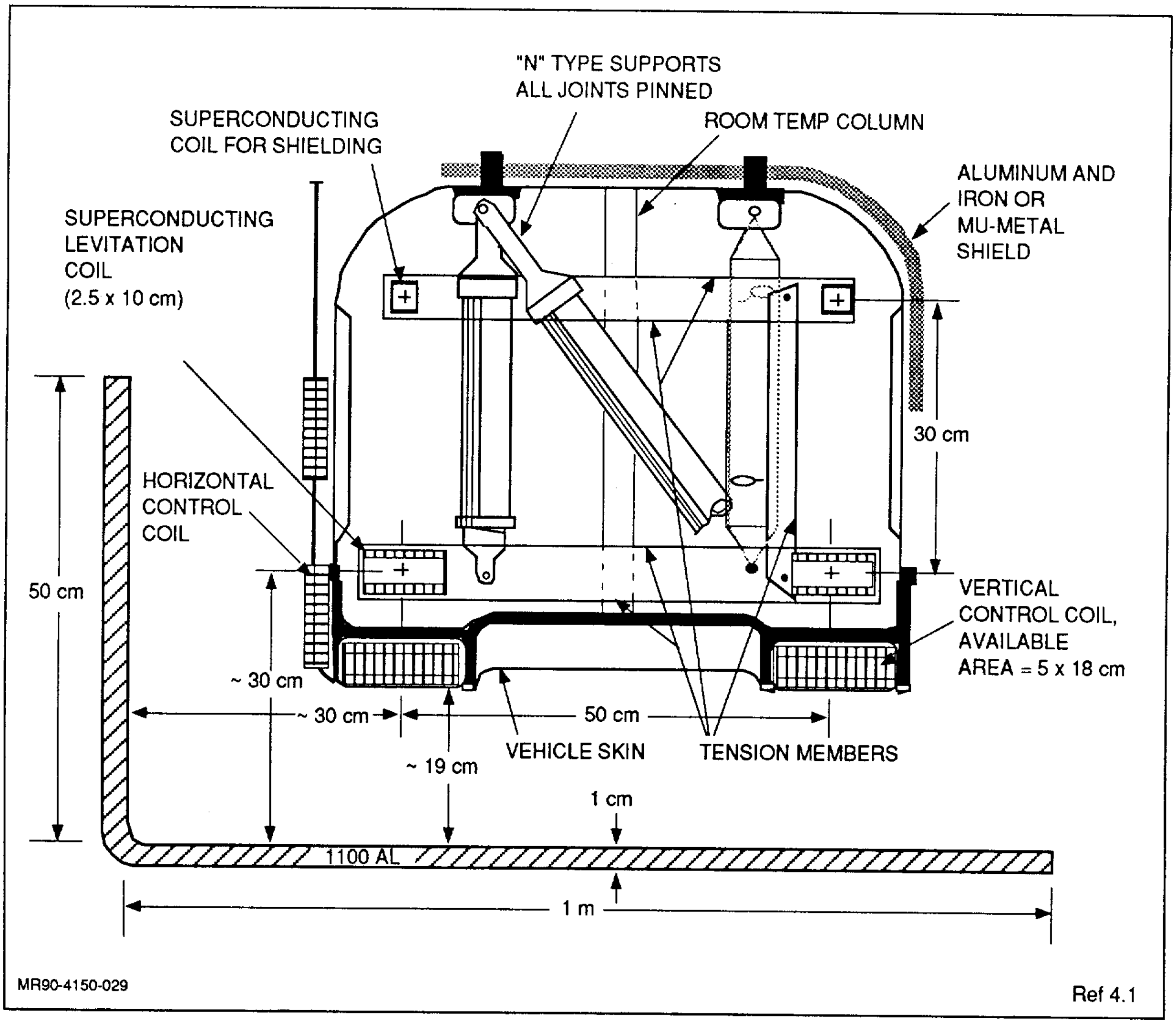


Fig. 4-6 Cross Section of Magnet Assembly with Shielding Coil – *This magnet cross section combines many of the required characteristics of a superconducting magnet for either aluminum sheet or coil guideway applications including superconducting coil for magnetic shielding, aluminum and iron or mumetal shield for magnetic shielding, and horizontal and vertical magnetic control coils.*

Appendix D provides an analysis of the effect on suspension height of failure of one of the coils of a two-coil set, showing that safe operation should be possible despite magnet failure.

4.4 MAGLEV PROPULSION SYSTEMS

The best vehicular suspensions combine levitation and propulsion. Magnetic suspension is natural for use with linear electromagnetic motors.

The differences between levitation and propulsion are determined by the directions of magnetic force. Suspension systems are used to counteract gravity and only contribute losses, while propulsion schemes create forward or reverse thrust and may be required to transfer power to or from the vehicle, as in accelerating and braking. Two generic types of motors, synchronous and asynchronous, suitable for propulsion are shown in Fig. 4-7.

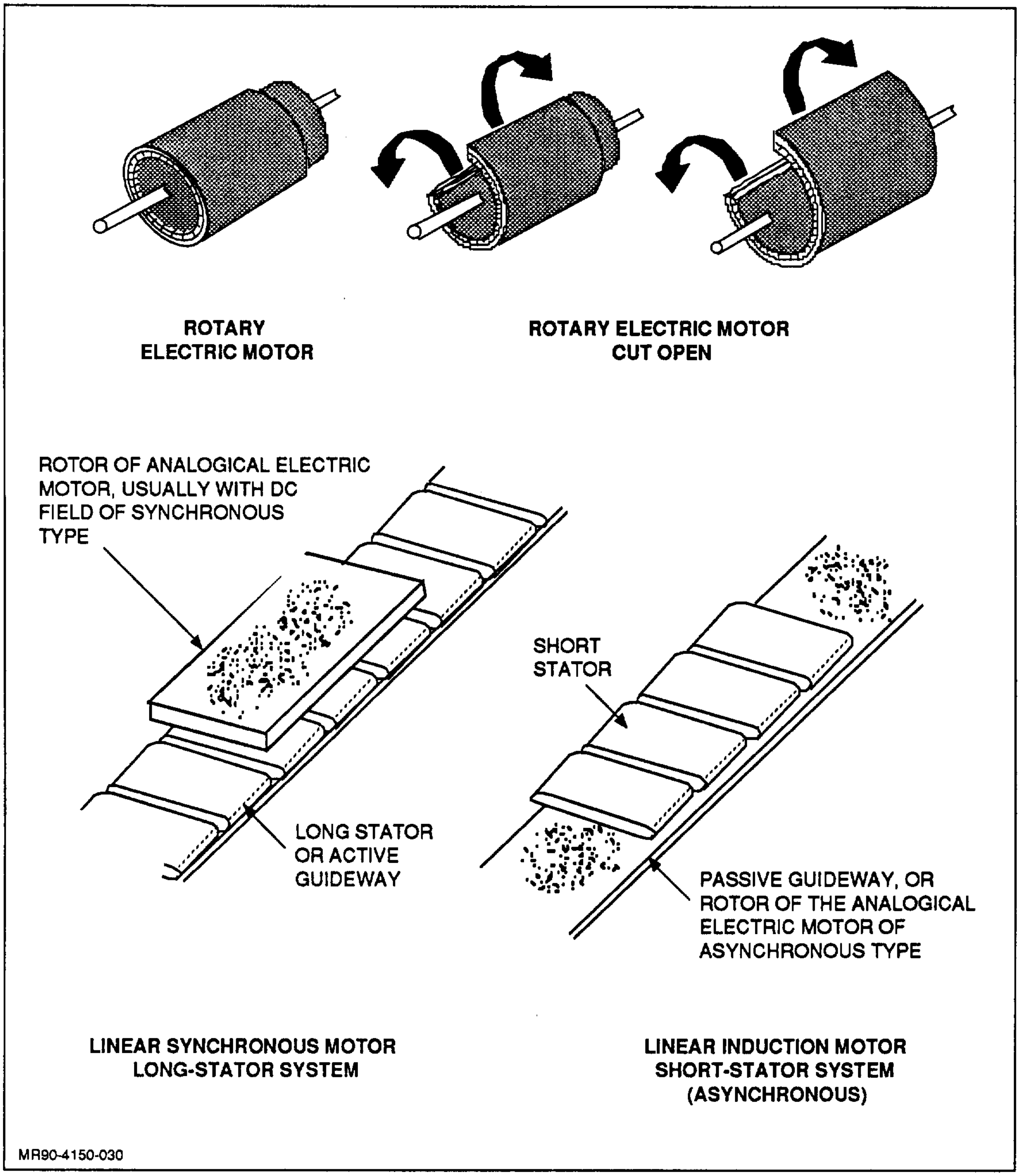


Fig. 4-7 Propulsion Motors – Synchronous & Asynchronous (Active & Passive Guideways) – *Alternate propulsion schemes are shown. The Linear Synchronous Motor (LSM) requires that power be applied to the guideway long stator. For the Linear Induction Motor (LIM), power must be transferred from the guideway onto the vehicle for short-stator operation.*

Synchronous motors create a magnetic field that moves at the same speed as the vehicle; suitable controls maintain the synchronism and propel or brake the vehicle. There are variations depending on whether the force is due to the attractive force of high-permeability ferromagnets, the force of permanent magnets, the force on a current-carrying wire in a magnetic field, or a combination of these effects.

Asynchronous motors create a magnetic field that moves faster or slower than the vehicle. Controls maintain a desired slip speed to propel or brake the vehicle. The differential velocity of the field creates eddy currents that provide a reaction field that produces the force. The eddy currents may react directly against the exciting field or may react against high-permeability ferromagnets.

Motor designers have an additional choice. The guideway can be active or passive according to whether the propulsion coils are on the guideway or on the vehicle. If they are on the vehicle, the motor is referred to as a Linear Induction Motor (LIM), and it is necessary to transmit power to the vehicle; otherwise, the propulsion power apparatus is on the guideway and is generally referred to as a Linear Synchronous Motor (LSM). While the LSM allows a lighter and less expensive vehicle, guideway costs are higher.

4.4.1 Linear Induction Motor

The linear induction motor (LIM) is a direct analog to the rotary electric motor shown in Fig. 4-7. For the LIM, a series of coils arranged on the vehicle are activated by a variable-voltage, variable-frequency power supply on the vehicle.

LIMs require small clearances of about 0.5 inches for operation and, as a result, would be incompatible with wide-clearance EDS systems. To compensate for this restriction, the LIM is independently suspended from the vehicle and is free to move in the vertical and transverse direction relative to the vehicle.

LIMs have been extensively used on low-speed vehicles and have been designed for use on some fairly high-speed vehicles such as the HSST 300. They have also been tested at speeds approaching 300 mph on the LIM Research Vehicle at the USDOT Test Center in Pueblo, Colorado.

A general problem with LIMs is their overall low efficiency (60 to 70 percent) that drops off rapidly at high speeds. Other problems include the low gap required by the achievable magnetic field strengths and high-speed power pickup. Using new developments in ac superconductors may increase the gap and developments may solve the power pickup problem.

4.4.2 Linear Synchronous Motor

The linear synchronous motor (LSM) is an analog of the rotary electric motor. However, the active coils are on the guideway and the vehicle carries only the magnet, which could also be the levitation magnet against which the guideway coils act. There is presently no requirement for power transfer to the vehicle except for housekeeping functions. The tradeoff is continuous coils on the guideway and power conditioning units distributed every 10 to 20 miles.

There are, however, some significant advantages to the LSM. With superconducting coils on the vehicle, there is no need for low-gap components, thus minimizing guideway tolerance requirements. Vehicle control and safety are easier because external speed and braking, always required at the speeds considered in this report, are controllable with the active components on the ground.

4.5 MAGNETIC SHIELDING

There are three basic approaches to static magnetic shielding: passive shielding with high-permeability materials or superconducting sheets; active shielding with compensation coils that produce a cancelling (bucking) field; and a combination of the two. For dc or low-frequency magnetic fields, shielding techniques use ferromagnetic metals or vibrating conducting sheets. AC fields can be effectively shielded with any good conductor such as an aluminum sheet; the vehicle structure itself will provide adequate shielding for ac fields. At the floor of the passenger cabin of a MAGLEV vehicle using superconducting magnets, dc fields can be as high as 0.03 teslas (300 gauss), so dc-shielding techniques are necessary. As previously discussed, ac fields are a recent concern, so data are limited. Preliminary data from the Transrapid System, shown in Fig. 4-8, indicate that ac fields ranging from 0.5 to 20 microteslas (0.005 to 0.2 gauss) are produced in the frequency range of 0 to 400 Hz. These values are based on magnetic flux density and are measured at a point on the floor of a Transrapid 06 vehicle. The indicated values are encouraging; however, the Transrapid is an EMS system and does not use high-field superconducting magnets.

The figure of merit for magnetic shields is given by the factor S, where S = Bo/B. B is the magnetic field induction inside the shield, and Bo is the induction at the same point in space if there were no shield. For simple geometries, such as spheres and cylinders, the dc shielding factor can be directly calculated. In cases of interest, the wall thickness (d) is usually small compared to the shield diameter (D). The general relationship for shielding then reduces to:

$$S = C \left\{\frac{\mu d}{D}\right\} + 1$$

where C=4/3 (sphere) and C=1 (cylinder). Since d<D, it is necessary to use materials that possess high values of μ (relative permeability) for passive shielding. Better results are obtained by combining several shields into one structure, the so-called multishell approach. Nominal shielding values of 400 μ can be obtained using the multishell approach. In the best case, a shielding value of 380 μ was achieved for static shielding and 4,000 μ for low-frequency field shielding between 1 to 100 Hz, using a combination of ferromagnetic and eddy current shielding, active compensation and shaking (Fig. 4-9). This result indicates that low-frequency magnetic fields (1 to 100 Hz) can be more effectively shielded than dc fields, which is important when considering the higher risk factors associated with exposure to low levels of ac magnetic fields.

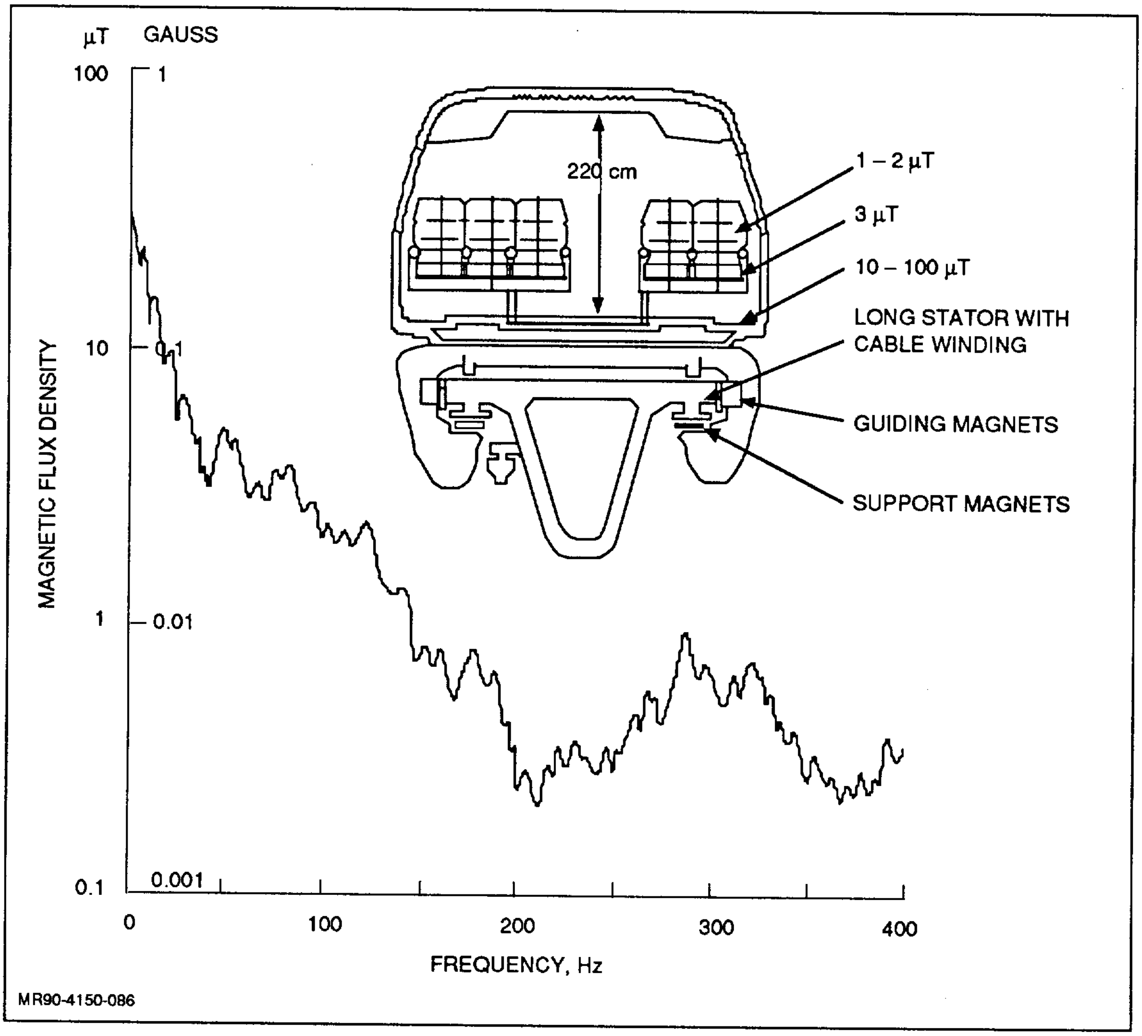


Fig. 4-8 Magnetic Flux Density vs Frequency and Magnitude in the Passenger Compartment (Transrapid 06 Vehicle) – *Measurements made on the Transrapid 06 MAGLEV vehicle of the magnetic field within the cabin area indicate that dc fields are well within acceptable levels (<5 gauss) and that ac fields are no greater than those in other transportation systems.*

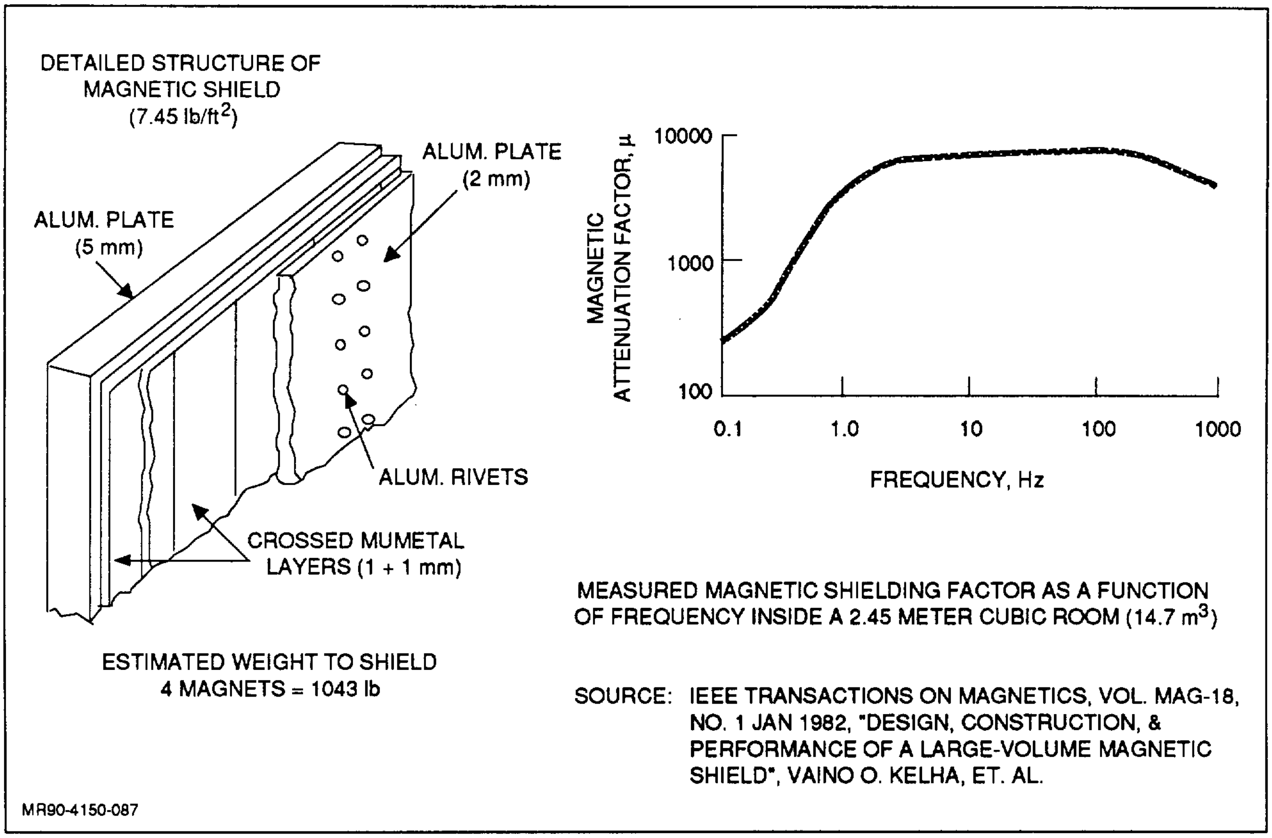


Fig. 4-9 Passive Magnetic Shielding – *Recent testing of a multi-layer aluminum and mumetal shielded room indicate that significant attenuation of DC fields (~380:1) and AC fields (4000:1) can be achieved.*

A magnet is termed "actively" shielded when a system of larger diameter coaxial coils that carry current in the opposite direction of the main coils is used to buck the magnetic field. This method reduces stray fields by channeling most of the flux into the spacing between the main coils and shielding coils. Active shielding offers the advantage of minimal degradation of the main coil field with a minimum increase in the magnetic system size and weight. It does, however, increase the design complexity, and requires numerical modeling and field testing to be effective. Previous work has concentrated on circular coils and solenoid magnets; there are limited studies of active shielding of the race track configuration of MAGLEV magnets. A recent study (Ref. 4.5) on reducing the stray field in MRI applications showed the reduction of a 1.5 tesla (1.5 x 10^4 gauss) solenoid superconducting magnet to the level of 1000 microteslas (10 gauss) at a distance of 3 meters by using a four-coil-pair system of shielding magnets, and reduction to the 100 microteslas (1 gauss) level using a five-coil-pair system (Fig. 4-10). An active shield can be wired in series with the main superconducting coil, which will help to attenuate ac current changes in the main coil as well as normal dc currents.

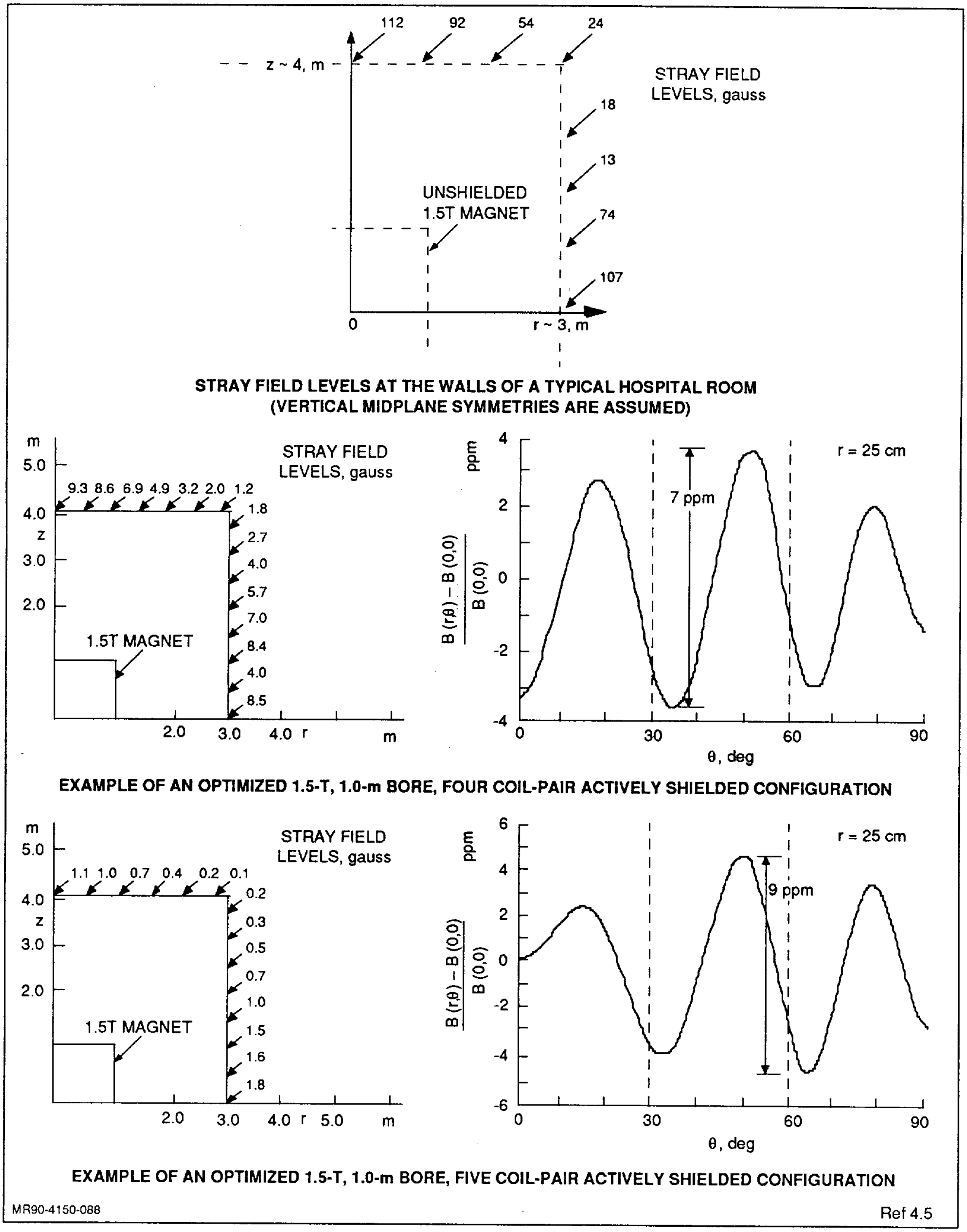
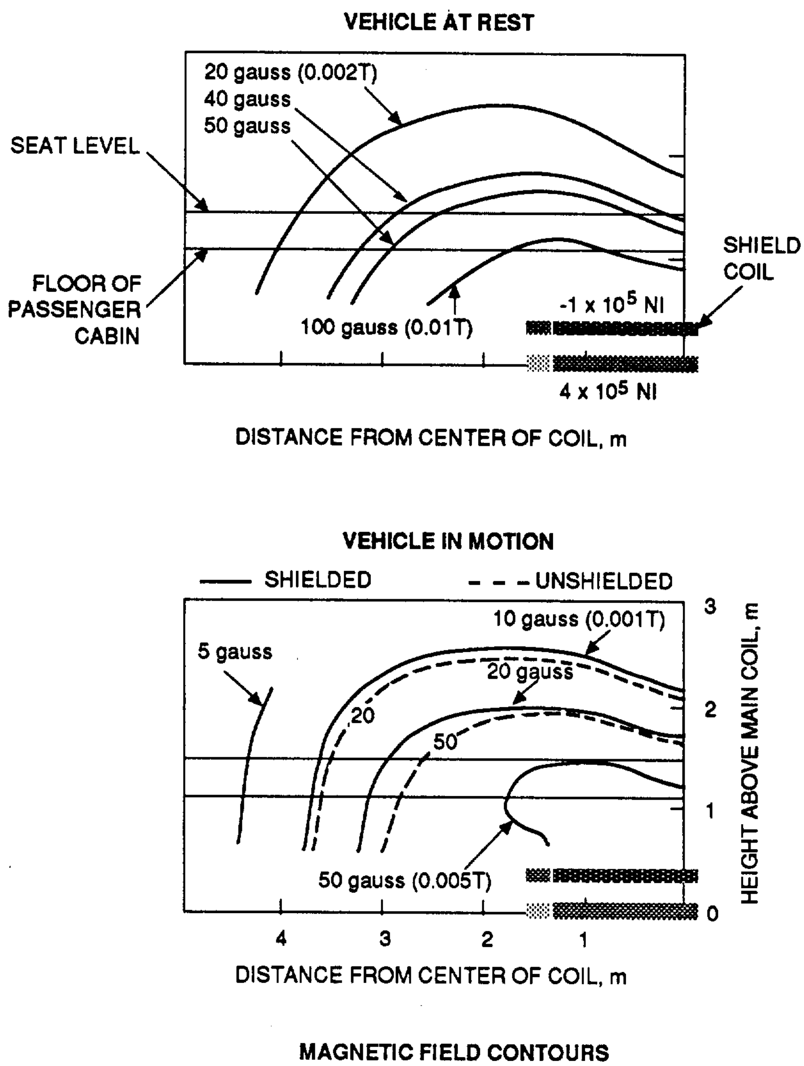


Fig. 4-10 Stray Field Reduction Using Four Coil-Pair & Five Coil-Pair Systems – *Active shielding using multiple shield coils for MRI applications have demonstrated attenuation levels of 60:1 to 240:1.*

In the EDS system of levitation, circulating currents are induced in the guideway near each lift magnet when the vehicle is moving. These currents flow in an opposite direction to the currents of the lift magnet and help shield dc fields. Therefore, the magnetic field of the moving magnets is less than the stationary magnets (Ref. 4.1 and Fig. 4-11). Factors such as guideway roughness, conductor inhomogeneity, vehicle stability and control, discrete coils in active guideways, propulsion systems, and mutual coupling between sources make the prediction of low-frequency magnetic fields very difficult. The qualification and quantification of sources



SOURCE: CONCEPTUAL DESIGN & ANALYSIS OF THE TRACKED MAGNETICALLY LEVITATED VEHICLE TECHNOLOGY PROGRAM PB-247-931, 1975

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Fig. 4-11 Active Magnetic Shielding

of low-frequency magnetic fields are a complex problem, and require further investigation. Previous design models that illustrate the instabilities of MAGLEV vehicles may provide a good starting point to determine the magnitude of the issue of low-frequency fields.

Health risks due to exposure to stray magnetic fields should be avoidable by adequate shielding measures. Health problems should not be trivialized and comprehensive modeling of the sources of low-frequency magnetic fields should be developed and integrated into an overall performance model. The abatement of stray fields should be a major factor in evaluating competing designs.

4.6 GUIDEWAY DESIGN

4.6.1 Guideway Configurations

Many different guideway cross-sectional shapes have been proposed and used in MAGLEV applications. Table 4-4 shows the guideway cross sections considered for this study. The flat-plate guideway is used by the German Transrapid MAGLEV in a wraparound configuration with its EMS design. The inverted "T" was recommended in the Ford study. The "U"-shaped channel is used by the Japanese MLU001 EDS system. The "V" and inverted "V" configurations were not recommended in the past because of perceived control system complexities which, with today's high-speed computers, could easily be overcome. These configurations were therefore included in this evaluation. The semicircle shape has been proposed by Magnaplane advocates, while the monorail has been recently proposed.

To evaluate these configurations, a number of different criteria were used. They are identified in Table 4-4. Cost was not included as a criterion because the cross-sectional shape is not expected to significantly affect overall guideway cost.

Numerical values ranging from 0.0 to 3.0, representing poor to very good characteristics, were established for each configuration, and assigned to each guideway shape criterion. The values were summed; the results are indicated in Table 4-4. The results indicate that the "U"-shaped configuration rated highest with the monorail a close second. The lowest rating was given to the Transrapid flat-shaped guideway, primarily because the track configuration does not allow this design to be compatible with non-movable track switching. Additional information is available in Subsection 4.7.

4.6.2 Elevated Guideway Structure Design

A considerable part of the MAGLEV guideway, especially in densely populated areas, will be elevated to maximize safety and to minimize conflict with existing transportation rights-of-way, especially in New York State and other Northeast corridor applications. Although less guideway will be elevated in rural areas, it is still important to have innovative, low-cost elevated guideway designs. The results of conceptual design analyses for various cross-sectional guideway shapes and construction follow.

Table 4-4 Guideway Shape Tradeoff – *Based on the evaluation of alternate guideway shapes, a U-shaped configuration is best suited for MAGLEV application.*

Criteria	Guideway shape and application						
	Transrapid	Ford study	MLU001	Inv "V"	"V"	Magnaplane	Monorail
Susceptibility to ice & snow	1.0	1.0	0.0	2.0	0.0	0.0	3.0
Susceptibility to wind & gusts	1.0	1.0	3.0	1.0	2.0	1.0	2.0
Adaptability to noise suppression	1.0	1.0	3.0	1.0	3.0	3.0	0.0
Track switching*	0.0	1.0	2.0	2.0	2.0	2.0	1.0
Susceptibility to derailment	3.0	2.0	2.0	0.0	1.0	1.0	2.0
Stability & control	2.0	3.0	3.0	2.0	2.0	1.0	3.0
Adaptability to banking	1.0	1.0	1.0	2.0	2.0	3.0	1.0
Totals	9.0	10.0	14.0	10.0	12.0	11.0	12.0

Key:

RECOMMENDED CONFIGURATION (shaded)

0.0 = poor
1.0 = fair
2.0 = good
3.0 = very good

* Based on ability to operate with a nonmoving track switch

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A typical elevated guideway design is illustrated in Fig. 4-12. Simply supported, prestressed concrete dual T-beam or box beam girders are supported by periodic pier structures. Sliding joints at one end of each girder provide for differential thermal expansion, and pinned joints at the other end transmit longitudinal loads from the girders to the piers. The pier structure may either be dual-column, side by side with reinforcements between the columns for side-load capability as shown in Fig. 4-12, or a single elongated column recommended by Parsons Brinckerhoff as shown in Figs. 4-13a through 4-13d. Although the cost evaluation presented in Section 9 assumed a dual-column design, the single-column design was chosen as the baseline system because it provides a better side-load stiffness for tight turn radii, with more aesthetic appeal.

The elevated guideway must support the various vehicle and environmentally induced loads and also provide a smooth surface to support and guide the vehicle without producing an unacceptable ride. The primary excitation of a vehicle by an elevated guideway is periodic and results from the deflection of the girders between the supporting piers. The effects of random guideway irregularities can be minimized by adjusting girder positions on the supporting piers during installation. Excitation frequencies for the vehicle traveling at 300 mph range from 4.4 Hz to 8.8 Hz for girder spans of 100 to 50 ft, respectively. An allowable vertical acceleration of 0.15 g rms was assumed for the 4.4 to 8.8 Hz range, and the elevated guideway girders have been designed so the predicted static and dynamic deflections will limit the vehicle vertical response to this range.

Span lengths of 20 to 100 ft have been considered. Similar designs could be used for somewhat longer spans, but the negotiation of rivers and other natural barriers usually requires spans greater than 150 ft and specialized design. The study of long spans was beyond the scope of this report.

Simply supported guideway spans were assumed for this analysis. Static stiffness and strength requirements suggest that continuous beams (i.e., beams allowing bending moment transfer from span to span) would be more efficient than simply supported beams. However, the dynamic response characteristics of continuous beams can be much more severe than those of simply supported beams and, in fact, can be great enough to overshadow the gain in static stiffness and strength. Also, fabrication costs for a continuous-beam elevated guideway are likely to be higher than for the simply supported system. Therefore, no clear advantage can be discerned for continuous beams.

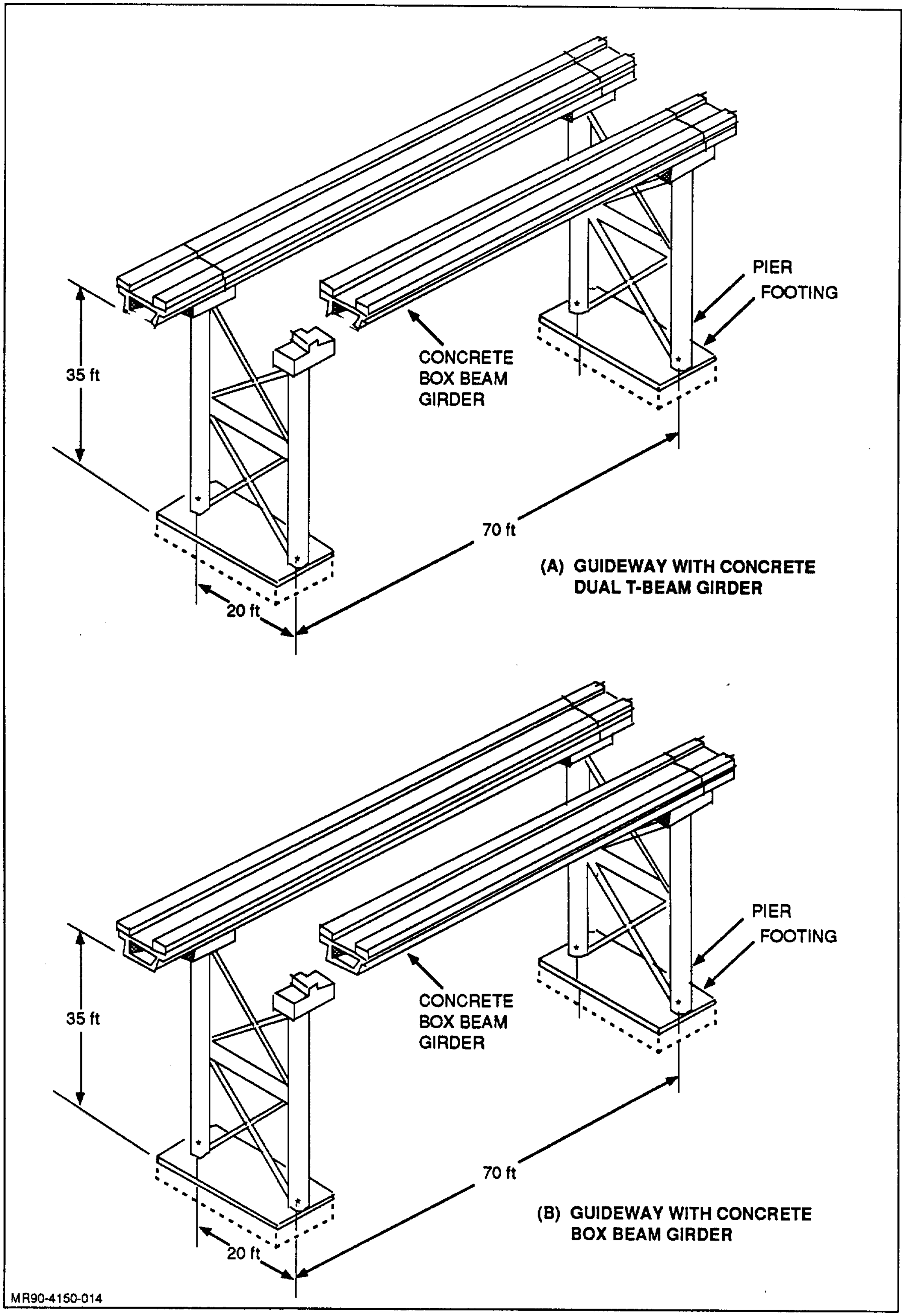


Fig. 4-12 Elevated Guideway Design – Dual-Column Pier – *Grumman investigated two guideway cross sections (dual T-beam and box beam girder configurations) with a dual-column support pier configuration.*

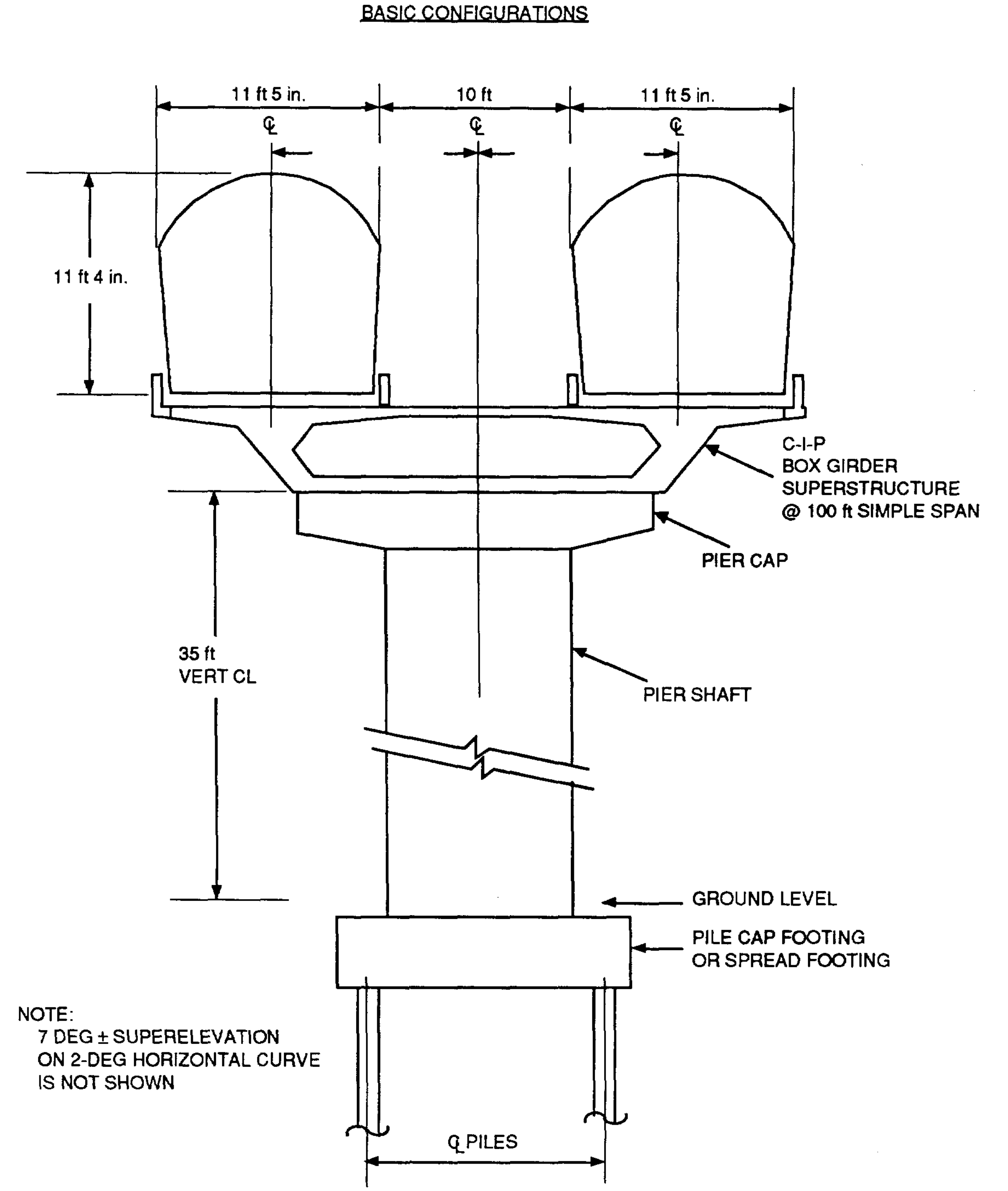


Fig. 4-13a Elevated Guideway Design – Single-Column Pier, Typical Section – *This figure shows the Parsons Brinckerhoff design; cost data is provided in Appendix C.*

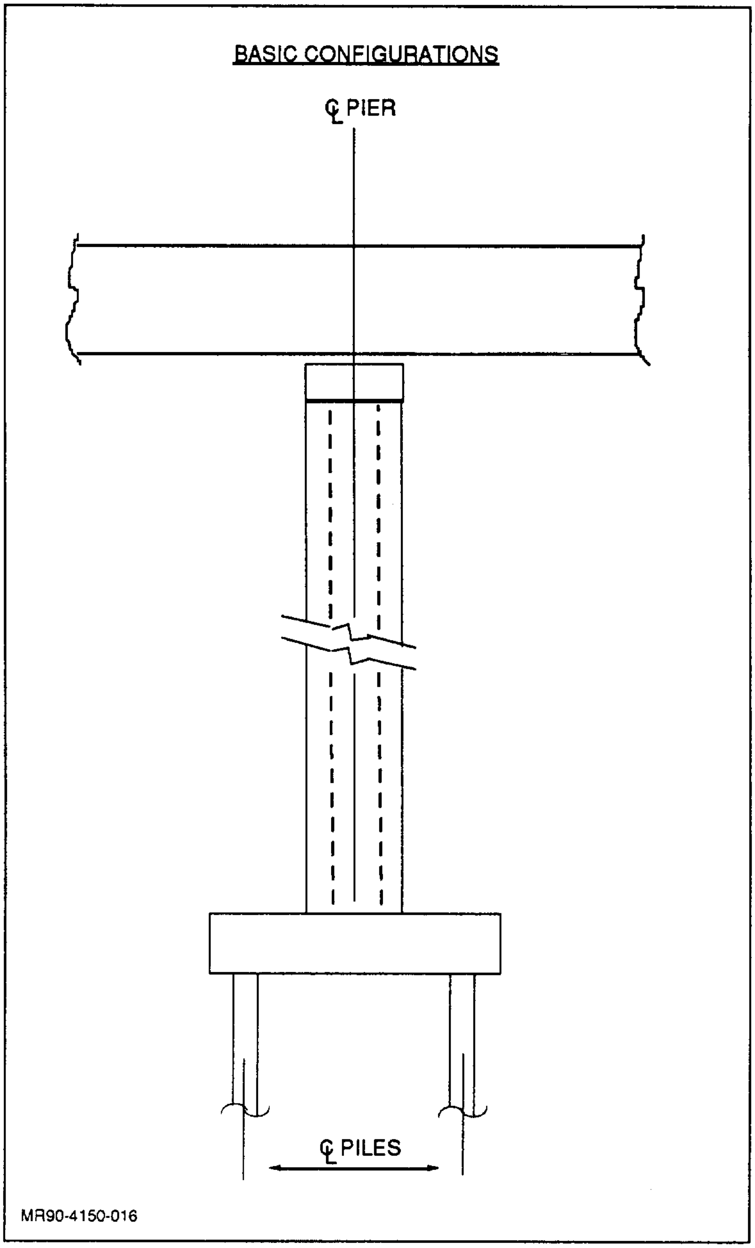


Fig. 4-13b Elevated Guideway Design – Single-Column Pier, Side Elevation View

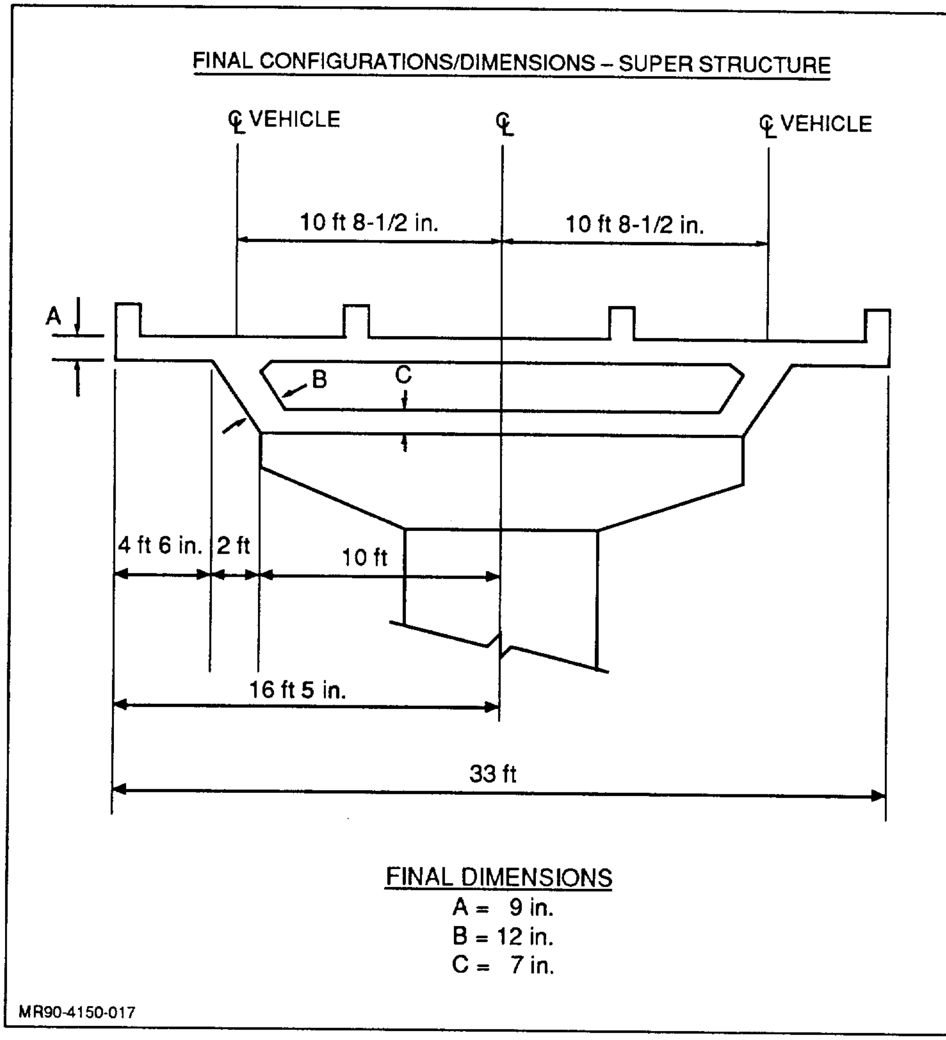
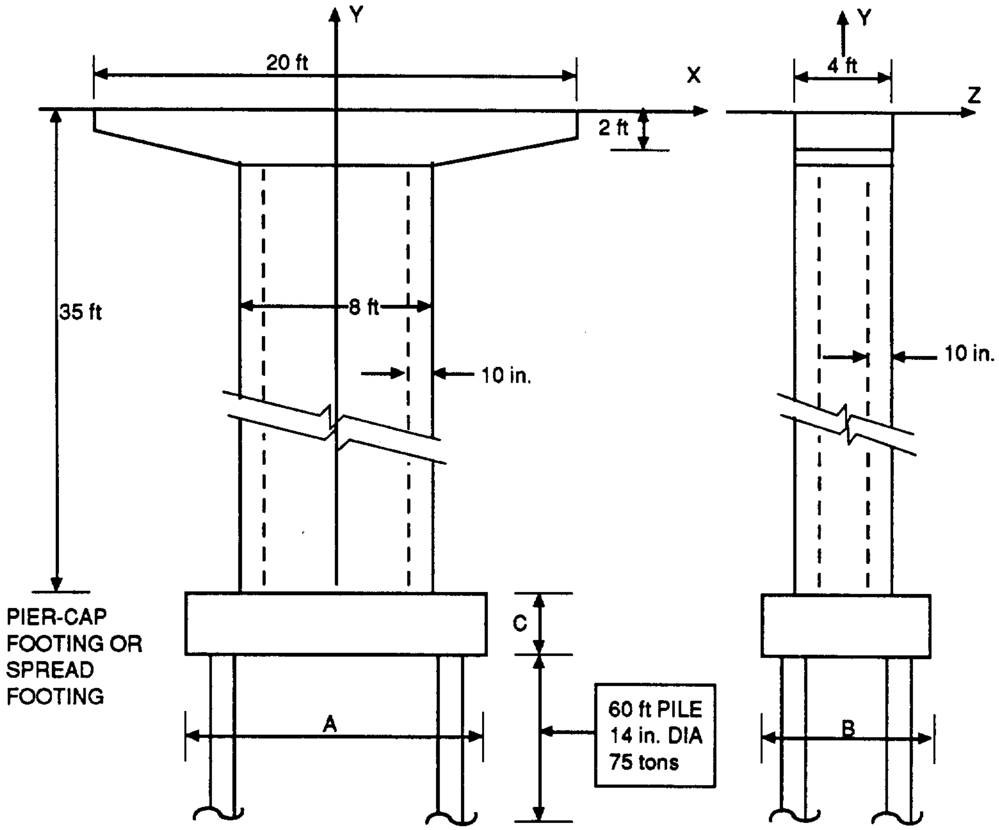


Fig. 4-13c Elevated Guideway Design – Single-Column Pier, Superstructure

FINAL CONFIGURATIONS/DIMENSIONS – SUBSTRUCTURE



FINAL DIMENSIONS

DIM.	FOOTING	
	SPREAD	PILE-CAP
A	28 ft	15 ft
B	16 ft	15 ft
C	2 ft 6 in.	3 ft
NO. OF PILES	–	16

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Fig. 4-13d Elevated Guideway Design – Single-Column Pier, Substructure

4.7 TRACK-SWITCHING EVALUATION

The German Transrapid 07 and the Japanese MLU00X groups propose using mechanical moving guideway track switches. The Transrapid uses a flexible switch (Fig. 4-14) wherein a guideway beam is flexibly bent in the branching position with hydraulic or mechanical actuators and then fixed and locked into position. The maximum speed on the diverging branch is 250 kph (155 mph). The MLU00X switch concept (Fig. 4-15) is based on using six movable concrete segments. The speed on the diverging branch is limited to 70 kph (44 mph). In both cases, the movement is horizontal with no superelevation (tilting) during the curved position. High-speed switching (>150 mph) would require both translation and tilting of the mechanical switch, further complicating the mechanism.

According to the Grumman team, from a safety and cost perspective, a non-movable high-speed switch mechanism is preferable, particularly if many off-line stations are used along a given run, with the need for extremely high reliability and safety, which are problematic with a mechanical switch hang-up in an intermediate position.

The fixed-switch concept shown in Fig. 4-16 uses a guide rail-type of design. All vehicles approaching the switch extend one of two onboard guide wheels, the left wheel for straight-through traffic, or the right guide wheel for switching to the right. The disadvantages of this type

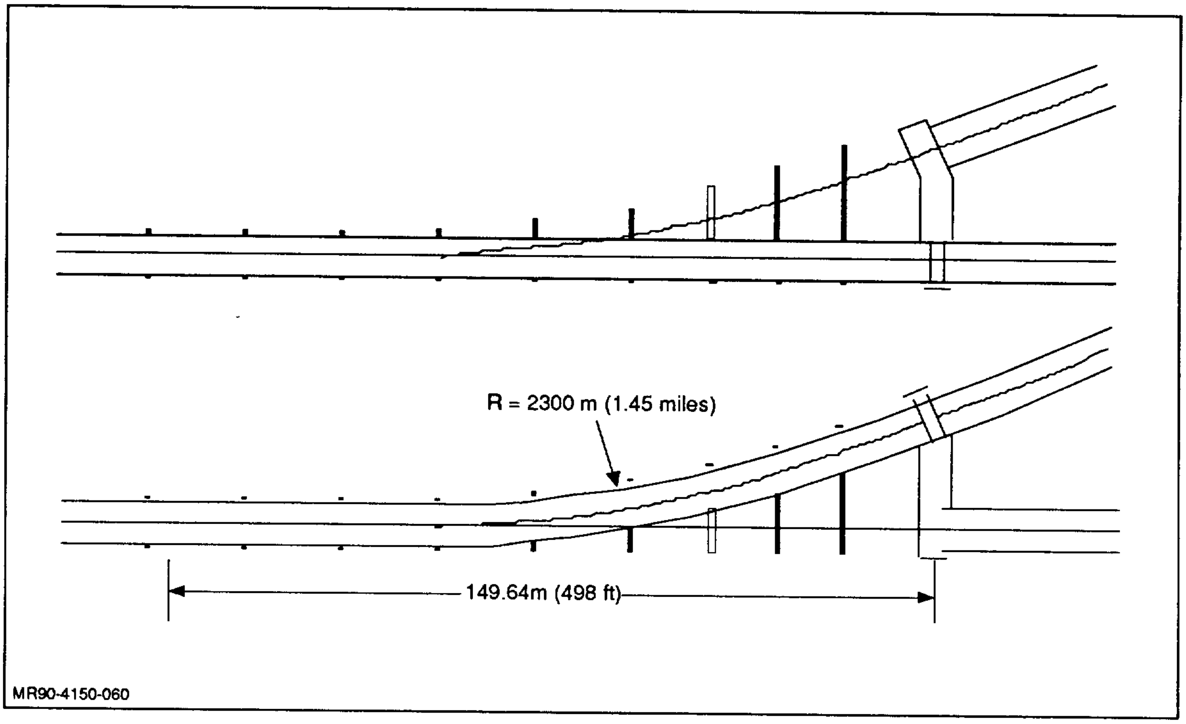

Fig. 4-14 Transrapid Switch – *The Transrapid uses a flexible single track mechanical switch with maximum speed on the diverging branch of 250 kph (155 mph).*

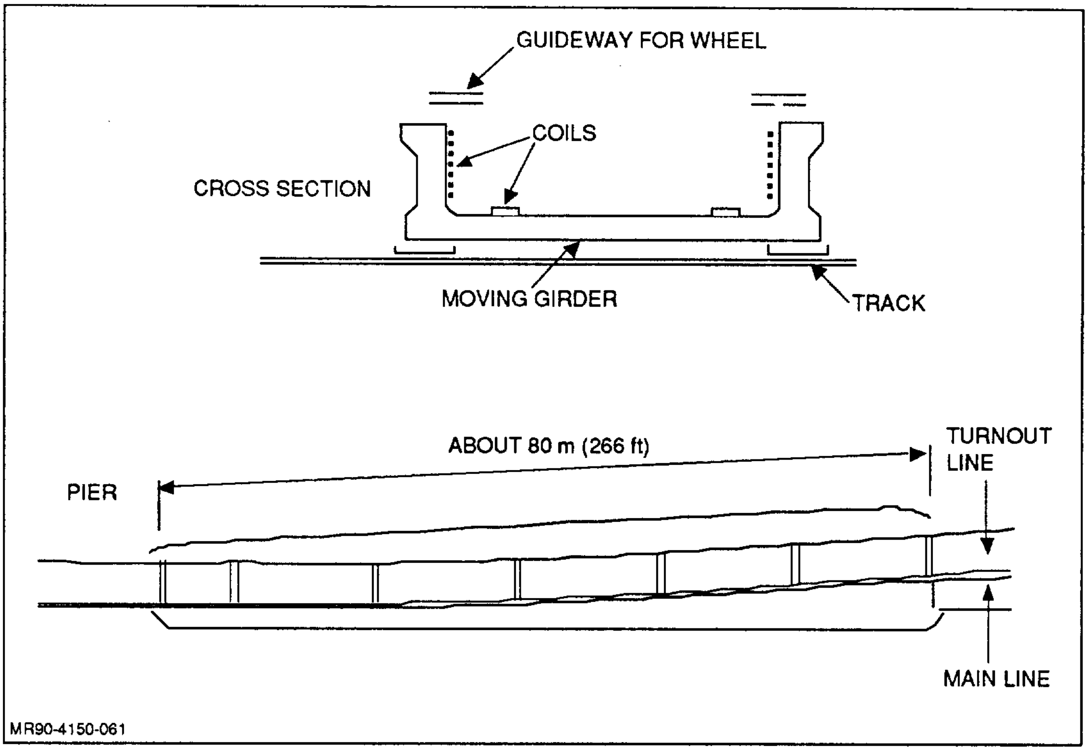

Fig. 4-15 MLU00X Double Track & Switch Concept – *The MLU00X uses a mechanical segmented track and switch concept.*

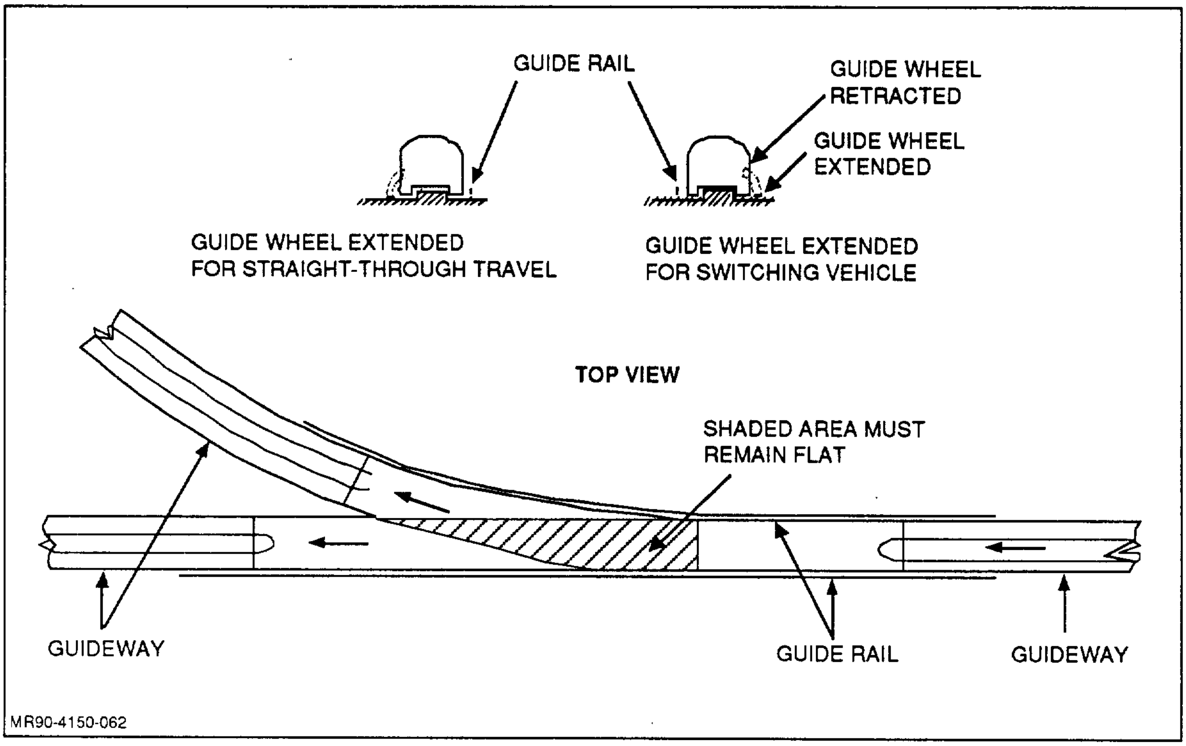

Fig. 4-16 Guide Rail Switch Design – *This switching process requires no mechanical motion of the guideway. It is implemented by extending a guide wheel from the vehicle to engage with a left or right guide rail depending on direction of travel desired.*

of switch are obvious. First, through-traffic must extend a guide wheel to maintain guidance through the switch. Failure to do so would cause loss of control and possibly hitting the guideway or other objects. Second, through-traffic will be required to traverse the switch at significantly reduced speed to assure a smooth transition with the guide rail, thereby penalizing the block speed. Another approach to this problem would be to combine the above procedure with active propulsion coils located in the guideway, installed in both directions of the switch. One coil side is activated to coincide with the appropriate extended guide wheel, so the propulsion system provides redundancy to the switching process, if one or the other method fails. Another problem with this switch is that, in the transitional part of the curve, superelevation cannot be included as indicated by the shaded section in Fig. 4-16.

Figure 4-17 shows a ramp-type switch and is simply two inclined ramps outboard of the normal guideway. The six wheels (three on each side) onboard the vehicle are extended out and down until they contact these inclined ramps, thus moving the vehicle up on the elevated switch. If the wheels are not extended, the vehicle continues without disturbance. If more than two of the six wheels fail to extend, the remaining wheels can be retracted, and the vehicle will continue in the straight-through direction. A problem with this design is that, at low speed, the vehicle may not have sufficient momentum to rise up the ramp, especially if the ramp is combined with a curve. This problem can be corrected by using propulsion coils mounted on the side of the guideway and appropriately activated to pull the vehicle up and maintain speed.

In conclusion, it is the ramp-type track-switching configuration that the Grumman team recommends at this time; however, a more detailed evaluation is required before a final design can be chosen.

4.8 VEHICLE DYNAMIC PERFORMANCE

The motions of the vehicle both horizontally and in rotation and the resulting ride quality for passengers as it travels along the guideway at different speeds are an important issue. These motions must be within the acceptable acceleration levels specified in Section 2 for passenger comfort, over a wide range of adverse conditions such as grade transitions, curves, guideway roughness, crosswinds, and gaps in aluminum sheets or spacing between levitation coils. A detailed study of these effects on an aluminum sheet guideway was performed by Ford in 1974 and the results were presented in Ref. 4.1. This analysis was reviewed and updated for application to the present study. For this study, it was assumed that magnetic control coils (vertical and horizontal) were located on the vehicle superconducting magnet assembly as shown in Fig. 4-6. These control coils, located at four corners of the vehicle, interact with the aluminum sheet to provide vertical, lateral and rotational forces on the vehicle for stabilization and control.

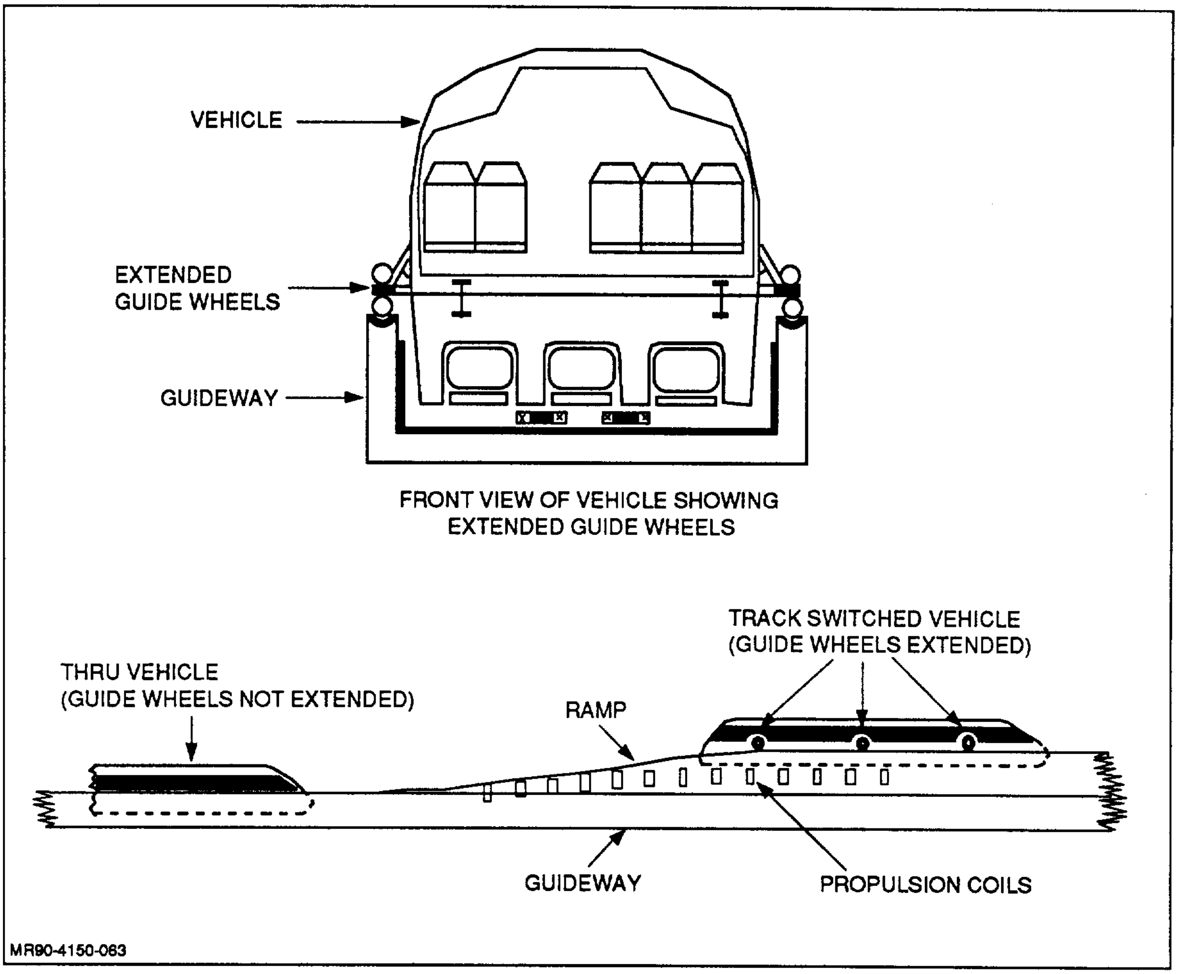

Fig. 4-17 Ramp Switch Design – *This switching process requires no mechanical motion of the guideway. It is implemented by extension or retraction of the guide wheels. Extension of the wheels results in a lifting of the vehicle on the ramp. Nonextension results in a straight-through operation. Propulsion coils on the side of the ramp are activated to aid in lifting the vehicle and maintaining speed. Design can simultaneously provide combined lift and curvature.*

The study examined the response of a 100-klb EDS vehicle without secondary suspension at a velocity of 300 mph when traversing a flat-plate guideway with a roughness-induced power spectral density specified in Fig. 4-18. The responses of this vehicle to gaps in the guideway, dynamic response of the guideway, crosswinds up to 45 mph, and grade transitions were studied. The conclusion was that the vehicle could meet the DOT ride quality requirements specified in Fig. 2-1 by using either an active feedback control system (sensing vehicle/guideway gap and vehicle velocity) or a passive system.

An RMS control coil power consumption of about 36 kW was predicted, which is small when compared to the 7 to 10 MW required to propel the vehicle.

The study assumed a vehicle with no secondary suspension, which implies that all springing and damping occurs in the primary magnetic suspension. Our requirements for an independent carriage bank might negate some of the advantages of eliminating the secondary suspension. Future studies should determine if incorporating a secondary suspension with the carriage bank feature could improve ride quality.

A more complete discussion of this topic, as extracted from Ref. 4.1, is provided in Appendix D.

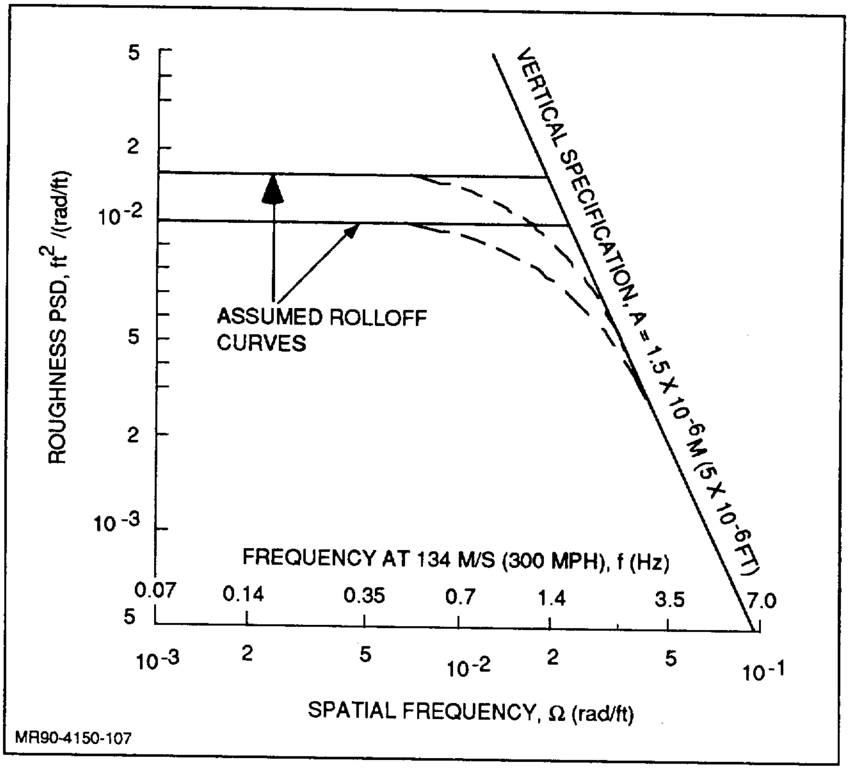

Fig. 4-18 Guideway Roughness Power Spectral Density Relationships – *This graph shows the two power spectral density roughness level profiles assumed for the guideway in this study.*

4.9 REFERENCES

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5 – ENVIRONMENTAL CONSIDERATIONS

5.1 INTRODUCTION

In 1970 the New York State Joint Legislative Commission on Transportation held its First Annual Legislative Transportation Forum, and published "The Crisis in Mass Transportation" (Ref. 5.1). According to this document, the problems of congestion, pollution, and need for new transportation technology were clearly understood. These problems have not materially changed in the intervening 20 years, and with some minor changes, the same report could be reissued, or at least instructively reread, today.

Reductions in transportation-generated air pollution during this same period are large by any measure, and a credit to what can be accomplished by firm, visionary policy. However, heavily populated areas that encompass the entire region are still plagued by unhealthy air, of which the primary cause is fuel combustion to propel vehicles, principally automobiles, but including trucks, aircraft, and buses. A shift to electricity for transportation is a key local and regional benefit from MAGLEV. Pollution from electricity production is easier to control, and is removed from where the service is provided.

Although MAGLEV alone cannot solve these problems, it may have a significant impact on them as described in Ref. 5.2. In this section, environmental issues specifically related to New York State's needs, with recognition of the broader implications for the rest of the nation, are discussed.

The material that follows is taken primarily from information provided by Dr. Richard E. Gibbs of the New York State Department of Environmental Conservation.

5.2 TRANSPORTATION CONGESTION

Road congestion from personal vehicles was the historical justification for building highway networks. Congestion of these massive public investments is again limiting mobility. Projections for vehicle use and air transportation show only increased demand.

For New York State, vehicle miles traveled have grown at a compound rate of three percent for more than 30 years, and are projected to double in the next 25 years. Some areas are growing at twice this rate. Over 50 million hours per year are spent in congestion in Manhattan alone. It is anticipated that congestion will increase in duration and scope, since it will be impossible to construct highways to add capacity in any amount to alleviate the problem (Ref. 5.3).

Transportation systems of any type must be used to be considered a success. Congestion may indicate both a successful transportation policy and failure to provide resources commensurate with demand. Unfortunately, the land and air space needed to provide significant congestion relief are unavailable. New solutions must be found that offer higher density mobility returns for the same land. Fundamental mobility needs should not, and need not, be defined by the congestive limits of present systems.

Congestion aggravates the onerous mobile source of air pollution for vehicles with on-board fuel combustion. Thus, projects aimed at expanding free movement of vehicles have been defended as air pollution control strategies; however, subsequent saturation of highway systems becomes the next air pollution problem. Unlike vehicles with on-board combustion, electric vehicles emit no pollution and use little or no fuel even when stalled in congested traffic. Conversely, the per-mile emissions from vehicles with on-board fuel combustion always increase under conditions of slow speed congestion (Ref. 5.4). In densely populated and trafficked urban areas, congestion exacerbates the heavy pollution burden from motor vehicles.

Despite increasing public support for a better environment, personal inconvenience and loss of time as a direct result of congestion will provide the primary impetus for change in transportation policies. However, if transportation congestion is relieved consistent with environmental planning, it must be accomplished without excessive need for land, which implies a more effective use of land already dedicated to transportation, or achievement of more personal mobility per lane of right-of-way. Transportation policy preoccupied with moving vehicles must refocus on the need to move people, in recognition of fixed physical space and unbounded demand for mobility. Roadway and airport congestion cannot be solved by physical expansion alone, and should be viewed in the context of new mixtures of transport means.

5.3 LOCAL AND REGIONAL AIR AND NOISE POLLUTION

A primary environmental impact from transportation is air pollution; however, this does not minimize other important environmental aspects such as land use for transportation, noise, electromagnetic fields, and secondary impacts. While each of these deserves comprehensive benefit and impact analyses with respect to MAGLEV, they are discussed only briefly in this report.

5.3.1 Air Pollution in the New England States

5.3.1.1 Regional Ozone – The six New England states, joined by New Jersey and New York, have formed an association called Northeast States for Coordinated Air Use Management (NESCAUM) to promote cooperation and coordination of air quality programs in technical and policy matters. NESCAUM's compilation of photo-chemical ozone pollution levels throughout the region during the summer of 1988 indicates the severity of the problems yet to be addressed (Ref. 5.5):

> "This summer, the Northeast experienced one of the most severe ozone seasons ever recorded....air quality monitors measured ozone levels exceeding the health standard 627 times during the 1988 ozone season."

Figure 5-1 shows the broad domain over which the ozone standard was exceeded during the summer of 1988. The ambient standard for ozone is considered conservative (i.e., there is reason to believe it should be lower). Recent trends in regional ozone levels indicate deterioration of air quality, with significant year-to-year variability affected by meteorological factors. Broad regional approaches will be required to effectively deal with this complex air quality problem.

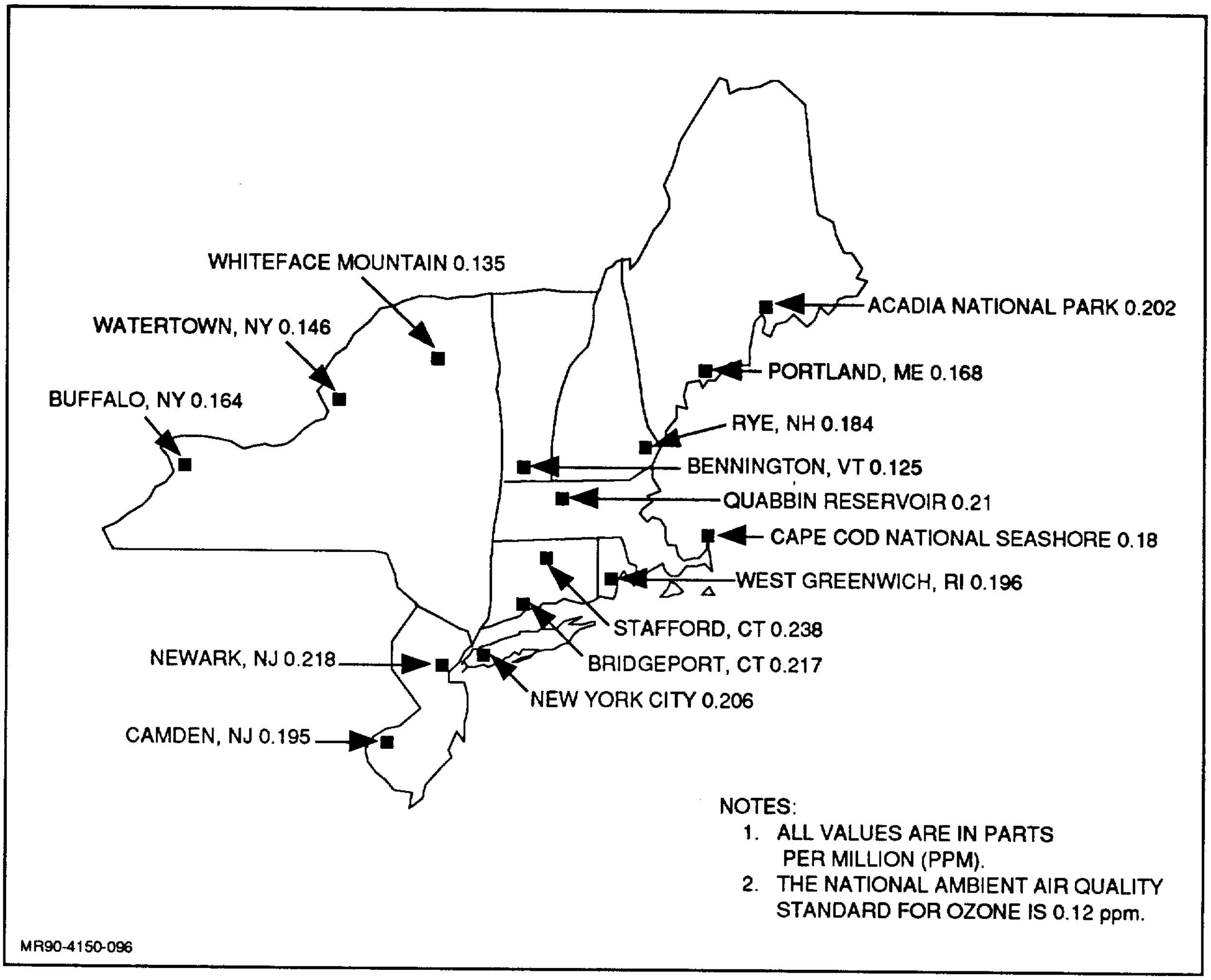

Fig. 5-1 High Ozone Levels in the Northeast States – Summer of 1988 – *In the summer of 1988, many New York State cities exceeded the national air quality health standard of 0.12 ppm for ozone more than 627 times. This reflects the severity of the pollution problems affecting this region.*

5.3.1.2 Carbon Monoxide (CO) – CO is a product of an oxygen-deficient (fuel-rich) combustion process. Most large stationary combustion facilities precisely control both fuel and air under relatively steady operation, and thus emit little CO. Mobile combustion, on the contrary, is a source of large amounts of CO. Mobile sources of CO include equipment deterioration, fuel-rich operation for transient power and starting, and improper functioning air/fuel systems. CO has long been recognized as a mobile combustion source problem; the environmental concern about CO has been due to its direct health impact.

The fuel-rich conditions that cause high CO emissions also cause high hydrocarbon (HC) emissions from motor vehicles. Both CO and HC are controlled by catalytic (oxidation) converters on board the vehicles, but these converters do not work effectively when engine operating conditions are excessively fuel-rich. It is common to see both high CO and HC emissions from vehicles with emission control problems. HC emissions also occur from non-combustion sources, such as fuel handling. Roadside monitoring for both CO and various HC emissions that may be toxic, such as benzene, has shown that CO levels are directly correlated (Ref. 5.6), and CO can be considered as a reasonable surrogate to indicate the degree of control of broader classes of automotive emissions.

Large reductions in CO from mobile sources have been achieved. Ambient air monitoring in cities across the nation has shown more than a 92 percent reduction in number of times per year the eight-hour National Ambient Air Quality Standard (NAAQS) has been exceeded over the past 10 years (Ref. 5.7). The yearly mean value of ambient CO has not decreased in the same proportion, showing only a 36 percent reduction over the same period. This disparity between reductions in peak and mean levels is becoming more important as regional and global environmental impacts of CO change the traditional view of CO as being important only in isolated vehicle intersections. CO is now understood as contributing to regional tropospheric ozone (Ref. 5.8) generation and also as indirectly increasing the greenhouse impact of atmospheric methane (Ref. 5.9). Reductions in the number of CO peaks may not be an adequate measure in the assessment of the net environmental impact.

5.3.2 Pollution Burden in New York Metropolitan Area

Despite the progress achieved, the 1985 estimate for CO emissions from the 4.5 million motor vehicles in the New York Metropolitan Area (NYMA) is more than 500,000 tons per year. Figure 5-2 compares the HC, CO, and NO_x and SO_x emissions in the NYMA from the motor vehicle fleet and the local generation of electricity. The motor vehicle fleet emits roughly 90 times more CO than the power generation facilities. The motor vehicle estimates could dramatically increase, since "running loss" of evaporated fuel during vehicle use was not included. In the NYMA, as well as in the broad NESCAUM region, the motor vehicle is the dominant source of atmospheric pollution.

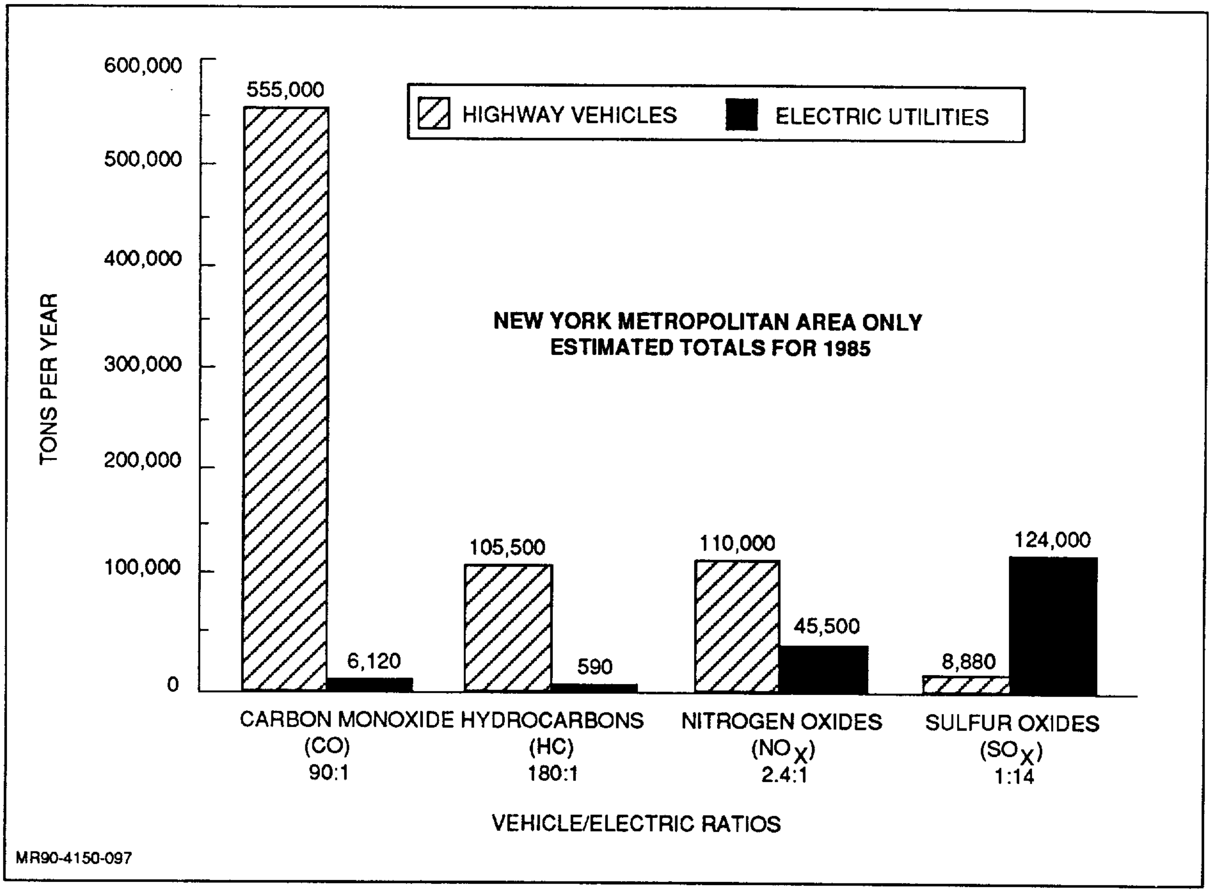

Fig. 5-2 Highway Vehicle and Electric Utility Emissions Comparison – *This chart shows that highway motor vehicles are the dominant source of atmospheric pollution in the NYMA. A reduction of highway vehicles in the area could have a significant effect on pollution levels. The corresponding increase in sulfur oxides could be minimized by using alternate fuels for electric generation or using cleaner methods to burn coal.*

5.3.2.1 Hydrocarbons (HC) – Motor vehicle exhaust contains HC from unburned fuel and incomplete combustion, with significant additional motor vehicle-related sources from fuel evaporation, on-board storage, and fuel handling. Most HC do not pose a health hazard, but a few (e.g., benzene, toluene, xylene, 1-3 butadiene) are referred to as automotive toxic emissions. Virtually all HC, however, participate in atmospheric photochemical oxidant reactions. HC and nitrogen oxides in sunlight undergo complex interrelated reactions that result in accumulation of ozone and other photochemical oxidant species, generically labeled smog. HC emissions are subject to regulation to control photochemical oxidant pollution, but there has been only limited success in achieving the NAAQS for ozone in urban and regional areas. Thus, the long-standing HC control strategies are the current subject of debate, controversy, and review. For the NYMA, mobile sources contribute 180 times more HC than power generation sources. There is no air standard for HC, and documentation regarding the ambient levels is based on limited-duration special studies rather than continuous air monitoring. Sophisticated computer models of photochemical reactions (Ref. 5.10) and pollution transport have shown that motor vehicle HC and nitrogen oxide emissions are a major factor in the frequent elevated O_3 levels in the NESCAUM region.

5.3.2.2 NO_x – The relative contributions of NO_x to the NYMA from the vehicle fleet and the power generation sources are about 2.4 times greater for the vehicles. Vehicular emissions are dispersed in the high population area, and mixed with abundant HC, so that the mix needed for photochemistry is already prepared. An NAAQS health standard for nitrogen dioxide (NO_2) exists, since it has direct health implications. The federal NAAQS for NO_2 is based on the yearly mean value and at present, no violations in the NESCAUM region have occurred. However, in New York State, the measured levels have not decreased in the past five years, and in fact are approaching the standard. California has adopted an hourly average standard for NO_2, and if this standard were applied, New York State would have violations. Furthermore, since NO_x is the critical ingredient for the ozone and other toxic formation reactions, this reservoir of NO_x indicates that major additional reductions will be needed before the region can reduce oxidant formation. New York State may soon exceed the NO_2 levels due to increasing vehicle use.

The oxidant pollution problem, the most intractable regional issue, is a subject of intense debate, since the easily implemented controls are in place, yet the air levels are increasing. New York State and the NESCAUM states are now in the process of adopting California vehicle emission standards, since NO_x standards are much tighter than the current U.S. EPA standards that apply in New York State.

5.3.2.3 Urban Toxic Soup – The cumulative impact of diesel and aircraft particles, toxic and non-toxic hydrocarbons, carbon monoxide, photochemical oxidation products, NO_2, and toxic nitrated reaction species (Ref. 5.11) combine to create a public issue beyond the analytical metrology provided by pollution monitoring. This smog perception has been called urban toxic soup, although it is not a precise term. A large proportion of these interrelated air problems come from vehicles that derive power from on-board combustion. In a lengthy U.S. EPA study of toxic air pollution throughout the United States, motor vehicles accounted for more than one-half of the aggregate cancer risk from all toxics in the air (Ref. 5.12).

5.3.2.4 Acid Deposition – It is currently estimated that about two-thirds of all acidic deposition is due to sulfur oxides (SO_x), and about one-third due to NO_x emissions. Figure 5-2 shows the emissions comparison of sulfur oxides from power generation and motor vehicles. These emissions are estimated to be about 124,000 tons per year for power sources in the NYMA, compared to approximately 9000 tons per year for the motor vehicle fleet. The highly refined liquid petroleum fuels for transportation contain much less sulfur than the heavy oils and coal used for power generation.

A small portion of electricity in the NYMA is used for mass transportation; however, this electricity provides over 10 billion passenger miles per year (Ref. 5.13). The inordinate contribution of the motor vehicle to air pollution in the NYMA is suggested by the data in Fig. 5-2, since power generation in the NYMA is used for much more than mass transportation. Emissions of sulfur oxides from power generation exceed those of the motor vehicle fleet, and present a real demerit for electrified transportation.

While transportation energy use in New York State is about 0.75 percent electricity (Ref. 5.14), it provides about 20 percent of the total passenger miles from all modes, including cars.

5.3.3 Noise Pollution

Noise pollution from a MAGLEV vehicle is primarily attributed to vehicle aerodynamics as it travels at high speeds through the air. Figure 5-3 presents a summary of noise data collected from various transportation sources including MAGLEV applications. The Transrapid 07 MAGLEV vehicle is close to meeting the ideal lowest estimates. MAGLEV provides the lowest possible noise levels of any other transportation system at any speed and meets the U.S. Department of Transportation (U.S. DOT) 73-dBA limit out to nearly 200 mph; however, with appropriate guideway design, these levels can be lowered to acceptable values, at grade, over the full speed range.

5.4 Transportation Energy Efficiency

Transportation, as the least efficient end-use sector (Ref. 5.15), needs continued focus on net intermodal methods to achieve major gains in mobility efficiency. The energy levels required to move a passenger one mile using various means of transportation are shown in Fig. 5-4. The three values marked by an asterisk are from Lynch (Ref. 5.16) based on submissions from bidders to the Florida High Speed Rail Commission. These values are for primary energy at the electrical generation plant, and include all losses. Other values are U.S. national averages for various transport modes, and do not include refinery or fuel delivery costs. MAGLEV energy intensities are necessarily based on limited data from developing technologies, for the MAGLEV technology is not as mature. The Florida MAGLEV and high-speed rail data are based on 70 percent occupancy, and in the case of MAGLEV, operating speeds will achieve 300 mph. The automotive energy intensity is based on assumed occupancies of 1.7 persons per automobile and 2.0 persons per truck, used for personal transportation. Occupancies less than these values, and vehicles used in congested zones, will significantly increase the net energy intensity. This congestive fuel penalty is evident in the comparison between the energy intensities for intercity

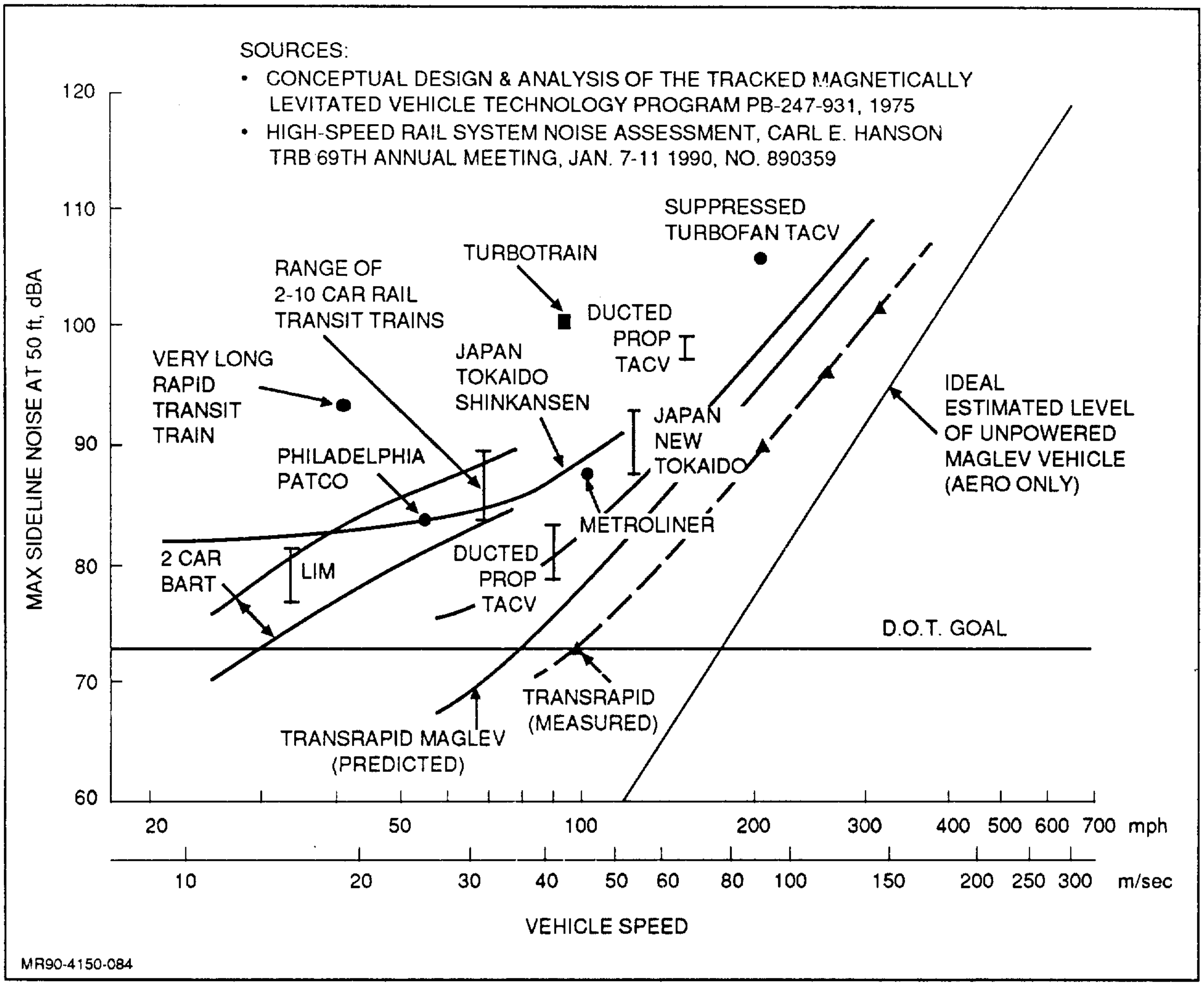

Fig. 5-3 Vehicle Noise Trends – *Of all the transportation system noise levels shown, MAGLEV comes closest to meeting the U.S. DOT noise level goal of 73 dB at all speeds.*

transit bus (939 Btu/mile), and urban transit bus (3,761 Btu/mile), a factor of four. Comparing MAGLEV to the automobile, the energy required is approximately one-third, yet the travel speed is about five times greater.

Electric power for transportation has important environmental benefits whether applied to highway vehicles, conventional steel-wheel on steel track, or to MAGLEV. From a global environmental perspective, these benefits occur on two levels: decreased greenhouse gas emissions relative to on-board petroleum combustion due to increased efficiency; and long-term flexibility in the source of electricity while achieving complete separation of power source and mobility technology.

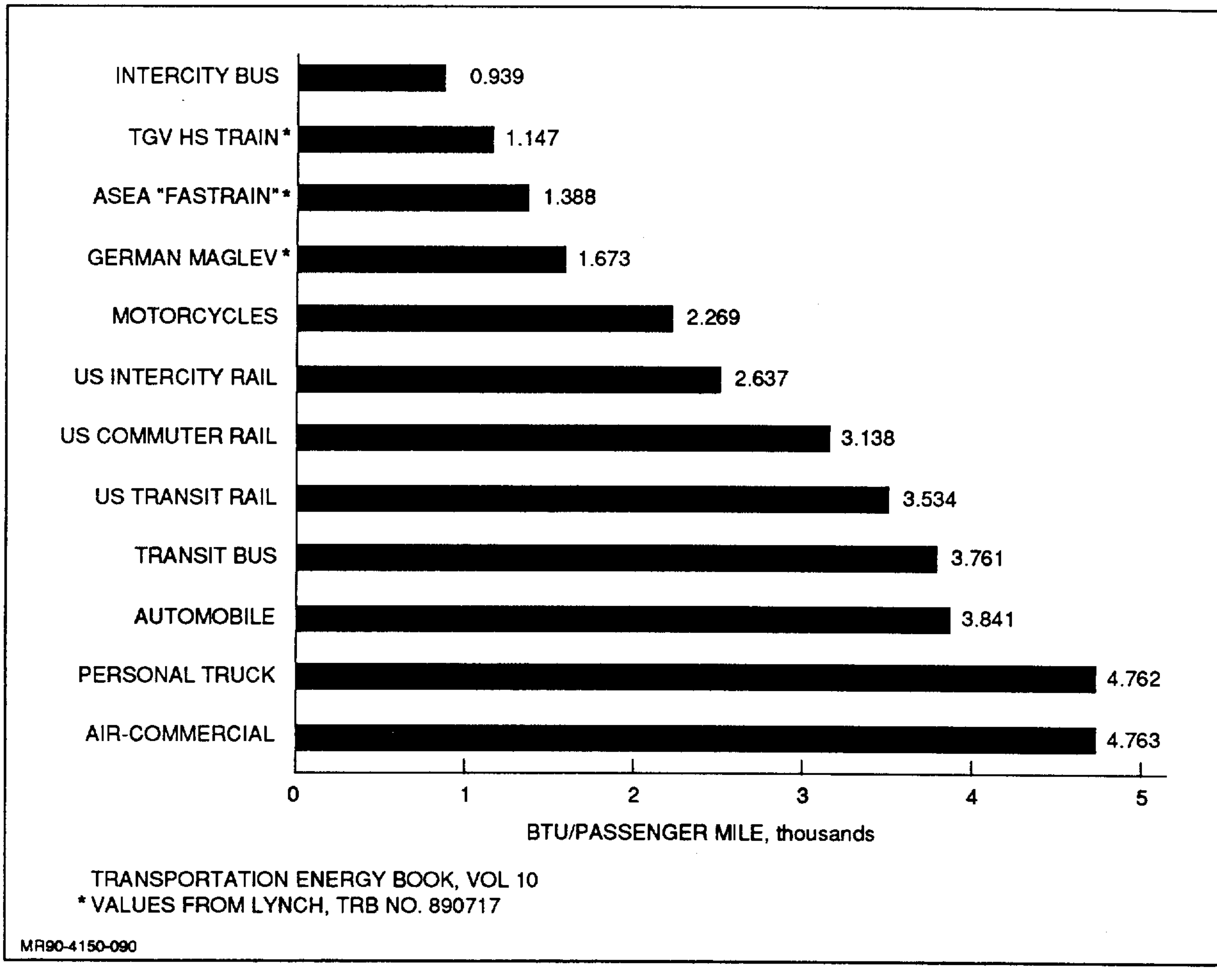

Fig. 5-4 Passenger Energy Intensities – *This chart compares the energy usage per passenger mile for a wide range of different transportation systems. MAGLEV fares well against all systems including the bus, TGV, and Fastrain when considering that the MAGLEV speed is significantly higher, which results in a higher passenger usage and therefore lower operating cost per passenger mile.*

By contrast, motorized vehicles will require simultaneous changes in both fuel specification and vehicle hardware to respond to future demands. This lock-step feature connecting the fuel and the vehicle presents the problem of how to change the existing vehicle fleet to a new fuel. The introduction of the methanol/gasoline flex-fueled vehicle concept provides a good working example of the problems in effecting a change in fuel supply while keeping the mobility technology unchanged.

5.5 MAGLEV AS A TRANSPORTATION SOLUTION

While development of a national transportation policy that resolves the competition among public transit alternatives is beyond the scope of this report, a legitimate question for the environmentalist is "Why should MAGLEV be supported when electrified high-speed train technology already exists?" The ability to place MAGLEV on elevated towers using existing rights-of-way opens the prospect of a system that can surpass rail. Further, the ability of MAGLEV to use lightweight vehicles and negotiate relatively steep inclines without need for huge earth cuts expands the implied range of applications. MAGLEV's need for a limited right-of-way along with vibration-free and quiet service give it the potential for wide implementation.

Given the lack of adequate high-speed surface transportation in the United States, the choice between building a rail and a MAGLEV component must take future needs into account. MAGLEV deserves consideration because of its environmental advantages.

Several MAGLEV implementation scenarios for New York State and New England would result in air pollution and general environmental benefits. Even lacking precise estimates of these benefits, it is possible to conclude that they deserve serious policy review.

The Northeast Corridor is a current and long-recognized area for high-speed rail improvements. The Coalition of Northeastern Governors (CONEG) high-speed rail task force should add the topic of a Northeast Corridor MAGLEV to its agenda.

MAGLEV commuter service connecting New York City with the communities of Long Island is an obvious application. The need for each lane of right-of-way to carry more passengers than can be accomplished with private vehicles and additional highway lanes is critical. The Empire Corridor connecting western New York along the path of the Erie Canal, or the NYS Thruway, are other prime candidates.

The need for a fourth major jet port to serve the New England region was identified in Ref. 5.1 as being important as far back as 1959. Even in 1970, the prospects of locating additional airport facilities was considered a closed topic because of lack of land, yet lack of airport facilities was identified as limiting the economic vitality of the entire region. Large highway construction projects were funded to alleviate major highway traffic problems as vehicles from distant locations were forced to gain access to JFK, LaGuardia, and Newark. MAGLEV link-up of the major jet ports in the region could have a beneficial impact on air and highway congestion.

In 1970, the Stewart Air Field near Newburgh, north of New York City and New Jersey, was under development to relieve the demand for increased service. This facility is just now coming into limited use for commercial air traffic. A MAGLEV link from Stewart to the other regional jet ports is especially deserving of study.

A MAGLEV ring in the New York Metropolitan Area (NYMA) that provided aircraft-quick, quiet, reliable service among JFK, LaGuardia, Newark, Stewart, and other sites deserves a comprehensive study.

New York City to Montreal, another corridor with sufficient traffic demand and growth potential, should be included in a comprehensive evaluation.

These and other potential locations for MAGLEV in the Northeast can provide a first link of suitable magnitude from which to start and prove next-generation technology, and ultimately its impact on traffic infrastructure.

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6 – NEW YORK STATE ROUTE EVALUATIONS

6.1 INTRODUCTION

This section presents some potential MAGLEV ground transportation opportunities in New York State that lead to identifying a demonstration corridor. In particular, this study preliminarily examines design guidance, potential alignments, areas of alignments where design guidance cannot easily be achieved, and environmental concerns. Other issues which require additional investigation are identified at the end of the evaluation.

A full alternative analysis was not performed at this time. Corridor selection was primarily based on a subjective evaluation of alignments that would provide the greatest ridership and alignments along rights-of-way that could be obtained through State authorization. Alignments and associated rights-of-way were evaluated assuming that the rights-of-way for the MAGLEV guideway were confined to the interstate corridor of the New York State (NYS) Thruway Authority. The NYS Thruway was evaluated in greater detail than other alignments because data were available through the NYS Thruway Authority. Data collected included segmental information on average and typical conditions such as grades, curve radii and existing infrastructure. Data should be developed and evaluated at later stages of design and alternative analyses.

6.2 PHYSICAL CHARACTERISTICS OF A MAGLEV GROUND TRANSPORTATION SYSTEM

The minimum design guidelines that would have to be met to achieve a MAGLEV optimum performance are described in the following paragraphs.

6.2.1 Station Spacing Requirements

A design for a 300-mph maximum speed and 250-mph cruise speed train for long-distance, intercity transportation would require station stops approximately 50 miles apart. In a design for a 120-mph speed within high-volume metropolitan areas, stations should be spaced approximately 15 miles apart. Closer station spacings would result in slower speeds unless high-speed (>150 mph) off- and on-ramp capability is implemented.

6.2.2 Grade Requirements

At a four-percent grade, the MAGLEV vehicle would be able to sustain its design cruise with a 30-mph head wind and at least half of the design acceleration rate.

6.2.3 Height Requirements

It is assumed that the bottom clearance of the guideway is 35 ft above ground level to provide a level ride and clearance over closely spaced overpasses and highway interchanges along the highway alignment. The bottom of the guideway shall be 35 to 40 ft above the highway and a minimum of 16.6 ft above any crossway. The average height of a crossway on the NYS Thruway is approximately 15 ft. With an average height of crossways at 15 ft, a MAGLEV guideway of 35 to 40 ft above the highway would still provide for the 16.6 ft height guideline for overpassing crossways.

6.3 POTENTIAL MAGLEV ALIGNMENTS

A MAGLEV system has the potential to provide alternative transportation options for New York State as increasing surface and air travel create new highway and airport congestion in high-density intercity corridors. At operating speeds approaching 300 mph, a MAGLEV ground transportation system could offer a transportation alternative to short-haul air services as well as to many mid- to long-distance highway trips. In many instances, a MAGLEV system could transport passengers and high-value freight into downtown areas, unlike airports which are located on the periphery of major urban centers. Interconnection of the downtown areas with major airports will also greatly enhance the utility of MAGLEV.

6.3.1 Primary Alignments

For this evaluation, potential alignments have been limited to segments of the approximately 495-mile NYS Thruway and the approximately 80-mile Long Island Expressway (LIE). These potential alignments are discussed in the following paragraphs. A description of how these primary New York State alignments might connect to a broader interstate MAGLEV system is given in Subsection 6.3.2, Secondary Alignments. A matrix summary of characteristics of each alignment is presented in Table 6-1.

6.3.1.1 ***New York City – Albany (Alignment I, Fig. 6-1)*** – A MAGLEV system could prove to be a viable and competitive transportation alternative between New York City and Albany by making the 172-mile trip, which would take approximately three hours by automobile, in less than an hour. Today, Amtrak, in two hours, provides service between New York City and Albany. This is also a potential first leg of a route to Boston via the Massachusetts Turnpike (see Subsection 6.3.2.2).

The NYS Thruway from Albany to Suffern provides an available alignment for MAGLEV, and would either proceed east across the Hudson River, into New York City via Interchange 1, and into Manhattan via the West Side Highway; or follow new or existing rights-of-way to the vicinity of Hoboken or Newark, New Jersey. A number of physical constraints would require some deviations from standard design guidelines or peak performance standards, or would require special consideration in design/cost estimating. It can be assumed that along the NYS Thruway the average right-of-way width in urban areas is approximately 150 to180 ft and approximately 210 to 240 ft in rural areas. The following physical constraints must be addressed:

Table 6-1 Primary Alignment Design Guidelines Evaluation Matrix (Sheet 1 of 2) – *A summary of design guidelines for three major New York State routes is presented. As a result of this evaluation all three are considered viable options with the NYC to Albany route favored because of its potential to be the first leg of a route to Boston via the Massachusetts Turnpike or to Buffalo with potential midwest and Canadian connections. More detailed studies are required, however, before a final choice can be made.*

Design guidelines	New York City to Albany	Albany to Buffalo	LIE to Sunnyside
Speed & banking limits	Discussed in Subsection 6.5.	Discussed in Subsection 6.5.	Not available.
Grade characteristics: number of instances and locations where a grade of 4.0% occurs and/or would be exceeded.	There is no instance where a grade larger than four percent exists along this corridor.	There is no instance where a grade larger than four percent exists along this corridor.	Not available.
Major utility crossings.	The NYS Thruway Authority reserves the right to relocate any utility lines which cross the Thruway.	The NYS Thruway Authority reserves the right to relocate any utility lines which cross the Thruway.	Not available.
Right-of-way: number of instances where right-of-way constraints exist.	Between Interchanges 1-9 there are serious right-of-way constraints due to service roads and residential and non-residential urban development.	Interchange 24 is a complex interchange; right-of-way constraints would exist. Service road constraints would exist in the urban areas of Buffalo. In Syracuse, the right-of-way is limited and adjacent areas are developed.	The potential for serious right-of-way constraints would exist in Queens and western Nassau County. This is primarily due to service roads and heavy residential and non-residential urban developments.
Water body crossings: number of locations of water body crossings that do not have the ability to support a MAGLEV structure.	The Tappan Zee Bridge crosses the Hudson River near Interchanges 9-10. The ability of this water body crossing to support a MAGLEV system segment must be evaluated. There may be a need to construct a separate MAGLEV river crossing structure.	The Mohawk River crossing located at Interchange 30 must also be evaluated to determine its ability to support a MAGLEV system segment.	Not available.
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Table 6-1 Primary Alignment Design Guidelines Evaluation Matrix (Sheet 2 of 2)

Design guidelines	New York City to Albany	Albany to Buffalo	LIE to Sunnyside
Interchanges: number of interchanges and average distance apart.	There are 30 interchanges along this alignment with an average distance between them of five miles. Between Interchanges 1 and 17, the spacing between interchanges averages 0.9 miles due to the urban nature of the area.	There are 32 Interchanges along this alignment if the MAGLEV system were terminated at Interchange 50, with an average distance between them of 7.5 miles. In the areas of Syracuse and Buffalo, spacing between Interchanges averages one mile due to the urban nature of these areas.	There are 27 interchanges long the LIE between MacArthur Airport and the Nassau/Queens County line. The spacing of interchanges along this potential MAGLEV alignment is approximately 1.6 miles. There are primarily service roads from the Nassau/Queens line to Sunnyside.
Conclusions and recommendations.	The New York City – Albany alignment could prove to be a viable MAGLEV corridor. However, there are a number of issues which must be addressed if this corridor is considered. These issues include: the crossing of the Hudson River; handling the deep rock cuts along this alignment; limited right-of-way due to service roads and urban development; and the issue of continuing service from Interchange 1 to the Manhattan central business district. This route is favored as a first leg to Boston or Buffalo with its Midwest and Canadian connection. More detailed studies are required.	The Albany – Buffalo corridor could prove to be a viable intrastate transportation system. A MAGLEV corridor from Albany to Buffalo could offer travelers a true alternative to short-haul air travel and mid- to long-range auto and truck trips. This corridor could also be extended into Canada which could prove valuable in transporting of high-value goods between the U.S. and Canada.	A MAGLEV system along this corridor would give daily commuters an opportunity to travel to and from New York City in a short amount of time. This corridor would have the potential to carry large numbers of passengers and could help alleviate traffic congestion on Long Island. However, there is limited right-of-way access between the Nassau/Queens County line continuing into Long Island City, Queens. There is also freight potential along this alignment.

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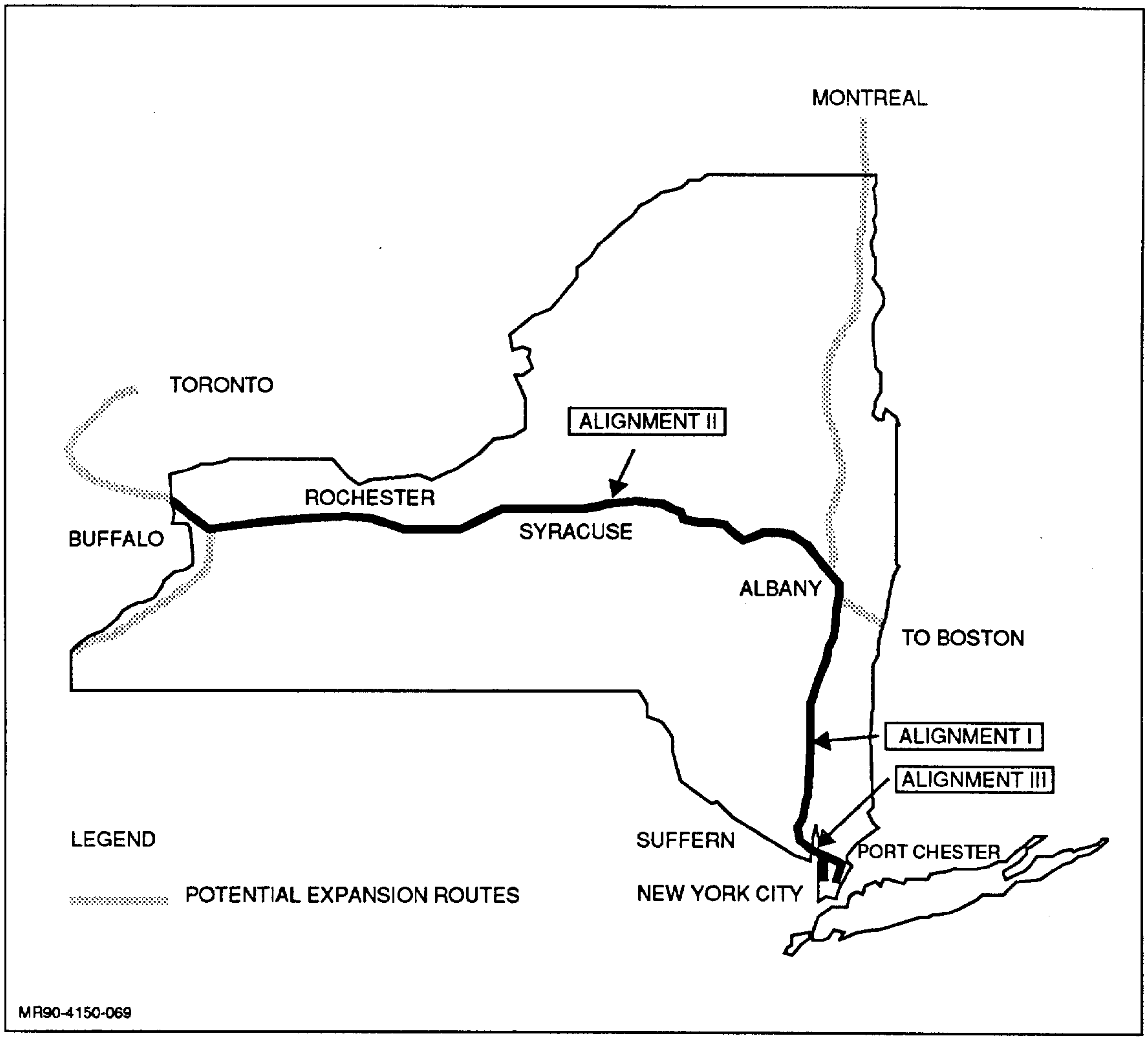

Fig. 6-1 New York State Potential Primary Alignments I, II, & III – *The three primary alignments along the NYS Thruway are identified on this map. Potential expansion routes into Boston, Canada, and the Midwest are also identified.*

- Between Interchanges 1 and 9, which extends from New York City to Tarrytown, constraints would be associated with limited right-of-way due to service roads and heavy residential and non-residential urban development along this segment of the NYS Thruway corridor;

- At Interchange 8, soil samples indicate that there are soil stability problems which may affect constructing a MAGLEV structure because this segment of the Thruway was constructed through a swamp. The Thruway Authority has been monitoring this segment of the highway and has concluded that it is sinking. It is estimated that there is approximately six feet of asphalt beneath the surface of the roadway in some areas of the swamp;

- The Tappan Zee Bridge, located between Interchanges 9 and 10, is a major river crossing, spanning 3.03 miles with a height of 200 ft. Its ability to support an additional structure required for the operation of a MAGLEV system must be evaluated. However, limited right-of-way opportunities do exist on either side of the bridge approaches. Similar comments are noted for the Mohawk River crossing near Exit 30;

- Near Interchange 15, several constraints exist. This is a complex interchange where little unused right-of-way remains. In some areas the highway is supported on retaining walls nearly to the edge of the right-of-way;

- Deep rock cuts near Interchange 15 will require modification of the pier design;

- At Interchange 22, the NY Central Railroad (CONRAIL) crosses the Thruway; and

- Extending a MAGLEV system to a suitable terminal location in New York City may require an alignment with a significantly reduced speed of operation, due to short curve radii and environmental concerns. Dense development and existing infrastructure may require that the MAGLEV system be built along the existing West Side Highway right-of-way.

6.3.1.2 ***Albany – Buffalo (Alignment II, Fig. 6-1)*** – The Albany – Buffalo corridor, which spans approximately 270 miles if terminated at Interchange 50, connects all the major population centers in upstate New York, including Albany, Utica, Syracuse, Rochester and Buffalo. With connecting service to New York City, an alignment in this corridor would provide a statewide MAGLEV transportation system via Albany that could promote economic development of the upstate cities and international trade through accessibility to major Canadian cities (Toronto, Quebec and Montreal). These West, Midwest and Canadian connections would be logical expansions to a cross-state MAGLEV corridor.

There would be a number of physical constraints within the Albany – Buffalo Alignment which would require deviations from standard design guidelines or peak performance standards, or would require special consideration in design/cost estimating. The following physical constraints must be addressed during further development of a MAGLEV transportation system along the corridor:

- Interchange 24, a complex interchange with Interstate routes 87 and 90 passing through it, poses structural and civil engineering challenges;

- At Interchange 30, a bridge over the Mohawk River, which spans 0.93 miles with a height of 65 ft, may not accommodate a MAGLEV structure. A separate MAGLEV structure may be needed to span the river if the existing structure cannot accommodate additional loading; and

- Extending a MAGLEV system into the city limits of Buffalo and Syracuse, or any of the other cities along the way, will be problematic, due to the high cost of right-of-way acquisition as well as the possibility of strong opposition from environmental and political public interest groups. There may be a tradeoff between placing the station in the best location from a market standpoint vs overly compromising the high-speed operation of MAGLEV. Placing the stations on lower-speed side tracks would, however, solve this difficulty.

6.3.1.3 ***Suffern – Port Chester (Alignment III, Fig. 6-1)*** **–** Unlike the traditional suburban to central city or inter-central city corridor, the Suffern – Port Chester corridor, which spans approximately 30 miles, would connect two suburban areas with growing residential and employment concentrations. Throughout the United States, there has been an increasing emphasis on the need for inter-suburban transit systems. A Suffern – Port Chester MAGLEV corridor may serve as a prototype for investigating this type of market. This corridor would follow the NYS Thruway from Suffern across the Hudson River and continue along the Thruway, previously the Cross Westchester Expressway, to Port Chester.

There would be a number of physical constraints within the Suffern – Port Chester Alignment which would require deviations from standard design guidelines or peak performance standards, or would require special consideration in design/cost estimating. The following physical constraints must be addressed prior to the development of a MAGLEV transportation system:

- There are a number of segments along the corridor with service roads and an absence of medians;

- The Tappan Zee Bridge, located between Interchanges 9 and 10, is a major river crossing which may be unable to support additional structures as previously discussed; and

- This corridor has a restricted right-of-way and numerous interchanges and overpasses. There are 32 bridges and structures along the Thruway portion of the corridor, and 46 bridges and structures along the Cross-Westchester Expressway portion.

6.3.1.4 ***Long Island Expressway (LIE) – New York City (Alignment IV, Fig. 6-2)*** – Long Island, one of the most densely populated corridors within New York State, has a high ridership demand for daily commuter traffic to and from New York City. Currently, transportation is provided via the Long Island Railroad or private vehicles that clog the highway arteries. A MAGLEV transportation system, following the LIE corridor, could alleviate Long Island's severe traffic congestion problems, and provide greater mobility for continued economic development.

This 55-mile alignment could extend from either Riverhead or MacArthur Airport, located in Central Suffolk County, to Sunnyside, located in the Long Island City section of Queens, with an intermediate stop at the intersection of the LIE and Route 110 corridor, located near the Nassau/ Suffolk County line, and Glen Cove Road in mid-Nassau county, with potential branches to LaGuardia and Kennedy airports in Queens. Compared to other interstate and intrastate corridors, the characteristics of the LIE right-of-way provide many advantages, including low grades, generally larger curve radii, and relatively wide medians throughout most of the corridor. However, this alignment is constrained by the development and limited right-of-way and access between the Nassau/Queens County line and Long Island City in Queens. The corridor would service heavy daily commuter traffic to and from Sunnyside with connections to Midtown Manhattan via the subway.

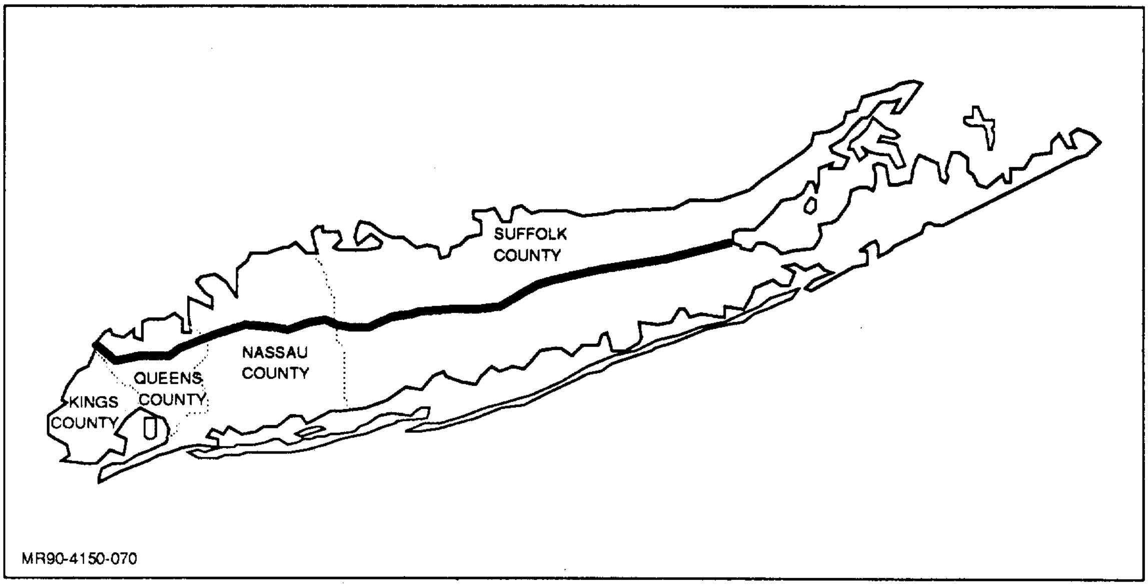

Fig. 6-2 Potential Primary Alignment IV – Long Island Expressway – *Long Island is a good MAGLEV candidate route because of its high ridership demand for daily commuter traffic to New York City. However, difficulties involved with getting into the city center itself, and the difficulties involved in expanding this system into a larger interconnecting system with the rest of the State, or with other states, limit its application as an early demonstration system.*

Sunnyside would be an ideal terminus because there are plans for large-scale commercial and residential development in the area, and because of its proximity to midtown Manhattan via subway connections. The Sunnyside rail yards are used by Amtrak, Long Island Railroad and NJ Transit for equipment maintenance and storage of surplus trains. Such a facility could potentially house MAGLEV vehicles during non-peak hours, and serve as a maintenance facility.

More detailed evaluation of corridor constraints must be pursued to outline potential problem areas that may require specific design requirements, possible speed restrictions, or right-of-way allowances. The major problem area appears to be within the western portion of Nassau County and Queens where the development is densest, medians are narrow, and service road congestion is heavy.

6.3.2 Secondary Alignments

6.3.2.1 ***Toronto – Buffalo – Albany*** – The potential alignment connecting Toronto to Buffalo with continuing service to Rochester, Syracuse and Albany, and with connecting service to New York City, would introduce the opportunity to rapidly transport passengers and goods from Canada to the United States. The movement of high-value goods could prove attractive to New York State businesses, due to a MAGLEV system's ability to transport high-value commodities across the State at speeds approaching 300 mph, which would make it possible for large shipments to be transported in a short time to the State's major wholesale and retail centers. A high-speed goods transportation network connecting Canada and New York State wholesale and retail centers is becoming increasingly meaningful due to the recent Free Trade Agreement between the United States and Canada.

6.3.2.2 ***New York City – Boston*** – A New York City-to-Boston MAGLEV alignment would follow the NYS Thruway from New York City to Interstate 90 near Albany and continue westward through Massachusetts, following the Massachusetts Turnpike, and terminate in Boston. Alternatively, an alignment could travel from New York City along Interstates 84 and 91 through Hartford to Springfield to reach Boston. This may provide a more viable alignment alternative to Interstate 95 due to the congestion of Interstate 95 in southwestern Connecticut. Currently three major commercial airlines and Amtrak operate a New York City-to-Boston service.

6.3.2.3 ***Port Chester – New Jersey*** – This alignment, an extension of the Suffern - Port Chester alignment, would connect the suburban and commercial areas of central and northern New Jersey with the suburban and commercial centers of Westchester County, New York. This alignment would follow the Suffern - Port Chester alignment, previously discussed, and continue southward following the Interstate 287 corridor in New Jersey.

6.4 ALIGNMENT EVALUATION AND CONCLUSIONS

A matrix evaluation of the primary alignments and selected design guidelines presented in Table 6-1 was conducted to present and compare the major differences among candidate alignments.

Further analysis of the ridership demand, market capabilities and corridor characteristics must be made before recommending a demonstration line. Based on this preliminary evaluation, the New York City – Albany corridor, with eventual expansion to Buffalo and Boston, appears to have the best potential for a demonstration MAGLEV alignment segment. However, additional market analysis must be performed to determine the economic viability of such a system, and to supplement policy decisions that may affect future economic development of this corridor. As previously discussed, this area is strategically located to benefit from expansion of American-Canadian trade, and to serve as a connection to the major midwest cities such as Chicago.

In contrast, the LIE currently has the more local transit demand for commuter traffic from Long Island to New York City. This corridor has some advantages in terms of the average grades, right-of-way, and typical curve geometry, but is increasingly constrained at the western terminus in Queens where existing infrastructure limits additions. A Long Island Alignment is not as well-suited to system expansion as the NYS Thruway.

A MAGLEV ground transportation system along the NYS Thruway has the potential to serve as a national demonstration project. The most attractive alignment would extend from New York City to Buffalo, with intermediate station stops in Albany, Utica, Syracuse and Rochester. This alignment would connect the major residential and commercial centers of upstate New York with New York City.

The NYS Thruway alignment may require deviations from standard design guidelines or peak performance standards, and special consideration in design/cost estimating. This would be especially true when the alignment would approach urban areas, where right-of-way restrictions apply due to either service roads or residential and non-residential urban development.

The principal highways that cross New York State and connect the State with other northeastern industrial and population centers have been designed for vehicles operating at speeds of 70 mph or less, and follow an irregular terrain. In contrast, the MAGLEV system's optimum performance is achieved along straight, flat guideways, tolerating broad curves. By constraining the MAGLEV guideway alignment within the median or general right-of-way of the highway system, the design of the vehicle and guideway must be modified to allow the system to operate at the target speed range of 200 to 300 mph. Typical curve radii of two deg noted on the NYS Thruway dictate slower average speeds to provide for passenger comfort while negotiating curves at high speeds. Banking the guideway allows the vehicle to negotiate the curves and resist some of the lateral loading forces within the structure. Additional incremental speed improvements can be accommodated by tilting the vehicle's secondary suspension system. This is discussed in more detail in Subsection 6.5.

Lateral loads increase with the vehicle speed and inversely with the curve radii. Along the Thruway it is important to determine the frequency of various curves of different radii to determine the speed performance capability of the MAGLEV vehicle as discussed in Subsection 6.5. Average speeds will be dictated by the curve frequencies, as the MAGLEV vehicle must decelerate prior to the curve and accelerate after leaving the curve. Lateral loads must be supported through the superstructure design. The effects of side loading on guideway structures require further investigation.

Although the interstate and other highways may provide an economical land alternative, deviations from this right-of-way may benefit the performance of the high-speed MAGLEV system. Land acquisition costs are dependent on local conditions that should be evaluated through a cost/benefit tradeoff analysis for each corridor. Where possible and economical, additional land may be obtained to straighten the alignment.

River crossings may prove to be a major consideration in the development of a MAGLEV system because of the issues related to site selection and access, right-of-way acquisition, environmental concerns, existing infrastructure on either side of the river crossing, aesthetics and construction costs.

Physical constraints would also affect station/terminal location. When evaluating the New York City – Albany alignment, the location of a New York City terminal becomes a key issue. A terminal location at Interchange 1 would not be attractive to travelers due to the need to transfer from the MAGLEV system to either the NYC subway or commuter rail into the Manhattan central business district (CBD). Due to the importance of having a terminal in the Manhattan CBD, deviations from the standard design guidelines previously discussed would be required.

Along the LIE alignment, station/terminal locations would be less of a problem due to sufficient land opportunities in Nassau and Suffolk counties. The Sunnyside rail yards would be able to accommodate a terminal and would have the potential for the development of a multimodal transportation center connecting a MAGLEV system with the two nearby airports, rail freight, commuter rail, NYC subway and ground transportation services.

6.5 SPEED AND BANKING LIMITS FOR NEW YORK STATE HIGHWAYS

6.5.1 Introduction

This subsection presents an analysis of the speed and banking limits for New York State highways relative to MAGLEV applications. An important feature of MAGLEV systems is their inherent high-speed capabilities, allowing them to compete with the airlines for passenger and freight traffic. While straightaway speeds of 300 mph are easily accommodated and allow trip times comparable with airlines up to distances of about 600 miles, the speeds which may be comfortably carried through turns are a critical consideration in MAGLEV application studies.

6.5.2 Speed and Banking Limit Analysis

To permit high speed in turns, some means of vehicle banking is necessary. To perform a coordinated turn (i.e., a turn in which the resultant of gravity and centrifugal force remains in line with the vertical axis of the passenger compartment as in airplanes), it is necessary to bank the vehicle in accordance with the following relationship:

$$\text{Bank Angle} = \tan^{-1}(V^2/g_c R) \qquad (1)$$

where:

V is vehicle velocity (ft/sec)
g_c is the acceleration of gravity (ft/sec^2)
R is the turn radius (ft)

This is shown graphically in Fig. 6-3. If we consider bank angles of 12 and 24 deg, the velocity relationship in mph is:

$$V = 1.783 \text{ SQRT}(R) \quad \text{for 12 deg bank angle} \qquad (2)$$

or

$$V = 2.581 \text{ SQRT}(R) \quad \text{for 24 deg bank angle} \qquad (3)$$

A total bank angle of 24 deg was specified as being similar to that frequently encountered in airline travel, and one that is considered comfortable for passengers. At this angle, the passenger feels an apparent 9.5 percent increase in weight but is unaware of turning without looking out the window.

While it is possible to provide this bank angle solely within the guideway, there are a number of disadvantages. With a fixed-bank angle, there is only one speed allowable for each turn. An angle of about 12 deg is about the maximum for a maintenance worker (or passenger departing a crippled vehicle) to walk on the guideway. We have therefore baselined a design in which the vehicle has the capability for independent carriage bank of up to 12 deg. This, combined with a

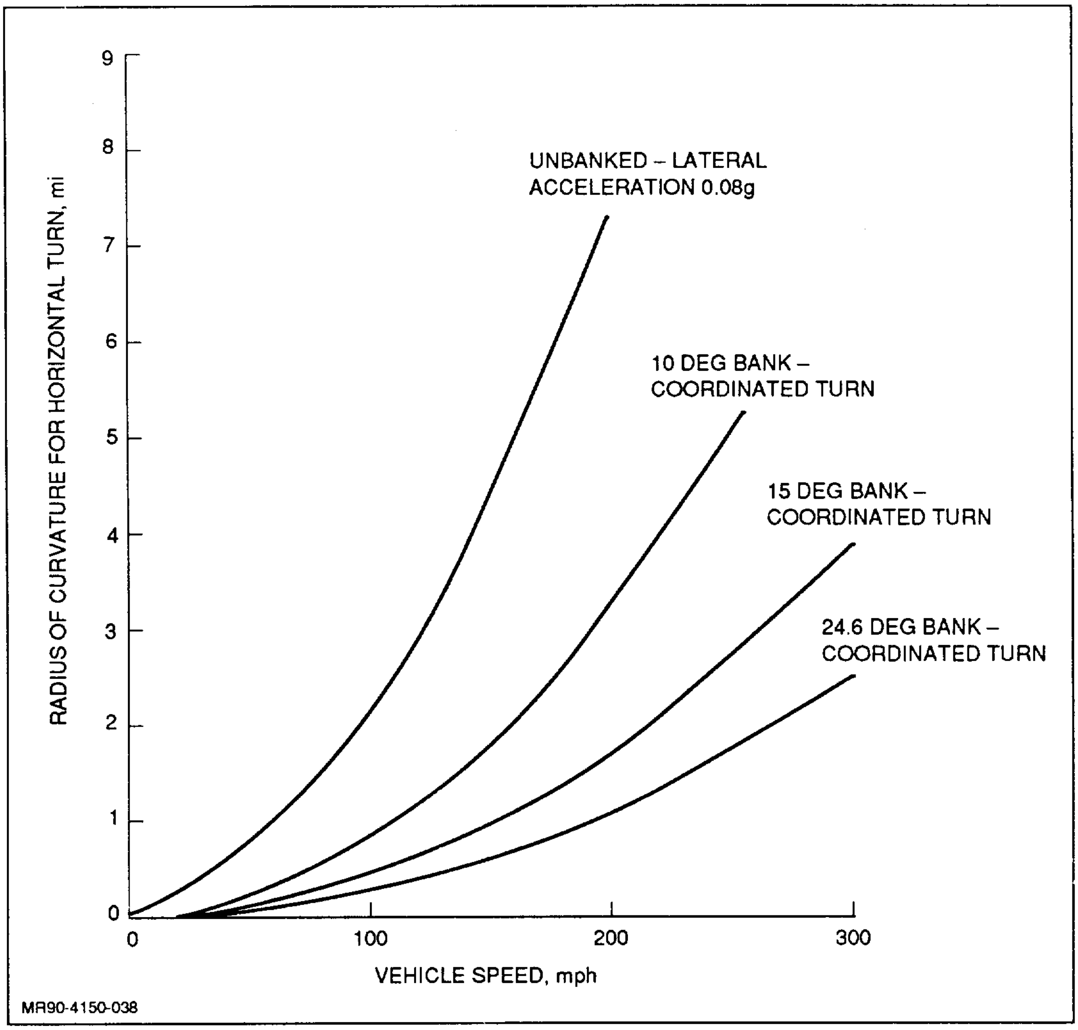

Fig. 6-3 Allowable Radius of Curvature as a Function of Bank Angle and Vertical Speed

fixed guideway bank of up to 12 deg, will allow variable bank angles of 0 to 24 deg. The concept of independent carriage bank is not new. It is used in some high-speed rail vehicles such as the X-2 by ABB and was incorporated (up to 14 deg) in the Grumman-built Tracked Air Cushion Vehicle constructed for the U.S. DOT.

Previous studies have illustrated the dominance of land acquisition cost in setting the economic viability of MAGLEV systems. Deployment scenarios in which existing public land may be used clearly show an advantage. The prospects for dual use of existing rights-of-way are particularly attractive. One such possibility is to use the interstate highway system. This would provide an attractive scenario in which the cost of land use would be zero; a highway would be available to provide access to the construction site; and the network already connects most of the population centers of interest. A possible problem, particularly in the Northeast, is that the hilly terrain results in a generally winding highway configuration. The speeds at which highway vehicles traverse these routes, 60 mph, are consistent with their profiles. To increase the speed by a factor of five, high banking or some other means of softening the turns must be used.

The NYS Thruway Authority supplied geometry data along the length of the Thruway, which had been selected as one of the prime right-of-way candidates in the State. This data is presented in Table 6-2 and consists of information divided into groups between each interchange, including the radius of the tightest bend, an estimate of the typical bend radius, and the steepness and length of the highest grade.

This data was analyzed in several different ways. In all cases, a maximum bank angle of 24 deg was assumed. In the first case, the speed on that segment of the highway between interchanges was calculated by Equation (3) above, and was assumed to be held constant between interchanges. This data is shown in Fig. 6-4 (dotted line - Run no. 1), and resulted in an average speed between New York City and Buffalo of 169 mph, far below the potential of the MAGLEV vehicle. In the second case, it was assumed that each segment consisted of one bend having the tightest radius and that the remainder of the segment was a continuous series of bends having the typical radius. The results of this analysis, also shown in Fig. 6-4 (solid line - Run no. 2), show an average speed of 192 mph.

In both of these cases, the MAGLEV guideway was constrained to follow exactly the assumed profile of the highway. The right-of-way width for the NYS Thruway and a modern superhighway is usually several hundred feet; the width for a dual-track MAGLEV is only 30 ft. This suggests the possibility of allowing the guideway to move from one side of the highway to the other in an enhanced turn as shown in Fig. 6-5, thereby increasing the guideway radius of curvature.

Referring to Fig. 6-5:

$$a = [R(i)-r(i)]\sin(ANG)$$

$$b = [R(i)-r(i)]\cos(ANG)$$

$$R(o) = r(o)+b \quad \text{and} \quad R(i) = R(o)-w(g)$$

then:

$$R(o) = r(o)+[R(o)-w(g)-r(i)]\cos(ANG)$$

rearranging:

Table 6-2 NYS Thruway Geometry Data (Sheet 1 of 2)

A	B	C	D	E	F
Interchange	Miles	Min radius, ft	Typ radius, ft	Max grade, %	Grade lgth, ft
0	0.00	0	0	0	0
1	0.48	1800	1800	4	1500
2	1.42	1800	2000	4	1800
3	1.77	1700	1700	0.76	2100
4	2.18	2001	2001	3	1400
5	2.40	8000	8000	3	1900
6	3.99	1955	2500	3	2700
6A	4.82	2025	2700	3	1900
7	7.54	3000	5000	3	3300
7A	10.33	2800	3200	3	1900
8	11.31	2900	2900	3	3500
9	12.85	3400	3400	3	5000
10	16.75	2850	2850	3	2300
11	17.60	6000	6000	3	3500
12	18.76	4000	5500	3	5200
13	20.94	11437	11460	3	6600
14	22.80	5707	5800	3	2400
14A	23.53	4275	4300	3	2800
14B	27.62	2837	5000	3	4600
15	30.44	1973	9000	2.58	2000
16	45.20	2825	5000	3.08	2300
17	60.10	3500	5500	3	6000
18	76.01	5000	10000	3	4300
19	91.37	2859	6000	3	4000
20	101.25	3767	5000	3	1100
21	113.89	3015	4500	3	3300
21B	124.53	5000	6000	3	1700
21A	133.60	3097	5000	3	1400
22	134.93	4092	4500	0.5	1800
23	141.92	2864	6000	3	1300
24	148.15	4044	5000	2.38	1200
25	153.83	6000	10000	1	2700
25A	158.82	5200	6000	2	2200
26	162.22	5200	6500	3	3500
27	173.59	5000	5200	3	2400
28	182.17	5055	6000	3	7600
29	194.10	4465	10000	3	1200
29-1	201.00	2864	5000	3	5700
29-2	208.00	2864	20000	3	5700
29A	210.62	2864	5000	3	5700
30	219.70	2819	5000	3	11400
31	232.85	5600	10000	2.96	4600
32	243.37	3809	5000	3	2600
33	252.71	5730	11500	0.02	1800
34	261.50	4371	5730	2.5	1500
34A	276.58	5370	5730	1.18	1200
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Table 6-2 NYS Thruway Geometry Data (Sheet 2 of 2)

A	B	C	D	E	F
Interchange	Miles	Min radius, ft	Typ radius, ft	Max grade, %	Grade lgth, ft
35	278.93	5370	5730	0.7	1600
36	282.93	5370	5730	2.2	1500
37	283.79	5370	5730	2.2	1500
38	285.95	5370	5730	3	1600
39	289.53	5370	5730	3	1700
40	304.19	5783	5730	2	1200
41	320.41	4583	5730	3	2000
42	327.10	5056	5730	3	1600
43	340.15	5730	8500	3	2500
44	347.13	17188	17188	2.36	1300
45	350.99	5730	5730	3	3600
46	262.44	5370	7000	3	4100
47	378.56	8595	11500	3.02	1700
48	390.13	5730	15000	3	3900
48A	401.72	7640	10000	2.9	1400
49	417.27	5730	5730	3	1200
50	420.34	5730	6000	2.3	800
50A	420.70	3016	3016	0.64	1600
51	421.57	3016	3016	1.02	1900
52	423.19	10000	10000	3	1500
52A	424.92	3016	3016	3	1700
53	426.17	1928	2000	2.87	1000
54	427.94	2010	2500	3	1600
55	429.47	2864	2864	2	800
56	432.45	2865	6000	3	1400
57	436.22	4000	7000	2.94	1000
57A	444.87	7200	20000	0.79	900
58	455.54	7813	12000	3	2000
59	467.74	2292	6000	3	1300
59-1	484.00	5730	7000	3	1300
60	485.00	5730	15000	3	1300
61	494.92	1500	10000	0.97	2100
Averages		4551.03	6573.65	2.63	2587.01
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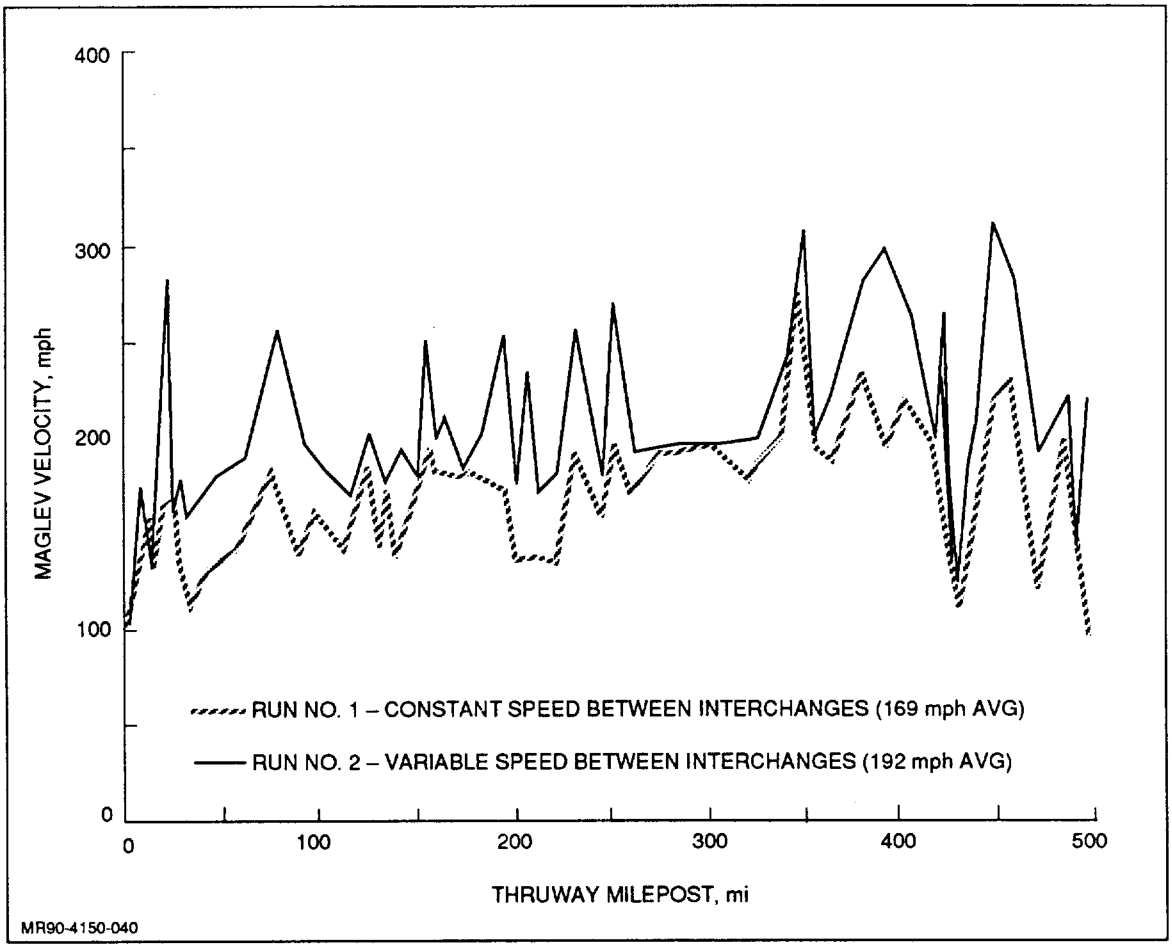

Fig. 6-4 NYS Thruway MAGLEV Speed Profiles

$$R(o)[1-\cos(ANG)] = r(o)-[w(g)+r(i)]\cos(ANG)$$

or:

$$R(o) = \frac{r(o)-[r(i)+w(g)]\cos(ANG)}{1-\cos(ANG)}$$

defining the midway radii as:

$$r = r(o)-w(row)/2 \quad \text{and} \quad R = R(o)-w(g)/2$$

then:

$$R = \frac{r+w(row)/2-[r-w(row)/2+w(g)]\cos(ANG)}{1-\cos(ANG)} - w(g)/2 \tag{4}$$

Equation (4) thus defines the guideway bend radius (R) as a function of the right-of-way radius

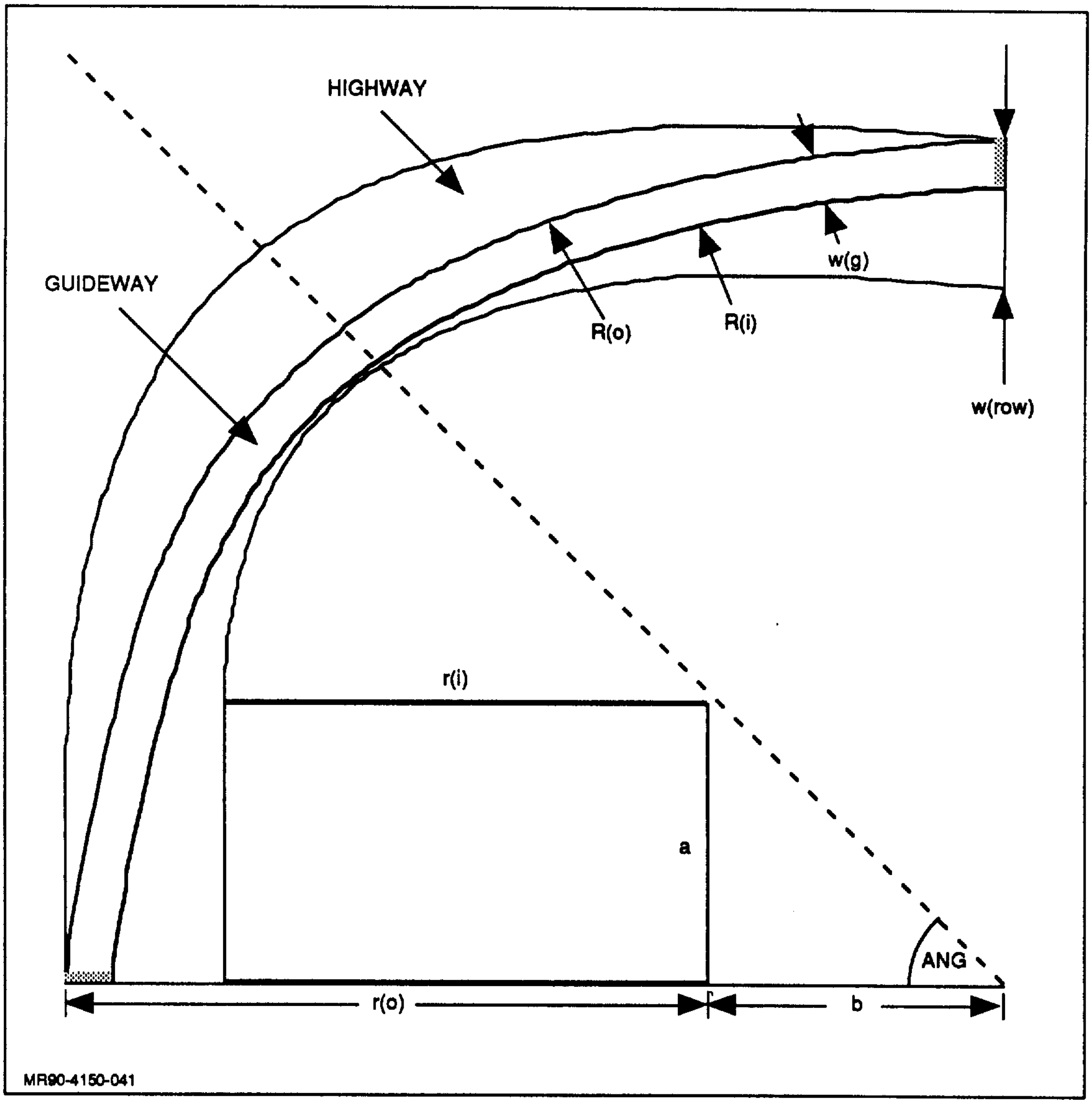

Fig. 6-5 Enhanced Turns Geometry

(r), right-of-way width [w(row)], and half angle of the bend (ANG). For small bend angles the radius enhancement is dramatic, but is less for large angles.

Figure 6-6 shows the speeds possible with enhanced turns based on the assumption of a 200-ft right-of-way width, 30-ft guideway width, and a total bend angle of 40 deg. The dashed line (Run no. 3) corresponds to a speed in each segment based on the minimum bend radius, and the solid line (Run no. 4) is based on the typical bend radius. The latter case recognizes some alignments out of the right-of-way on the tightest bends. These two cases provide average speeds of 217 and 240 mph, respectively.

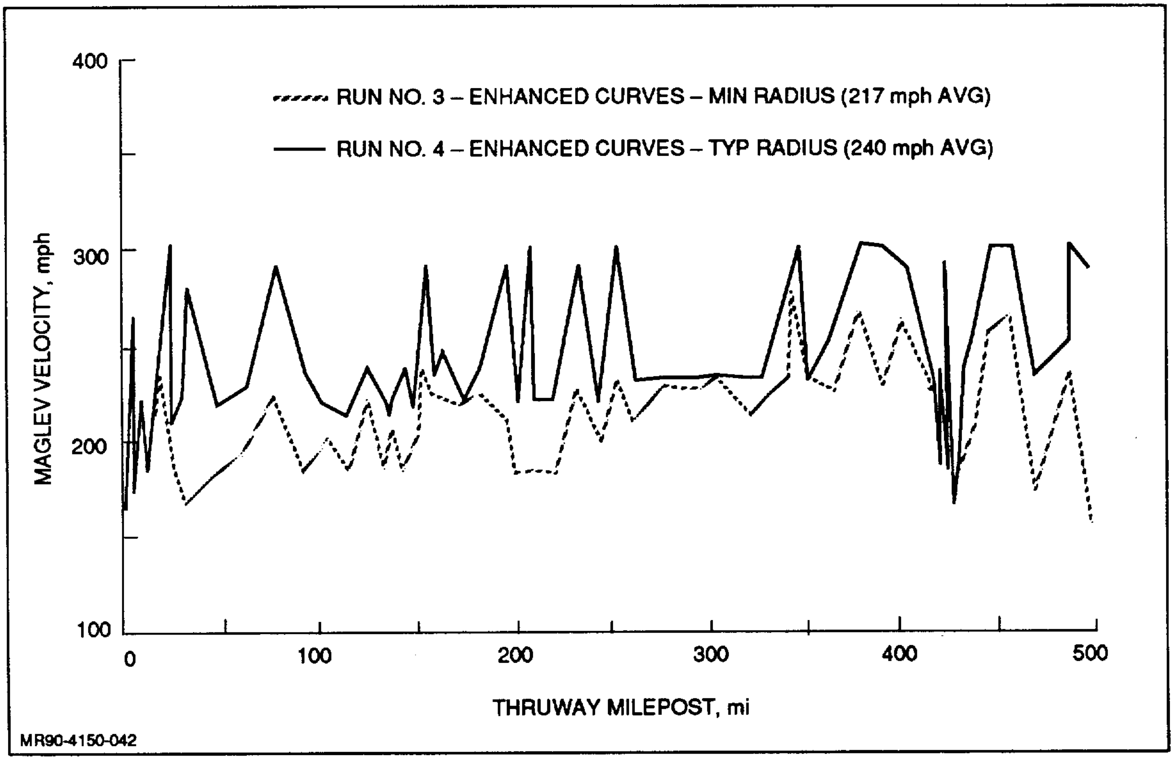

Fig. 6-6 NYS Thruway MAGLEV Speed Profiles with Enhanced Turns

There is a section of the Thruway near Interchange 15 where there are several tight bends. This is the area where the Thruway turns north. To understand the speed capability in depth, extensive information was provided by the NYS Thruway Authority for this Thruway section. This data, presented in Table 6-3, gives the bend radius and length for each turn, indicates the length of each straight (tangent) section, gives the average right-of-way (row) width, and indicates the subtended angle given by the radius-to-length ratio for each location along the Thruway. This permitted a more accurate analysis of a small section of the Thruway for comparison with the basic analysis for the entire length.

Figure 6-7 presents the bend radii for each discrete section of the highway segment. The spaces between the bars indicate straight sections (infinite radius). Figure 6-8 shows the right-of-way width for each of the sections. It will be noted that the average width is closer to 275 ft than to the 200 ft assumed in the previous analysis.

Table 6-3 NYS Thruway Data – Vicinity of Interchange 15 (Sheet 1 of 2)

Milepost	Radius, ft	Length, ft	Average row width, ft	Subtended angle, deg
Int 14-22.8	5700	3600	290	36.2
	Tangent	2800	340	–
Int 14A-23.53	4300	3600	280	48.0
	Tangent	7300	260	–
	3800	2000	250	30.2
	Tangent	900	250	–
	2900	1600	300	31.6
Int 14B-27.62	Tangent	13000	250	–
	4300	2800	260	37.3
	Tangent	2200	260	–
	8500	600	250	4.0
	1970	1800	180	52.4
	3000	500	260	9.6
Int 15-30.44	6000	1500	280	14.3
	8000	3900	280	27.9
	2800	3900	280	79.8
	Tangent	1000	290	–
	2800	2600	400	53.2
MP 33.2	4000	4200	380	56.0
	Tangent	500	250	–
	2800	2400	*	49.0
	Tangent	1200	260	–
	2800	1800	320	36.8
	Tangent	3300	260	–
	4500	2000	280	25.5
	Tangent	1500	330	–
MP 36.13	10000	1200	340	6.9
	5500	900	280	9.4
	Tangent	500	380	–
	4000	1200	480	17.2
	Tangent	600	320	–
	5000	1000	360	11.5
	Tangent	1000	310	–
	7000	1200	300	9.8
	8000	1600	290	11.4
	Tangent	1000	370	–
	3500	1400	300	22.9
	2800	1800	290	36.8

* MP34 – 320 back, 600 ahead

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Table 6-3 NYS Thruway Data – Vicinity of Interchange 15 (Sheet 2 of 2)

Milepost	Radius, ft	Length, ft	Average row width, ft	Subtended angle, deg
MP 38.6	5000	500	270	5.73
	Tangent	600	290	–
	5000	500	270	5.73
	6500	2800	310	24.7
	Tangent	1400	290	–
	15000	2500	340	9.55
	10000	1700	290	9.74
	Tangent	1800	300	–
	9000	1100	300	7.0
	7000	1000	380	8.18
MP 41.57	Tangent	2500	380	–
	30000	1200	330	4.0
	5600	700	290	7.16
	7000	700	200	5.73
	Tangent	3800	290	–
	5000	1500	300	17.2
	7600	500	340	3.8
	Tangent	1900	340	–
MP 44.0	8000	2700	350	19.3
	25000	2400	340	5.5
	10000	880	250	5.0
	6000	750	340	7.16
Int 16-45.2	Tangent	1600	290	–
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The maximum theoretical speed for each of these sections is shown by the dotted line in Fig. 6-9, and is based on the analytical technique previously described using the full right-of-way width to increase the radius of the turns. It is obvious that it will not be possible to accelerate and decelerate to meet this speed profile. A more reasonable profile is represented by the solid line which was calculated to include the specified acceleration rate of the vehicle (5 ft/sec^2). For this highway segment, one of the more complex on the Thruway, the average speed resulting from this analysis is 235 mph, which compares favorably with the 240 mph figure calculated for the entire Thruway in the previous analysis; therefore, cruising speeds close to the desired 250 mph are possible on existing highway corridors.

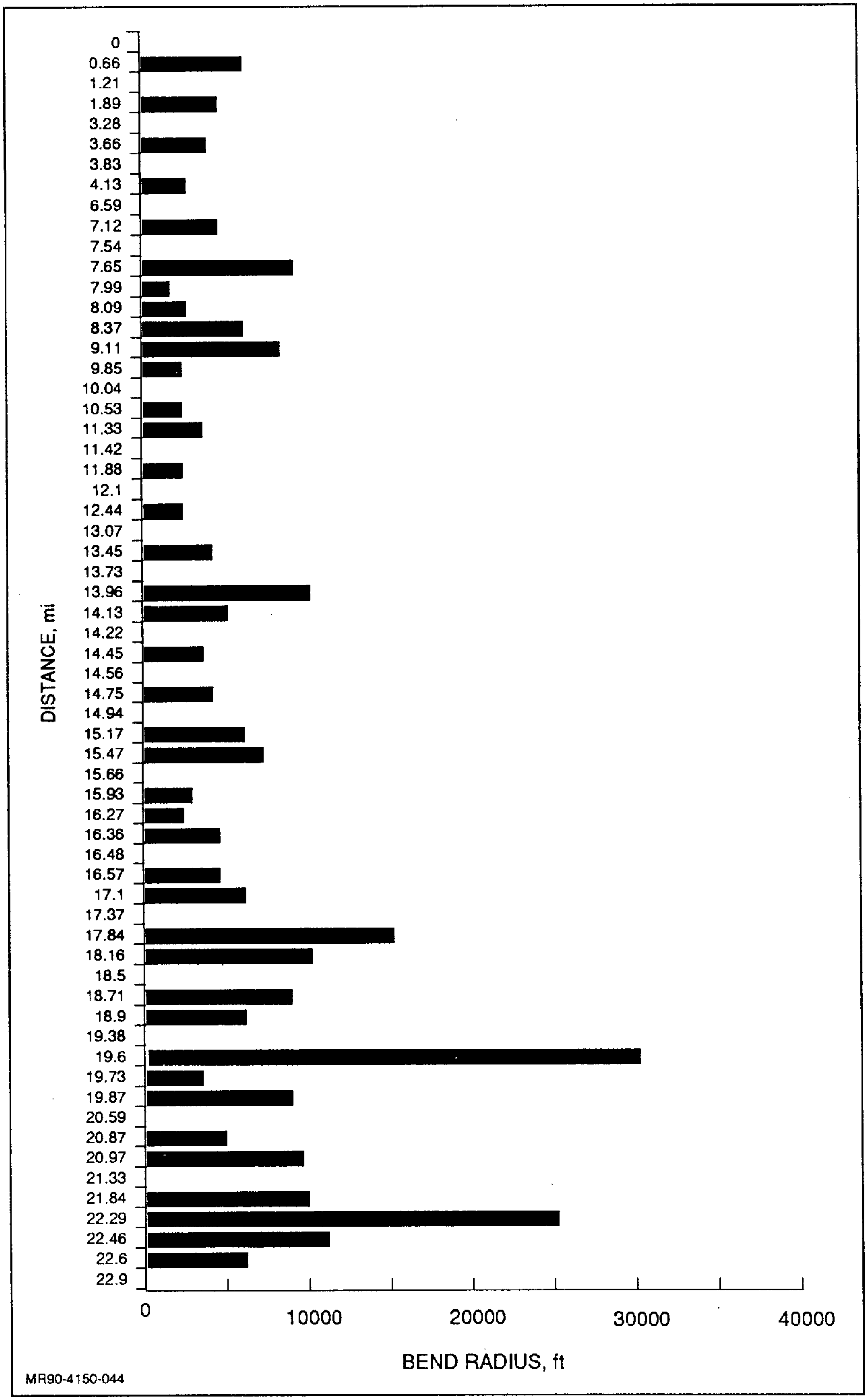

Fig. 6-7 NYS Thruway Bend Radii – Vicinity of Interchange 15

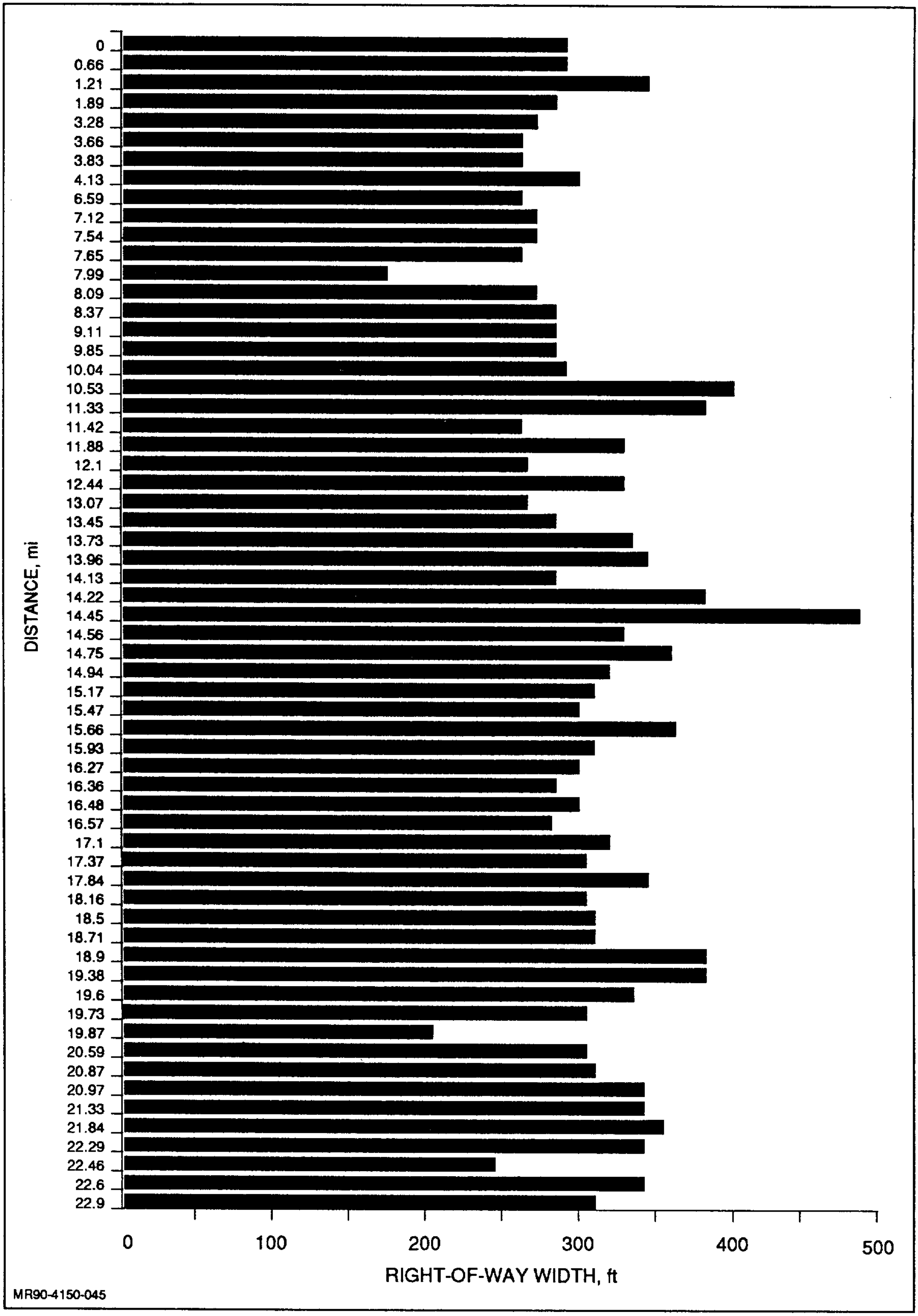

Fig. 6-8 NYS Thruway Right-of-Way Width – Vicinity of Interchange 15

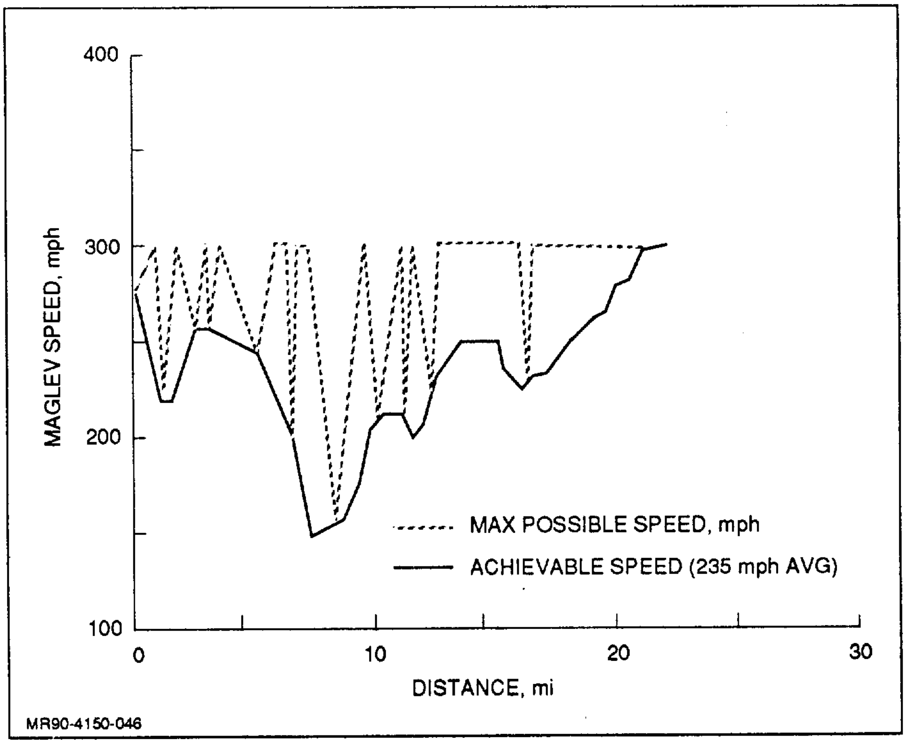

Fig. 6-9 NYS Thruway MAGLEV Speed Profiles – Vicinity of Interchange 15

Enhancing the curves cannot be done without a cost because the guideway must be transitioned from one side of the highway to the other at a very shallow angle. A long span length or some other structure must allow this transition with adequate clearance for the highway traffic below. Additional studies are recommended to identify the cost impact associated with this requirement. The analysis also assumes a total bank angle of 24 deg. There is no anticipated difficulty in providing the 12 deg angles in both the guideway and the vehicle, but the comfort impact on riders experiencing a relatively continuous series of banked turns, represented by a 0.15 G acceleration or deceleration, must be studied.

This study confirms the important relationship between the attainable vehicle speed and bank angle. The analysis which produced the 240-mph average speed at the 24-deg bank angle was repeated for a maximum bank angle of 12 deg. The average speed dropped to 169 mph as shown in Fig. 6-10.

None of the present MAGLEV designs, neither Transrapid nor MLU002, include independent carriage bank which may limit their total bank angles to about 12 deg, and result in reduced speeds in Northeast applications. Likewise, steel-on-steel high-speed rail is limited to 10 or 12

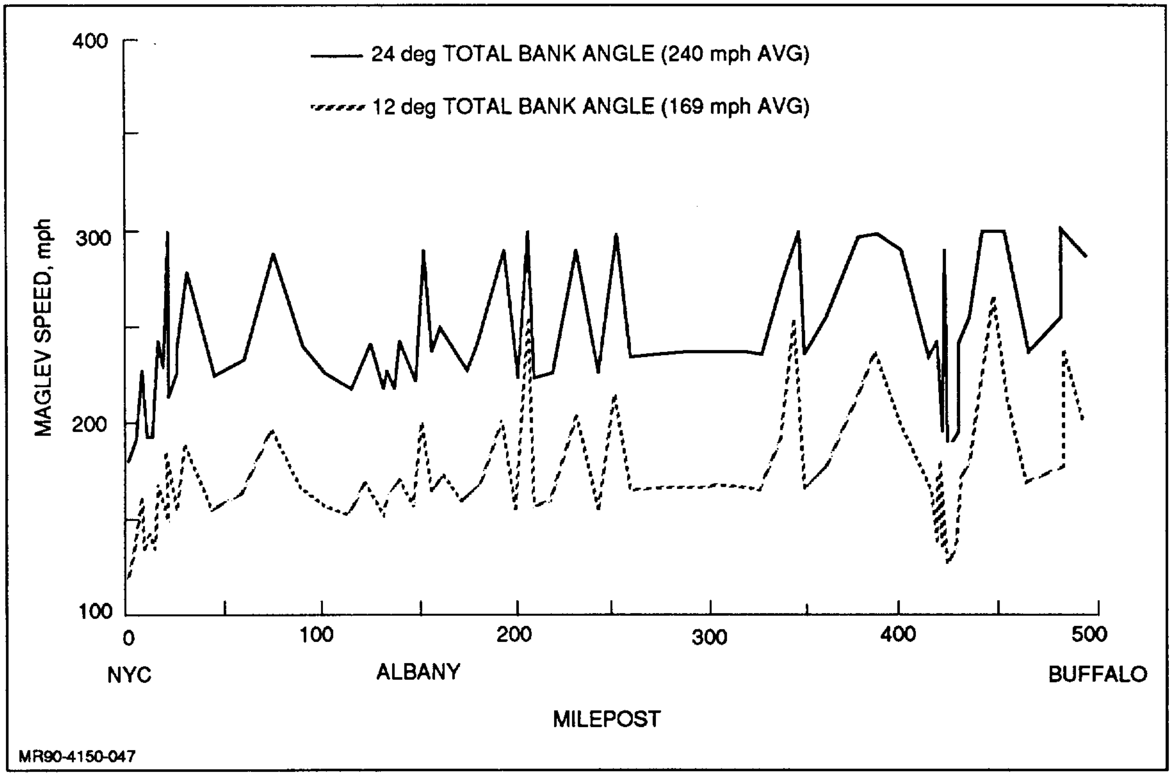

Fig. 6-10 NYS Thruway MAGLEV Speed Profiles – 12 Deg vs 24 Deg Bank Angles

deg bank angles for tilt-train versions and several degrees for fixed-geometry cars. In the latter case, the average speed would drop severely. It is clear that if we wish to provide comfortable high-speed transport over corridors which were designed for one-fifth the speed, the vehicles must be designed specifically for this service.

6.5.3 Implications of Banking Analysis

The analysis presented in this subsection and Subsection 6.5.4 was provided in private communication from Dr. James Powell and Dr. Gordon Danby.

While it may be necessary for the guideway to span the roadway at special locations, it may not be practical to do it routinely as is implied by the previous analysis. There are, for example, 12 sharp curves from milepost 22.8 to milepost 36.13, or an average of one every mile. It might be annoying to both MAGLEV passengers and motorists to have the guideway criss-crossing the highway once every mile.

In addition, the high average speed on this and other sections of the Thruway will require repeated acceleration and deceleration at 0.15g; the vehicle would slow down for sharp curves and speed up on straightaways. Motorists do this routinely when driving, and the assumed acceleration is certainly well within comfort limits. However, it is not clear that passengers would accept this in a MAGLEV system.

The degree of maximum bank angle that will be acceptable to passengers is not clear. Air travelers do experience 24 deg with little or no discomfort; however, this generally occurs at takeoff and landing, and the total number of such maneuvers is usually two or three. In addition, visual reference to ground level for airplane banking is usually absent or greatly reduced compared to the visual impact MAGLEV passengers would experience. The answer to the question of passenger acceptance of trips with many banks at 24 deg along with a strong visual reference to ground level is unclear at this time.

The conclusion, therefore, is that although the motions dictated in Subsection 6.5.2 are within acceptable passenger comfort levels as identified in Section 2, it is not clear that passengers, especially very young children or older people, will feel comfortable on a MAGLEV vehicle travelling at 260 mph along an interstate highway originally designed to accommodate vehicles travelling at 60 mph. Testing a broad spectrum of potential passengers (i.e., men, women, children, elderly, and disabled) should be conducted using flight simulators similar to those used by aerospace companies to evaluate interacting flight/pilot characteristics of aircraft systems under development. When this is done, we will know the allowable levels of bank angle, bank angle rates, and bank angle accelerations under repeated applications of coordinated turns from a visual and physiological perspective.

6.5.4 Alternative Approach

If the results of flight simulator testing described in Subsection 6.5.3 prove to be restrictive on banking levels and number of banks to be negotiated in a given timeframe, an alternative approach should be examined. This approach would have the guideway deviate from the highway right-of-way at some locations in order to maintain speed and/or minimize bank angle. The required deviations are usually minor. The Thruway in most sections is rural; however, the developed areas are usually the ones that require right-of-way deviations.

The most problematic section of the Thruway in terms of alignment appears to be the section from milepost 22.38 to milepost 45.2, as previously discussed and identified in Table 6-3. There are a number of sharp turns with turn angles above 20 deg and radii of curvature less than 50 percent of the allowed MAGLEV radius of curvature at 300 mph (13,000 ft at 24-deg bank angle). These turns are usually followed by a tangent (straight-line) section. Most of the tangent sections are somewhat shorter in length than the turn length.

The relative signs (clockwise or counterclockwise) of the curve directions are not given; however, the sum of the magnitudes for all turns is large, on the order of 900 deg, so that there will be about equal amounts of turning in each direction. One would expect, for example, a 30-deg or greater turn in one direction to be followed by a sharp turn in the other direction. A substantial portion of this deviation, approximately 100 ft, can be accommodated in the right-of-way width. The maximum possible net deviation from the right-of-way is approximately 100 ft.

Thus, it appears that an approach to dealing with highway turns and nonstraight alignments is to allow the guideway to deviate occasionally from the right-of-way when necessary and minimize:

- Guideway spans across the roadway; and
- Frequent acceleration/deceleration.

No single approach to high-speed banking (allowing for crossing the Thruway or deviating from it) will accommodate all curves. A combination of the two will be used depending on a detailed investigation of each turn, with limitations dictated by flight simulator testing of each turn. The sharp turns can be divided into two classes:

- Class I: Isolated - The given turn is preceded and followed by a straight section of substantial length; and

- Class II: Sequential - The given turn is preceded and/or followed by another sharp turn.

Analyses have been made by Dr. James Powell for Class I-type turns with results shown in Fig. 6-11 through 6-14. Maximum deviation of the guideway from its nominal position along the roadway right-of-way is shown as a function of MAGLEV speed and curve angle for both inside and outside curves. Bank angle is assumed to be 24.6 deg in all cases.

The highway curves are assumed to be sharp angles (i.e., zero radius of curvature), the worst case. A non-zero radius of curvature for roadway turn reduces the deviation of the MAGLEV guideway from the highway right-of-way (e.g., by roughly 50 percent if the roadway radius of curvature is 50 percent of the allowable MAGLEV radius of curvature).

Even for sharp angle curves, however, the maximum deviation is acceptable if the curve is the inside type, or only about 200 ft for a 20-deg angle at 300 mph. Maximum deviation is considerably greater, by a factor of about four, for outside curves. It would be preferable to have only inside curves; unfortunately, an inside curve will usually be followed by an outside curve.

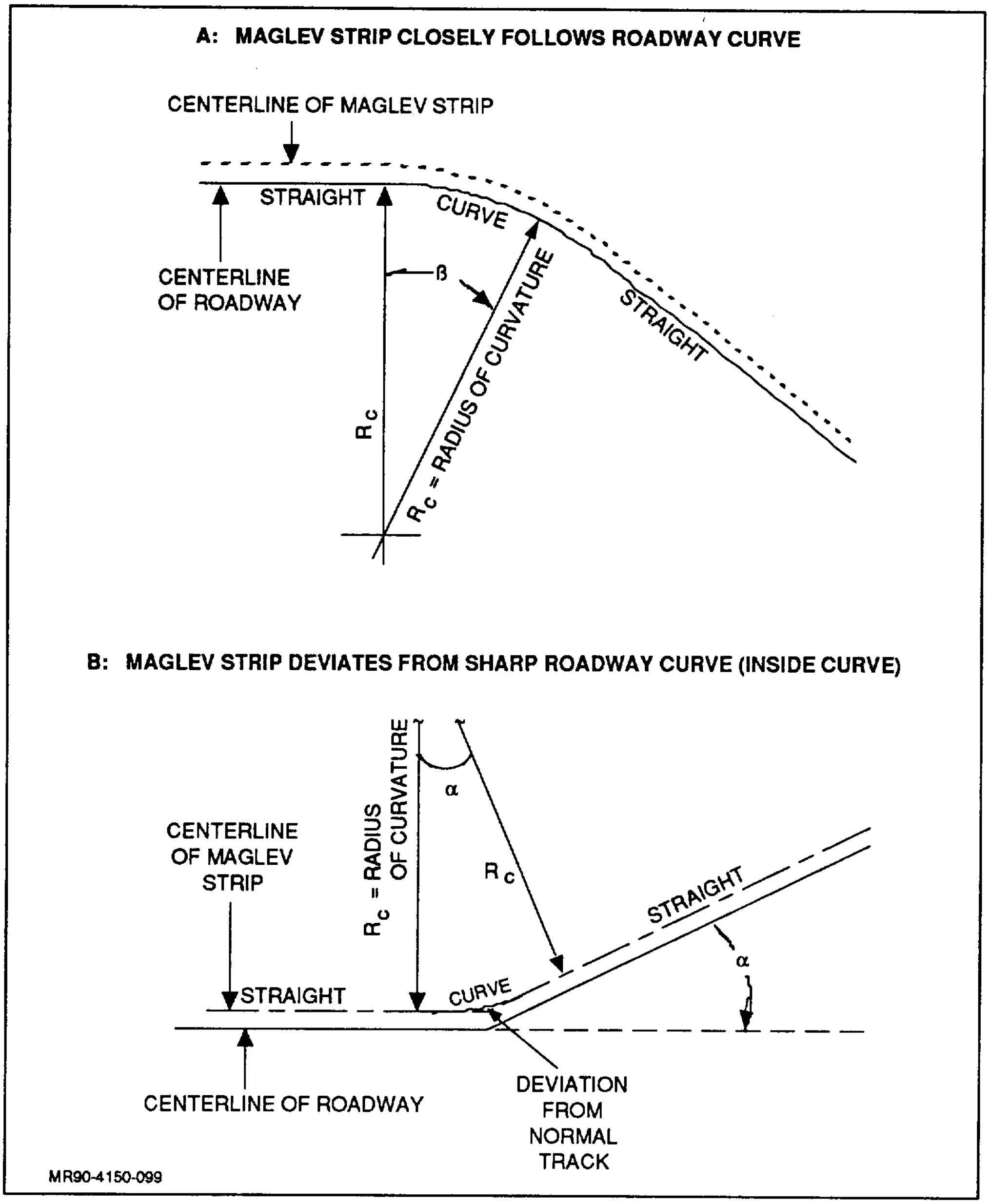

Fig. 6-11 Relationship of MAGLEV Guideway to Interstate Highway at Curves

Guideways following Class II-type turns will also have relatively small deviations from the nominal roadway right-of-way, if, for example, the roadway is composed of alternating segments of 30-deg positive curvature (clockwise) with radii of curvature R_1, followed by 30-deg curves of negative curvature (counterclockwise) with the same radii of curvature R_1.

For the case where the radius of curvature of MAGLEV guideway (R_2) is ~15,000 ft (300 mph, 24-deg bank angle), the maximum deviation (ΔH) of the guideway from the roadway right-of-way is given in Table 6-4 as a function of roadway radius of curvature.

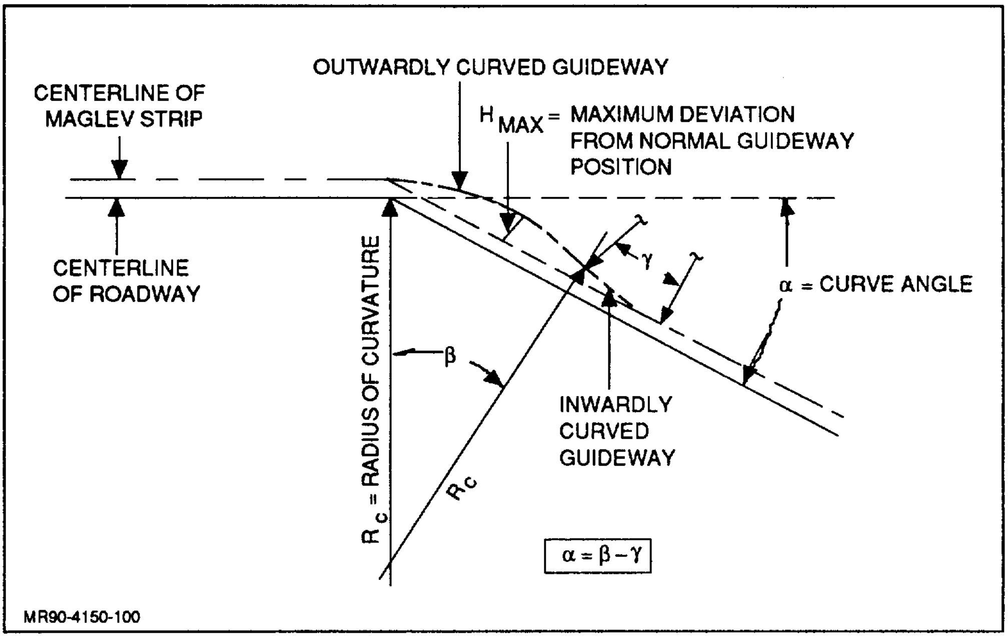

Fig. 6-12 Guideway Position in Outside Curve

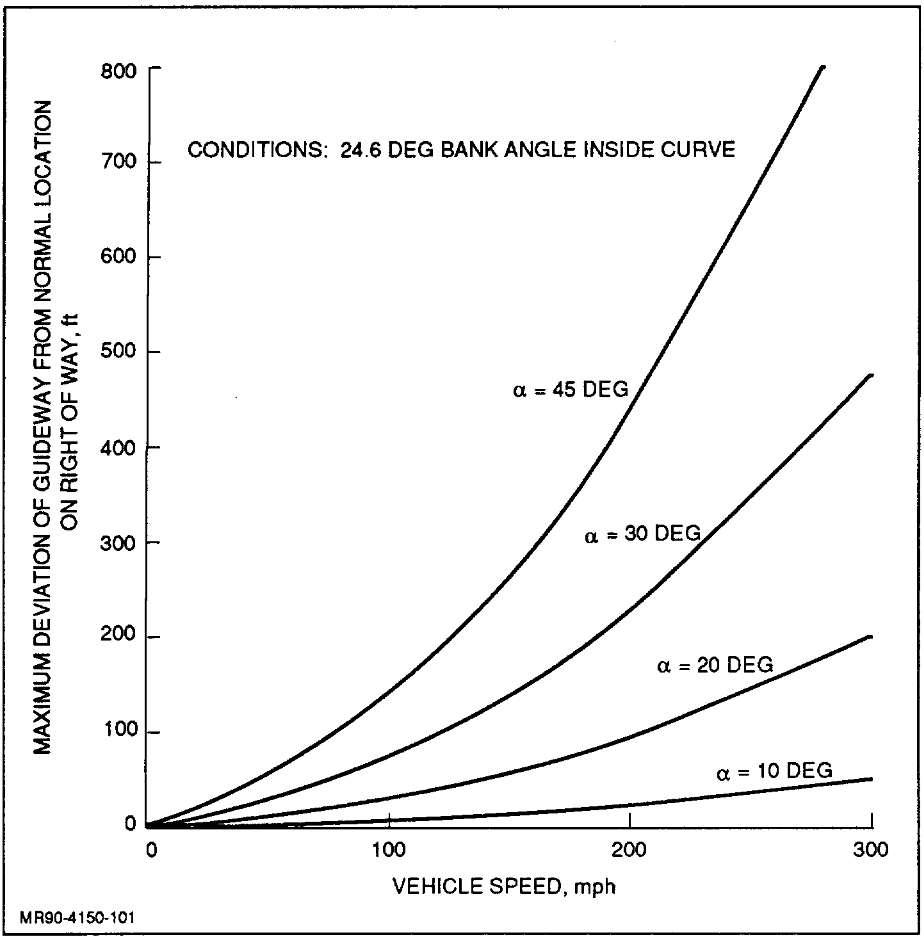

Fig. 6-13 Maximum Deviation of MAGLEV Guideway from Normal Location on Right-of-Way vs Curve Angle & Vehicle Speed

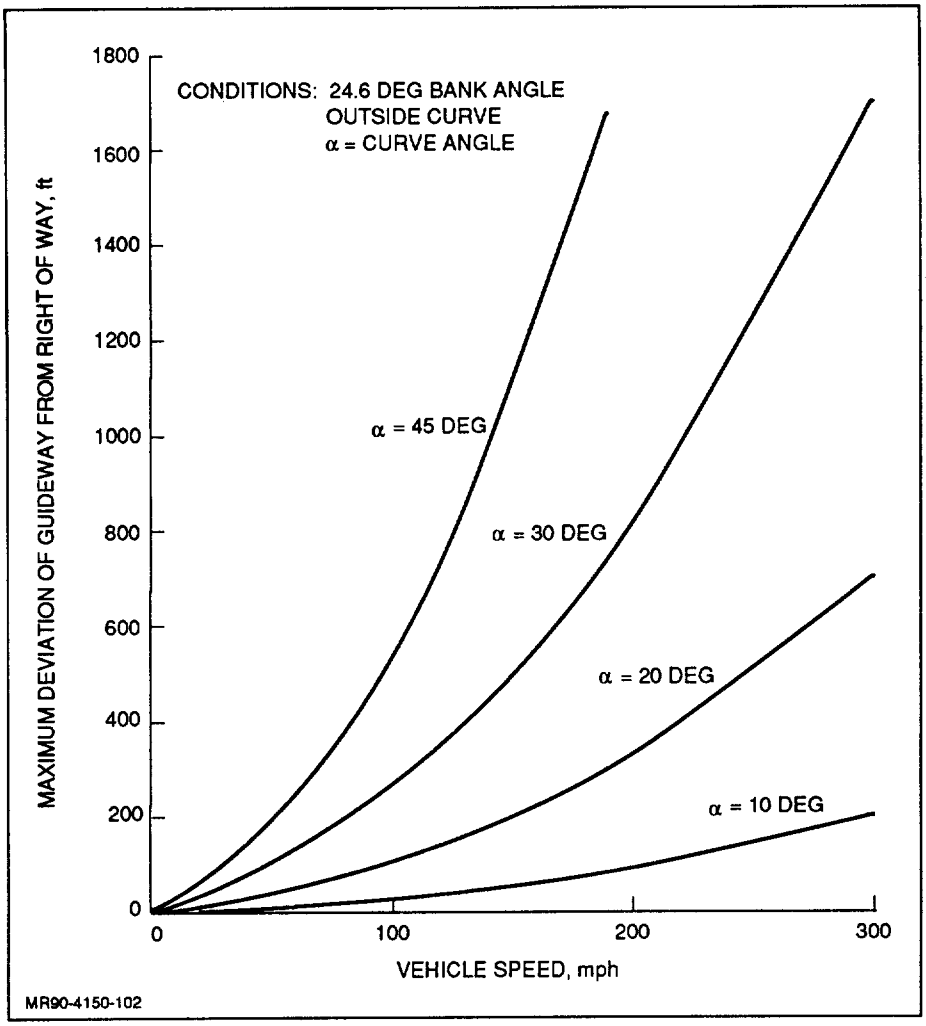

Fig. 6-14 Maximum Deviation of MAGLEV Guideway from Right-of-Way vs Vehicle Speed & Roadway Angle of Curve

Table 6-4. Maximum Deviation (ΔH) of Guideway as a Function of Roadway Radius of Curvature

ΔH, ft	Radius of curvature, ft (1)
63	1,000
118	2,000
163	3,000
226	5,000
225	10,000
0	15,000

1. R_1 radius of curvature of 30 deg turn in roadway

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7 – MARKET DEMAND FORECASTS AND CONCEPTUAL CORRIDOR PLANNING

7.1 INTRODUCTION

This study of the market demand and potential transportation corridors for a MAGLEV system was performed by the New York State Department of Transportation (NYSDOT) in conjunction with the NYS MAGLEV Task Force. The goal of this effort is to provide conceptual MAGLEV corridor planning and corresponding market assessments. Specifically, the analysis presented in this section will provide information on the effect that MAGLEV systems will have on the transportation network and markets in New York State and the Northeast region of the United States.

7.2 TYPE OF MARKET FORECAST PERFORMED

This analysis of future intercity travel and MAGLEV ridership focused on three types of travel market forecasts:

- Projected future ridership growth of the intrastate market that would be served by a MAGLEV system;

- Projected intracorridor trips that could be diverted from existing modes to the MAGLEV system; and

- Projected totally new trips or induced trips that under present conditions would not be made, but would be created by the improved level of service or by the new tourism, recreation, and associated economic development in the corridor provided by implementing an intrastate MAGLEV system.

7.3 ASSUMPTIONS MADE FOR DEMAND ANALYSIS

7.3.1 Route Alignment

For this study, the intrastate corridor chosen follows the NYS Thruway right-of-way from the New York City area north to Albany and west to the Buffalo/Niagara Falls area. Specific corridors and related information are contained in Section 6.

7.3.2 Speeds

To forecast demand estimates, station-to-station travel times have been developed for the intrastate corridor assuming a maximum MAGLEV vehicle speed of 300 mph. The three analyzed speed scenarios assumed using the NYS Thruway's right-of-way. Two of the options correspond to Run no. 3 using enhanced curves – minimum radius, and Run no. 4 using enhanced curves – typical radius discussed in Subsection 6.5 (see Fig. 6-6). These relate to average operating speeds along the corridor of approximately 217 mph and 240 mph, respectively. The third speed scenario assumed an ideal situation where MAGLEV could perform at its practical technological limits. This conforms to an average corridor speed of approximately 280 mph.

7.3.3 Service Frequency

Three different frequency patterns were analyzed. The patterns assumed two vehicles per hour at 30-minute headways, three vehicles per hour at 20-minute headways, and four vehicles per hour at 15-minute headways. For this analysis, it was assumed that this pattern would provide direct express service between every station combination throughout the system.

7.3.4 Station Locations

As a starting point, and due to limitations that will be discussed later, stations were located in the following general areas: New York City, Croton-Harmon/Tarrytown, Newburgh/Poughkeepsie, Kingston/Rhinecliff, Catskill/Hudson, Albany, Schenectady, Amsterdam, Utica/Rome, Syracuse, Rochester, Buffalo, and Niagara Falls. A discussion of station locations and related issues is contained in Subsection 7.9.

7.3.5 Fares

Various estimates of MAGLEV travel demand were made using fares equal to 100 percent, 200 percent and 300 percent of 1989 intercity rail fares. Intercity rail fares were defined as half the regular round trip excursion fares. Typical 1989 rail fares for major city pairs are shown in Table 7-1.

Table 7-1 Typical 1989 Rail Fares – *Various MAGLEV travel demands were made using fares equal to 100 percent, 200 percent and 300 percent of the intercity rail fares.*

City pairs	Rail fares, $
NYC-Albany	56
Albany-Buffalo	69
NYC-Buffalo	111

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7.3.6 Air Ridership

Volumes of air ridership were based on NYSDOT's enplanement data. Projections of origin/destination information were based on NYSDOT's 1988 travel surveys performed at Buffalo, Rochester, Syracuse and Albany airports.

7.3.7 Rail Ridership

Volumes of intercity rail ridership were based on actual trip information supplied by AMTRAK. Origin/destination projections were based on NYSDOT's 1988 travel surveys of various trains operating within New York State.

7.3.8 Auto Traffic

Volumes of auto traffic were based on actual entry/exit data supplied by the NYS Thruway Authority. Origin/destination data were based on travel surveys performed at various interchanges by NYSDOT and the NYS Thruway Authority.

7.3.9 Bus Ridership

Bus ridership volumes were based on existing data and observations made during the 1988 travel survey. Origin/destination information was also based on travel surveys made in 1988.

7.4 FORECAST MODELLING, LIMITATIONS, AND MODIFICATIONS

The projections of future travel demand and MAGLEV ridership reflected in this study were developed using the HORIZONS intercity travel demand forecasting model. The HORIZONS model is a micro-computer based multimodal demand forecasting tool incorporating time series and tradeoff analyses.

It is important to address the model's application and associated limitations in attempting to project MAGLEV ridership. The HORIZONS model was developed to assist NYSDOT in analyzing service changes to the existing intercity transportation network in New York State in general, and the Albany to Buffalo corridor specifically, with an emphasis on the rail mode; the data collection, survey work, and other aspects of the model's development and calibration were performed in this context. It was not specifically designed or developed to perform the type of analyses needed for a complex transportation network and unique service provided by an advanced surface transportation system such as MAGLEV.

Additionally, HORIZONS, like most, if not all, forecast demand models currently used for transportation planning, divides or splits travel demand according to the four existing travel modes: air, auto, bus, and rail. To properly model or predict MAGLEV's relationship and corresponding future trip estimates between the various modal options, the typical four-mode split must be modified to include MAGLEV as a fifth mode.

As a result, some specific conditions and assumptions were made that affected the forecast demand estimates of the MAGLEV system. Due to the limiting four-mode design of the model, the intrastate rail system was assumed to be replaced by a MAGLEV system. Outside of the New York City – Albany – Buffalo – Niagara Falls corridor, the model reflects the current intercity rail service. Consequently, the MAGLEV station areas reflect the general locations of the existing intrastate/intercity rail stations.

Accordingly, the analyses performed for this study should be viewed as an order of magnitude. They are the most reasonable estimates achievable under the existing conditions using the available resources and, despite the acknowledged limitations, are acceptable at this conceptual stage of study.

Future study of MAGLEV systems will require the appropriate resources for data collection and survey work, model design and calibration, and output and reporting capability to assess the unique transportation network, market effect, and ridership generation that a MAGLEV system would provide.

7.5 IMPLEMENTATION SCHEDULE

This conceptual study was performed assuming that revenue service on an intrastate MAGLEV system would begin at the start of the calendar year 2000. The actual start of revenue MAGLEV service could be earlier or later, depending on numerous factors, including the speed and success of research and development efforts for an American MAGLEV system, the funding commitment behind such work, and the outcome of federal MAGLEV initiatives.

7.6 RESULTS OF ANALYSIS

7.6.1 Future Ridership Growth Projections

Run no. 4 was selected as the operational speed condition in performing the fare and frequency ridership sensitivity tests. As shown in Fig. 7-1, Run no. 4 (240 mph average speed) yielded an intermediate ridership level. As expected, the slower operating speeds of Run no. 3 (217 mph average speed) produced lower ridership results. Likewise, the higher operating speeds of the maximum operating schenario (280 mph average speed) produced greater ridership volumes.

7.6.2 Diverted Trip Projections

Sensitivity tests were performed to focus on a combination of frequency and fare structure for Run no. 4 which would yield a tradeoff of maximum revenues, sufficient ridership and reasonable vehicle numbers to serve the frequency pattern. Results of the sensitivity tests performed for Run no. 4 are shown in Fig. 7-2, 7-3 and 7-4.

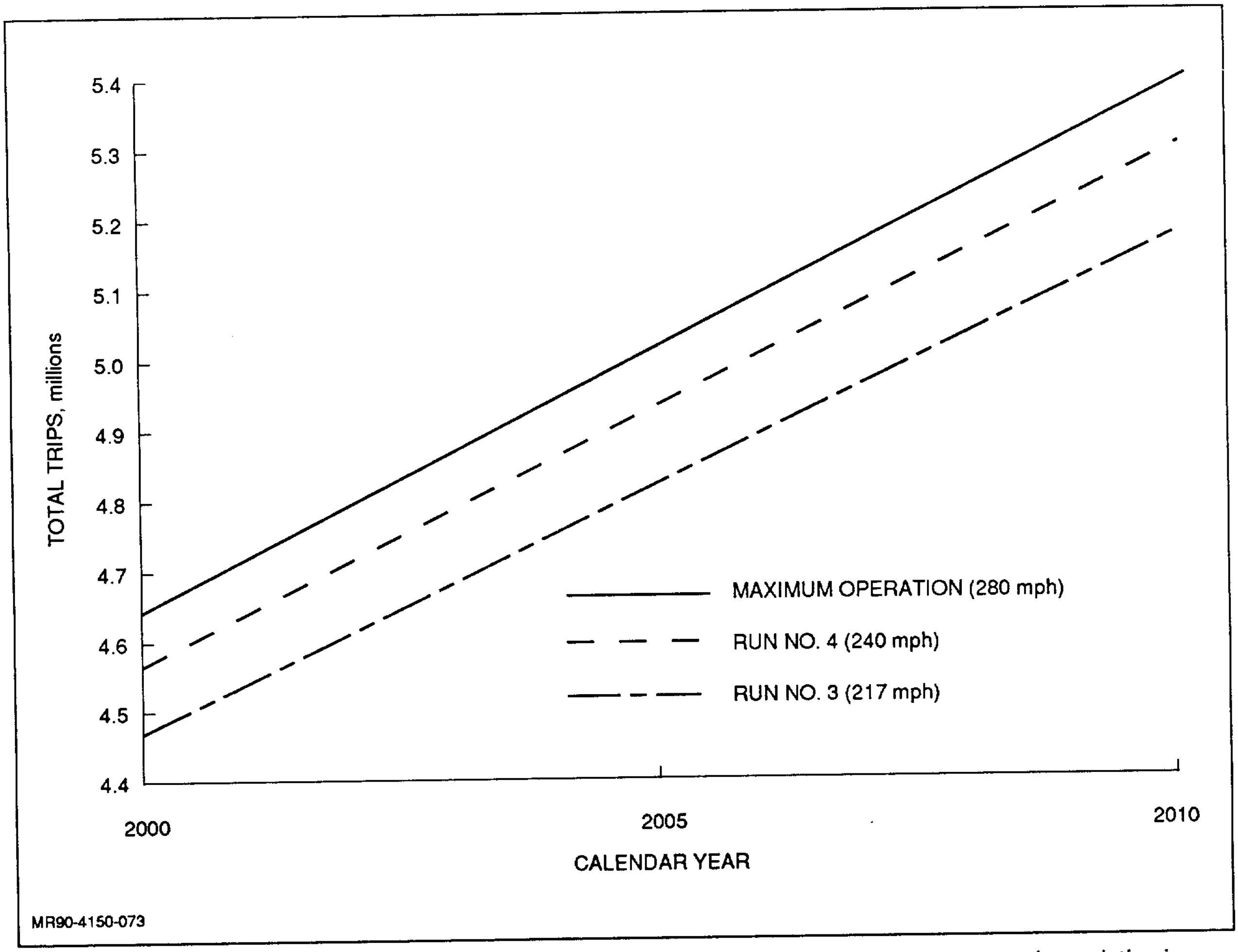

Fig. 7-1 Fare and Frequency Ridership Sensitivity Test Results – *This figure illustrates the variation in ridership demand with average trip speed.*

Based on the sensitivity test results, the option of Run no. 4 with a fare structure of two times the existing intercity rail fares and a frequency pattern of 54 frequencies per day (three express vehicles per hour between every station in the intrastate system) was chosen for a detailed analysis.

The estimates of total ridership for the chosen operating scenario of the intrastate MAGLEV

Table 7-2 MAGLEV Estimated Trips

Year	Base Demand	Market Growth	Diverted	Induced	Total
2000	1,540,000	0	1,900,000	1,050,000	4,490,000
2010	1,540,000	300,000	2,100,000	1,400,000	5,340,000

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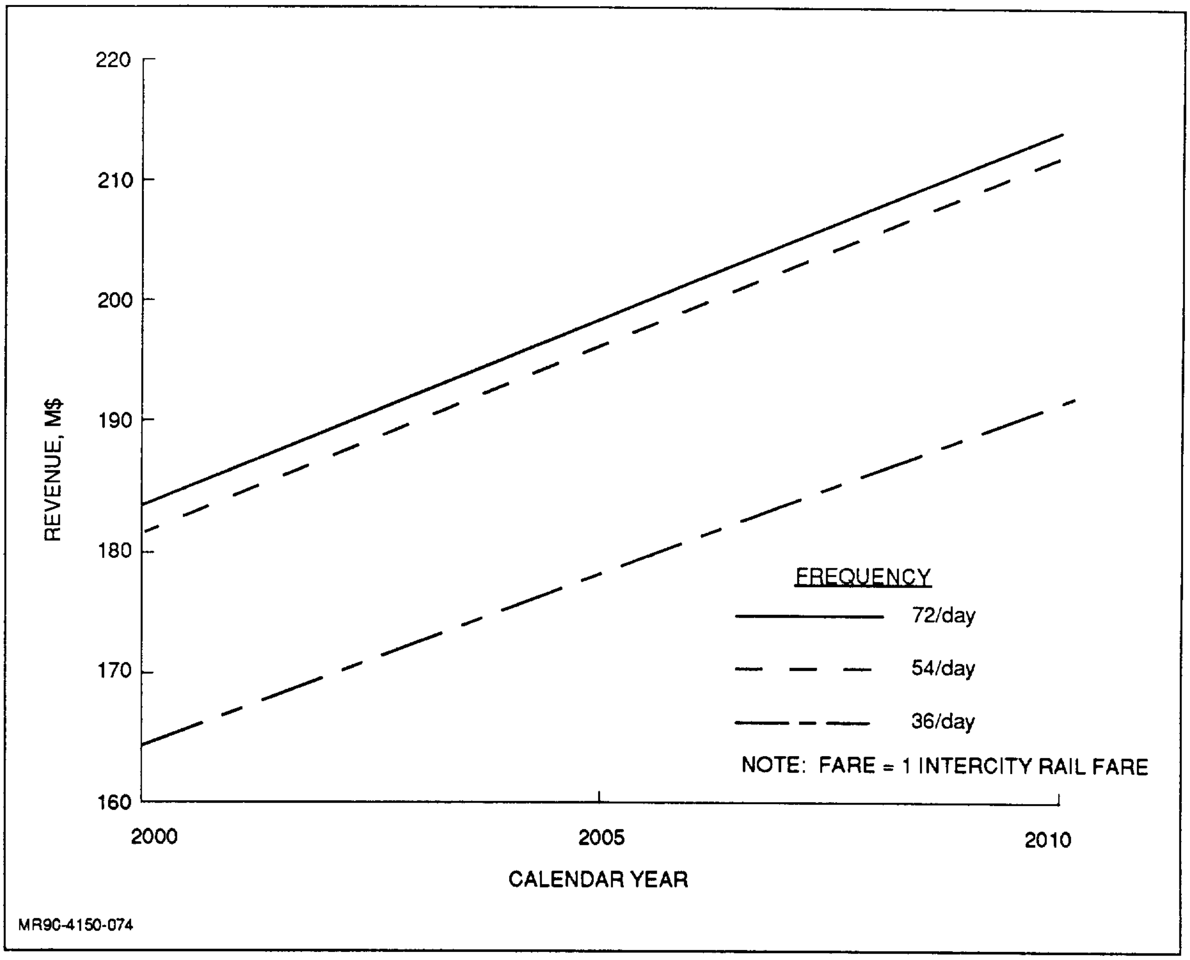

Fig. 7-2 Ridership Revenue Sensitivity Test Results – Fare = One Intercity Rail Fare – *The lowest fare structure examined produces the lowest revenues.*

system for 2000 and 2010 are given in Table 7-2. This projection also includes the MAGLEV market growth, the diverted trips, and the induced trips.

For this conceptual study, corresponding to Run no. 4, with 54 frequencies per day, and at a fare structure of two times the existing intercity rail prices, the estimated intrastate demand is approximately 5.34 million trips.

Based on the preceding estimate, it is projected that 1.43 million trips would be diverted from the auto mode. Additionally, it is estimated that approximately 300,000 trips would be diverted from the air mode.

7.6.3 Ridership Revenues

Based on a total of 5.34 million trips for an intrastate MAGLEV system, and on an average trip length of 167 miles, the estimated revenue for 2010 is approximately $340 million. Some additional revenue from the transport of freight, dependent on the system's design, may be

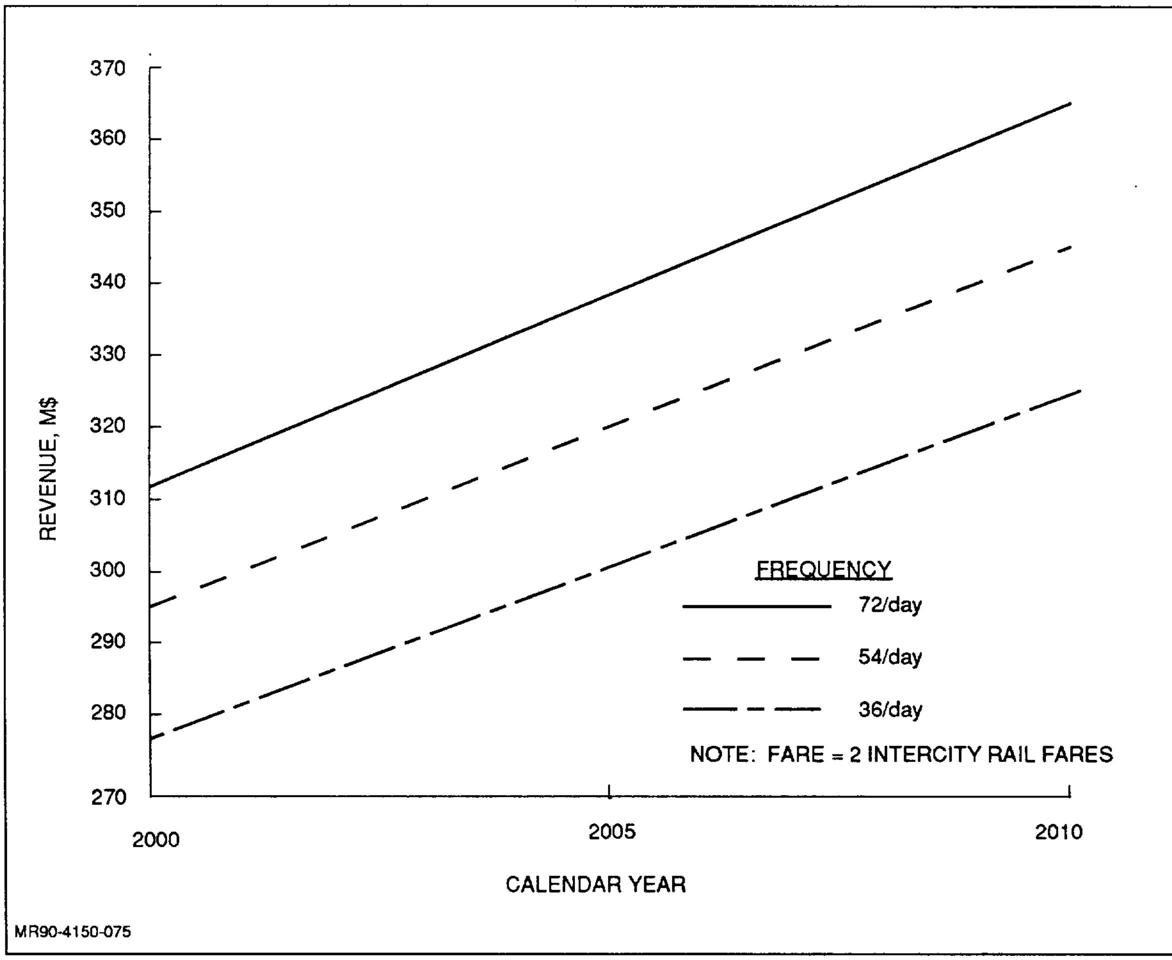

Fig. 7-3 Ridership Revenue Sensitivity Test Results – Fare = Two Intercity Rail Fares – *The intermediate fare structure shown here provides the peak revenues.*

possible. This issue is discussed in Section 8.

7.7 ADDITIONAL BENEFITS AND IMPACTS

7.7.1 Environmental Benefits

Based on the projected diversions of trips from the air, auto, and bus modes, estimates of the reduced emissions of cabon monoxide, hydrocarbons, and nitrous oxide were calculated. In 2010, 11,600 tons of carbon monoxide, 1,500 tons of hydrocarbons, and 800 tons of nitrous oxide emissions would be eliminated from the atmosphere due to the projected modal diversions.

7.7.2 Energy Savings

Calculations were performed to estimate the gallons of fuel that would be saved if the estimated diverted trips were made on a MAGLEV system instead of by aircraft, automobiles or buses. It is estimated that a total of 7.8 million gallons of fuel would be saved in 2010 due to

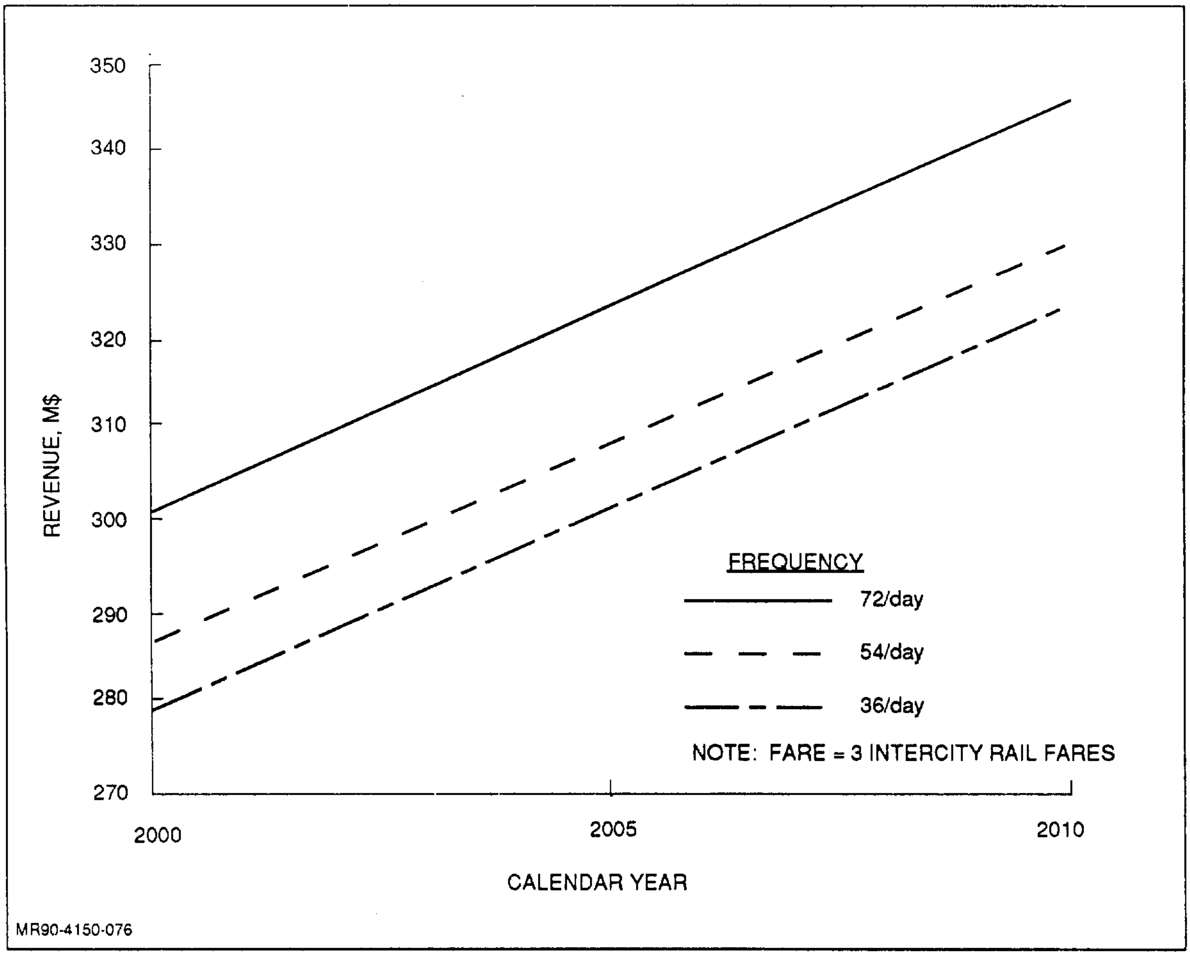

Fig. 7-4 Ridership Revenue Sensitivity Test Results – Fare = Three Intercity Rail Fares – *A high fare structure discourages ridership and revenues drop.*

diverted trips made on an intrastate MAGLEV system.

7.7.3 Economic Impacts

Due to constraints of time and resources, this conceptual study did not quantify all of the specific long-term economic impacts and benefits. However, some short-term economic impacts were computed relating to the construction of the system. It is reasonable to assume that any corridor implementation of a MAGLEV system would result in substantial economic impacts in the following areas:

- Employment and associated economic activity as a result of the construction, operation and maintenance of the MAGLEV system; it is estimated that more than 90,600 construction jobs with $4.24 billion in construction wages would be created by building an intrastate MAGLEV system; additionally, more than 131,800 construction-related jobs with $6.75 billion in construction-related wages would be created;

- Short-term, construction-generated economic activity output estimates show $4.7 billion and $11.6 billion in direct construction and construction-related economic benefits, respectively;

- Economic activity as a result of the purchase of services and goods by the MAGLEV system;
- Urban and regional development, particularly in the station areas of the corridor;
- Tax base changes; and
- Changes in economic activities as a result of the MAGLEV system's operation.

Due to the construction and operation of a MAGLEV system, major economic impacts would be expected. Initially, impacts would derive from the direct expenditures related to constructing, maintaining and purchasing services for the system, and from the associated employment generated for residents and businesses of the region. Since these economic effects are direct and immediate, economic stimulation would occur throughout the area due to the multiplier effects of capital construction spending.

After construction of the MAGLEV system, additional economic impacts would be obtained directly from its operation and maintenance. These direct impacts would also have a continued multiplier effect on the economy.

Implementing MAGLEV service would in all likelihood change the economic level and increase the competitiveness of the region with respect to other areas of North America. For instance, as a focal point of advanced futuristic transportation technology, the attractiveness and improved accessibility of a MAGLEV system may significantly strengthen and expand the area's recreational and tourism markets. In fact, at least initially, the system may be a tourist attraction in its own right. Additionally, due directly to the system itself, the improvement of the region's mobility, the associated economic impacts, and changes in the business community, including the development of new opportunities and expansion of existing businesses and manufacturing, can be anticipated.

7.8 REGIONAL MAGLEV CONCEPTUAL CORRIDOR ANALYSIS

7.8.1 Introduction

The preceding analysis of a New York State intrastate MAGLEV system addressed various aspects of ridership demand, revenues, and economic, energy and environmental benefits. However, greater benefits and ridership would be gained by New York State if its system became part of a regional MAGLEV network spanning the Northeast and Midwest regions of the

United States. While regional analyses similar to the intrastate assessment were not possible under the constraints of this study, the following paragraphs outline some issues and offer preliminary conclusions on the potential of regional MAGLEV systems using New York State corridors. Economic viability of an intrastate MAGLEV system will likely be related to its use as a route within a regional MAGLEV network.

7.8.2 New York City – Boston Corridor

Studies have been performed analyzing the existing and future travel demand between the greater metropolitan area of New York City and Boston. The following volume reflects the 1989 ridership volume for air and rail travel between the two cities: air – 3,015,240; rail – 440,000 (estimated).

Applying the same proportion of diversion predicted for the New York State intrastate air market, the expected MAGLEV market from current air travelers would be 700,000 trips. This number is conservative since there are apparently fewer business trips made within New York State than between New York City and Boston. Also, the current number of flights between those cities is much higher, and the cost much lower, than for the intrastate air market. It is conceivable that a MAGLEV system of sufficient service quality would replace short-haul air service such as that between New York City and Boston. This may lead to a policy decision to support MAGLEV service for short-haul service, in part, to free capacity at congested airports for longer-haul air service. Similar public policy decisions have been made in France involving the competitive advantage of the TGV service in certain air travel markets.

Further research would have to be performed to determine the percentage of rail trips that could be diverted to a MAGLEV system. Auto volumes and origin/destination information would also have to be collected and analyzed to determine potential trips that could be diverted. It appears, however, that this market holds significant potential for a MAGLEV system.

7.8.3 New York City – Boston Route Considerations

In considering an existing corridor for New York City to Boston travel that may hold potential as a MAGLEV right-of-way, the present rail and interstate highway corridors should be assessed. The portion of AMTRAK's Northeast Corridor extending from New York City to Boston appears to have limited potential as a high-speed MAGLEV route because of the narrow width and poor alignment of the right-of-way. The same appears to be true for the parallel I-95 highway corridor.

In general, the existing rail and highway rights-of-way of the Northeast Corridor, particularly in the New York City/Western Connecticut and Boston areas, have numerous limitations and pose difficulties in building a high-speed MAGLEV system due to the age of the present infrastructure and limited available land and access to construct system facilities.

An alternative to the New York City – Boston shore corridor is a route that follows the NYS Thruway from the NYC area to Albany and proceeds east along the Thruway's Berkshire Spur to the Massachusetts border and on to the Boston area via the Massachusetts Turnpike. This route, though longer in distance, holds some apparent alignment advantages over following the shore route directly between New York City and Boston. Due to the higher potential speed of MAGLEV vehicles in the corridor, the longer distance may add little to the trip time. It also would, in all likelihood, present fewer difficulties in constructing system facilities due to more available land and access potential. It may also have more development potential and benefits than the already congested Northeast Corridor shore route.

7.8.4 Buffalo – Toronto Corridor

Based on the conceptual analysis of an intrastate MAGLEV system, the potential of the Buffalo area as a terminus is limited. However, if viewed as a hub of a system extending to Toronto, to Boston and New York City via Albany, and to the Midwest/Great Lakes region, the economic and market potential improves drastically.

Based on the population and economic potential of the Toronto corridor, a route from Buffalo/Niagara Falls to Toronto certainly warrants further study. The potential benefits from such a route apparently would be enhanced by the recent Free Trade Agreement.

7.8.5 Buffalo – Midwest/Great Lakes Corridor

As with the route to Toronto, Buffalo as a center of a larger MAGLEV system extending to the Great Lakes/Midwest region of the United States holds great potential. Routes to Cleveland, Detroit and Chicago offer increased ridership and economic benefits. A MAGLEV system could provide an alternative to air transportation between the Northeast region to Chicago, removing a substantial burden from Chicago airports while increasing long-distance capacity.

7.8.6 Albany – Montreal Corridor

Another corridor that holds potential as a candidate for a MAGLEV system is one that connects Albany with Montreal, Canada. As part of a regional network, particularly one encompassing the New York City area, this would allow greater mobility to an area that is the primary financial and business region of Canada.

One possible route involves the right-of-way of I-87 (Northway) which connects many of the larger population centers and recreational areas of Northern New York State including Clifton Park, Saratoga, Glens Falls and Plattsburgh. The first three areas are among the largest growing areas of New York State outside the New York City area. Some concern could be raised due to this corridor passing through the Adirondack Park.

With the Free Trade Agreement and the superior mobility offered by a MAGLEV system connecting the Montreal and New York City areas, there appears to be a great potential for ridership and economic development.

7.9 STATION LOCATIONS

The issue of station locations is a critical aspect of a MAGLEV system and involves complex problems, particularly in the New York City area. In general, the location chosen must enable the MAGLEV system to connect with the existing transportation network. Since many of the existing highway transportation problems are urban and suburban in nature, MAGLEV station locations must reduce, not increase, the existing capacity and mobility constraints. One area not addressed by this analysis, which potentially merits its own investigation, is the use of low-speed MAGLEV systems for intracity service. MAGLEV stations may offer great potential for economic development. Areas around MAGLEV stations have the potential to increase localized residential and commercial development. Therefore, it can be assumed that development rights may offer the opportunity to finance at least a portion of the capital costs of a MAGLEV system.

New York City poses numerous and, in many instances, unique problems that must be addressed regarding transportation projects in general, and MAGLEV station locations in particular. Issues and questions that need to be addressed include:

- If MAGLEV follows the NYS Thruway's right-of-way, how does the route cross the Hudson River?
- If the route crosses the river, where does it terminate?
- Should MAGLEV provide direct access to the Kennedy and LaGuardia Airports? If so, how?
- How would MAGLEV solutions affect existing transportation plans and proposals?
- How will a MAGLEV system connect to the existing transit and highway system?
- Will a lower-speed MAGLEV or alternative system be required to integrate Connecticut, Long Island and other densely populated areas into a regional MAGLEV network?
- Will the demand be sufficient to warrant multiple stations in the greater New York City metropolitan area?

8 – FREIGHT-CARRYING CAPABILITY

8.1 INTRODUCTION

For many years passenger transportation services have also provided efficient freight transportation. Passenger railroads, airlines, intercity bus operators and even taxi companies provide freight transportation. It is perceived that any future MAGLEV service can and will provide at least similar levels of freight services as these other modes, and possibly a much higher level of freight service.

A potential market for freight movement by MAGLEV is diversion of current air freight cargo. This freight is primarily time-sensitive and high-value. It is likely that, for air cargo movements of less than 500 miles, diversion to MAGLEV could be substantial due to the highly congested surface access to major airports. Although the size of this market is unknown, there are other factors that favor MAGLEV's diversion potential for current air cargo movements in addition to airport congestion. Because the design of MAGLEV "car bodies" resembles that of airplanes, standard air freight containers could be used on MAGLEV with little or no modification which could allow shippers more choices.

Another major market niche for using MAGLEV service for freight is the transportation of high-value, time-sensitive commodities between urban areas less than 500 miles apart. High-value, time-sensitive commodities could include such items as overnight mail, express packages, critical manufacturing replacement components, and some "just-in-time" manufacturing materials. Preliminary estimates are that a minimum of 2 percent of 24.0 million commercial truck movements on the NYS Thruway carry these types of commodities, which translates to over 480,000 potentially divertible truck loads annually. Although some of these commercial movements are local, it has been estimated that 38 percent of commercial movements on the NYS Thruway are made in trailers or tandem trailers, indicating longer trips. Application of the 2 percent time-sensitive percentage factor results in 182,000 movements annually, or 214,000 trailerloads considering tandems separately.

It is difficult to determine the specific commodities carried and the origins and destinations of the commercial traffic which travels on the Thruway due to the lack of data. Therefore, it is impossible to make accurate estimates of divertible commercial traffic. The potential for further diversion of freight movements from other modes will increase as specialized MAGLEV freight movement equipment becomes available and economically feasible. Despite the limits of available information, an investigation was undertaken to determine the implication of carrying heavy container and trailer-trucks on a MAGLEV vehicle.

8.2 HEAVY FREIGHT CHARACTERISTICS AND THEIR EFFECT ON MAGLEV SYSTEMS

Truck traffic falls into two basic categories. The first is container cargo, which includes truck transportation of overseas shipping containers from Montreal to New York and New York to Boston. It is estimated that 9 percent of all the truck traffic on the NYS Thruway fall into this category. The second is the trailer-truck category which accounts for the majority of the freight carried on the NYS Thruway. This section investigates the potential for MAGLEV to provide such a capability.

The discussions that follow apply only to the EDS MAGLEV system, since limited information was available on the Transrapid EMS system. It would appear, however, that because of the large iron and coil load associated with the EMS design, the weight and cost penalty would be significantly higher than the values identified for the EDS.

Figure 8-1 shows the various shipping container configurations presently used for transporting overseas cargo in the Northeast region. Their dimensions and weights are listed in Table 8-1. A typical trailer of a large trailer-truck system is shown in Fig. 8-2 along with its dimensions. The overall system is 48 ft long, 8.5 ft wide, 9.5 ft high, and has a gross weight of 62 klb (80 klb with tractor).

Using the typical 100-passenger MAGLEV vehicle configuration shown in Fig. 8-3, any of the configurations identified in Fig. 8-1 and 8-2 can reflect the 64 ft passenger cabin length, without the need for major modification. However, the passenger cabin height of 81 inches (6.75 ft) shown in Fig. 8-4(A) will not accommodate the higher containers shown in Fig. 8-1 and will require modification to the cabin height as shown in Fig. 8-4(B). Figure 8-4(C) shows how the vehicle's passenger and lower compartment must be modified for trailer-truck handling. Modifications to the cabin are relatively minor to accommodate container cargo, but are not minor for trailer-truck applications. Trailer-trucks require major changes to the MAGLEV vehicle structure and the relocation of housekeeping and power conditioning equipment housed in the lower compartment area. However, neither cargo design shown in Fig. 8-4(B) or 8-4(C) is considered impractical.

A weight breakdown of the various subsystems in the MAGLEV vehicle for both a passenger and freight configuration is given in Table 8-2. With the same gross weight assumed for both vehicles, a cargo payload of 18.3 klb can be accommodated without any change to the subsystems, except for the increased height requirement. As the freight load increases above 18.3 klb, the vehicle and its subsystem weight must be modified to handle it, which is reflected in increased guideway costs and MAGLEV system costs. This relationship is shown in Fig. 8-5 as a function of cargo loading.

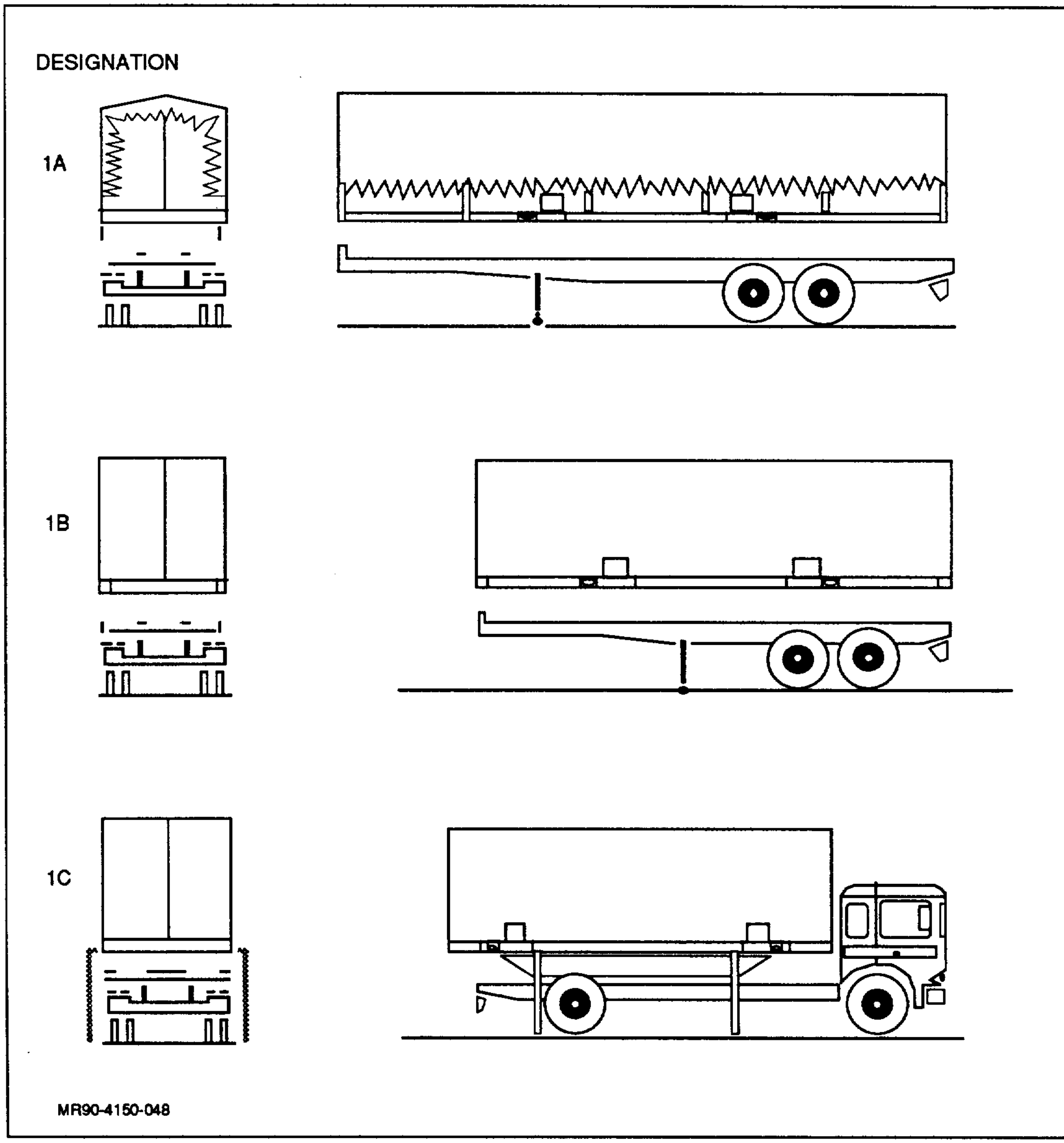

Fig. 8-1 Shipping Container Configurations

Up to 60 klb cargo loading, there is less than 10 percent penalty in the guideway cost. Even with the largest loading of 65 klb, the guideway cost does not increase by more than 12 percent. This raises the question as to what loading factor can be accommodated by a MAGLEV system and still be economically viable. This question is discussed in the following subsection.

8.3 ECONOMIC CONSIDERATIONS FOR CARRYING FREIGHT

The value added by allowing for freight-carrying capabilities on a MAGLEV system was analyzed on an incremental cost basis. It was assumed that a MAGLEV system was designed only for passenger traffic, and that the additional costs associated with making the system

Table 8-1 Shipping Container Dimensions and Weights – *Typical shipping container characteristics used on the New York State Thruway are given. It is estimated that 9 percent of the truck traffic on the Thruway falls into this category.*

Designation (ref fig. 8-1)	Length, ft	Width, ft	Height, ft	Max gross weight, klb
1A	40	8	8	67.0
1B	30	8	8	56.0
1C	20	8	8	44.8
1D	10	8	8	22.4

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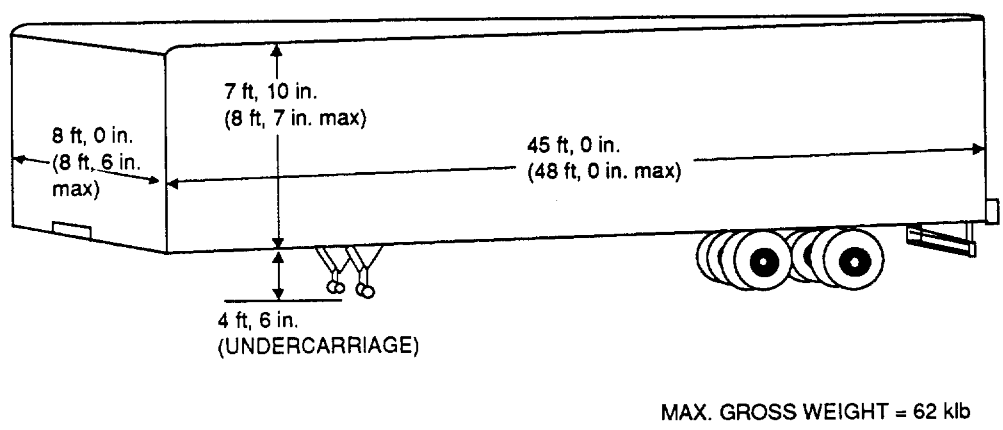

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Fig. 8-2 Typical Trailer Dimensions – *Trailer-trucks represent the most difficult systems to incorporate into a freight MAGLEV configuration because of their large size, weight, and undercarriage wheel structures. At the same time, they represent the majority of Thruway truck traffic.*

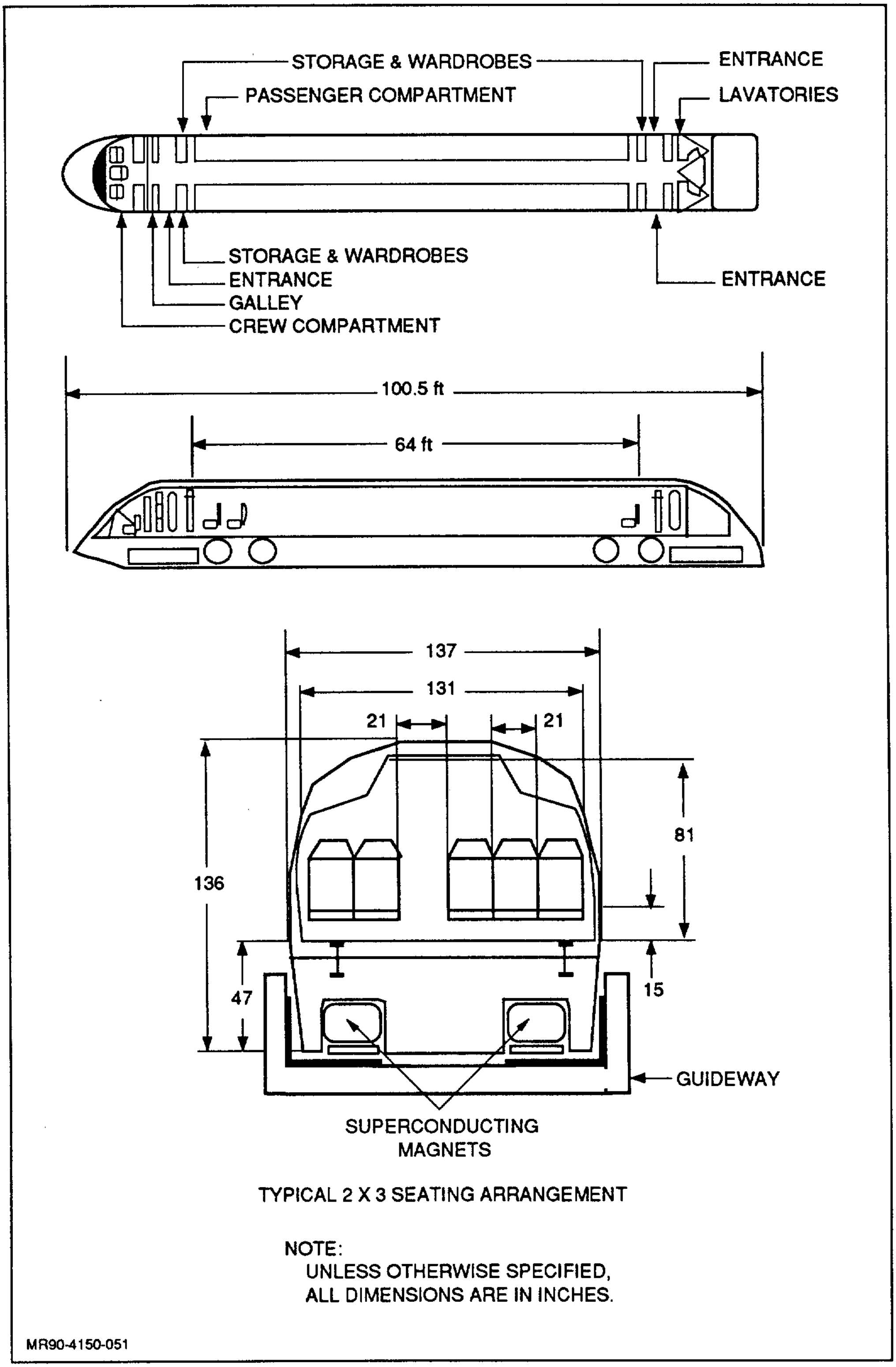

Fig. 8-3 Typical MAGLEV Vehicle Baseline Configuration – 100 Passengers – *The freight configuration consists of the baseline USA Configuration 001 identified in Section 4 modified to a "U" shaped guideway for added storage capability below the cabin section of the vehicle.*

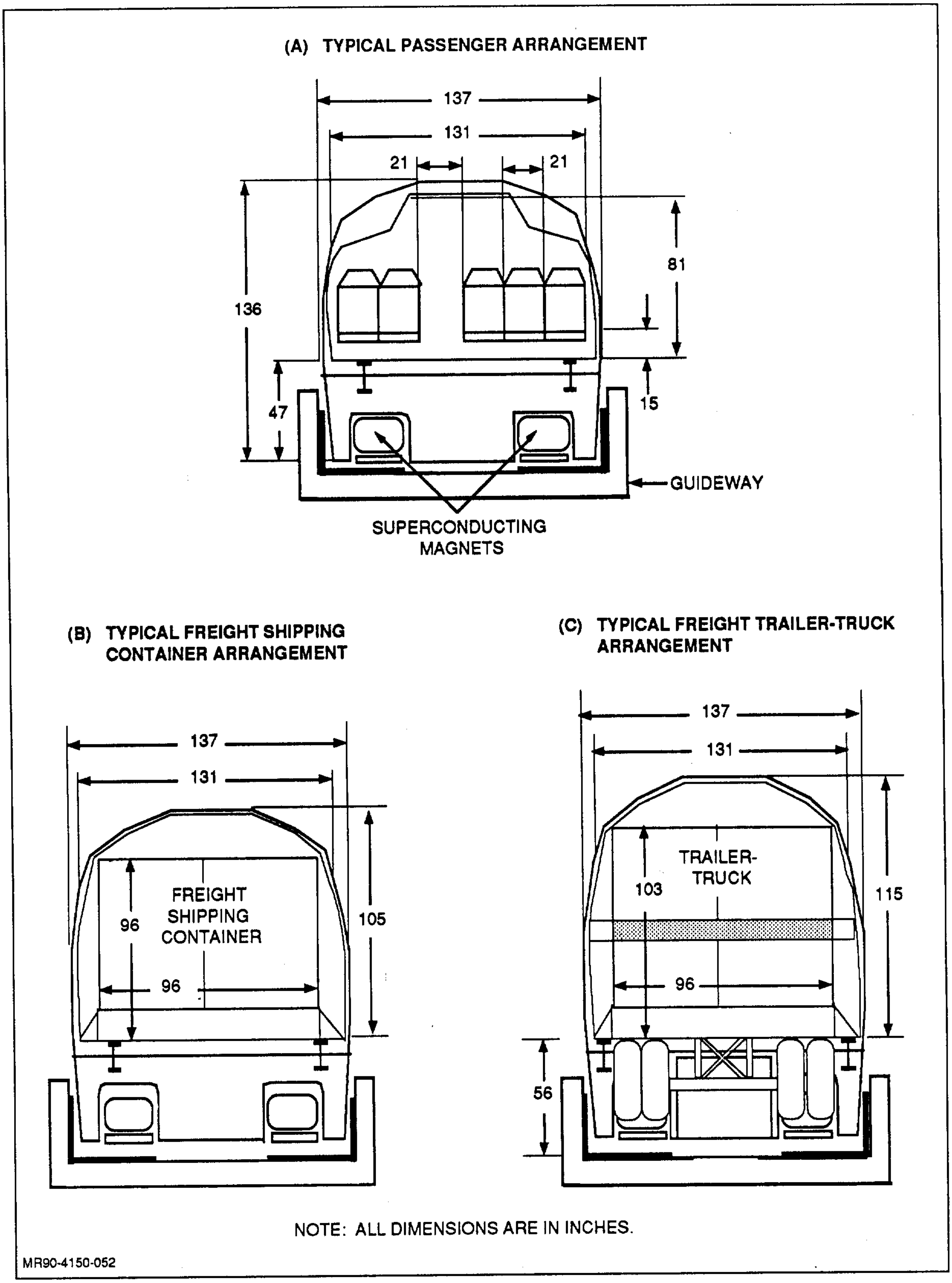

Fig. 8-4 Typical Passenger and Freight Arrangements – *The shipping container and trailer-truck configurations require increased cabin height relative to the passenger configuration. The trailer-truck arrangement requires major structural changes to the area below the cabin section.*

Table 8-2 MAGLEV Vehicle Weight Breakdown Summary – *Weight comparison breakdown of a freight configuration designed to provide a gross weight no different from the passenger version.*

Item	Passenger configuration*, klb	Freight configuration, klb
Suspension system	15.0	15.0
Structure	12.3	15.0
Furnishing	5.5	0.5
Auxiliaries	4.7	4.7
Brakes	4.5	4.5
Crew compartment	3.5	3.5
Propulsion	21.5	21.5
Contingency	3.0	3.0
Empty weight	70.0	67.7
Payload	16.0	18.3
Gross weight	86.0	86.0

* 100 passenger configuration

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freight-capable were calculated. For an assumed range of annual demand in one-way freight trips per year, the break-even cost was calculated on a per-mile basis for each of six classes of cargo carriers. This cost output, compared with existing fare schedules, is the main determinant of economic viability. These six classes of freight include the four designations of container cargo configurations listed in Table 8-1 (1A-1D), a "no-penalty" class at 18.3 klb (the payload from Table 8-2) and a 62 klb load representative of the truck-trailer identified in Fig. 8-2.

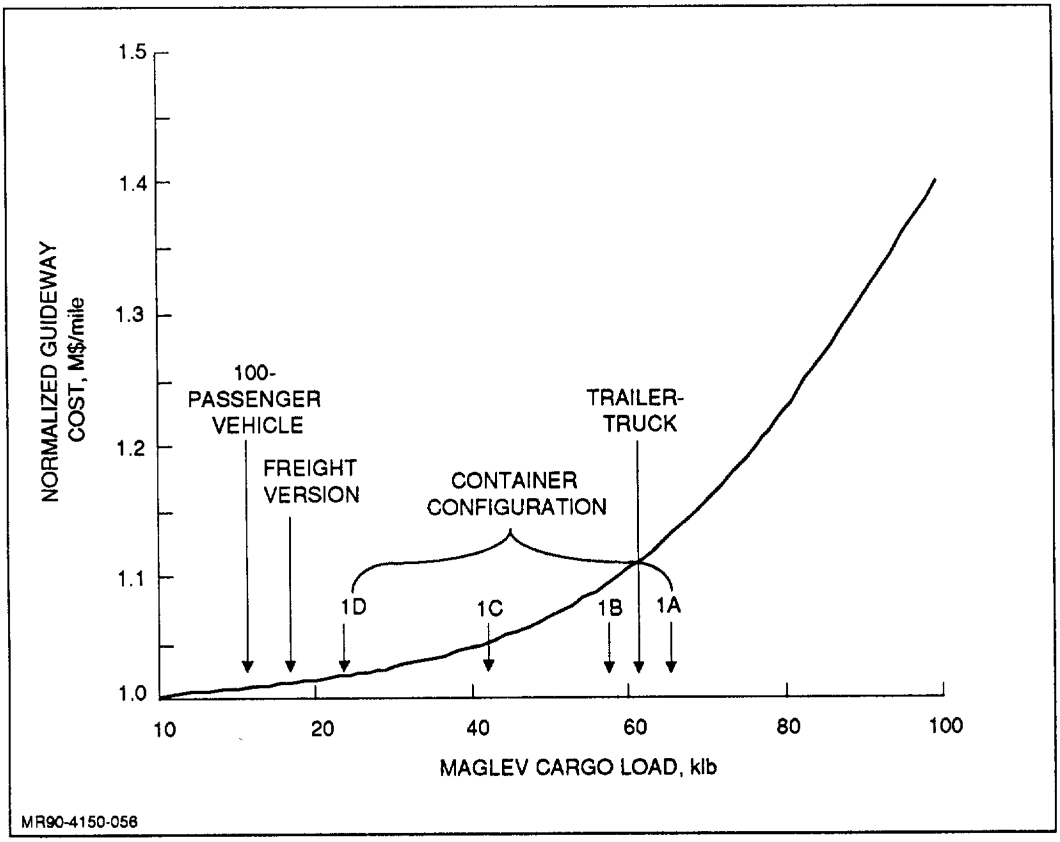

Fig. 8-5 Guideway Costs vs MAGLEV Cargo Load – *Normalized guideway cost increases exponentially as a function of the MAGLEV cargo load.*

8.4 FREIGHT-CARRYING ECONOMIC ANALYSIS

The incremental costs to convert the MAGLEV system to handle freight as well as passengers include some elements which can be classified as fixed costs and other elements which are variable and depend on operating levels. The major fixed costs include land acquisition for cargo storage and handling, additional costs to modify the guideway to handle increased loads, provisions for cargo terminals and handling systems, and cargo vehicle costs. While vehicle costs are in some respect variable since the number required depends on freight demand, they are grouped as fixed because these costs, including tooling, are one-time investments. It should be noted that these vehicles are different from the passenger version.

Variable incremental costs in addition to those for passenger service may include additional vehicle maintenance, additional electric power use, and the cost increases associated with additional personnel to operate freight. For a 15-year operation, the break-even charge rates are shown parametrically in Fig. 8-6. These rates represent an amortization of all additional freight-related fixed costs, including operating costs for combinations of the demand levels of the six different load classes previously identified. The rates are calculated on a per-mile basis to provide a comparison with New York State Department of Transportation data.

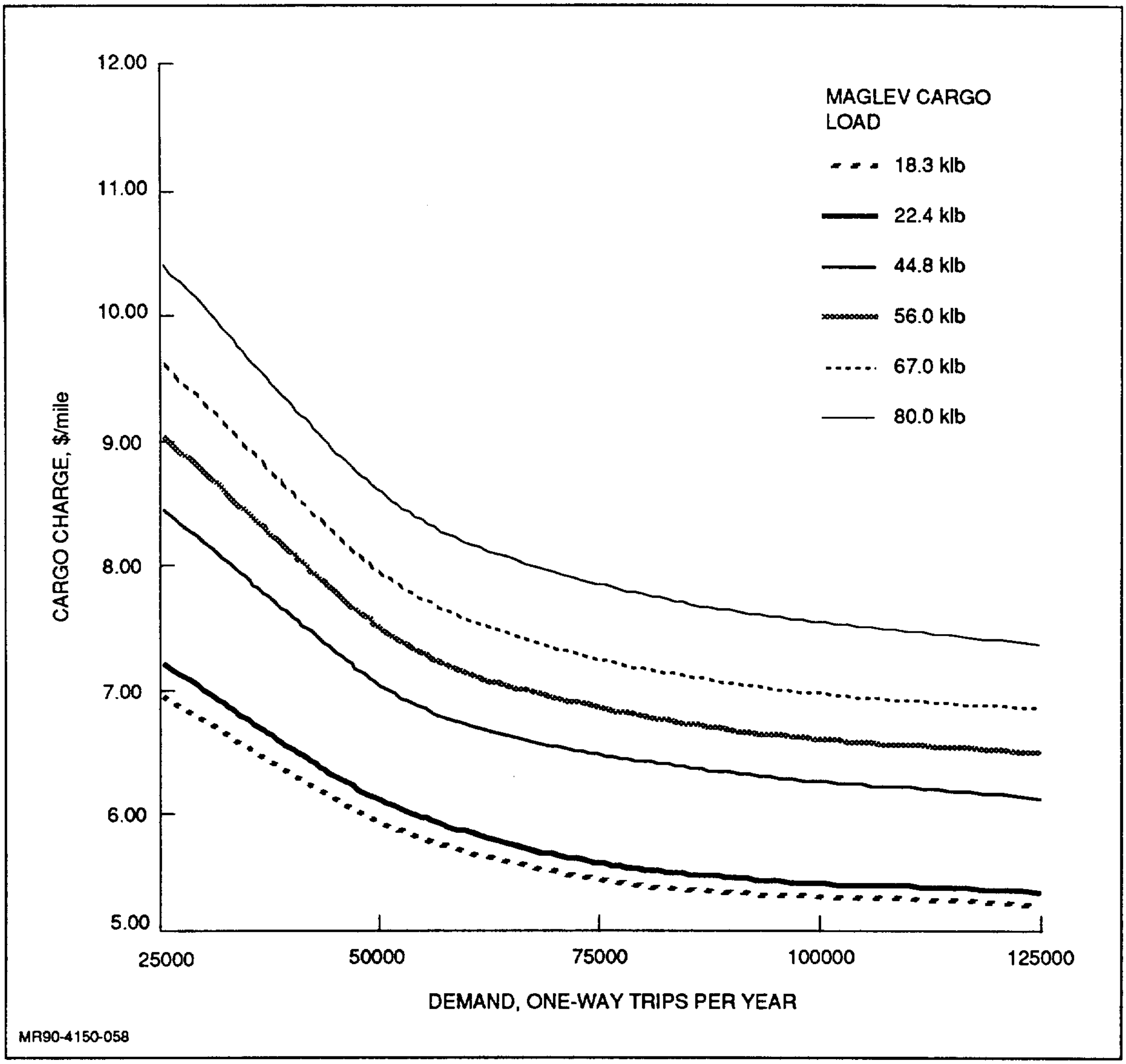

Fig. 8-6 Break-Even MAGLEV Cargo Charges – Assumed 400 Mile NYS Corridor – *This shows that, for a 50,000 one-way trip demand per year, a $6.2/mile charge is required to break-even with a 22.4 klb cargo load, and $8.70/mile for an 83 klb cargo load. Only high-priced commodities such as camcorders at $6.27/mile and computers at $3.49/mile come close to providing break-even capability. Commodities such as tomatoes at $2.50/mile and charcoal briquettes at $1.99/mile are not as economical.*

Taking into consideration the freight commodity price data provided by NYSDOT, it appears that given sufficient demand (more than 50,000 trips per year) and a loading less than 20 klbs, the higher-priced commodities such as camcorders at $6.27/mile and computers at $3.49/mile come closest to making economic sense for adding heavy freight capability to the MAGLEV system. Other commodities such as charcoal briquettes at $1.99/mile and tomatoes at $2.50/mile would not be cost-effective. More detailed information on the percentage of existing freight traffic on the Interstate System, as well as priority package delivery systems such as UPS and air freight, will be required to provide a complete economic picture. Additional studies in this area are recommended.

9 – SYSTEM COSTING AND ECONOMIC ANALYSIS

9.1 INTRODUCTION

This section presents the cost estimates for the major components of a MAGLEV system. Operating and maintenance cost data and a top-level economic analysis of the return on investment for route applications are included.

9.2 GUIDEWAY COST ESTIMATES

9.2.1 Grumman Evaluation

Based on 1974 cost data in Ref. 9.1, Grumman estimated the elevated guideway cost per mile for a double "T" cross section shown in Fig. 4-12(A), using prestressed concrete and an L-shaped aluminum sheet along each side of a center post section which is described in Section 3 as Configuration 001. The cost data in Ref. 9.1 were adjusted to 1989 dollars and compared to data given in the 1989 Means Heavy Construction Cost Data handbook. The results are plotted in Fig. 9-1 and show good correlation between the two sources. The guideway structural cost (excluding vehicle or electrification costs) was estimated as a function of span length and the loading based on the number of passengers per vehicle. The results, shown in Fig. 9-2, indicate that the guideway costs minimize at around 50- to 60-ft span lengths and range from $12 to $13 million/mile depending on the vehicle passenger load. The evaluation was then extended to include an overall 300-mile dual-elevated track system cost including the guideways, vehicles, power, and costs relative to a capital recovery factor (CRF) and a 2000 passenger/hour usage rate. The results, also plotted in Fig. 9-2, show that a minimum system cost will occur with a 100 passenger/vehicle configuration at 50- to 60-ft span lengths.

A similar minimization process occurs with the guideway aluminum sheet thickness. This effect is shown in Fig. 9-3 which indicates that a minimum system cost occurs at an aluminum thickness of 0.4 inch. At thicker values, the cost increases due to the greater quantities of aluminum, plus the added weight of the aluminum results in higher guideway cost. At the thinner values, the lift-to-drag ratio for the vehicle decreases to a point where the cost to power the vehicles becomes excessive. Assuming a 0.4-inch thickness with a dual 60-inch-wide L-shaped aluminum sheet (shown in Fig. 4-6), the result is 0.61 Mlb per mile of aluminum for a dual two-way guideway. Assuming a cost of $2.60/lb for materials and installation, the result is a cost of $1.6 million/mile for aluminum sheet.

This analysis was also performed assuming a dual box cross section, shown in Fig. 4-12(B), instead of the double "T" discussed above. The results of this work are presented in Fig. 9-4. The purpose of this latter study was to provide some form of comparison with the Parsons Brinckerhoff study which follows.

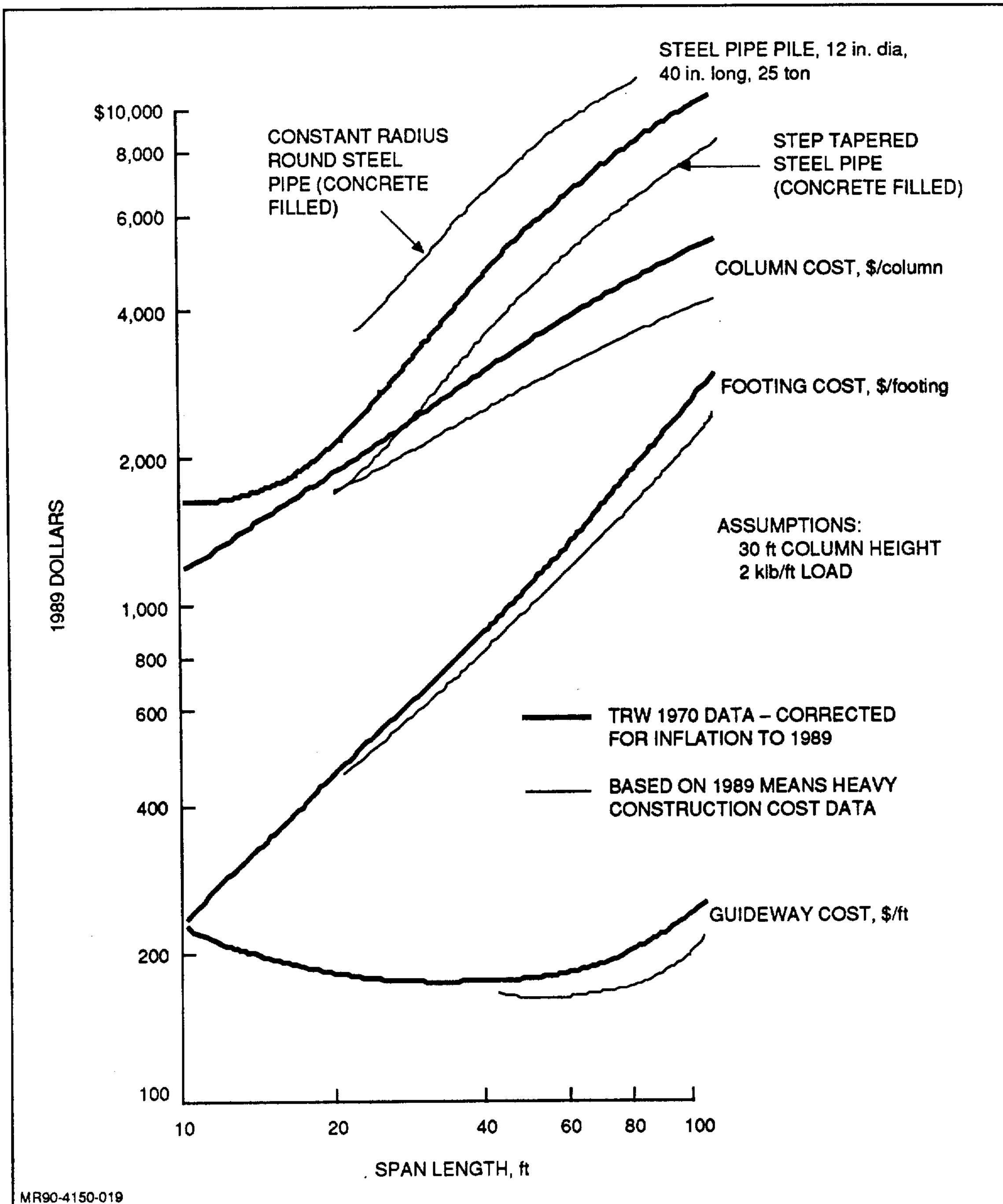

Fig. 9-1 Guideway Cost Comparison Data (1989 Dollars) – *A comparison of the 1970 TRW Construction Data (corrected for inflation to 1989) and the 1989 Means Heavy Construction Cost Data for various components of the elevated guideway system shows good correlation between the two sources.*

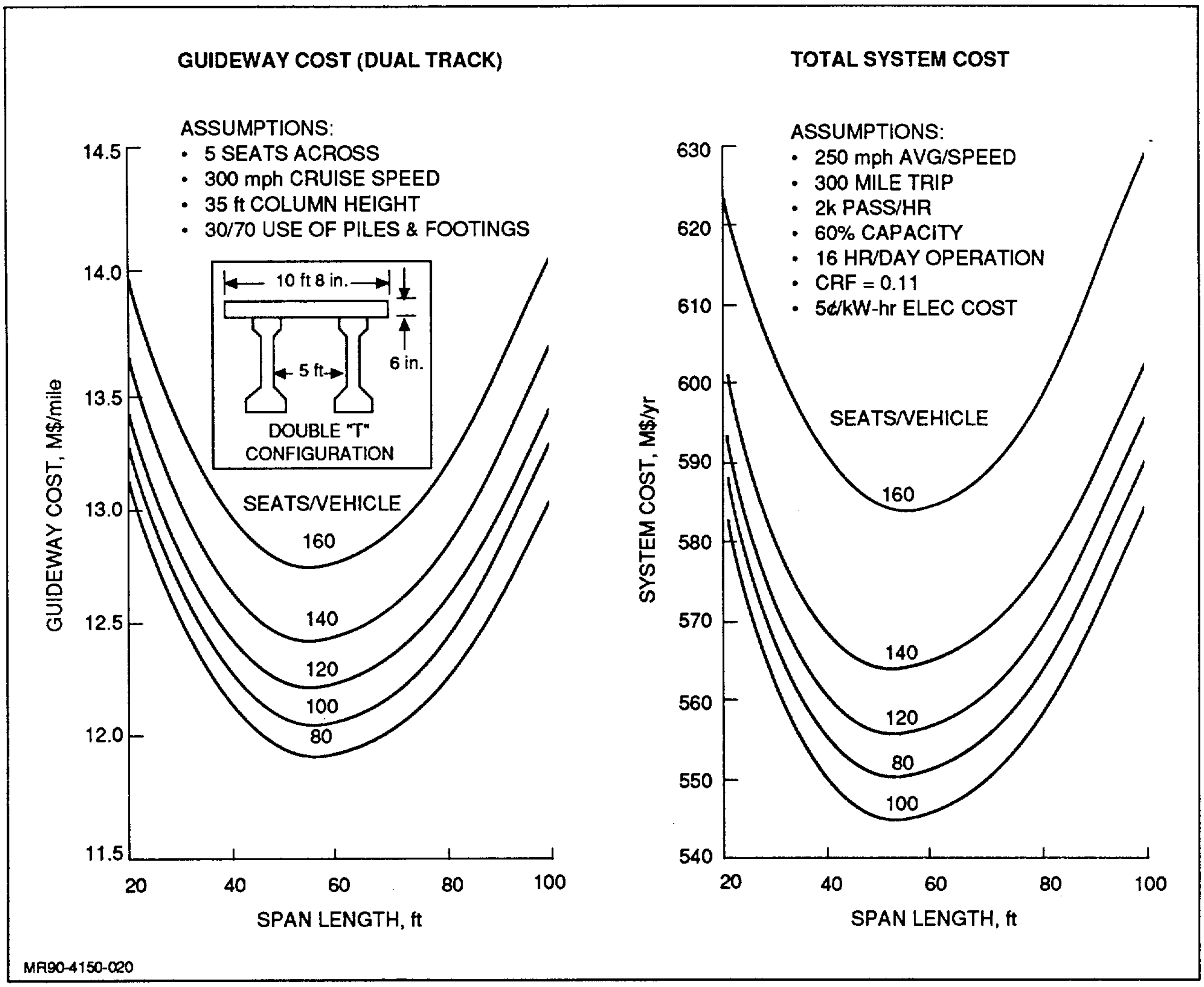

Fig. 9-2 Guideway Structural Cost Evaluation (1990 Dollars) – Double "T" Cross-Section – *For the Double "T" guideway cross-section shown, the guideway cost per mile minimizes at 50-60 ft span length and the total system costs minimize at 100 passenger seats per vehicle.*

9.2.2 Parsons Brinckerhoff Evaluation

The parametric cost estimate previously discussed is based on standard elevated structures supporting low-speed traffic. To determine whether the cost would differ significantly for a more sophisticated high-speed elevated transport system, Parsons Brinckerhoff made a structural analysis and cost estimate using specific design criteria, a specific vehicle design, and a designated corridor. Their analysis was confined to a discrete set of assumptions based on a previous structural analysis and cost estimate with similar specified design criteria and current cost data.

This study provided a structural analysis and cost estimate of the basic guideway materials and construction using preliminary structural concepts and general site characteristics for the

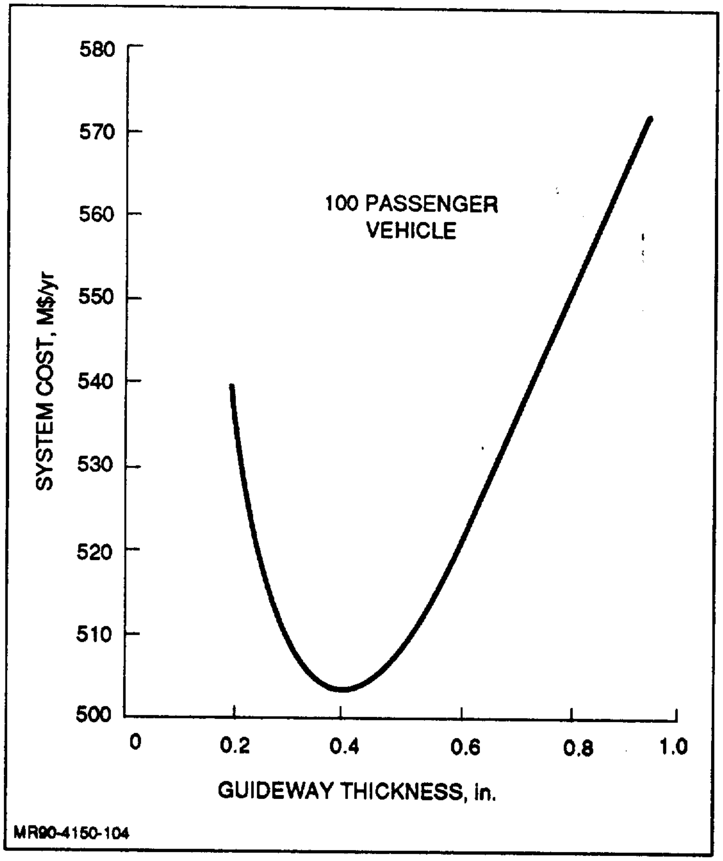

Fig. 9-3 Guideway Thickness Tradeoff – *This figure shows that the minimum system cost occurs with a guideway thickness of about 0.4 inch.*

NYS Thruway. The structural analysis includes lateral, longitudinal and vertical forces on the guideway resulting from a high-speed vehicle traveling on an elevated and curving guideway located within the Thruway right-of-way.

In making an independent cost estimate of the basic guideway structure, Parsons Brinckerhoff based the design and cost information on one guideway configuration. Costs were established for a single design, assuming a one-mile section of prestressed cast-in-place concrete box girders supported on cast-in-place concrete piers every 100 ft as shown in Fig. 4-13a through 4-13d. Simple spans were selected based on preliminary consideration of dynamic response. The alignment characteristics are based on the general characteristics including average grades, typical curve radii, frequency of overpasses and interchanges of the NYS Thruway.

The guideway configuration is continuously elevated to reduce the footprint of the structure within the right-of-way, to account for closely spaced overpasses and interchanges along the

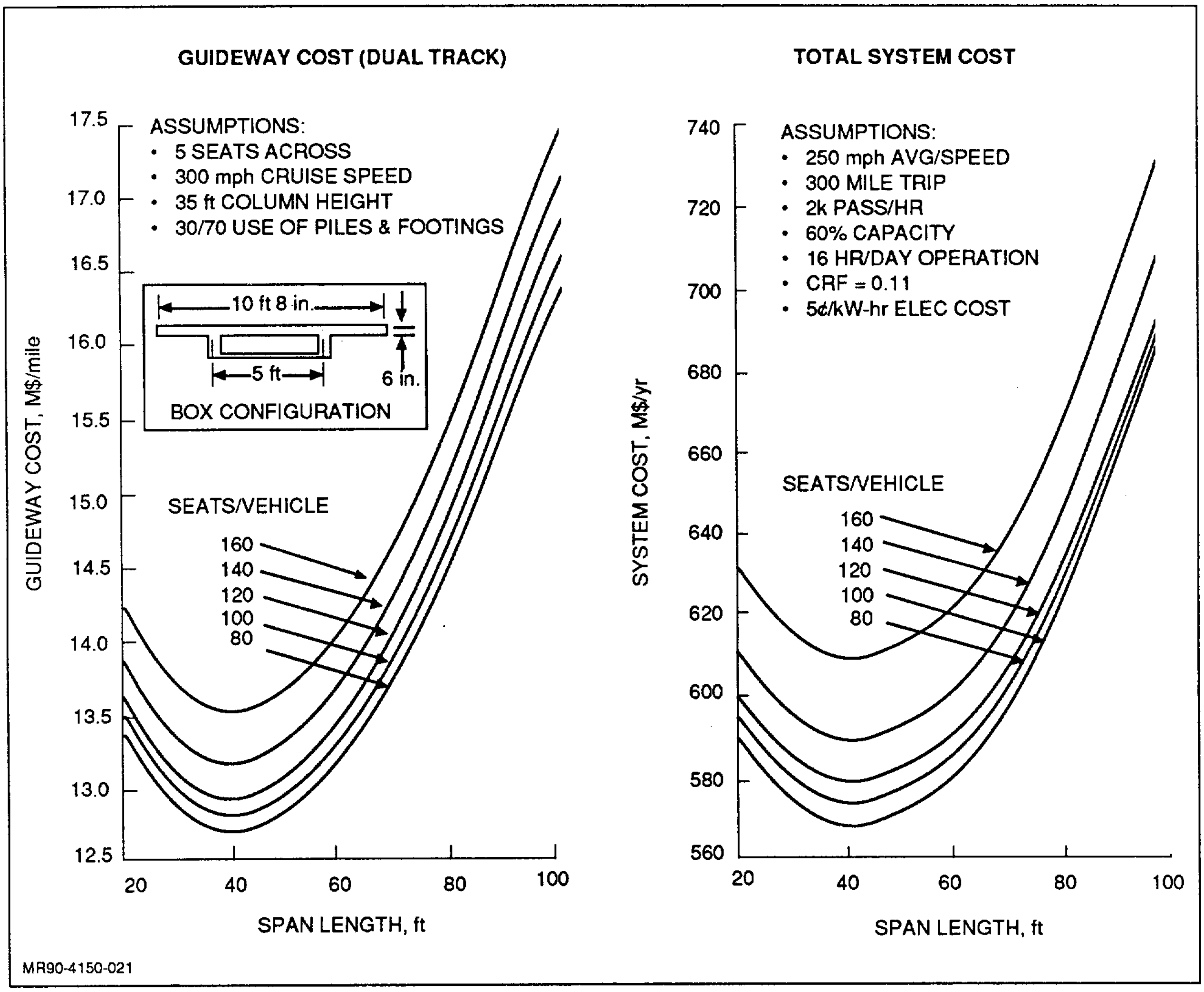

Fig. 9-4 Guideway Structural Cost Evaluation (1990 Dollars) – Dual Box Cross-Section – *For the dual box guideway cross-section shown, the guideway cost per mile minimizes at a 40 to 50 ft span length and the total system costs minimize at 100 passenger seats per vehicle.*

NYS Thruway, and to eliminate vertical curve constraints. The base of the box girder superstructure is located 35 ft above the ground level and the guideway platform is assumed to be superelevated +7 deg on a 2-deg curve.

Structural design criteria and assumptions are listed in Table 9-1. It was assumed 30 percent of the piers were constructed on pile foundations and 70 percent were built on shallow spread footings. Foundation conditions other than those assumed would affect the guideway construction cost and schedule. Details of the guideway design characteristics are presented in Fig. 4-13a through 4-13d and Appendix C of this report.

Table 9-1 Guideway Structural Design Criteria – *Assumed structural design criteria by Parsons Brinckerhoff for their point design elevated guideway structure.*

Item	Criteria
Live load	860 plf, including passengers
Wind load	50 mph wind, 70 mph gust
Seismic	Zone 2 (does not control design)
Lateral load	0.08g passenger 0.20g structural
Longitudinal load	0.20g
Grades	3%
Vertical acceleration	0.10g
Vehicle dimensions	100 ft long, 11.5 ft wide
Deflection/span length	1/1000 max
Horizontal curve	2 deg type for design conditions
Structural lateral g	0.2 g
Height of structure	35 ft normal bottom clearance
Material strength assumptions	
Concrete	fc' = 4,000 psi superstructure fc' = 3,500 psi substructure
Reinforcing steel	fy = 60,000 psi
Prestressing strands	fy = 270,000 (1/2 in dia)
Guideway	Bidirectional on single pier

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The total estimated costs for materials and construction of a double-track, elevated, concrete box-girder guideway is $13,647,775 per mile as detailed in Table 9-2. This cost includes structural excavation for the footings, and placement of prestressed concrete piles, cast-in-place concrete footings, pier shafts, pier caps and prestressed box girders. Estimates are included for traffic control, miscellaneous site work that would occur in the turnpike median, a continuous concrete guard rail to protect the concrete piers, and the contractor's overhead and profit.

Table 9-2 Guideway Structural Cost Estimates – *A summary unit cost estimate of the Parsons Brinckerhoff guideway structure defined in Subsection 4.6.2.*

Item	Qty	Unit	Unit cost, $	Total cost, $/mile
Traffic control	1	LS	649,893.97	649,894
Miscellaneous site work	4.5	AC	4,200.00	18,900
Guard rail	10560	LF	45.36	479,002
Structural excavation	2538	CY	28.54	72,443
PCC piles	15360	LF	34.03	522,728
CIP concrete substructure	3437	CY	690.98	2,374,885
CIP concrete superstructure	8410	CY	1,133.17	9,529,923
			Total estimated cost/mile	13,647,775

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Because actual construction conditions are unknown, the cost includes a 25 percent contingency to cover costs that could result from factors such as soil conditions, rights-of-way, construction logistics, or scheduling restrictions.

This analysis was limited by certain basic assumptions and design elements; a thorough design effort could investigate various alignments, structural configurations, and tradeoffs.

9.2.3 Comparison of Guideway Cost Studies

The Grumman and Parsons Brinckerhoff evaluations were compared to determine if a correlation could be established. Figure 9-5 shows an overlay of the Grumman guideway cost, as a function of span length, plotted in Figs. 9-2 and 9-4 for a 100-passenger vehicle. Also plotted for a 100-ft span length is the Parsons Brinckerhoff point design cost value given in Table 9-2, assuming that $1.6 million/mile is added to include the cost of laying 0.4-inch-thick aluminum for levitation. The Parsons Brinckerhoff cost of $15.1 million/mile is just below the dual-box configuration since the single-pier/single-box design would be more efficient. Using the Parsons Brinckerhoff point design value in Fig. 9-5, an extrapolation down to a 70-ft span length resulted in a $13 million/mile cost. The value of 70 ft was chosen because it corresponds to the span length used by Transrapid. Subtracting the $1.6 million/mile for the levitation coil costs previously discussed produces a guideway cost of $11.4 million/mile. This value was the baseline guideway cost used for costing Configurations 001 and 002 (USA) in this study.

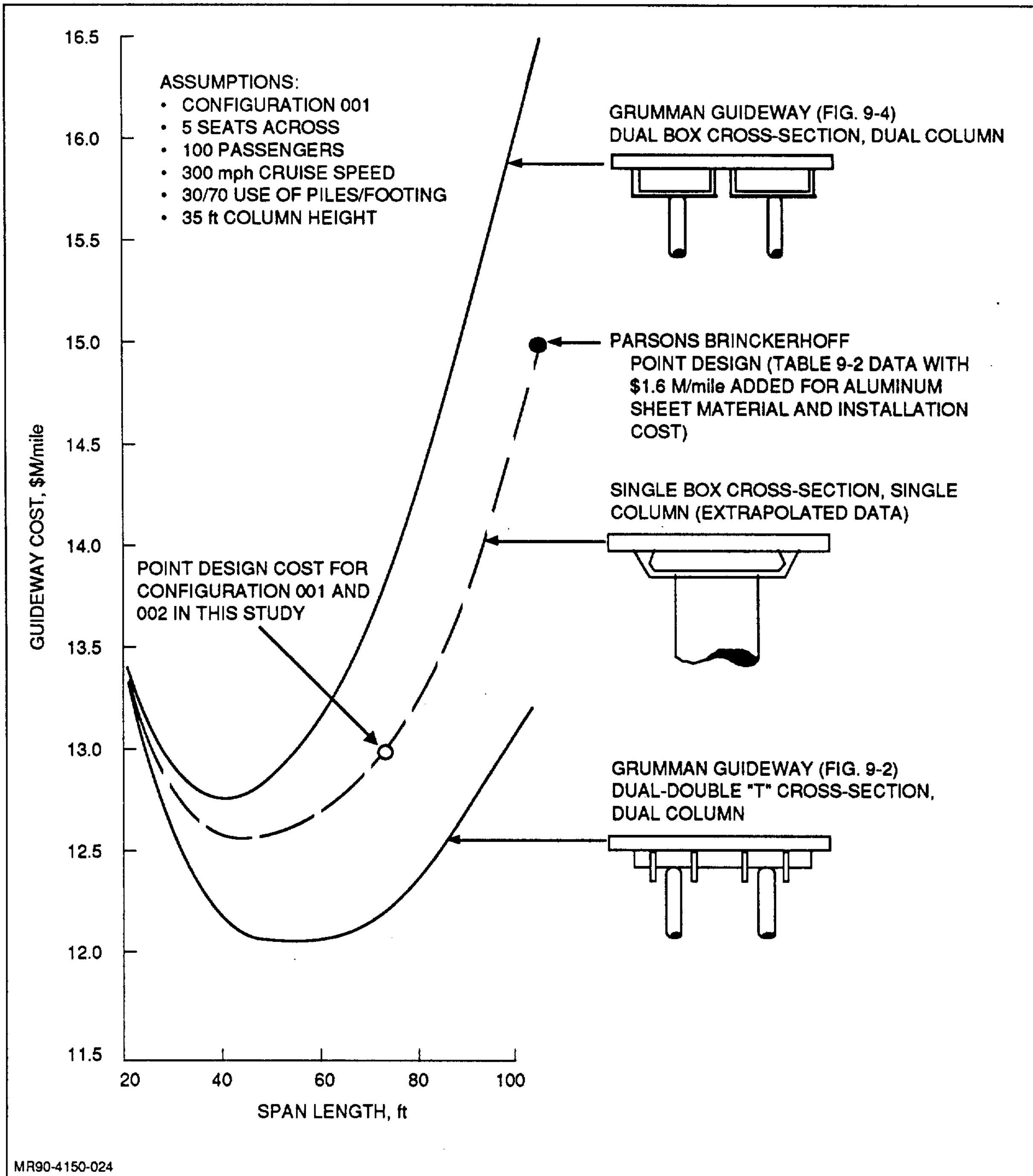

Fig. 9-5 Guideway Cost Estimates for Three Different Beam Cross-Sections (1990 Dollars) – *Combining the Grumman data with the Parsons Brinckerhoff point design has allowed extrapolation of a unit guideway cost of $13M/mile (including $1.6M/mile for aluminum sheet), assuming a 70-ft span length.*

9.3 POWER SYSTEM COST ESTIMATES

9.3.1 Guideway Coil Cost Estimate

The guideway coils for the Japanese Railroad (JR) system are aluminum, but data on their dimensions or number of turns are limited. Using designs in Ref. 9.2, and drawing on years of motor design experience, GE Transportation Systems (GETS) estimated the manufacturing costs for these coils. As shown in the sketches in Ref. 9.2, there are two sets of coils in the Yamanashi guideway: the three-phase stator set for the LSM, and the figure-eight "null-flux" levitation and guidance coils. The cost of the three-phase motor windings was estimated carefully, and that of the latter coil set scaled from the former by estimating the ratio of the weights and volumes. This estimate was made using the sketches in Ref. 9.2, and may be incorrect. A paper describes JR's previous MLU002 test system, saying that guideway coils are molded with epoxy and buried in the concrete guideway (Ref. 9.3). The additional costs of installing these coils in the guideway are difficult to estimate accurately, given the diverse technologies and labor rates, but they are undoubtedly significant and may be as much as the manufacturing costs. The JR design uses no iron in the guideway.

The analysis uses costs of $4.20/lb for wound, insulated aluminum coils, and $3.30/lb for copper coils based on manufacturing costs of the Series 752 field coils for heavy traction motors and the EX47 reactor coils used for smoothing. To estimate the weight of the JR propulsion coils, GETS used the following equations:

$$pp = v/2f \tag{1}$$
$$V = 2wt(h+pp)/144 \tag{2}$$
$$h = pp/3 \tag{3}$$

where:

pp is the coil pole pitch
v is the vehicle velocity
f is the motor frequency
V is the coil volume in ft^3
w and t are the coil width and thickness in inches
h is the coil height in ft

Equation (3) is an assumption supported by the sketches in Ref. 9.2. These may be combined to yield the volume of coils down one side of the guideway at

$$V = 146wtL \tag{4}$$

where:

L is the guideway length in miles.

The volume of coils per mile is independent, to the first approximation, of the frequency and pole pitch. To estimate the quantity "wt," GETS estimated the active armature conductor passing frequency for a normal motor, defined as a motor with flux density similar to an iron core motor. It was assumed that the superconducting magnets make up the shortfall in flux since there is no iron in the motor. For a 10000 hp (7.5 MW) motor of the 752 series, at a speed of 327 mph, the pole pitch at 60 Hz would be 4 ft, and the height 1.33 ft, yielding a volume pole passing velocity of 16720 in^3/sec. Dividing this value by 2f and again by three for the three-phase system yields a value for wth of 46 in^3, which, with the 16-inch value of h, yields wt = 2.9 in^2. This value is based on the copper conductor in the 752 series motor, so must be scaled up by the resistivity ratio of copper to aluminum of about 1.5, which yields a wt value of 4.7 in^2.

The coil volume for the propulsion coils down both sides of the guideway would therefore be

$$V = 2(146)(4.7)L \qquad (5)$$

or 1381 ft^3 per mile of guideway length. Dividing by an aluminum density of 0.1 lb/in^3 yields a 239000 lb/mile, or almost exactly $1 million/mile for the motor coils.

The estimated volume of the levitation and guidance coils, based on a visual estimate of their size and spacing relative to that of the propulsion coils, is half that of the propulsion coils, yielding a total coil manufacturing cost of $1.5 million/mile. These cost estimates are for a one-way guideway, and must be doubled for a two-way guideway. Adding a contingency to costs for uncertainties and installation costs, a safe estimate of the costs would therefore be about $4.5 million per two-way mile ($3 million/mile for the propulsion coils and $1.5 million/mile for the levitation coils).

The Japanese system uses two sets of propulsion coils, one down each side of the guideway. Configuration 002 (USA) will require similar coils, but uses only one set, in the center of the guideway. These coils must handle the same power, but we estimate that they will be of a simpler design, and will cost about $1.7 million/mile. The total estimated installed cost of the propulsion levitation coils for the 002 configuration is, therefore, $3.3 million per mile compared to $4.5 million for the Japanese system.

9.3.2 Power Conditioning Unit (PCU) Cost Estimate

Power conditioning equipment for the JR systems to date includes condensers, cycloconverter transformers, cycloconverters, and controllers to handle the 10 MVA power requirement. According to Ref. 9.2, newer designs such as the Yamanashi facility may use inverters to provide more flexibility in the frequency and therefore the pole pitch of the motor windings. Data on the ratings of the JR equipment are limited. The estimated costs of the Transrapid system assume that the JR system will cost roughly the same amount, since the same amount of power is used.

The PCU for the Transrapid test facility at Emsland has been well documented, and includes a 110/20 kV, 31.5 MVA high-voltage transformer, two 20/1.2 kV, 5.6 MVA rectifier transformers, two 3300 A, 1300 V rectifiers, rectifier circuit breakers, 16 2 MVA, 0 – 2027 V, 680A, 0 – 215 Hz inverters, eight 1.8 MVA, 55 – 215 Hz output transformers, output circuit breakers, and a controller (Ref. 9.4). The cost of this equipment may be estimated using the per-kVA cost of similar lower-rated equipment built by GE in Erie, Pennyslvania, and Salem, Virginia. Costs vary from $130 to $400/kVA for installed transformer and inverter sets to perform roughly the same function. The large range in the values is caused by differences in technology and rating; these values apply for systems from 500 to 2000 hp, while the Transrapid system is rated at 40,000 hp. Using the conservative figure of $400/kVA, the total cost of the Transrapid system is about $12 million. Assuming that such a system can economically power a 30-km line, the per-mile figure is $0.67 million.

Note, however, that in their literature, the Transrapid group claims that their inverter system is the largest installed on a dc link in the world; it may indeed be a one-of-a-kind system with correspondingly high costs. The assumption that a similar system would be required only every 18 miles is based on a single test track with one system for an 18-mile length. Despite the Transrapid group's claim of high motor efficiency, the overall system efficiency is not reported, so the optimal PCU spacing could actually be shorter than 18 miles. This figure could only be verified with detailed motor analysis.

To estimate requirements for power conditioning, a Configuration 002 vehicle requiring 8.6 MW and operating on a 50 sec headway was considered. This relates to two vehicles (one in each direction on a two-way guideway) each within a 4.17-mile corridor, or 0.48 vehicle per mile. Using an oversizing factor of 1.5 and an installed cost of $400/kVA, a PCU cost of $2.5 million/mile is projected.

An interesting result is the figure of $1.5 million per two-way mile for levitation and guidance coils. These are the coils which would be obviated by use of a flat-plate suspension system, so the net savings would be this figure minus the flat-plate costs. Configuration 002 uses multiple sets of superconducting coils on the vehicle, with different coils providing the field for levitation and propulsion. The net system cost savings associated with using a flat-plate guideway are likely to be small, especially since the guideway levitation coils are unpowered. Since the flat-plate system produces higher magnetic drag than discrete coil designs, it is recommended that the Japanese-type system, and in particular, a null-flux configuration, be examined in greater detail.

9.4 MAGLEV VEHICLE COST ESTIMATES

9.4.1 Superconducting Magnet Cost Estimate

The relevant superconducting magnet parameters have been previously discussed. The magnet size, current density, and ampere turns are the major factors in estimating the cost. These parameters, together with estimates for magnet structure and cryostat costs, allow magnet costs to be estimated.

These magnets are similar in size and weight to MRI magnets, but construction and support of racetrack-shaped magnets and cryostats is difficult. Although energized MRI magnets are now routinely moved by truck from site to site, the MAGLEV dynamic environment will require more rugged supports and the superconductor will be selected based on its capability to operate in a basically ac environment. The fact that the magnets support the weight of the vehicle has a major effect on the mechanical support system.

The magnets must be designed with a total heat load, including that due to dynamic or transient effects, low enough to allow open-cycle operation, with helium supplied periodically or with an on-board helium recondenser or liquefier to maintain the coils at 4.2 deg K.

Cost estimates for prototype and production units are presented in Table 9-3. The costs of the magnets do not dominate the vehicle cost when the vehicle itself and all the electronic sensing and control equipment costs are included.

The production units for two coils are shown for an unshielded system as well as for an iron shield and for a shielded (bucking coil) configuration. The cost is predictably highest for a system with a shield coil. Estimates for installation, instrumentation and refrigeration were added to get production costs of $268,000, $285,000, and $321,000 for the three systems. Costs for prototype quantities were $690,000, independent of the type of coil.

In addition to the cost of electricity, it was assumed that the magnets will operate five percent of their time in an open-cycle mode (for charging/discharging, filling etc.), which results in an annual cost of $108,000 per coil set.

While not included in this cost estimate, the closed-cycle refrigerator will have a heat rejection requirement at room temperature of 15 kW which must be handled by additional systems.

Table 9-3 Superconducting Magnet Cost Estimate Summary – *Estimates of the manufacturing, operating, and maintenance costs for the superconducting magnets are summarized.*

Manufacturing costs, K$ (single levitation module, dual superconductor)				
		Production units		
Item	**Prototype units**	**With iron shield**	**Without shield**	**With bucking coil**
Magnet (2 coils)	400	145	128	181
Installation	50	20	20	20
Instrumentation	40	20	20	20
Refrigeration	200	100	100	100
Total	690	285	268	321
Assumption: The heat rejection load of 15 kW must be handled by other systems.				
Operation costs, K$ (per car/per year)				
Liquid helium (assuming 5W heat load. 5% of time in the open cycle mode. 95% in the closed cycle)			108	
Electricity (40 kW for hotel, refrigeration)			28	
Total			136	
Maintenance costs, K$ (per car/per year)				
Total			5 - 10	

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9.4.2 Refrigeration Cost Estimate

The superconducting coils require 4.2 deg K-level refrigeration to maintain a superconducting mode. On-board reliable refrigeration is the selected method, although other approaches should be investigated. The general arrangement of the refrigerator is shown in Fig. 9-6.

The magnitude of the refrigeration power requirement depends on the amount of heat to be removed from the low-temperature region as well as the particular refrigeration cycle used.

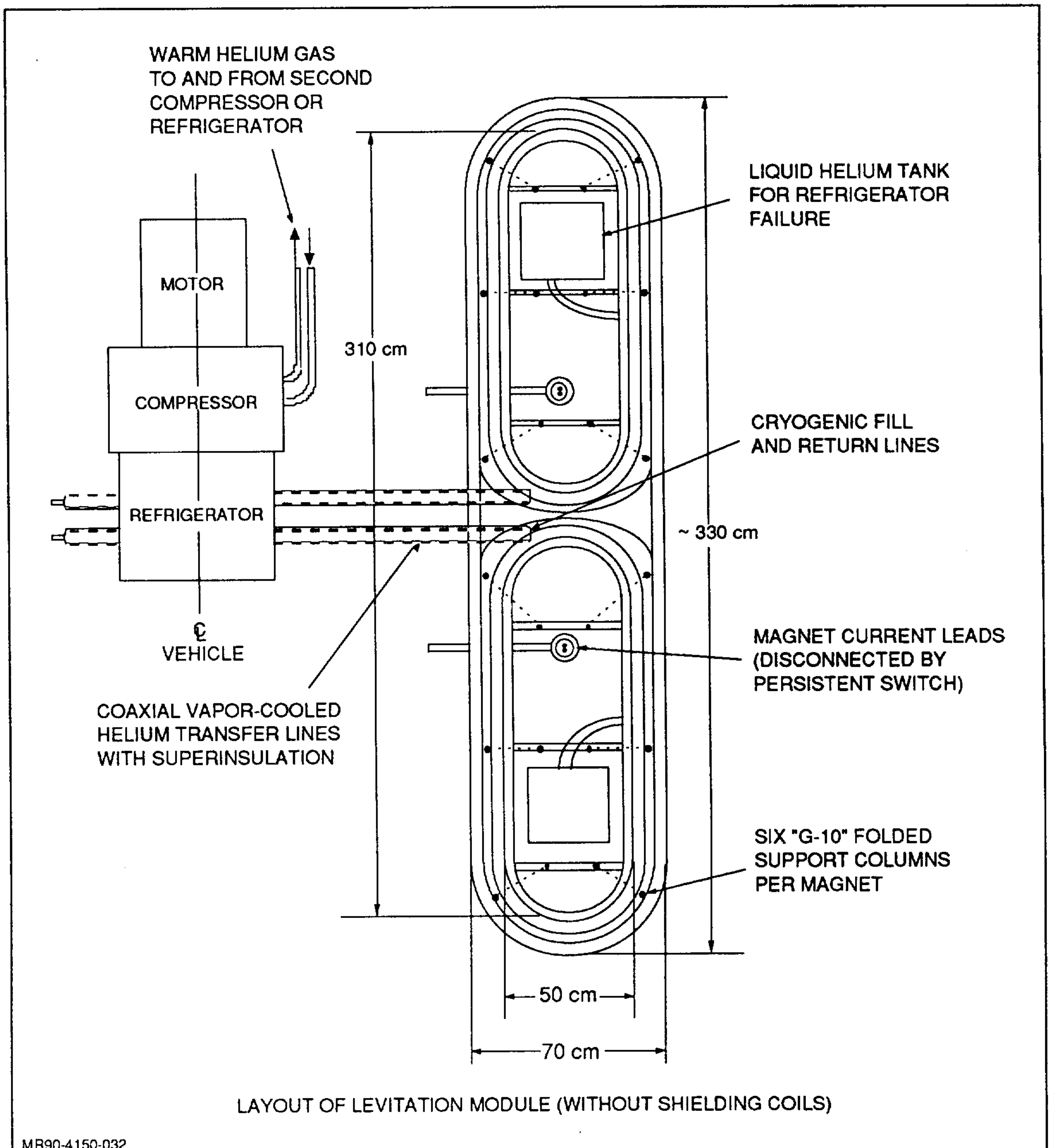

Fig. 9-6 Refrigerator Arrangement – *The layout of a levitation module with a closed cycle helium liquefier, feeding separate dual superconducting coil dewar housings is shown.*

Gifford-McMahon refrigerators are currently used in applications such as MRI and cryopumps, and have excellent reliability records. These units are considerably less efficient in terms of power required to remove a given heat load than other refrigerators based on the Claude or Stirling cycles developed by the Japanese for their MAGLEV Systems. While the latter are more efficient, their reliability needs to be demonstrated.

Because of the lower efficiency of the refrigerators, MRI system designs have reduced heat loads to an absolute minimum, which is the approach recommended for our MAGLEV studies. This approach requires the following general features: two cooled intermediate thermal shields; removable electrical power leads, using a superconductor designed for low loss; and a nonconducting or eddy-current minimized cryostat.

Characteristics of currently available reliable Gifford-McMahon refrigerators are summarized in Table 9-4.

9.4.3 Vehicle Cost Estimate

Weight and cost estimates for the Grumman MAGLEV vehicle subsystems are provided in Table 9-5. Suspension costs are based on levitation module information previously presented. Vehicle structure costs are estimated based on current Grumman airframe manufacturing costs; the remaining subsystem costs are based on empirical data obtained from Ref. 9.5 adjusted for 1989 costs.

A cost comparison was made using 1981 data from Ref. 9.6, as shown in Fig. 9-7. Based on

Table 9-4 Typical Refrigerator Characteristics – *Characteristics of currently available Gifford-McMahon helium refrigerators are summarized.*

Item	Refrigeration capacity, Watts			Power, kW	Weight, lb	Cost, K$
	77 deg K	20 deg K	4 deg K			
1. Shield cooler	80	7.5	–	4.5	200	24
2. Recondenser	–	–	4.4	15	800	70
3. Combination	58	3	0.6	7.5	400	57

For items 1 and 2:

21.4 K$/Watt of combined refrigeration at 4 deg. K
4.4 kW/Watt of combined refrigeration at 4 deg. K
227 lb/Watt of combined refrigeration at 4 deg. K

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Table 9-5 MAGLEV Vehicle Weight/Cost Breakdown (1989 Dollars)

Vehicle		Config 001[3]			Config 002[3]		
System	Subsystem	Weight, klb		Cost, K$	Weight, klb		Cost, K$
Suspension			15	1,200		15	1,200
	Lift/guidance magnetic modules[1] (4 sets)	5			5		
	Cryogenic refrigeration[2]	1.6			1.6		
	Landing/switching wheels, bogies & brakes (4 sets)	4.4			4.4		
	Cryogenic piping, insulation, attachments, etc.	1			1		
	Electronic control for lift/guidance magnets	3			3		
Structure			12.6	6,300		10.9	5,450
	Primary structure	9.6			8.6		
	Secondary structure	3			2.3		
Furnishings			6.6	415		6.6	415
	Seats (100)	3			3		
	Carpeting & lining	2.2			2.2		
	Windows & exterior doors	1.4			1.4		
Auxiliaries			4.7	78		4.7	78
	Air conditioning (air cycle machines & ducting)	1.4			1.4		
	Auxiliary power unit & lighting	0.8			0.8		
	Partitions & baggage racks	1.7			1.7		
	Lavatories (2), portable water & tanks	0.8			0.8		
Brakes			4.5	265		4.5	265
	Aerodynamics panels & emergency parachute						
Crew compartment			3.5	220		3.5	220
	Communications	0.5			0.5		
	Electrical distribution	2			2		
	Galley	0.6			0.6		
	Console instruments & furnishings	0.4			0.4		
Propulsion			24.5	6,964	7.5[4]	7.5	600
	Linear induction motor	14.5					
	Speed & power controller	10					
Contingency	10% of total		7.14	1,544		5.27	823
Empty vehicle weight			78.54			57.97	
Payload (100% loading)	100 passengers & 2 crew members (Average weight including luggage = 195 lb)		19.9			19.9	
	Gross vehicle		98.44	16,986		77.87	9,051

1. Includes levitation/guidance coils, shielding coils, dewars and control coils
2. Includes basic system consisting of one compressor and two refrigerators plus one backup system
3. Evaluated for baseline trip profile of 300 mi length with five equidistant intermediate stops
4. Superconducting coils to react against guideway propulsion coils

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this figure, a 100-passenger aircraft in the DC-9, 727, or 737 category would cost approximately $10 million per aircraft in 1981 dollars. If $3.6 million for three jet engines is subtracted and the cost is reduced by 15 percent for wings, engine cowling, and tail surfaces, the resulting aircraft cost is $5.44 million in 1981 dollars. Escalation of this cost by 6 percent per year to 1989 dollars results in a 1989 price of $8.6 million per aircraft, which compares favorably with the $9 million for Configuration 002 (Configuration 001 data include the cost and weight of a LIM for propulsion).

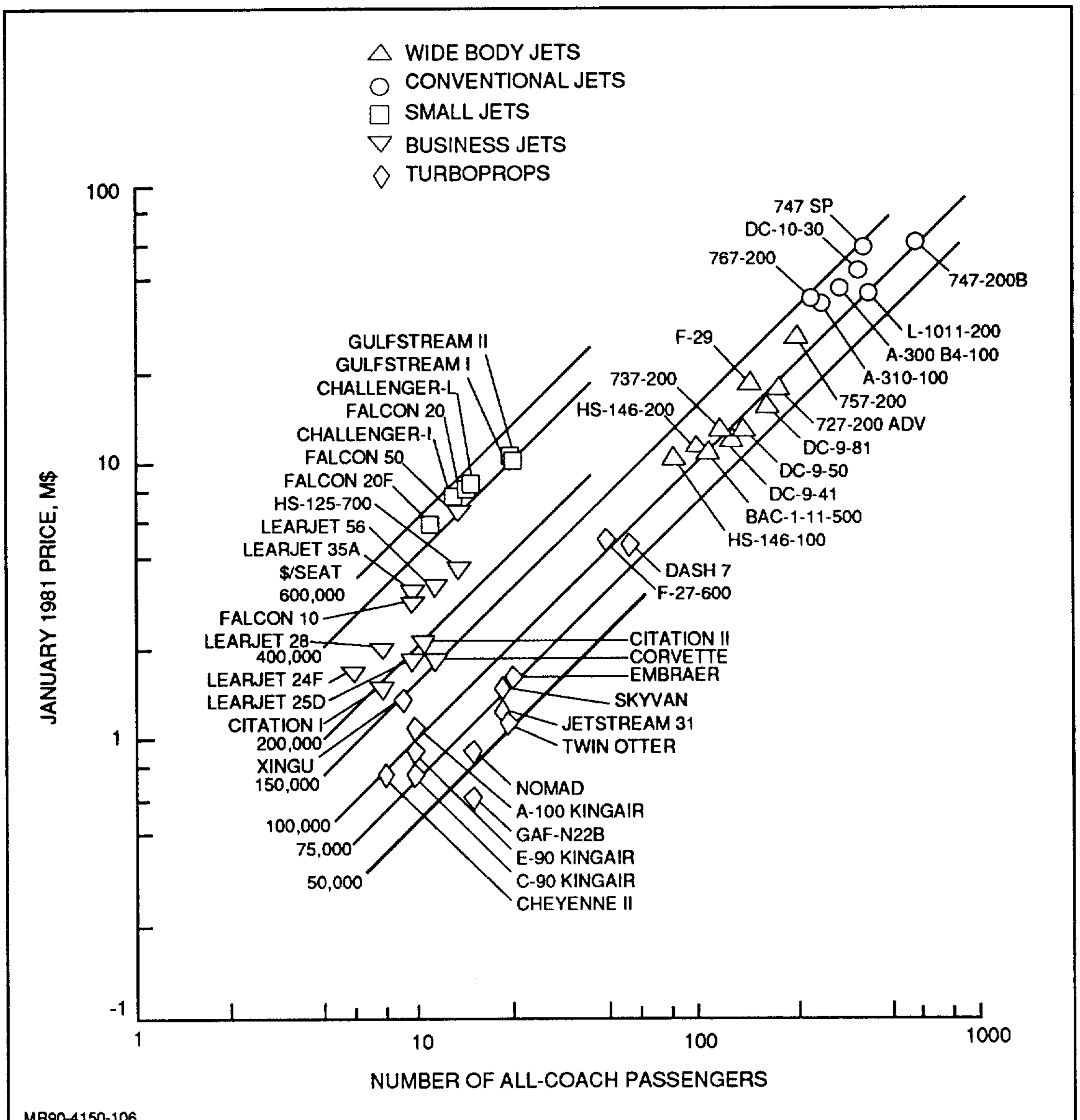

Fig. 9-7 Variation of Transport Aircraft Price with Passenger Seat Capacity – All Coach Seating with 34-Inch Row Spacing (January 1981 Dollars)

9.5 COST COMPARISON OF SELECTED MAGLEV SYSTEMS

Based on the preceding cost estimates and additional information supplied by Transrapid (Ref. 9.7) on the proposed Los Angeles-to-Las Vegas MAGLEV system, a cost comparison of the various MAGLEV configurations identified in Section 3 was made. The Japanese MLU002 configuration was not included in this evaluation because of limited information that prevented meaningful estimates. The existing data indicate a per-mile cost of at least $27 million, which is significantly higher than any of the systems that were evaluated. Our estimate of the MLU00X cost was based on information developed for Configurations 001 and 002.

Table 9-6 identifies the estimated cost for each major MAGLEV subsystem in terms of million $/mile. The lowest-cost system, as expected, Configuration 001 (USA) at $15.5 million/mile, uses a vehicle-mounted LIM for propulsion. The LIM, however, previously discussed in Paragraph 4.4.1, has major technology development problems and was rejected as a viable option for this study. It is also interesting to note that the Transrapid cost is 20 percent higher than Configuration 002 (USA). Although significant from an overall system cost standpoint, it was anticipated at the beginning of the study that it would be much higher. In any case, cost was not found to be a major factor for any system configuration. Guideway structure is the major cost, and

Table 9-6 MAGLEV Cost Estimates by Subsystem(1)

Subsystem	Transrapid German(3)	Config. 001 USA	Config. 002 USA	MLU00X Japan(6)
Guideway structure(2)	15.00(4)	11.40	11.40	11.40
Levitation	0.00(5)	1.60	1.60	1.50
Propulsion	2.80	0.80	1.70	3.00
PCU	2.40	0.00	2.50	2.50
Power distribution	0.75	1.00	0.75	0.75
Switches	0.22	0.10	0.10	0.10
Signal & communication	0.66	0.66	0.66	0.66
Totals, M$/mile	21.83	15.56	18.71	19.91

1. Values are in terms of M$/mile
2. Includes 35 ft elevated guideway, excavation & backfill
3. Data based on Transrapid information
4. Adjusted for 35 ft column height
5. Included in propulsion coil
6. Based on Grumman data developed for USA Configurations 001 and 002

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finding ways to reduce this cost is important. Follow-on studies in this area are strongly recommended.

9.6 SYSTEM COST ESTIMATE

As shown in Table 9-6, the cost for the selected Configuration 002 system is estimated at $18.7 million/mile which includes all guideway and electrification equipment, but not the MAGLEV vehicles. For the 495-mile New York City-to-Buffalo system, the capital cost would be $9.2 billion.

At maximum speed, the vehicles travel at five miles per minute with a minimum headway of about one minute. The round-trip 1000-mile system thus could accommodate a maximum of about 200 vehicles. Estimating the vehicles required to meet the passenger-miles-per-year requirement produces a much smaller number. Assuming 150 vehicles each costing $9 million, the total cost of vehicles is $1.35 billion.

The total system capital cost is estimated at $10.6 billion, with $9.2 billion for the guideway and $1.4 billion for the vehicles. This results in approximately $21.4 million per two-way mile.

9.7 OPERATING AND MAINTENANCE COST ESTIMATE

The primary operating and maintenance costs accrue from the energy cost to operate the vehicles plus costs for guideway maintenance, station maintenance, and personnel. These costs were estimated as follows.

The traffic demand analysis (Section 7) projected 5.34 million passenger trips per year with an average trip length of 167 miles. This yields 892 million passenger miles per year. The Configuration 002 vehicle consumes about 0.25 kWh per passenger mile at an assumed cost of $0.05 per kWh. This is an annual electricity cost of $11.2 million. Adding 20 percent for other electrical costs results in a total power cost of $13 million.

Thirteen stations with annual maintenance costs of $1 million each were assumed. Guideway maintenance was estimated at $100,000 per mile for the 495-mile system length, or $50 million per year. In addition, an operating cost of $12 million per year was assumed for personnel. The total operating and maintenance costs would be $88 million per year .

9.8 REVENUE ESTIMATES

The ridership demand analysis presented in Section 7 shows a maximum revenue income of about $340 million for the system. This income corresponds to operation in 2010 and a fare price of two times the intercity rail fares at that time.

9.9 ECONOMIC IMPACTS OF A NEW YORK STATE MAGLEV SYSTEM

9.9.1 General

One of the most critical areas in assessing MAGLEV, or any high-speed ground transportation system, is the magnitude and type of economic effects associated with developing and constructing a transportation system. Information about economic issues will help federal, state, and local officials, as well as potential private investors, determine whether the relatively high cost of construction and operation of such systems is justified.

Because of the importance and the large-scale nature of the benefits of these economic issues, it is imperative that New York State evaluate the economic impacts of these systems. While detailed economic analysis is beyond the scope of this study, a preliminary assessment is discussed and, where possible, quantified in this subsection.

9.9.2 Background

The three general categories of economic impacts for a project of this type and scale include the following:

- Construction – these economic impacts are related directly to the actual construction of the MAGLEV system;

- Operation – these economic impacts are related directly to the maintenance and operation of the MAGLEV system; and

- Structural Changes/Ancillary Development – these economic impacts include both direct and indirect effects that involve areas such as industrial growth, land development, MAGLEV-related service industries, and other services and industries that gain competitive advantages from the increased mobility and accessibility provided by a MAGLEV system.

Additional impacts may be expected in other areas such as the environment, where benefits would include reduction of pollution due to reduced tailpipe and airplane emissions. Energy benefits would also be gained and would include reduced fossil fuel usage. These issues are covered in more detail in sections of this report that deal with energy and environmental issues.

The magnitude of the economic impacts will vary over time. Initially, impacts are likely to be generated from the direct expenditures associated with material procurement and construction of the MAGLEV system, with employment and income generated for businesses and residents in the construction region. The impacts directly related to construction would be immediate and would provide additional economic stimulation through multiplier effects within a regional economy (i.e., the spending and respending of the same dollar).

After construction is completed and the initial impacts have been integrated, direct impacts from the maintenance and operation of the MAGLEV system would be generated. These economic effects would be ongoing as long as the MAGLEV service is operated. The long-term operation and maintenance impacts would also have a multiplier effect on the economy.

In addition to the direct impacts due to the construction, operation, and maintenance of the system, the MAGLEV service would in all probability cause major structural changes in the regional economy and ancillary development throughout the region. The structural changes would relate to the increased mobility and attractiveness of the region due to the superior service provided by MAGLEV, enhancing New York State's competitive status in the regional economy and thus stimulating economic growth in the State.

9.9.3 Construction-Related Economic Impacts

The construction-related economic impacts associated with building a MAGLEV system are direct, short-term benefits that extend throughout the construction time period and end when the system is completed. The estimated economic benefits are directly related to the total dollar amount spent on construction. New York State's share or capture of these benefits varies with the type of expenditure.

For every $1 billion spent on MAGLEV construction, it is estimated that 8550 construction jobs with $400 million in construction wages would be created. (For this discussion, job equals a person-year of employment.) In addition, for every $1 billion spent on MAGLEV construction, another 12,440 construction-related jobs are created, along with $637 million of construction-related wages. For a New York City to Buffalo MAGLEV system, for example, it is estimated that a total of 90,600 construction jobs with $4.24 billion in construction wages would be created. In addition, more than 131,800 construction-related jobs with more than $6.75 billion in construction-related wages would be generated from the total project.

As described, construction of a MAGLEV system in New York State would generate substantial economic benefits. The benefits realized directly from constructing a MAGLEV system would be from direct expenditures for material and equipment used in construction. Residents and businesses from the State would be the main recipients of these activities. In addition, the creation of employment and wages would stimulate the identified economic activity due to the multiplier effects of the construction and construction-related spending occurring in the region.

9.9.4 Operating and Maintenance-Related Economic Impacts

Unlike the economic impacts due to construction, which only extend over the project's construction period, the economic impacts associated with the operation and maintenance (O & M) of the MAGLEV system are generated every year of the system's operation. Additionally, the share of these impacts captured by New York State's economy would, in all likelihood, be greater than those due to construction of the system since O & M activities are predominantly local. Of these O & M-related economic impacts, it is expected that the urban areas of New York State would capture a larger share of the total. Economic impacts would grow over time along with ridership growth.

While detailed analysis cannot be performed at this stage, some generalities may be useful. By postulating one economic factor for this size and type of project, every $85,000 worth of direct investment should create one permanent new job. The new jobs would be in the direct O & M of the system (such as technicians, station and vehicle personnel) and in those industries benefiting from O & M, such as food and beverage suppliers. Using a New York City-to-Buffalo MAGLEV system as an example, the annual O & M cost is estimated at approximately $88 million. Therefore, approximately 1,035 new jobs would be created, of which approximately 300 would be directly involved in the O & M of the system. Using salary estimates of $50,000 for employees directly involved in the O & M of the system and $30,000 for O & M-related jobs, the total wages for direct and indirect O & M employees is $37 million.

Based on these estimates of jobs and wages relative to O & M of the MAGLEV system, another $52.9 million in economic activity output would be generated in the region due to multiplier effects.

Travel-related expenditures also would create substantial economic impacts. It is estimated that approximately 30 percent of the expected travel would be trips made, or induced, only if a MAGLEV system were in place. These travelers will spend money for local transportation, lodging, food, entertainment and incidentals which represent additional economic impacts. Secondary impacts to the region would also be gained through these expenditures.

9.9.5 Economic Impacts of Structural Changes/Ancillary Development

In addition to the economic impacts generated by the construction, operation and maintenance of the MAGLEV system, other benefits would be generated within the region due to structural changes and ancillary development caused by an efficient, high-speed transportation network.

Although these economic impacts would be substantial, it is premature to estimate their nature or magnitude. However, such impacts would enhance New York State's competitive position and status relative to the regional and national economics. For instance, with a MAGLEV system that provides high-speed superior service, New York State industries may become more competitive due to the increased mobility such a system provides. Also, with such a system in place, New York State may become a more attractive location for industrial development due to transportation improvements provided by the MAGLEV system. Additionally, by improving accessibility, the MAGLEV service could expand the tourist market, which could then increase the potential of investment in new tourist attractions. In fact, at least initially, the MAGLEV system could become a tourist attraction in its own right.

Economic impacts would also be expected in land development. Although difficult to quantify at this time, historical observations of the effect of transportation systems (i.e., railroad stations, interstate highways, airports, etc.) and, recently, rail-rapid transit systems, imply that this is realistic. This development is likely to include commercial, retail, office, lodging and restaurant components. It is difficult to estimate the size of these economic impacts, but a factor of three is sometimes used. This implies that the $10-billion investment might yield a $30-billion increase in New York State business.

In some instances, the MAGLEV system would only affect the location and timing of development that would naturally occur. However, a certain amount of new, induced development would occur due to the increased attractiveness of a location accessible to the MAGLEV system. This new development would in turn attract and promote secondary growth.

The land around station locations, in particular, would be among the first areas to benefit from the economic impacts of a MAGLEV system. The development at these locations should generate substantial revenue. Public policy may be needed to capitalize on the potential secondary investment opportunities offered by a MAGLEV system. In a favorable investment climate, substantial development activity in the station areas could be generated. Capture of some of these benefits may be a mechanism for paying a portion of the system's construction cost.

9.10 REFERENCES

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10 – OPPORTUNITIES FOR NEW YORK STATE INDUSTRIES IN MAGLEV DEVELOPMENT

10.1 INTRODUCTION

Assuming that an economic opportunity for MAGLEV development exists, it would be appropriate to identify candidate business interests, such as industries, research facilities, and universities within New York State; to establish an outreach program to inform them of this opportunity; and to provide assistance in initiating their participation. After start-up activities, free-market economic dynamics would theoretically drive the system.

A development program comprising three elements, regional promotion, public cooperation, and business participation, is described in this section.

10.2 REGIONAL PROMOTION

The MAGLEV concept offers significant advantages in transportation improvement, energy conservation, and pollution control. Many of these factors are regional and address issues that concern local and regional planners. MAGLEV may be considered a regional transportation system. While it is possible to envision a coast-to-coast MAGLEV system with New York City-to-Los Angeles trip times of less than 24 hours, in the forseeable future, most cross-country passenger service will remain with the present modes.

For these reasons, regional governments and civic organizations should promote the MAGLEV concept. They and their constituents will be the first to benefit from an improved transportation system and the attendant energy conservation and pollution improvements.

There are several examples of regional action that have proposed projects using existing technologies, including the proposed Transrapid system from Los Angeles to Las Vegas and the proposed system from Orlando, Florida, International Airport to International Drive. Similar projects have been studied in Pennsylvania, Texas and elsewhere. New York State has formed a State coalition of agencies that sponsored this project and which hosted the High-Speed Rail and MAGLEV Conference in Albany in September 1990.

There are two approaches to promoting MAGLEV. The first approach could build on work that has been done for the German and Japanese MAGLEV programs. The German effort produced a system that soon will be commercially viable, and it would be possible to install such a system in about five years. The German Transrapid system, however, has limited bank angle capability and would be speed-restricted in New York State. Significant modifications would be required to match the speed capabilities of the Transrapid system to New York State's needs. While it would not necessarily provide a vehicle manufacturing business, it would create a construction business associated with the guideway and terminals. The time frame for commercial applications of the Japanese system is still unclear.

The second approach would be to invest in producing an all-new U.S. system. This would provide a system designed for and best-suited to U.S. applications, and would enhance our domestic business base and trade balance. Building on the experience of foreign programs, and considering that most of the required technologies are well-developed, an aggressive success-oriented development program could produce a domestic system in a short time frame at reasonable cost. Industry and the federal government estimate the cost at about $1 billion and development time at less than eight years. An accelerated program could possibly reduce development time to five years.

Federal MAGLEV development funds this year are less than $15 million. Additional funding legislation is being considered.

Specific activities which should be considered to support MAGLEV development in New York State include:

- Conducting detailed application studies to determine the economics and transportation impacts of MAGLEV implementation;

- Coordinating these efforts with neighboring states to develop a regional approach; investigating the high-traffic Northeast Corridor through Boston, Albany, New York City, Philadelphia, Baltimore, and Washington, D.C., would be important in developing a regional transportation scenario;

- Urging the federal government to take the necessary action to develop a U.S. MAGLEV system; support local congressional representatives in their efforts to establish a national MAGLEV program; and

- Cooperating with the federal government in establishing a local demonstration project; providing route studies and cost-sharing these projects.

10.3 PUBLIC COOPERATION

It is critical, in the early stages of development of a new technology to inform the public of benefits, costs and associated hazards. The State must act in concert with local governments, business/industry groups, environmental groups, the media, and regional planning organizations to ensure that local interests are considered in the development of MAGLEV routes.

There is a significant amount of public awareness of MAGLEV due to numerous articles in the media. In general, these news items have been positive, and the public is aware of MAGLEV benefits and is also aware that this U.S.-initiated technology may have to be purchased from abroad if a U.S. effort is not started soon. The New York State Energy Research and Development Authority and the New York State Energy Office have developed a number of successful outreach programs related to energy conservation; these programs could be adapted to inform the public about MAGLEV.

Although high-speed modes of transport will supplement existing modes, including air, at competitive fares, MAGLEV may not appeal to passengers who use conventional rail or automobile. It will be important to stress the reduced speed, high-volume capability of MAGLEV operating in a commuter scenario to attract as many riders as possible.

Specific actions that New York State could take to heighten public support of MAGLEV activities are:

- Informing the public about MAGLEV;
- Promoting media exposure; and
- Sponsoring MAGLEV conferences that attract technical, public, and media attention.

10.4 BUSINESS PARTICIPATION

It is estimated that development of a U.S. MAGLEV system will require the expenditure of about $1 billion. In addition, system deployment could be estimated at about $21.4 million per mile with vehicles included. If we assume an ultimate system length of 495 miles in New York State, then a potential investment of about $10.6 billion could be envisioned. At least half of this would represent construction work done by local firms. The remainder would be equipment that could be locally procured if a MAGLEV industry in New York State is supported.

In addition to the construction work associated with land preparation and guideway fabrication, the technologies involved with MAGLEV implementation include those typical of aircraft construction and electrical power equipment. New York State has numerous firms with the capability to provide these goods and services as well as the universities, consultants, and research organizations to develop the concept.

To encourage the participation of New York State businesses in developing MAGLEV systems, it will be necessary to both advise appropriate firms of opportunities and provide them with support.

To start this process, a data base scan was conducted with the assistance of the New York State Department of Economic Development (DED). We identified categories of companies likely to have an interest in MAGLEV business in the list of Standard Industrial Classification Codes (SIC). DED performed a computer scan on their general list that identified more than 1,000 firms in these categories in New York State. It should be noted that some firms with potential interest in MAGLEV development may not have been identified in this scan because of the nature of the classification system. Nonmanufacturers such as service companies, research firms, and universities are not included in the data base.

This scan must be supplemented by outreach efforts, which could include:

- Direct mailings to firms and industry associations identified as having a potential interest in MAGLEV. Using industry associations will be particularly helpful in contacting nonmanufacturers. The mailing should include technical background information, such as the Executive Summary Report of the MAGLEV Technology Advisory Committee;

- Publish notices in the *Contract Reporter,* the bid paper in which New York State agencies publish contract lettings for goods and services exceeding $5,000 in value;

- Advertise in industry, transportation and construction periodicals and regional business publications, soliciting firms for a New York State MAGLEV mailing list;

- Attract the attention of the media by issuing press releases; and

- Sponsor conferences for the business community, similar to the conference held in Albany in September 1990. State officials could also attend selected industry trade shows.

11 - CONCLUSIONS AND RECOMMENDATIONS

11.1 INTRODUCTION

Although this study was limited in the scope and depth in which MAGLEV applications in New York State could be explored, it provided a beginning, and identified areas that need additional work. In general, we feel that MAGLEV systems soon will be incorporated into the transportation scenario of the United States. MAGLEV is an attractive alternative to New York State's congested and polluting transportation systems. There are several areas that warrant additional research to address critical issues identified in this study. These areas are summarized below.

11.2 CONCLUSIONS

- There appear to be no insurmountable engineering or technological obstacles to developing and constructing MAGLEV systems in New York State.

- Since the guideway is the most expensive component of a MAGLEV system, innovative and refined designs and manufacturing techniques are needed to minimize system costs.

- A high-speed intercity MAGLEV system should attract a substantial level of ridership, with the associated farebox revenue covering the operating and maintenance costs of the system.

- MAGLEV systems could alleviate the airport congestion attributed to short- and medium-haul air trips.

- Benefits can be realized from the MAGLEV system by using it to carry high-value or time-critical freight, as well as passengers. This may reduce some truck-related highway maintenance costs.

- Considerable economic benefits could be generated through the research and development, construction, operation and maintenance of a MAGLEV system in New York State. In addition to these direct economic benefits, the improved system will help stimulate economic growth in the State.

- Development in the proximity of station locations could enhance the economic viability of a MAGLEV system.

- Integration of high-speed MAGLEV with the existing transportation network is extremely important; however, this will require consideration of intermodal concepts.

- There is potential to develop a new-design MAGLEV system that would incorporate various aspects of current systems to optimize its application in the Northeast.

- Implementation of MAGLEV systems would help solve some aspects of transportation-related problems such as air pollution and reliance on fossil fuels.

- MAGLEV systems can potentially be operated at high degrees of safety and the technology exists to minimize potential health issues involving induced magnetic fields.

- New York State has a substantial presence in research, manufacturing and service firms related to MAGLEV development and implementation. Considerable economic benefits would accrue to New York State business from the various phases of MAGLEV.

11.3 RECOMMENDATIONS

Based on the investigations and conclusions of this study, the following recommendations are offered involving development of MAGLEV systems in New York State:

- One of the competitive advantages of MAGLEV as a transportation mode is its ability to operate at speeds approaching 300 mph. The ability of the vehicles to sustain as high an operating speed as possible is critical to implementation. Therefore, it is recommended that further, refined analysis of potential routes and their application as MAGLEV rights-of-way is critical and should be investigated;

- Market demand and ridership forecasts for an intercity MAGLEV system are critical in estimating the potential farebox revenue and its relation to total system costs and financing. A detailed market assessment, including a forecast demand model with appropriate origin and destination data as its foundation, should be made as soon as possible;

- Since the potential economic activities associated with the development, construction, operation and maintenance of a MAGLEV system are substantial, it is recommended that additional economic analysis be conducted to refine these estimates. Detailed economic evaluation will be crucial in determining the overall benefits and advantages of a MAGLEV system compared to major investments in other transport modes. Station development may offer the potential for providing non-farebox revenues and should be analyzed;

- Station location must consider real estate development, market demand, and integration with existing transportation systems. A thorough analysis of low-speed MAGLEV system development in suburban and urban areas is recommended;

- Additional research should be conducted in vehicle and guideway design and their interaction. This work should include analysis of banking requirements and ride comfort criteria for vehicles and guideways. Other areas of research should include study of passive coil and flat-plate guideway design including the null-flux design;

- Freight-carrying capability requires further study; and

- Due to the importance of transportation safety, the ongoing research into the effects of magnetic fields should be monitored. All MAGLEV design research should address this issue. Designs should be developed that can effectively shield the induced magnetic fields generated. Further investigation of MAGLEV systems also should be used to develop system safety standards and operational standards that can minimize all potential safety situations that may be encountered, such as guideway misalignments, power failures, and levitation failures.

APPENDIX A

DETAILED MAGLEV SYSTEM DATA

A.1 INTRODUCTION

This appendix contains detailed system data for the Transrapid, MLU002, MLU00X, Configuration 001 and Configuration 002 MAGLEV systems. These systems are under consideration for use in the development of a MAGLEV ground transportation system for New York State.

MAGLEV SYSTEM DATA
TRANSRAPID

1.	TYPE	Electromagnetic levitation with normal coils, linear synchronous motor propulsion with an active guideway
2.	DEVELOPMENT STATUS	Prototype in operation, no commercial service
	– Proposed for Revenue Service	Cal/Nevada, Orlando/International Drive
3.	DESIGN CRITERIA	Passenger and light freight
	– Max. speed	500 kph
4.	TRAINSET	2 – 10 cars
	– Train Length	51 – 251 m
	– Total Weight	up to 550 MT
	– Total Seats	120 to 1000 depending on the mix between first and second class (60-100 per car)
5.	VEHICLE	
	– Length	25 m
	– Height	4.06 m
	– Width	3.7 m
	– Gross Weight	50 MT
	– Payload	20 MT

6. SPEED CHARACTERISTICS

– Target Speed	500 kph
– Max. Speed Achieved	N/A
– Lift-off Speed	0 kph
– Max. Grade	10%

7. DRAG CHARACTERISTICS

– Max. Total Drag	45 kN (2 cars @ 450 kph)
– Aerodynamic Drag	37 kN (2 cars @ 450 kph)
– Induction Generator Drag	5 kN (2 cars @ 450 kph)
– Levitation Drag	3 kN (2 cars @ 450 kph)

8. PROPULSION SYSTEM

– Type	Iron core linear synchronous motor
– Thrust	60 kN @ 400 kph measured for theTR006, target for the TR007: 36 kN @ 400 kph, 52 kN @ 500 kph (2 cars)

9. POWER SUPPLY

– System Characteristics	110/220 kv, 50 Hz
– On-board Supply	Batteries up to 120 kph, induction from guideway above 120 kph
– Substation Spacing	30 km avg.

10. POWER REQUIREMENTS	
– Propulsion	5.6 MW (2 cars @ 450 kph)
– Levitation	130 kW (2 cars @ 450 kph)
– Housekeeping	N/A
11. SPECIFIC ENERGY CONSUMPTION	
– Passenger	0.15 kWh/passenger-km
– Freight	0.69 kWh/MT-km
12. GUIDANCE	
– Type	Electromagnetic against either side of guideway
13. SUSPENSION	
– Type	Electromagnets, attractive
– Clearance	10 mm
14. BRAKING SYSTEM	
– Primary	Linear motor reverse thrust
– Secondary	Eddy current via guidance magnets
– Tertiary	Skids at under 50 kph
15. VEHICLE STRUCTURE	Honeycomb aluminum plate structure, aluminum profiles, GREP composite

16. CONTROL AND COMMUNICATION	
– Type	Automatic central control
– Subsystems	40 GHz RF, fiber optics
17. MAGNETIC FIELDS	Max. 5 gauss DC
18. SAFETY	Automatic control, no derailment, high safety standards inside the vehicle, fail-safe levitation and braking, fire protection, grounding
19. MAINTENANCE	
– Guideway	Alignment consistent with 10 mm clearances
– Vehicle	Exchangeable modules
20. RIDE COMFORT	
– Max. Acceleration	1.0 m/sec^2
– Max. Deceleration	0.8 m/sec^2
– Max. Jerk	0.5 m/sec^3
21. SEATING CONFIGURATION	
– First Class	2+2
– Second Class	2+3

22. SEAT DIMENSIONS

– First Class Width	690 mm
– Second Class Width	530 mm
– First Class Spacing	1050 mm
– Second Class Spacing	850 mm

23. RELIABILITY — Functional redundancy, decentralized power supply, electronic diagnostic system

24. ENVIRONMENTAL TOLERANCE

– Cross Winds	90 kph at full speed
– Earthquake	Frequencies up to 2-3 Hz, accelerations up to 0.5 g can be balanced

25. GUIDEWAY

– Type	Elevated, mounted on pillars
– Design	Concrete pillars with steel or concrete beams
– Typical Span	25 – 34 m
– Height	2 – 40 m
– Beam Mass	Steel – 1.2 MT/m Concrete – 3.6 MT/m
– Bank Angle	12°

26. SWITCHES

– Design	Flexible bend
– Max. Speed	250 kph (high-speed switch) 100 kph (low-speed switch)
– Length	186 m (high-speed switch) 65 m (low-speed switch)

27. INVESTMENT COST

– Guideway	\$15 – 20 million/mi (2-track)
– Vehicle	\$5.5 million/car
– Life Span	Infrastructure – 60 years Superstructure – 35 years Vehicle – 25 years

28. OPERATING COSTS

– Staff	20%
– Energy	37%
– Power Supply	18%
– Vehicle Maintenance	10%
– Guideway Maintenance	15%

MAGLEV SYSTEM DATA
MLU002

1. TYPE	Electrodynamic levitation with superconducting coils, linear synchronous motor propulsion with an active guideway
2. DEVELOPMENT STATUS	Demonstrator in operation, no commercial service
– Proposed for Revenue Service	No
3. DESIGN CRITERIA	Passenger
– Max. speed	420 kph
4. TRAINSET	One car
– Train Length	22 m
– Total Weight	17 MT
– Total Seats	44
5. VEHICLE	
– Length	22 m
– Height	3.7 m
– Width	3.0 m
– Gross Weight	17 MT
– Payload	N/A

6. SPEED CHARACTERISTICS	
– Target Speed	420 kph
– Max. Speed Achieved	362 kph
– Lift-off Speed	170 kph
– Max. Grade	N/A
7. DRAG CHARACTERISTICS	N/A
8. PROPULSION SYSTEM	
– Type	Air core linear synchronous motor
– Thrust	N/A
9. POWER SUPPLY	
– System Characteristics	66 kv, 60 Hz
– On-board Supply	Batteries up to 170 kph, induction from guideway above 170 kph
– Substation Spacing	One substation
10. POWER REQUIREMENTS	
– Propulsion	N/A
– Levitation	Negligible
– Housekeeping	40 kW
11. SPECIFIC ENERGY CONSUMPTION	N/A

12. GUIDANCE	
– Type	Electrodynamic, combined with propulsion devices
13. SUSPENSION	
– Type	Electrodynamic, repulsive
– Clearance	110 mm
14. BRAKING SYSTEM	
– Primary	Linear motor reverse thrust
– Secondary	Skids
15. VEHICLE STRUCTURE	Semi-monocoque aluminum structure, GREP composite
16. CONTROL AND COMMUNICATION	
– Type	Automatic central control
– Subsystems	N/A
17. MAGNETIC FIELDS	200 Gauss at floor level over the truck
18. SAFETY	Automatic control, no derailment
19. MAINTENANCE	
– Guideway	Alignment consistent with 100 mm clearances
– Vehicle	Cryosystems, landing gear

20. RIDE COMFORT

– Max. Acceleration	2.7 m/sec^2 (due to short track)
– Max. Deceleration	2.1 m/sec^2
– Max. Jerk	N/A

21. SEATING CONFIGURATION

– First Class	2+2

22. SEAT DIMENSIONS	N/A
23. RELIABILITY	Separate superconducting magnets

24. ENVIRONMENTAL TOLERANCE

– Cross Winds	N/A
– Earthquake	More sensitive to lateral than vertical track displacements

25. GUIDEWAY

– Type	Elevated, mounted on pillars
– Design	U-shaped guideway, use of steel should be minimized
– Typical Span	N/A
– Height	N/A
– Beam Mass	N/A
– Bank Angle	N/A

26. SWITCHES

– Design	Segment
– Max. Speed	70 kph
– Length	80 m
27. INVESTMENT COST	N/A
28. OPERATING COSTS	N/A

MAGLEV SYSTEM DATA
MLU00X

1. TYPE	Electrodynamic levitation with superconducting coils, linear synchronous motor propulsion with an active guideway
2. DEVELOPMENT STATUS	In preliminary design
– Proposed for Revenue Service	No
3. DESIGN CRITERIA	Passenger
– Max. speed	500 – 600 kph
4. TRAINSET	6 – 14 cars
– Train Length	141 – 315 m
– Total Weight	270 MT (14 cars)
– Total Seats	952 (14 cars)
5. VEHICLE	
– Length	21.6 m (intermediate car) 27.6 m (end car)
– Height	2.65 m
– Width	2.8 m
– Gross Weight	18 MT (intermediate car) 27 MT (end car)
– Payload	N/A

6. SPEED CHARACTERISTICS	
– Target Speed	500 – 600 kph
– Max. Speed Achieved	N/A
– Lift-off Speed	100 kph
7. DRAG CHARACTERISTICS	N/A
8. PROPULSION SYSTEM	
– Type	Air core linear synchronous motor
– Thrust	N/A
9. POWER SUPPLY	
– System Characteristics	N/A
– On-board Supply	Batteries up to 100 kph, induction from guideway above 100 kph
– Substation Spacing	Average 40 km
10. POWER REQUIREMENTS	
– Propulsion	N/A
– Levitation	Negligible
– Housekeeping	N/A
11. SPECIFIC ENERGY CONSUMPTION	N/A
12. GUIDANCE	
– Type	Electrodynamic, combined with propulsion devices

13. SUSPENSION	
– Type	Electrodynamic, repulsive
– Clearance	100 mm
14. BRAKING SYSTEM	
– Primary	Linear motor reverse thrust
– Secondary	Skids
15. VEHICLE STRUCTURE	N/A
16. CONTROL AND COMMUNICATION	
– Type	Automatic central control
– Subsystems	Leakage coaxial cable, inductive wires, data cable
17. MAGNETIC FIELDS	Less than 10 gauss
18. SAFETY	Automatic control, no derailment
19. MAINTENANCE	
– Guideway	Alignment consistent with 100 mm clearances
– Vehicle	Cryosystems, landing gear
20. RIDE COMFORT	N/A
21. SEATING CONFIGURATION	
– First Class	2+1
– Second Class	2+2

22. SEAT DIMENSIONS	
– First Class Width	525 mm
– Second Class Width	N/A
– First Class Spacing	N/A
– Second Class Spacing	N/A
23. RELIABILITY	Separate superconducting magnets
24. ENVIRONMENTAL TOLERANCE	
– Cross Winds	N/A
– Earthquake	N/A
25. GUIDEWAY	
– Type	Elevated, mounted on pillars
– Design	U-shaped guideway, use of steel should be minimized
– Typical Span	15 m
– Height	N/A
– Beam Mass	N/A
26. SWITCHES	
– Design	Segment
– Max. Speed	N/A
– Length	N/A

27. INVESTMENT COST

– Guideway	\$18.5 million/km exclusive of land
– Vehicle	N/A
– Life Span	N/A

28. OPERATING COSTS N/A

MAGLEV SYSTEM DATA
CONFIGURATION 001

1.	TYPE	Electrodynamic levitation with superconducting coils, linear induction motor propulsion with a passive guideway
2.	DEVELOPMENT STATUS	In conceptual Design
	– Proposed for Revenue Service	No
3.	DESIGN CRITERIA	Passenger and freight
	– Max. speed	483 kph
4.	TRAINSET	One or more cars
5.	VEHICLE	
	– Length	30 m
	– Height	3.4 m
	– Width	3.4 m
	– Gross Weight	39 MT
	– Payload	7.3 MT
6.	SPEED CHARACTERISTICS	
	– Target Speed	483 kph
	– Max. Speed Achieved	N/A
	– Lift-off Speed	96 kph
7.	DRAG CHARACTERISTICS	N/A

8. PROPULSION SYSTEM	
– Type	Air core linear induction motor
– Thrust	N/A
9. POWER SUPPLY	
– System Characteristics	N/A
– On-board Supply	Wayside power through high-speed brush gear
– Substation Spacing	N/A
10. POWER REQUIREMENTS	
– Propulsion	10.3 MW
– Levitation	Negligible
– Housekeeping	TBD
11. SPECIFIC ENERGY CONSUMPTION	
– Passenger	.38 kWh/seat-mile @ 483 kph
– Freight	N/A
12. GUIDANCE	
– Type	Electrodynamic, combined with propulsion devices
13. SUSPENSION	
– Type	Electrodynamic, repulsive
– Clearance	100 mm

14. BRAKING SYSTEM	
– Primary	Linear motor reverse thrust
– Secondary	Skids
15. VEHICLE STRUCTURE	N/A
16. CONTROL AND COMMUNICATION	
– Type	Automatic central control
– Subsystems	N/A
17. MAGNETIC FIELDS	N/A
18. SAFETY	Automatic control, no derailment
19. MAINTENANCE	
– Guideway	Alignment consistent with 100 mm clearances
– Vehicle	Cryosystems, landing gear
20. RIDE COMFORT	
– Max. Acceleration	1.5 m/sec^2
– Max. Deceleration	1.5 m/sec^2 (9.8 m/sec^2 in emergency)
– Max. Jerk	0.3 m/sec^3
21. SEATING CONFIGURATION	
– First Class	2+2
– Second Class	N/A

22. SEAT DIMENSIONS	N/A
23. RELIABILITY	Separate superconducting magnets
24. ENVIRONMENTAL TOLERANCE	
– Cross Winds	113 kph
– Earthquake	N/A
25. GUIDEWAY	
– Type	Elevated, mounted on pillars
– Design	N/A, use of steel should be minimized
– Typical Span	N/A
– Height	10-12 m
– Beam Mass	N/A
26. SWITCHES	N/A
27. INVESTMENT COST	
– Guideway	$15 million/mi exclusive of land (double track)
– Vehicle	N/A
– Life Span	N/A
28. OPERATING COSTS	N/A

MAGLEV SYSTEM DATA
CONFIGURATION 002

1. TYPE	Electrodynamic levitation with superconducting coils, linear synchronous motor propulsion with an active guideway
2. DEVELOPMENT STATUS	In conceptual design
– Proposed for Revenue Service	No
3. DESIGN CRITERIA	Passenger and freight
– Max. speed	483 kph
4. TRAINSET	One or more cars
5. VEHICLE	
– Length	30 m
– Height	3.4 m
– Width	3.4 m
– Gross Weight	30 MT
– Payload	7.3 MT
6. SPEED CHARACTERISTICS	
– Target Speed	483 kph
– Max. Speed Achieved	N/A
– Lift-off Speed	96 kph
7. DRAG CHARACTERISTICS	N/A

8. PROPULSION SYSTEM

– Type	Air core linear synchronous motor
– Thrust	N/A

9. POWER SUPPLY

– System Characteristics	N/A
– On-board Supply	Batteries at low speed, induction from guideway at high speed
– Substation Spacing	N/A

10. POWER REQUIREMENTS

– Propulsion	7.4 MW
– Levitation	Negligible
– Housekeeping	N/A

11. SPECIFIC ENERGY CONSUMPTION

– Passenger	0.25 kWh/seat-mile @ 483 kph
– Freight	N/A

12. GUIDANCE

– Type	Electrodynamic, combined with propulsion devices

13. SUSPENSION

– Type	Electrodynamic, repulsive
– Clearance	100 mm

14. BRAKING SYSTEM	
– Primary	Linear motor reverse thrust
– Secondary	Skids
15. VEHICLE STRUCTURE	N/A
16. CONTROL AND COMMUNICATION	
– Type	Automatic central control
– Subsystems	N/A
17. MAGNETIC FIELDS	5 gauss max.
18. SAFETY	Automatic control, no derailment
19. MAINTENANCE	
– Guideway	Alignment consistent with 100 mm clearances
– Vehicle	Cryosystems, landing gear
20. RIDE COMFORT	
– Max. Acceleration	1.5 m/sec^2
– Max. Deceleration	1.5 m/sec^2 (9.8 m/sec^2 in emergency)
– Max. Jerk	0.3 m/sec^3
21. SEATING CONFIGURATION	
– First Class	2+2
– Second Class	N/A

22. SEAT DIMENSIONS	N/A
23. RELIABILITY	Separate superconducting magnets
24. ENVIRONMENTAL TOLERANCE	
– Cross Winds	113 kph
– Earthquake	N/A
25. GUIDEWAY	
– Type	Elevated, mounted on pillars
– Design	N/A, use of steel should be minimized
– Typical Span	N/A
– Height	10-12 m
– Beam Mass	N/A
26. SWITCHES	N/A
27. INVESTMENT COST	
– Guideway	$18 million/mi exclusive of land (double track)
– Vehicle	N/A
– Life Span	N/A
28. OPERATING COSTS	N/A

APPENDIX B

TOP-LEVEL REQUIREMENTS AND PERFORMANCE SPECIFICATION-01

for the development of a

MAGNETICALLY LEVITATED HIGH-SPEED GROUND TRANSPORTATION SYSTEM FOR NEW YORK STATE

Prepared for

The New York State
Energy Research and Development Authority
2 Rockefeller Plaza
Albany, N.Y. 12223-9998

by

Grumman Corporation
Parsons Brinckerhoff
General Electric
Intermagnetics

October 19, 1990

APPENDIX B

TOP-LEVEL REQUIREMENTS AND PERFORMANCE SPECIFICATION FOR THE DEVELOPMENT OF A MAGNETICALLY LEVITATED GROUND TRANSPORTATION SYSTEM

B.1 PURPOSE

The purpose of this Specification is to define the top-level operating and performance requirements of a Magnetically Levitated (MAGLEV) Ground Transportation System. The MAGLEV Ground Transportation System will be designed to provide a safe, economical, high-speed, high-volume passenger and cargo transportation system between major cities and within high-volume metropolitan commuter areas. Where differences between an intercity and a metropolitan transportation system exist, they are identified in the specification.

B.2 MAJOR ASSUMPTIONS AND GUIDELINES

The following major assumptions and guidelines have been established for purposes of this specification:

- Rights-of-way are provided to the system along existing major interstate highways, bridges, railways, power lines, etc.;

- Guideways will be elevated above existing highways and crossways and designed to be aesthetically pleasant. On-grade and below-grade rights-of-way will be considered in special cases;

- The MAGLEV design shall be a complete transportation systems approach, i.e., the concept shall not only include the guideways, cars, and support structure of the proposed high-speed transportation system, but also shall take into account the following:

  - The location of station stops will consider factors such as proximity to major work areas and availability of convenient transportation, including airports, bus, train, and/or taxi service to these areas;

  - The construction of large rural-area parking facilities, office buildings and/or shopping malls, with convenient access to station platforms, shall be provided at each station;

  - Provision of express tracks for rapid nonstop transportation of passengers and cargo to the end of the line;

  - Provision of a central control station that will automatically monitor the location, number of cars, and speed of each train in the system; safety of operation, long life, and minimum maintenance shall be prime considerations;

  - Provision of access to garaging and maintenance facilities for the transportation system; and

– Provision of administration and training facilities for the transportation system.

B.3 MAJOR REQUIREMENTS AND PERFORMANCE SPECIFICATION

Based on the assumptions and guidelines identified in Section B.2, the following major requirements and performance specifications will be used to develop the MAGLEV Ground Transportation System:

1. Design for a 300-mph maximum speed and 250-mph cruise speed for long-distance, intercity transportation (50 miles minimum distance between stops) and 120-mph cruise speed for high-volume metropolitan areas (15 miles minimum distance between stops). The same vehicle shall provide both the 300-mph and 120-mph speed applications with minimum design differences.

2. The system shall be capable of accommodating up to 4,000 passengers per hour in each direction for the intercity transportation system, and up to15,000 passengers per hour for the high-volume metropolitan areas.

3. Acceleration and deceleration rates shall be nominally 5 ft/sec^2 but shall not exceed 16 ft/sec^2 under emergency conditions. If practical, energy developed for deceleration shall be stored in the acceleration drive system with minimal losses.

4. With a four-percent grade and a 30-mph head wind, the vehicle shall be capable of sustaining its design cruise speed and at least half of the designed acceleration rate.

5. Under any normal operating condition and at all speeds below 300 mph, the values of sustained or steady-state acceleration and rate of change of acceleration (jerk) specified in Table B-1 shall not be exceeded at any time.

6. Noise level within the train shall, at all times, be less than 65 dbA in the passenger compartment and 75 dbA in the crew compartment.

Table B-1 Acceptable Values of Sustained Acceleration & Jerk

Direction	Sustained acceleration, ±g	Jerk, ±g/sec
Longitudinal	0.20	0.03
Lateral	0.08	0.03
Vertical	0.10	0.04

MR90-4150-079

7. Under all speed conditions, noise levels outside the train shall be less than the levels shown in Fig. B-1 at 70 ft from the guideway.

8. For all operating speed conditions, spectral acceleration levels within the interior of the car shall be less than those shown in Fig. B-2.

9. Steady-state magnetic environment to passengers and crew shall not exceed 0.0005 Tesla (5.0 gauss) within the cabin area. Cyclic magnetic variations shall not exceed (TBD) Tesla rms.

10. Sustained environmental temperatures ranging from a low of -20°F (-29°C) and a high of +120°F (40°C) shall not affect operation of the transportation system.

11. The bottom of the guideway shall be at least 35 to 40 ft above the highway and a minimum of 16.5 ft above any crossway.

12. Banking of the track up to 12 deg will be provided to minimize both vehicle and passenger side loads. Vehicle carriage banking will also be provided, but the combined guideway and vehicle bank angle shall not exceed 24.6 deg. Banking rate shall not exceed 3 deg/sec.

13. The minimum radius of curvature for transition to new grades shall be designed not to exceed the vertical acceleration and jerk levels specified in Table B-1.

14. Guideways, supporting structure and cars shall be designed to withstand a steady side wind of 100 mph with no vehicles operating, and a steady 50-mph wind with gusting of up to 70 mph while traveling at 300 mph. Snow accumulations of up to 0.5 ft, or heavy rains up to 2 inches/hr, shall not affect operation of the transportation system. Ice accumulation of up to 0.25 inches on the guideway shall not affect operation of the vehicles.

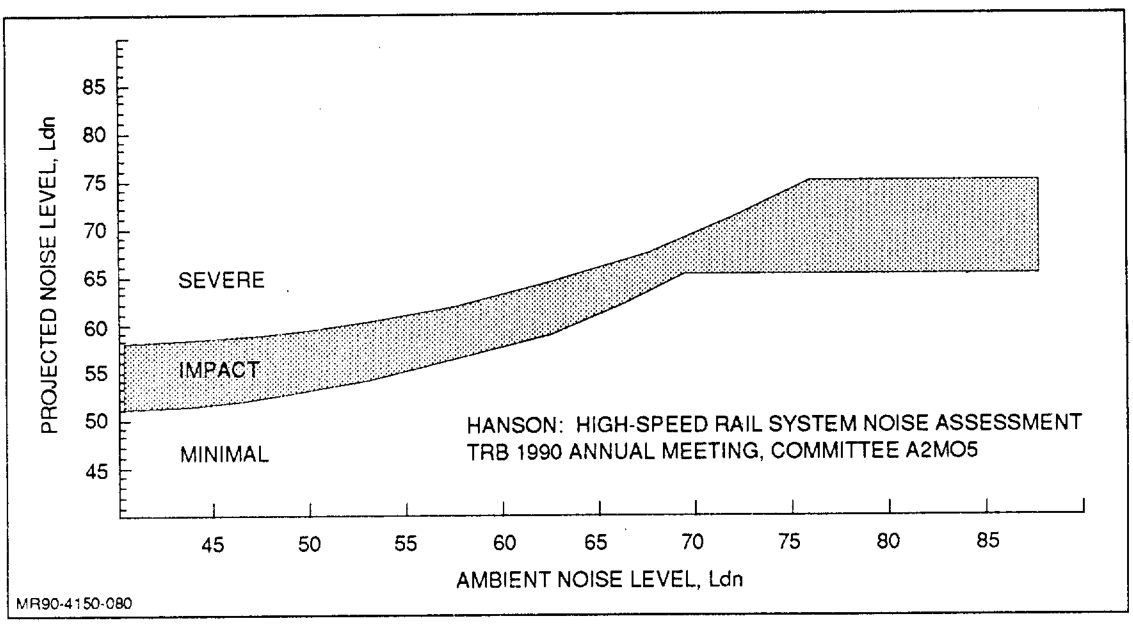

Fig. B-1 Noise Impact Criteria Based on Projected Ldn vs Ambient Ldn

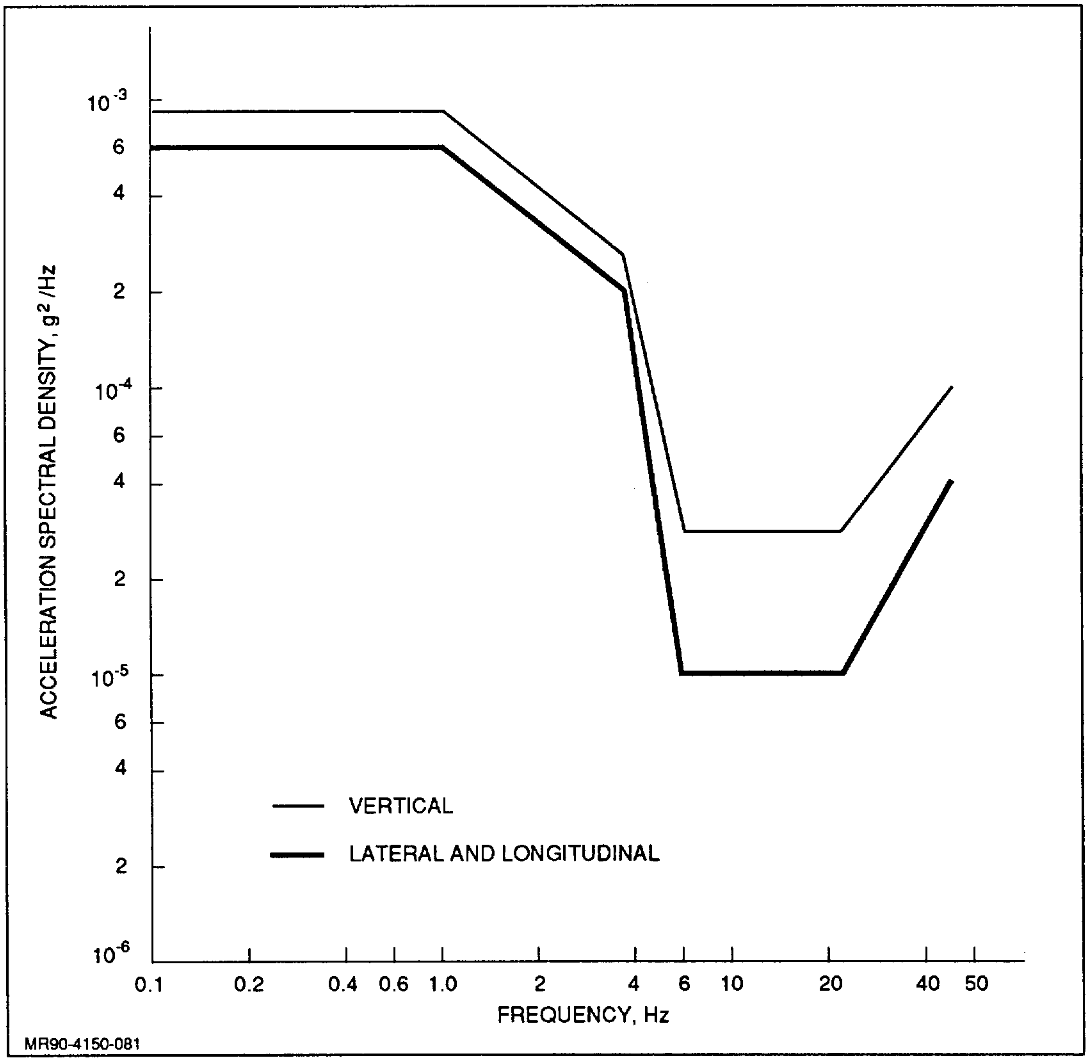

Fig. B-2 DOT Specification for Spectral Composition of Acceleration

15. Guideway, supporting structure and cars shall be designed to withstand a Zone 2-level earthquake without disruption of operation. Zone 4-level earthquakes shall not cause a catastrophic failure such as a guideway collapse.

16. Guideway and supporting structure shall be protected against any car or truck vehicle traffic accidents during construction and subsequent operation of the MAGLEV transportation system.

17. The construction and operation of the MAGLEV transportation system shall have a minimum impact on normal automobile and truck traffic on the Interstate Highway.

18. All transmission and power lines for operation of the train system shall be an integral part of the guideway design. Provisions for local power, telephone and gas lines may also be included in the design. Possible human contact with live wires or rails shall be minimized.

19. Any equipment malfunction which can cause a catastrophic failure shall be redundant with an automatic switching logic and reporting (warning) process to the central control station. The failure of any safety-of-operation equipment on the vehicle shall be displayed in the crew compartment and the central control station.

20. A guideway switching procedure shall be provided near both the entry and exit locations of each station platform. Guideway switching shall be performed at speeds up to 150 mph.

21. Position, velocity, and power usage of each vehicle in the system shall be measured and displayed at the central control station.

22. An automatic approaching or stationary object-sensing device and braking system will be installed in each car.

23. Each vehicle shall be capable of transporting 80 to 150 passengers (actual value to be specified by design constraints) or 20 tons of cargo. Cargo vehicle design should be as similar as possible to the passenger design.

24. Cargo vehicles shall be designed to provide for ease of loading and unloading existing containers or containers designed for this purpose. Passenger vehicles shall be able to unload and load full seating capacity within two minutes.

25. Each vehicle shall be air-conditioned and equipped with voice and television video communication to the central control station.

26. Overhead and underseat carry-on storage similar to commercial aircraft shall be provided for each passenger.

27. Walkways from parking location to station platform or from station platform to other means of transportation shall be protected from the elements and shall not exceed 0.25 mile in length.

28. An automated ticketing procedure will be established, allowing the use of credit cards or currency for paying the cost of one-way or round-trip tickets covering a period of per-day, -week, -month, or -year.

29. An appropriately trained operator will be able to control the speed and operation of each vehicle.

30. An automatic emergency speed deceleration procedure for all vehicles along the guideway will be provided. Activation of this system will be initiated from the central control station.

31. Vehicles must include emergency systems for fire fighting, emergency lighting, evacuation, communication, etc.

32. If the system is shut down for an emergency, measures for safely and efficiently evacuating passengers from each vehicle will be implemented.

33. Car structure and its support framework shall be designed for a minimum 30-year life with minimal inspection and no maintenance requirements. Guideways and their associated support structures shall be designed for a 50-year life with minimal inspection and maintenance requirements. Mechanical devices (any equipment with moving parts) will be designed for five years mean time between failures with reliability of 0.95, and a minimum of inspection and maintenance requirements.

34. Space shall be provided for sanitary facilities, including a retention system.

APPENDIX C

PARSONS BRINCKERHOFF GUIDEWAY COST DATA

C.1 INTRODUCTION

This appendix contains the cost data and estimates, prepared by Parsons Brinckerhoff for construction of a proposed MAGLEV guideway.

C.2 ESTIMATE ASSUMPTIONS & LIMITATIONS

The estimates were prepared based on design and quantity information provided by the Parsons Brinckerhoff Atlanta structural group. The cost for constructing a one-mile section of prestressed cast-in-place concrete box girder supported on cast-in-place concrete piers spaced at 100 ft down the median of the New York State Thruway is estimated. For this one-mile section, it was assumed there would be 53 piers, 16 constructed on pile footings and 37 on spread footings. The estimated cost includes structural excavation for the footings, placement of prestressed concrete piles, cast-in-place concrete footings, pier shafts, pier caps, and prestressed box girder. Allowances have also been included for traffic control, for miscellaneous site work which would occur in the Thruway median, and for a continuous concrete guard rail to protect the concrete piers. No other costs are included.

All the estimated costs were made at the direct cost level, to which a percentage was added for the contractor's overhead and profit. In addition, a 25-percent contingency was added to cover items that are not definable at this design level. Based on these considerations, the total estimated cost per mile of guideway is $13,647,775.

PARSONS BRINCKERHOFF QUADE & DOUGLAS, INC.
PROJECT: MAGLEV GUIDEWAY - NEW YORK TURNPIKE
JOB NO.: 3435A101
DATE: 09-04-90
ESTIMATOR: R. HARBUCK
CHECKED BY/DATE:

MAGLEV GUIDEWAY STRUCTURAL ESTIMATE

ITEM	DESCRIPTION	QTY	UNIT	ADJUSTED UNITS	BID AMOUNT
	TRAFFIC CONTROL	1	LS	$649,893.97	$649,894
	MISC. SITE WORK	4.5	AC	$4,200.00	$18,900
	GUARD RAIL	10560	LF	$45.36	$479,002
	STRUCTURAL EXCAVATION	2538	CY	$28.54	$72,443
	PCC PILES	15360	LF	$34.03	$522,728
	C.I.P CONC SUBSTRUCTURE	3437	CY	$690.98	$2,374,885
	C.I.P CONC SUPERSTRUCTURE	8410	CY	$1,133.17	$9,529,923
	TOTAL ESTIMATED COST/MILE				$13,647,773

PARSONS BRINCKERHOFF QUADE & DOUGLAS, INC.
PROJECT: MAGLEV GUIDEWAY - NEW YORK TURNPIKE
JOB NO.: 3435A101
DATE: 09-04-90
ESTIMATOR: R. HARBUCK
CHECKED BY/DATE:

MAGLEV GUIDEWAY STRUCTURAL ESTIMATE

ITEM	DESCRIPTION	QTY	UNIT	LABOR	E.O.E.	EQUIP RENT	SUPPLIES	PERM MATL	SUB CONTR	TOTAL DIRECT	UNIT COST	ADJUSTED UNITS	BID AMOUNT
	TRAFFIC CONTROL	1	LS	$0	$0	$0	$0	$0	$386,842	$386,842	$386,842	$649,894	$649,894
	MISC. SITE WORK	4.5	AC	$0	$0	$0	$0	$0	$11,250	$11,250	$2,500.00	$4,200.00	$18,900
	GUARD RAIL	10560	LF	$0	$0	$0	$0	$0	$285,120	$285,120	$27.00	$45.36	$479,002
	STRUCTURAL EXCAVATION	2538	CY	$5,914	$0	$2,183	$2,030	$0	$32,994	$43,121	$16.99	$28.54	$72,443
	PCC PILES	15360	LF	$57,991	$0	$11,061	$11,885	$230,400	$0	$311,148	$20.26	$34.03	$522,728
	C.I.P CONC SUBSTRUCTURE	3437	CY	$476,302	$0	$32,313	$157,309	$271,575	$475,923	$1,413,822	$411.30	$690.98	$2,374,885
	C.I.P CONC SUPERSTRUCTURE	8410	CY	$2,328,066	$0	$376,000	$976,853	$686,925	$1,325,729	$5,672,573	$674.50	$1,133.17	$9,529,923
	TOTAL DIRECT COST			$2,868,473	$0	$421,557	$1,147,886	$1,187,900	$2,517,857	$8,123,675			$13,647,773

CONTRACTOR'S OVERHEAD	20%	$1,624,735
CONTINGENCY	25%	$2,437,102
CONTRACTOR'S PROFIT	12%	$1,462,261
TOTAL COST		$13,647,773
MULTIPLIER		1.6800

PARSONS BRINCKERHOFF QUADE & DOUGLAS
PROJECT:.................MAGLEV GUIDEWAY - NEW YORK TURNPIKE
JOB NO.:.................3635A101
DATE:....................09-04-90
ESTIMATOR:...............R. HARBUCK
CHECKED BY/DATE:

BID ITEM	DESCRIPTION	QTY	UNIT	LABOR	E.O.E.	EQUIP RENT	SUPPLIES	PERM MATL	SUB CONTR	TOTAL DIRECT
	STRUCTURAL EXCAVATION	2538	CY	$5,914	$0	$2,183	$2,030	$0	$32,994	$43,121

ITEM	DESCRIPTION	QTY	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
1	EXCAVATION (HAND)	25	CY	$67.95	$1,898.63	$3.64	$91.00	$6.79	$169.75
2	EXCAVATION (MACHINE)	2513	CY	$1.67	$4,204.23	$0.83	$2,088.66	$0.75	$1,872.63
3	LOAD & HAUL TO WASTE	2538	CY						
	SUBTOTAL	2538	CY	$2.33	$5,902.86	$0.86	$2,179.66	$0.80	$2,042.38

CONTINUED:

ITEM	DESCRIPTION	QTY	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
1	EXCAVATION (HAND)	25	CY	$0.00	$0.00	$0.00	$0.00	$78.38	$1,959.38
2	EXCAVATION (MACHINE)	2513	CY	$0.00	$0.00	$0.00	$0.00	$3.25	$8,165.52
3	LOAD & HAUL TO WASTE	2538	CY			$13.00	$32,994.00	$13.00	$32,894.00
	TOTAL DIRECT COST	2538	CY	$0.00	$0.00	$13.00	$32,994.00	$16.99	$43,116.90
	STRUCTURAL EXCAVATION								$43,116.90

EXCAVATION (HAND)

ITEM	DESCRIPTION	QTY	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	PU	1	HR	$0.68	$0.68	$1.72	$1.72	$3.55	$3.55
	LAB FOREMAN	1		$19.69	$19.69				
	COMMON LAB	4		$18.76	$75.04				
	A-C 450	1		$3.08	$3.08	$5.35	$5.35	$9.67	$9.67
	AIR-TOOLS	1		$0.13	$0.13	$0.21	$0.21	$0.36	$0.36
	ATO	2		$18.63	$37.26				
	SUBTOTAL	7	MH		$135.89		$7.28		$13.58
	PRODUCTION:	25	CY			2	CY/CR-HR	13	CREW HOURS

CONTINUED:

ITEM	DESCRIPTION	QTY	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	PU	1	HR		$0.00		$0.00	$5.95	$5.95
	LAB FOREMAN	1			$0.00		$0.00	$19.69	$19.69
	COMMON LAB	4			$0.00		$0.00	$18.76	$75.04
	A-C 450	1			$0.00		$0.00	$18.10	$18.10
	AIR-TOOLS	1			$0.00		$0.00	$0.70	$0.70
	ATO	2			$0.00		$0.00	$18.63	$37.26
	DIRECT COST/CR HR	7	MH		$0.00		$0.00		$156.75
									$156.75

EXCAVATION (MACHINE)

ITEM	DESCRIPTION	QTY	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	PU	1	HR	$0.68	$0.68	$1.72	$1.72	$3.55	$3.55
	LAB FOREMAN	1		$19.69	$19.69				
	CAT 245	1		$11.36	$11.36	$22.42	$22.42	$16.37	$16.37
	FELW 950	1		$5.13	$5.13	$18.98	$18.98	$18.74	$18.74
	HOE-OZR OPER	2		$24.97	$49.93				
	SUBTOTAL	3	MH		$86.80		$43.12		$38.66
	PRODUCTION:								
	SPREAD FOOTING	1833	CY @			55	CY/CR-HR	33	
	PILE CAP FOOTING	680	CY @			45	CY/CR-HR	15	
		2513	CY					48	CREW HOURS

CONTINUED:

ITEM	DESCRIPTION	QTY	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	PU	1	HR		$0.00		$0.00	$5.95	$5.95
	LAB FOREMAN	1			$0.00		$0.00	$19.69	$19.69
	CAT 245	1			$0.00		$0.00	$50.15	$50.15
	FELW 950	1			$0.00		$0.00	$42.85	$42.85
	HOE-OZR OPER	2			$0.00		$0.00	$24.97	$49.93
	DIRECT COST/CR HR	3	MH		$0.00		$0.00		$168.58
									$168.58

END

PARSONS BRINCKERHOFF QUADE & DOUGLAS, INC.
PROJECT: MAGLEV GUIDEWAY - NEW YORK TURNPIKE
JOB NO.: 3435A101
DATE: 09-04-90
ESTIMATOR: R. HARBUCK
CHECKED BY/DATE:

ITEM	DESCRIPTION	QTY	UNIT	LABOR	E.O.E.	EQUIP RENT	SUPPLIES	PERM MATL	SUB CONTR	TOTAL DIRECT
	DRIVEN PRECAST CONC PILES	15360	LF	$57,991	$0	$11,061	$11,695	$230,400	$0	$311,148

ITEM	DESCRIPTION	QTY	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	DRIVE 14in. SQ. PCC PILES	15360	LF	$3.78	$57,990.90	$0.72	$11,061.12	$0.76	$11,695.49

CONTINUED:

ITEM	DESCRIPTION	QTY	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	DRIVE 14in. SQ. PCC PILES	15360	LF	$15.00	$230,400.00	$0.00	$0.00	$20.26	$311,147.51

****

DRIVE 14in. SQ. PCC PILES

ITEM	DESCRIPTION	QTY	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	PICKUP 1/2	1	HR	$0.68	$0.68	$1.72	$1.72	$3.55	$3.55
	PD FOREMAN	1		$26.43	$26.43				
	PILEDRIVERS	4		$25.53	$102.11				
	R T CRANE 30T	1		$12.30	$12.30	$21.96	$21.96	$21.77	$21.77
	LIFT CRANE OPER	1		$26.55	$26.55				
	LEADS & HAMMER	1		$5.50	$5.50	$10.00	$10.00	$3.00	$3.00
	A-C 650	1		$4.91	$4.91	$7.47	$7.47	$15.19	$15.19
	ATO	2		$18.63	$37.26				
		8	MH		$215.74		$41.15		$43.51

PRODUCTION:

SET UP & MOVE PILE DRIVER	16	EA	4	CR-HR/EA	64 CR-HRS
DRIVE 14in. SQ. PCC PILES	15360	LF	75	LF/CR-HR	205
					269 TOTAL CR-HRS

CONTINUED:

ITEM	DESCRIPTION	QTY	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	PICKUP 1/2	1	HR		$0.00		$0.00	$5.95	$5.95
	PD FOREMAN	1			$0.00		$0.00	$26.43	$26.43
	PILEDRIVERS	4			$0.00		$0.00	$25.53	$102.11
	R T CRANE 30T	1			$0.00		$0.00	$56.03	$56.03
	LIFT CRANE OPER	1			$0.00		$0.00	$26.55	$26.55
	LEADS & HAMMER	1			$0.00		$0.00	$18.50	$18.50
	A-C 650	1			$0.00		$0.00	$27.57	$27.57
	ATO	2			$0.00		$0.00	$18.63	$37.26
		8	MH		$0.00		$0.00		$300.40 $300.40

MATERIALS:

14in. SQ. PCC PILES	15360	LF	$15.00	$230,400.00

END **

PARSONS BRINCKERHOFF QUADE & DOUGLAS
PROJECT: MAGLEV GUIDEWAY - NEW YORK TURNPIKE
JOB NO.: 3635A101
DATE: 09-04-90
ESTIMATOR: R. HARDUCK
CHECKED BY/DATE:

ITEM	DESCRIPTION	QTY	UNIT	LABOR	E.O.E.	EQUIP RENT	SUPPLIES	PERM MATL	SUB CONTR	TOTAL DIRECT
	GUIDEWAY SUBSTRUCTURE	3437	CY	$476,502	$0	$32,313	$157,309	$271,575	$475,923	$1,413,622

WORK ITEM COSTS:	QTY	UNIT	U/C	LABOR	U/C	EQUIP	U/C	SUPPLIES
BUILT-IN-PLACE FORM	2545	SF	$6.07	$15,450.92	$0.65	$1,664.11	$2.52	$6,420.72
FOUNDATION PREP	2242	SY	$2.25	$5,044.50	$1.35	$3,026.70	$1.80	$4,035.60
FORM FAB- SHOP BUILD	29247	SF	$3.62	$105,945.09	$0.00	$0.00	$4.00	$116,986.67
ES&M WALLS	87740	SF	$3.01	$264,455.06	$0.26	$22,667.89	$0.26	$22,471.76
ES&M [	0	SF	$7.32	$0.00	$0.63	$0.00	$0.62	$0.00
FALSEWK	0	CF	$0.19	$0.00	$0.00	$0.00	$0.10	$0.00
RAIL/PARAPET	0	LF	$7.24	$0.00	$0.00	$0.00	$0.00	$0.00
BENTONITE PNLS	0	SF	$0.25	$0.00	$0.00	$0.00	$0.00	$0.00
FINISH, SCREED	23686	SF	$0.49	$11,605.60	$0.00	$0.00	$0.00	$0.00
FINISH, TROWEL	4240	SF	$1.22	$5,193.76	$0.00	$0.00	$0.00	$0.00
CURE	27926	SF	$0.07	$1,954.82	$0.00	$0.00	$0.04	$1,117.04
MOISTURE PRF	0	SF	$0.50	$0.00	$0.00	$0.00	$0.00	$0.00
WATERSTOP	0	LF	$3.02	$0.00	$0.00	$0.00	$0.00	$0.00
KEYWAY	1274	LF	$1.81	$2,307.51	$0.00	$0.00	$0.34	$433.16
PLACE CONC-SPREAD FTG	1589	CY	$14.59	$23,185.44	$0.84	$1,337.97	$0.99	$1,578.27
- PILE CAP FTG	412	CY	$14.59	$6,012.62	$1.68	$693.95	$1.99	$818.58
- PIER SHAFT	1100	CY	$27.36	$30,087.55	$2.11	$2,315.03	$2.48	$2,730.80
- PIER CAP	432	CY	$12.16	$5,259.58	$1.40	$607.03	$1.60	$716.05
-	0	CY	$54.73	$0.00	$6.32	$0.00	$7.45	$0.00
-	0	CY	$54.73	$0.00	$6.32	$0.00	$7.45	$0.00
-	0	CY	$14.59	$0.00	$1.68	$0.00	$1.99	$0.00
REINFORCING STEEL	793205	LB	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PURCHASE CONCRETE	3621	CY	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
SUBTOTAL	3437	CY	$138.64	$476,502.45	$9.40	$32,312.68	$45.77	$157,306.64

CONTINUED:

WORK ITEM COSTS:	QTY	UNIT	U/C	PERM MATL	U/C	SUBCONTR	U/C	TOT DIR COST
BUILT-IN-PLACE FORM	2545	SF	$0.00	$0.00	$0.00	$0.00	$9.25	$23,535.74
FOUNDATION PREP	2242	SY	$0.00	$0.00	$0.00	$0.00	$5.40	$12,106.80
FORM FAB- SHOP BUILD	29247	SF	$0.00	$0.00	$0.00	$0.00	$7.62	$222,931.76
ES&M WALLS	87740	SF	$0.00	$0.00	$0.00	$0.00	$3.53	$309,594.70
ES&M [	0	SF	$0.00	$0.00	$0.00	$0.00		$0.00
FALSEWK	0	CF	$0.00	$0.00	$0.00	$0.00		$0.00
RAIL/PARAPET	0	LF	$20.00	$0.00	$0.00	$0.00		$0.00
BENTONITE PNLS	0	SF	$0.65	$0.00	$0.00	$0.00		$0.00
FINISH, SCREED	23686	SF	$0.00	$0.00	$0.00	$0.00	$0.49	$11,605.60
FINISH, TROWEL	4240	SF	$0.00	$0.00	$0.00	$0.00	$1.22	$5,193.76
CURE	27926	SF	$0.00	$0.00	$0.00	$0.00	$0.11	$3,071.86
MOISTURE PRF	0	SF	$0.65	$0.00	$0.00	$0.00		$0.00
WATERSTOP	0	LF	$5.50	$0.00	$0.00	$0.00		$0.00
KEYWAY	1274	LF	$0.00	$0.00	$0.00	$0.00	$2.15	$2,740.67
PLACE CONC-SPREAD FTG	1589	CY	$0.00	$0.00	$0.00	$0.00	$16.43	$26,101.68
- PILE CAP FTG	412	CY	$0.00	$0.00	$0.00	$0.00	$18.26	$7,525.14
- PIER SHAFT	1100	CY	$0.00	$0.00	$0.00	$0.00	$31.95	$35,133.39
- PIER CAP	432	CY	$0.00	$0.00	$0.00	$0.00	$15.22	$6,582.67
-	0	CY	$0.00	$0.00	$0.00	$0.00		$0.00
-	0	CY	$0.00	$0.00	$0.00	$0.00		$0.00
-	0	CY	$0.00	$0.00	$0.00	$0.00		$0.00
REINFORCING STEEL	793205	LB	$0.00	$0.00	$0.60	$475,923.00	$0.60	$475,923.00
PURCHASE CONCRETE	3621	CY	$75.00	$271,575.00		$0.00	$75.00	$271,575.00
TOTAL DIRECT COST	3437	CY	$79.02	$271,575.00	$138.47	$475,923.00	$411.30	$1,413,621.77
								$1,413,621.77

QUANTITIES:

	SPREAD FTG	PILE CAP FTG	PIER SHAFT	PIER CAP			TOTALS
CONCRETE	1535	400	1078	424	0	0	3437
- OVERBRK	54	12	22	8	0	0	96
- WASTE	40	10	27	11	0	0	88
FINISH, SCREED	16576	3600	3510	0	0	0	23686
FINISH, TROWEL	0	0	0	4240	0	0	4240
CURE	16576	3600	3510	4240	0	0	27926
FOUNDATION PREP	1842	400	0	0	0	0	2242
CONSTR. JT	0	0	0	0	0	0	0
STAY-IN-PLACE	0	0	0	0	0	0	0
FORM L/	8140	2880	70145	6575	0	0	87740
FORM [	0	0	0	0	0	0	0
FORM —	0	0	0	2545	0	0	2545
RAILING/PARAPET	0	0	0	0	0	0	0
FALSEWORK	0	0	0	0	0	0	0
H20 STOP	0	0	0	0	0	0	0
KEY	890	384	0	0	0	0	1274
REBAR	337660	80000	269545	106000	0	0	793205

FABRICATE FORMS-SHOP

ITEM	DESCRIPTION	QTY	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	CARP FOREMN	1	HR	$26.66	$26.66		$0.00		$0.00
	CARP JNYMN	6		$25.53	$153.16		$0.00		$0.00
	COMMON LAB	2		$18.76	$37.52		$0.00		$0.00
	SUBTOTAL	9	MH		$217.35		$0.00		$0.00

CONTINUED:

ITEM	DESCRIPTION	QTY	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	CARP FOREMN	1	HR		$0.00		$0.00	$26.66	$26.66
	CARP JNYMN	6			$0.00		$0.00	$25.53	$153.16
	COMMON LAB	2			$0.00		$0.00	$18.76	$37.52
	DIRECT COST/CR HR	9	MH		$0.00		$0.00		$217.35
									$217.35

UNIT PRODUCTION COSTS-

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	WALL: STEEL PAT'D L/	60	SF	$3.62		$0.00		$0.00	
	COLS:)	36	SF	$6.04		$0.00		$0.00	
	COLS: L/	45	SF	$4.83		$0.00		$0.00	
	TRANSITIONS:	18	SF	$12.07		$0.00		$0.00	
	BLKOUTS:	36	SF	$6.04		$0.00		$0.00	
	STAIRS-PARAPETS:	27	SF	$8.05		$0.00		$0.00	

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	WALL: STEEL PAT'D L/	60	SF	$0.00		$0.00		$3.62	
	COLS:)	36	SF	$0.00		$0.00		$6.04	
	COLS: L/	45	SF	$0.00		$0.00		$4.83	
	TRANSITIONS:	18	SF	$0.00		$0.00		$12.07	
	BLKOUTS:	36	SF	$0.00		$0.00		$6.04	
	STAIRS-PARAPETS:	27	SF	$0.00		$0.00		$8.05	

FORMS: BUILD IN PLACE

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	CARP FOREMN	1	HR	$26.66	$26.66		$0.00		$0.00
	CARP JNYMN	6		$25.53	$153.16		$0.00		$0.00
	COMMON LAB	2		$18.76	$37.52		$0.00		$0.00
	R T CR 18TN	1		$12.30	$12.30	$21.96	$21.96	$21.77	$21.77
	LIFT CR OPER	1			$0.00		$0.00		$0.00
	FLTBD W/CR	0.5		$3.26	$1.63	$8.39	$4.20	$10.29	$5.15
	FORKLIFT	0.5		$23.13	$11.57		$0.00		$0.00
	SUBTOTAL	10.5	MH		$242.84		$26.16		$26.92

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	CARP FOREMN	1	HR		$0.00		$0.00	$26.66	$26.66
	CARP JNYMN	6			$0.00		$0.00	$25.53	$153.16
	COMMON LAB	2			$0.00		$0.00	$18.76	$37.52
	R T CR 18TN	1			$0.00		$0.00	$56.03	$56.03
	LIFT CR OPER	1			$0.00		$0.00	$0.00	$0.00
	FLTBD W/CR	0.5			$0.00		$0.00	$21.94	$10.97
	FORKLIFT	0.5			$0.00		$0.00	$23.13	$11.57
	DIRECT COST/CR HR	10.5	MH		$0.00		$0.00		$295.91 $295.91

UNIT PRODUCTION COSTS-

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	OFF ROCK: WOOD	14	SF	$17.35		$1.87		$1.92	
	)	33	SF	$7.36		$0.79		$0.82	
	FOOTING	40	SF	$6.07		$0.65		$0.67	
	SUPP SLAB UP	60	SF	$4.05		$0.44		$0.45	
	SUPP SLAB DOWN	60	SF	$4.05		$0.44		$0.45	

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	OFF ROCK: WOOD	14	SF	$0.00		$0.00		$21.14	
	)	33	SF	$0.00		$0.00		$8.97	
	FOOTING	40	SF	$0.00		$0.00		$7.40	
	SUPP SLAB UP	60	SF	$0.00		$0.00		$4.93	
	SUPP SLAB DOWN	60	SF	$0.00		$0.00		$4.93	

E S & M FORMS

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	CARP FOREMN	1	HR	$26.66	$26.66		$0.00		$0.00
	CARP JNYMN	6	HR	$25.53	$153.16		$0.00		$0.00
	COMMON LAB	2	HR	$18.76	$37.52		$0.00		$0.00
	HOOK TIME	1	HR		$38.85		$21.96		$21.77
	SUBTOTAL	9	MH		$256.20		$21.96		$21.77

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	CARP FOREMN	1	HR		$0.00		$0.00	$26.66	$26.66
	CARP JNYMN	6	HR		$0.00		$0.00	$25.53	$153.16
	COMMON LAB	2	HR		$0.00		$0.00	$18.76	$37.52
	HOOK TIME	1	HR		$0.00		$0.00	$82.58	$82.58
	DIRECT COST/CR HR	9	MH		$0.00		$0.00		$299.93
									$299.93

UNIT PRODUCTION COSTS-

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	WALLS	85	SF	$3.01		$0.26		$0.26	
	COLS	60	SF	$4.27		$0.37		$0.36	
	COLS	35	SF	$7.32		$0.63		$0.62	
	TRANSITION	45	SF	$5.69		$0.49		$0.48	
	STAIRS	18	SF	$12.07		$0.00		$0.00	
	CONST JT	45	SF	$4.83		$0.00		$0.00	
	BLKOUTS	30	SF	$7.24		$0.00		$0.00	
	KEYWAYS	120	LF	$1.81		$0.00		$0.00	
	SCREEDS	54	LF	$4.02		$0.00		$0.00	
	SHORING	1170	CF	$0.19		$0.00		$0.00	
	EXP JT MATL	65	SF	$3.34		$0.00		$0.00	
	WATERSTOP	72	LF	$3.02		$0.00		$0.00	

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	WALLS	85	SF	$0.00		$0.00		$3.53	
	COLS	60	SF	$0.00		$0.00		$5.00	
	COLS	35	SF	$0.00		$0.00		$8.57	
	TRANSITION	45	SF	$0.00		$0.00		$6.67	
	STAIRS	18	SF	$0.00		$0.00		$12.07	
	CONST JT	45	SF	$0.00		$0.00		$4.83	
	BLKOUTS	30	SF	$0.00		$0.00		$7.24	
	KEYWAYS	120	LF	$0.00		$0.00		$1.81	
	SCREEDS	54	LF	$0.00		$0.00		$4.02	
	SHORING	1170	CF	$0.00		$0.00		$0.19	
	EXP JT MATL	65	SF	$0.00		$0.00		$3.34	
	WATERSTOP	72	LF	$0.00		$0.00		$3.02	

PLACE CONC.-CRANE/BKT

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	LAB FOREMN	1	HR	$19.69	$19.69		$0.00		$0.00
	PU	1		$0.68	$0.68	$1.72	$1.72	$3.55	$3.55
	ATO	2		$18.63	$37.26		$0.00		$0.00
	COMMON LAB	5		$18.76	$93.81		$0.00		$0.00
	LIFT CR OPER	1		$26.55	$26.55		$0.00		$0.00
	OILER	1		$22.70	$22.70		$0.00		$0.00
	CRLR 100TN	1		$12.30	$12.30	$21.96	$21.96	$21.77	$21.77
	VIBS & GEN	2		$0.21	$0.42	$0.56	$1.12	$1.41	$2.82
	FLTBD	0.25		$0.72	$0.18	$1.86	$0.47	$6.65	$1.66
	FLTBD (TMSTR)	0.25		$21.28	$5.32		$0.00		$0.00
	SUBTOTAL	8.25	MH		$218.91		$25.27		$28.80

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	LAB FOREMN	1	HR		$0.00		$0.00	$19.69	$19.69
	PU	1			$0.00		$0.00	$5.95	$5.95
	ATO	2			$0.00		$0.00	$18.63	$37.26
	COMMON LAB	5			$0.00		$0.00	$18.76	$93.81
	LIFT CR OPER	1			$0.00		$0.00	$26.55	$26.55
	OILER	1			$0.00		$0.00	$22.70	$22.70
	CRLR 100TN	1			$0.00		$0.00	$56.03	$56.03
	VIBS & GEN	2			$0.00		$0.00	$2.18	$4.36
	FLTBD	0.25			$0.00		$0.00	$9.23	$2.31
	FLTBD (TMSTR)	0.25			$0.00		$0.00	$21.28	$5.32
	DIRECT COST/CR HR	8.25	MH		$0.00		$0.00		$273.97 $273.97

UNIT PRODUCTION COSTS-

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	SLABS <40CY	15	CY	$14.59		$1.66		$1.99	
	SLABS >40CY	30	CY	$7.30		$0.84		$0.99	
	WALLS 1FT	8	CY	$27.36		$3.16		$3.73	
	WALLS >1FT <2FT	12	CY	$18.24		$2.11		$2.48	
	CAPS	18	CY	$12.16		$1.40		$1.66	
	COLUMNS	8	CY	$27.36		$3.16		$3.73	
	SHEAR BLKS	4	CY	$54.73		$6.32		$7.45	

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	SLABS <40CY	15	CY	$0.00		$0.00		$18.26	
	SLABS >40CY	30	CY	$0.00		$0.00		$9.13	
	WALLS 1FT	8	CY	$0.00		$0.00		$34.25	
	WALLS >1FT <2FT	12	CY	$0.00		$0.00		$22.83	
	CAPS	18	CY	$0.00		$0.00		$15.22	
	COLUMNS	8	CY	$0.00		$0.00		$34.25	
	SHEAR BLKS	4	CY	$0.00		$0.00		$68.49	

FINISH - WET, HARD

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	CEM MSN 4M	1	HR	$26.36	$26.36	$0.00	$0.00	$0.00	$0.00
	CEM MSN	3		$25.79	$77.37	$0.00	$0.00	$0.00	$0.00
	COMMON LAB	1		$18.76	$18.76	$0.00	$0.00	$0.00	$0.00
	SCREED	1		$2.53		$5.76		$6.27	
	SUBTOTAL	5	MH		$122.49		$0.00		$0.00

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	CEM MSN 4M	1	HR		$0.00		$0.00	$26.36	$26.36
	CEM MSN	3			$0.00		$0.00	$25.79	$77.37
	COMMON LAB	1			$0.00		$0.00	$18.76	$18.76
	SCREED	1							
	DIRECT COST/CR HR	5	MH		$0.00		$0.00		$122.49 $122.49

UNIT PRODUCTION COSTS-

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	SCREED FIN.	250	SF	$0.49		$0.00		$0.00	
	MACHINE FIN	150	SF	$0.83		$0.04		$0.04	
	STEEL TRWL	100	SF	$1.22		$0.00		$0.00	
	PP&R	125	SF	$0.98		$0.00		$0.00	

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	SCREED FIN.	250	SF	$0.00		$0.00		$0.49	
	MACHINE FIN	150	SF	$0.00		$0.00		$0.91	
	STEEL TRWL	100	SF	$0.00		$0.00		$1.22	
	PP&R	125	SF	$0.00		$0.00		$0.98	

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HOOK TIME - FORM WORK

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	RT CR 30TN	1	HR	$12.30	$12.30	$21.86	$21.96	$21.77	$21.77
	LIFT CR OPER	1		$26.55	$26.55				
	SUBTOTAL	1	CRHR		$38.85		$21.96		$21.77

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	RT CR 30TN	1	HR		$0.00		$0.00	$56.03	$56.03
	LIFT CR OPER	1						$26.55	$26.55
	DIRECT COST/CR-HR	1	CRHR		$0.00		$0.00		$82.58 $82.58

END

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PARSONS BRINCKERHOFF QUADE & DOUGLAS
PROJECT: MAGLEV GUIDEWAY - NEW YORK TURNPIKE
JOB NO.: 3536A101
DATE: 08-04-90
ESTIMATOR: R. HARBUCK
CHECKED BY/DATE:

ITEM	DESCRIPTION	QTY	UNIT	LABOR	E.O.E.	EQUIP RENT	SUPPLIES	PERM MATL	SUB CONTR	TOTAL DIRECT
	GUIDEWAY SUPERSTRUCTURE C.I.P. BOX GIRDER	8410	CY	$2,328,066	$0	$376,000	$976,853	$665,925	$1,325,729	$5,672,573

WORK ITEM COSTS:	QTY	UNIT	U/C	LABOR	U/C	EQUIP	U/C	SUPPLIES
BUILT-IN-PLACE FORM	268280	SF	$3.77	$1,015,054.43	$1.11	$299,780.45	$0.92	$246,865.66
STAY-IN-PLACE FORM	0	SF	$2.69	$0.00	$0.80	$0.00	$2.66	$0.00
FORM FAB- SHOP BUILD	16896	SF	$3.62	$61,205.21	$0.00	$0.00	$4.00	$67,584.00
ES&M WALLS	84480	SF	$3.01	$254,629.17	$0.26	$21,825.66	$0.26	$21,636.82
ES&M (	0	SF	$7.32	$0.00	$0.63	$0.00	$0.62	$0.00
FALSEWK	5808000	CF	$0.11	$631,178.70	$0.00	$0.00	$0.10	$580,800.00
RAIL/PARAPET	0	LF	$7.24	$0.00	$0.00	$0.00	$0.00	$0.00
BENTONITE PNLS	0	SF	$0.25	$0.00	$0.00	$0.00	$0.00	$0.00
FINISH, SCREED	105600	SF	$0.49	$51,741.58	$0.00	$0.00	$0.00	$0.00
FINISH, DECK	174240	SF	$0.83	$145,228.19	$0.04	$6,680.82	$0.04	$7,283.23
CURE	279840	SF	$0.07	$19,588.80	$0.00	$0.00	$0.04	$11,193.60
MOISTURE PRF	0	SF	$0.50	$0.00	$0.00	$0.00	$0.00	$0.00
WATERSTOP	0	LF	$3.02	$0.00	$0.00	$0.00	$0.00	$0.00
KEYWAY	0	LF	$1.81	$0.00	$0.00	$0.00	$0.34	$0.00
PLACE CONC-	0	CY	$17.25	$0.00	$2.75	$0.00	$2.39	$0.00
- BOX GIRDER	8662	CY	$17.25	$149,439.76	$5.51	$47,703.29	$4.78	$41,389.91
-	0	CY	$32.35	$0.00	$6.86	$0.00	$5.97	$0.00
-	0	CY	$14.38	$0.00	$4.59	$0.00	$3.98	$0.00
-	0	CY	$64.69	$0.00	$20.65	$0.00	$17.92	$0.00
-	0	CY	$64.69	$0.00	$20.65	$0.00	$17.92	$0.00
-	0	CY	$17.25	$0.00	$5.51	$0.00	$4.78	$0.00
REINFORCING STEEL	1259280	LB	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PRESTRESSING STEEL	493680	LB	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PURCHASE CONCRETE	8879	CY	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
SUBTOTAL	8410	CY	$276.82	$2,328,065.82	$44.71	$376,000.21	$116.15	$976,853.23

CONTINUED:

WORK ITEM COSTS:	QTY	UNIT	U/C	PERM MATL	U/C	SUBCONTR	U/C	TOT DIR COST
BUILT-IN-PLACE FORM	268280	SF	$0.00	$0.00	$0.00	$0.00	$5.80	$1,561,800.54
STAY-IN-PLACE FORM	0	SF	$0.00	$0.00	$0.00	$0.00		$0.00
FORM FAB- SHOP BUILD	16896	SF	$0.00	$0.00	$0.00	$0.00	$7.62	$128,789.21
ES&M WALLS	84480	SF	$0.00	$0.00	$0.00	$0.00	$3.53	$298,091.64
ES&M (	0	SF	$0.00	$0.00	$0.00	$0.00		$0.00
FALSEWK	5808000	CF	$0.00	$0.00	$0.00	$0.00	$0.21	$1,211,978.70
RAIL/PARAPET	0	LF	$20.00	$0.00	$0.00	$0.00		$0.00
BENTONITE PNLS	0	SF	$0.65	$0.00	$0.00	$0.00		$0.00
FINISH, SCREED	105600	SF	$0.00	$0.00	$0.00	$0.00	$0.49	$51,741.58
FINISH, DECK	174240	SF	$0.00	$0.00	$0.00	$0.00	$0.91	$159,202.23
CURE	279840	SF	$0.00	$0.00	$0.00	$0.00	$0.11	$30,782.40
MOISTURE PRF	0	SF	$0.65	$0.00	$0.00	$0.00		$0.00
WATERSTOP	0	LF	$5.50	$0.00	$0.00	$0.00		$0.00
KEYWAY	0	LF	$0.00	$0.00	$0.00	$0.00		$0.00
PLACE CONC-	0	CY	$0.00	$0.00	$0.00	$0.00		$0.00
- BOX GIRDER	8662	CY	$0.00	$0.00	$0.00	$0.00	$27.54	$238,532.96
-	0	CY	$0.00	$0.00	$0.00	$0.00		$0.00
-	0	CY	$0.00	$0.00	$0.00	$0.00		$0.00
-	0	CY	$0.00	$0.00	$0.00	$0.00		$0.00
-	0	CY	$0.00	$0.00	$0.00	$0.00		$0.00
-	0	CY	$0.00	$0.00	$0.00	$0.00		$0.00
REINFORCING STEEL	1259280	LB	$0.00	$0.00	$0.50	$629,640.00	$0.50	$629,640.00
PRESTRESSING STEEL	493680	LB	$0.00	$0.00	$1.41	$696,088.80	$1.41	$696,088.80
PURCHASE CONCRETE	8879	CY	$75.00	$665,925.00		$0.00	$75.00	$665,925.00
TOTAL DIRECT COST	8410	CY	$79.18	$665,925.00	$157.64	$1,325,728.80	$674.50	$5,672,573.06
								$5,672,573.06

QUANTITIES:

		BOX GIRDER					TOTALS
CONCRETE	0	8410	0	0	0	0	8410
- OVERBRK	0	252	0	0	0	0	252
- WASTE	0	217	0	0	0	0	217
FINISH, SCREED	0	105600	0	0	0	0	105600
FINISH, TROWEL	0	174240	0	0	0	0	174240
CURE	0	279840	0	0	0	0	279840
FOUNDATION PREP	0	0	0	0	0	0	0
CONSTR. JT	0	2280	0	0	0	0	2280
STAY-IN-PLACE	0	0	0	0	0	0	0
FORM L/	0	84480	0	0	0	0	84480
FORM [	0	0	0	0	0	0	0
FORM —	0	269280	0	0	0	0	269280
RAILING/PARAPET	0	0	0	0	0	0	0
FALSEWORK	0	5808000	0	0	0	0	5808000
H20 STOP	0	0	0	0	0	0	0
KEY	0	0	0	0	0	0	0
PRESTRESSING STEEL	0	493680	0	0	0	0	493680
REBAR	0	1259280	0	0	0	0	1259280

FABRICATE FORMS-SHOP

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	CARP FOREMN	1	HR	$26.66	$26.66		$0.00		$0.00
	CARP JNYMN	6		$25.53	$153.16		$0.00		$0.00
	COMMON LAB	2		$18.76	$37.52		$0.00		$0.00
	SUBTOTAL	9	MH		$217.35		$0.00		$0.00

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	CARP FOREMN	1	HR		$0.00		$0.00	$26.66	$26.66
	CARP JNYMN	6			$0.00		$0.00	$25.53	$153.16
	COMMON LAB	2			$0.00		$0.00	$18.76	$37.52
	DIRECT COST/CR HR	9	MH		$0.00		$0.00		$217.35 $217.35

UNIT PRODUCTION COSTS-

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	WALL: STEEL PAT'D L/	60	SF	$3.62		$0.00		$0.00	
	COLS:]	36	SF	$6.04		$0.00		$0.00	
	COLS: L/	45	SF	$4.83		$0.00		$0.00	
	TRANSITIONS:	18	SF	$12.07		$0.00		$0.00	
	BLKOUTS:	36	SF	$6.04		$0.00		$0.00	
	STAIRS-PARAPETS:	27	SF	$8.05		$0.00		$0.00	

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	WALL: STEEL PAT'D L/	60	SF	$0.00		$0.00		$3.62	
	COLS:]	36	SF	$0.00		$0.00		$6.04	
	COLS: L/	45	SF	$0.00		$0.00		$4.83	
	TRANSITIONS:	18	SF	$0.00		$0.00		$12.07	
	BLKOUTS:	36	SF	$0.00		$0.00		$6.04	
	STAIRS-PARAPETS:	27	SF	$0.00		$0.00		$8.05	

FORMS: BUILD IN PLACE

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	CARP FOREMN	1	HR	$26.66	$26.66		$0.00		$0.00
	CARP JNYMN	6		$25.53	$153.16		$0.00		$0.00
	COMMON LAB	2		$18.76	$37.52		$0.00		$0.00
	CRLR 200TN	1		$52.17	$52.17	$79.30	$79.30	$63.64	$63.64
	LIFT CR OPER	1			$0.00		$0.00		$0.00
	FLTBD W/CR	0.5		$3.26	$1.63	$8.38	$4.20	$10.29	$5.15
	FORKLIFT	0.5		$23.13	$11.57		$0.00		$0.00
	SUBTOTAL	10.5	MH		$282.71		$83.50		$68.79

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	CARP FOREMN	1	HR		$0.00		$0.00	$26.66	$26.66
	CARP JNYMN	6			$0.00		$0.00	$25.53	$153.16
	COMMON LAB	2			$0.00		$0.00	$18.76	$37.52
	CRLR 200TN	1			$0.00		$0.00	$195.11	$195.11
	LIFT CR OPER	1			$0.00		$0.00	$0.00	$0.00
	FLTBD W/CR	0.5			$0.00		$0.00	$21.94	$10.97
	FORKLIFT	0.5			$0.00		$0.00	$23.13	$11.57
	DIRECT COST/CR HR	10.5	MH		$0.00		$0.00		$434.99
									$434.99

UNIT PRODUCTION COSTS-

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	OFF ROCK: WOOD	14	SF	$20.19		$5.96		$4.81	
	STAY-IN-PLACE	105	SF	$2.69		$0.80		$0.66	
	SUPP SLAB UP	75	SF	$3.77		$1.11		$0.92	
	SUPP SLAB DOWN	75	SF	$3.77		$1.11		$0.92	

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	OFF ROCK: WOOD	14	SF	$0.00		$0.00		$31.07	
	STAY-IN-PLACE	105	SF	$0.00		$0.00		$4.14	
	SUPP SLAB UP	75	SF	$0.00		$0.00		$5.80	
	SUPP SLAB DOWN	75	SF	$0.00		$0.00		$5.80	

E S & M FORMS

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	CARP FOREMN	1	HR	$26.66	$26.66		$0.00		$0.00
	CARP JNYMN	6	HR	$25.53	$153.16		$0.00		$0.00
	COMMON LAB	2	HR	$18.76	$37.52		$0.00		$0.00
	HOOK TIME	1	HR		$38.85		$21.96		$21.77
	SUBTOTAL	9	MH		$256.20		$21.96		$21.77

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	CARP FOREMN	1	HR		$0.00		$0.00	$26.66	$26.66
	CARP JNYMN	6	HR		$0.00		$0.00	$25.53	$153.16
	COMMON LAB	2	HR		$0.00		$0.00	$18.76	$37.52
	HOOK TIME	1	HR		$0.00		$0.00	$82.58	$82.58
	DIRECT COST/CR HR	9	MH		$0.00		$0.00		$299.93 $299.93

UNIT PRODUCTION COSTS-

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	WALLS ✓	85	SF	$3.01		$0.26		$0.26	
	COLS ✓	60	SF	$4.27		$0.37		$0.36	
	COLS]	35	SF	$7.32		$0.63		$0.62	
	TRANSITION	45	SF	$5.69		$0.49		$0.48	
	STAIRS	18	SF	$12.07		$0.00		$0.00	
	CONST JT	45	SF	$4.83		$0.00		$0.00	
	BLKOUTS	30	SF	$7.24		$0.00		$0.00	
	KEYWAYS	120	LF	$1.81		$0.00		$0.00	
	SCREEDS	54	LF	$4.02		$0.00		$0.00	
	SHORING	2000	CF	$0.11		$0.00		$0.00	
	EXP JT MATL	65	SF	$3.34		$0.00		$0.00	
	WATERSTOP	72	LF	$3.02		$0.00		$0.00	

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	WALLS ✓	85	SF	$0.00		$0.00		$3.53	
	COLS ✓	60	SF	$0.00		$0.00		$5.00	
	COLS]	35	SF	$0.00		$0.00		$8.57	
	TRANSITION	45	SF	$0.00		$0.00		$6.67	
	STAIRS	18	SF	$0.00		$0.00		$12.07	
	CONST JT	45	SF	$0.00		$0.00		$4.83	
	BLKOUTS	30	SF	$0.00		$0.00		$7.24	
	KEYWAYS	120	LF	$0.00		$0.00		$1.81	
	SCREEDS	54	LF	$0.00		$0.00		$4.02	
	SHORING	2000	CF	$0.00		$0.00		$0.11	
	EXP JT MATL	65	SF	$0.00		$0.00		$3.34	
	WATERSTOP	72	LF	$0.00		$0.00		$3.02	

PLACE CONC.-CRANE/BKT

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	LAB FOREMN	1	HR	$19.69	$19.69		$0.00		$0.00
	PU	1		$0.68	$0.68	$1.72	$1.72	$3.55	$3.55
	ATO	2		$18.63	$37.26		$0.00		$0.00
	COMMON LAB	5		$18.76	$93.81		$0.00		$0.00
	LIFT CR OPER	1		$26.55	$26.55		$0.00		$0.00
	OILER	1		$22.70	$22.70		$0.00		$0.00
	CRLR 200TN	1		$52.17	$52.17	$79.30	$79.30	$63.64	$63.64
	VIBS & GEN	2		$0.21	$0.42	$0.56	$1.12	$1.41	$2.82
	FLTBD	0.25		$0.72	$0.18	$1.86	$0.47	$6.65	$1.66
	FLTBD (TMSTR)	0.25		$21.28	$5.32		$0.00		$0.00
	SUBTOTAL	8.25	MH		$258.78		$82.61		$71.67

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	LAB FOREMN	1	HR		$0.00		$0.00	$19.69	$19.69
	PU	1			$0.00		$0.00	$5.95	$5.95
	ATO	2			$0.00		$0.00	$18.63	$37.26
	COMMON LAB	5			$0.00		$0.00	$18.76	$93.81
	LIFT CR OPER	1			$0.00		$0.00	$26.55	$26.55
	OILER	1			$0.00		$0.00	$22.70	$22.70
	CRLR 200TN	1			$0.00		$0.00	$195.11	$195.11
	VIBS & GEN	2			$0.00		$0.00	$2.18	$4.36
	FLTBD	0.25			$0.00		$0.00	$9.23	$2.31
	FLTBD (TMSTR)	0.25			$0.00		$0.00	$21.28	$5.32
	DIRECT COST/CR HR	8.25	MH		$0.00		$0.00		$413.05 $413.05

UNIT PRODUCTION COSTS-

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	SLABS <40CY	15	CY	$17.25		$5.51		$4.78	
	SLABS >40CY	30	CY	$8.63		$2.75		$2.39	
	WALLS 1FT	8	CY	$32.35		$10.33		$8.96	
	WALLS >1FT <2FT	12	CY	$21.56		$6.88		$5.97	
	CAPS	18	CY	$14.38		$4.59		$3.98	
	COLUMNS	8	CY	$32.35		$10.33		$8.96	
	SHEAR BLKS	4	CY	$64.69		$20.65		$17.92	

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	SLABS <40CY	15	CY	$0.00		$0.00		$27.54	
	SLABS >40CY	30	CY	$0.00		$0.00		$13.77	
	WALLS 1FT	8	CY	$0.00		$0.00		$51.63	
	WALLS >1FT <2FT	12	CY	$0.00		$0.00		$34.42	
	CAPS	18	CY	$0.00		$0.00		$22.95	
	COLUMNS	8	CY	$0.00		$0.00		$51.63	
	SHEAR BLKS	4	CY	$0.00		$0.00		$103.26	

FINISH - WET, HARD

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	LABOR & EQUIP:								
	CEM MSN 4H	1	HR	$26.36	$26.36	$0.00	$0.00	$0.00	$0.00
	CEM MSN	3		$25.79	$77.37	$0.00	$0.00	$0.00	$0.00
	COMMON LAB	1		$18.76	$18.76	$0.00	$0.00	$0.00	$0.00
	SCREED	1		$2.53		$5.76		$6.27	
	SUBTOTAL	5	MH		$122.49		$0.00		$0.00

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	LABOR & EQUIP:								
	CEM MSN 4H	1	HR		$0.00		$0.00	$26.36	$26.36
	CEM MSN	3			$0.00		$0.00	$25.79	$77.37
	COMMON LAB	1			$0.00		$0.00	$18.76	$18.76
	SCREED	1							
	DIRECT COST/CR HR	5	MH		$0.00		$0.00		$122.49
									$122.49

UNIT PRODUCTION COSTS-

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	SCREED FIN.	250	SF	$0.49		$0.00		$0.00	
	MACHINE FIN	150	SF	$0.83		$0.04		$0.04	
	STEEL TRWL	100	SF	$1.22		$0.00		$0.00	
	PP&R	125	SF	$0.98		$0.00		$0.00	

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	SCREED FIN.	250	SF	$0.00		$0.00		$0.49	
	MACHINE FIN	150	SF	$0.00		$0.00		$0.91	
	STEEL TRWL	100	SF	$0.00		$0.00		$1.22	
	PP&R	125	SF	$0.00		$0.00		$0.98	

HOOK TIME - FORM WORK

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	LABOR	U.C.	EQUIP	U.C.	SUPPLIES
	RT CR 30TN	1	HR	$12.30	$12.30	$21.96	$21.96	$21.77	$21.77
	LIFT CR OPER	1		$26.55	$26.55				
	SUBTOTAL	1	CRHR		$38.85		$21.96		$21.77

CONTINUED:

ITEM	DESCRIPTION	QUANT	UNIT	U.C.	PERM MATL	U.C.	SUBCONTR	U.C.	TOTAL DIRECT
	RT CR 30TN	1	HR		$0.00		$0.00	$56.03	$56.03
	LIFT CR OPER	1						$26.55	$26.55
	DIRECT COST/CR-HR	1	CRHR		$0.00		$0.00		$82.58
									$82.58

END

APPENDIX D

VEHICLE RIDE CONTROL AND DYNAMIC ANALYSIS

This study stresses the need to concentrate on the impact of right-of-way contours on vehicle ride quality and passenger comfort. Negotiation of highway profiles at six times normal highway vehicle speeds will require special designs to assure that passengers can tolerate the ride.

While detailed vehicle dynamic analysis was not included in this study, Sections D.1 through D.3 are excerpts from the Ford report that describe the ability of their baseline vehicle to meet ride quality requirements.

The results of this multimode dynamic response analysis of the Ford baseline control concept to random guideway irregularities are given in the following sections. A five-degree-of-freedom mathematical model was used for this analysis. Since the pitch/heave degrees of freedom are decoupled from roll/sway/yaw, the pitch coupling effects are examined separately from roll/sway/yaw effects.

D.1 CONCLUSIONS OF STUDY

D.1.1 Straight and Level Operation

The following conclusions refer to straight and level operation of a 445 kN (100 klb) repulsion MAGLEV vehicle at 134 m/s (300 mph) over the baseline guideway with a nominal statistical roughness coefficient, A, of 1.5 x 10^{-6} m (5 x 10^{-6} ft) with profiles shown in Fig. 4-18 of this study.

D.1.1.1 Ride Quality – The Department of Transportation (DOT) vertical and lateral ride quality specifications given in Fig. 2-1 are achievable for the baseline active control system using position feedback in conjunction with absolute (inertial) velocity feedback. The results are shown in Figs. D-1 and D-2. Alternate systems using acceleration feedback instead of position feedback or only heavy absolute damping also meet the ride quality specifications and do not require gap sensors. For the baseline control system, the following detailed conclusions are drawn:

- Vertical acceleration response to guideway random irregularities is well below the specified limits;

- Lateral acceleration response to random guideway irregularities is below the specified limits, provided the guideway lateral roughness power spectral density (PSD) has a long wavelength (low frequency) rolloff at 1.0 x 10^{-2} ft^2/(rad/ft); and

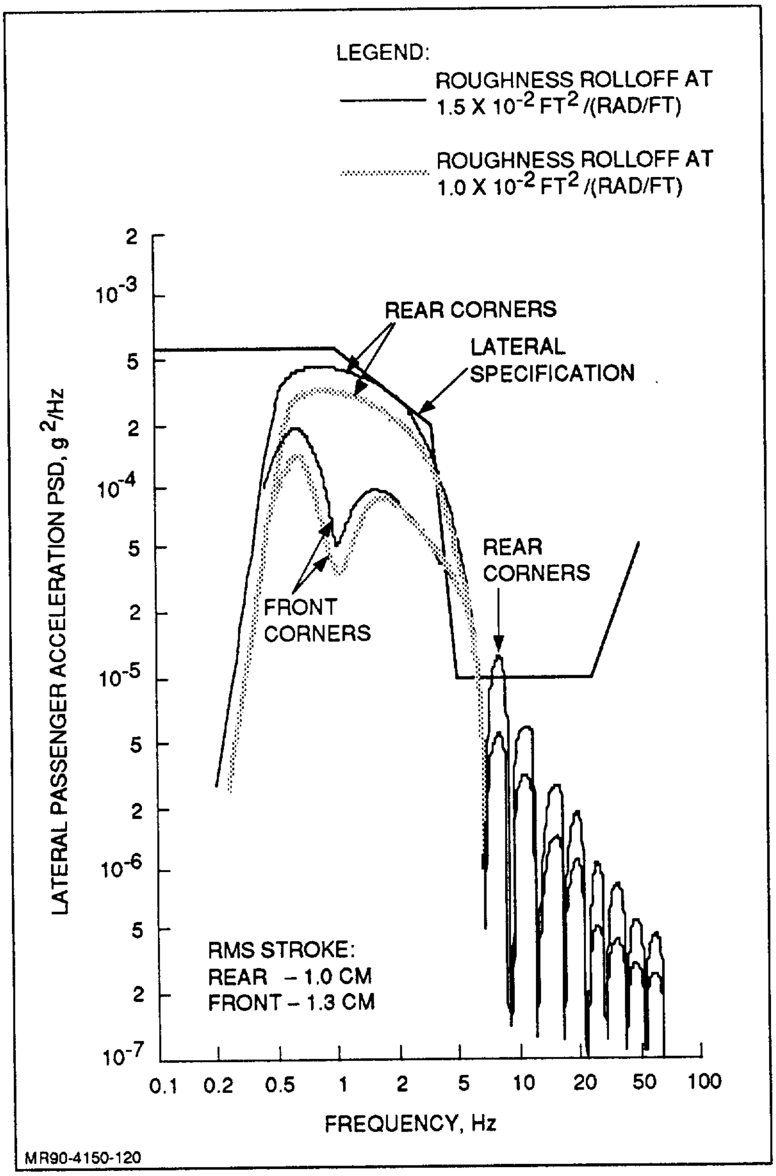

Fig. D-1 Lateral Acceleration Response to Guideway Lateral Random Irregularities – *Lateral acceleration response to guideway roughness levels identified in Fig. 4-18 show that they are within the required lateral ride quality specifications identified in Fig. 2-1.*

- Elimination of relative damping improves ride quality but requires increased control power.

D.1.1.2 Gap Response – Vehicle dynamic response to gaps in the aluminum guideway elements is acceptable. The vehicle maximum excursion is less than 0.5 cm (0.2 inches) for a single gap. For periodic gaps spaced 15 m (50 ft) apart, the cruise height above the guideway is reduced by less than 1.5 cm (0.6 inches).

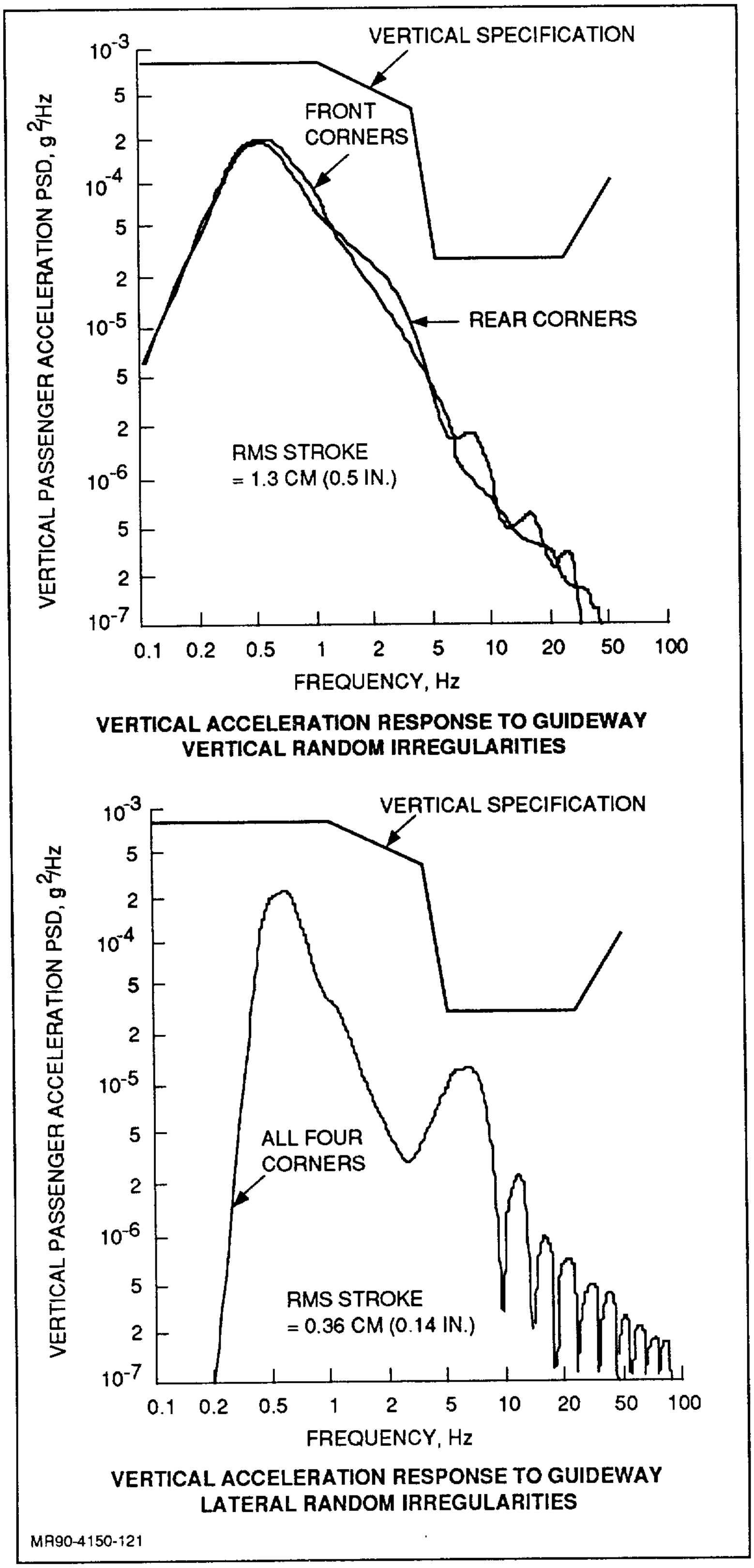

Fig. D-2 Response of the Vehicle in the Vertical Direction due to Guideway Vertical and Lateral Random Irregularities – *The response is well within the vertical specification.*

D.1.1.3 Elevated Guideway – The dynamic behavior of a properly designed elevated guideway will not result in unsatisfactory ride quality.

D.1.1.4 Power Consumption – The heavy damping control scheme consumes more power than either the baseline scheme or the acceleration feedback scheme, but the difference is minor compared to the vehicle's overall power requirements.

D.1.2 Grade Transitions

The following conclusions refer to operation of a 445 kN (98 klb) repulsion MAGLEV vehicle at 134 m/s (300 mph) over a transition section connecting the straight and level guideway to a guideway at a two-percent grade. The baseline hat-shaped or inverted-T guideway is used, with a nominal statistical roughness coefficient, A, of 1.5×10^{-6} m (5×10^{-6} ft).

D.1.2.1 Stroke – All of the control system concepts studied permit negotiation of both up-grade and down-grade transitions for a design goal maximum stroke of 5 cm (2 inches). The baseline position feedback system consumes the least control power, but the difference in power consumption compared with the alternate control schemes is probably not significant when compared with the overall vehicle power consumption. The required transition lengths differ as follows:

- The baseline position feedback system requires a transition length of ~1 km (0.62 miles). Nonlinear position feedback reduction is provided to avoid possible unstable dynamic behavior on transition to a down-grade. Relative damping has negligible effect on maximum stroke except for very short transitions, i.e., <<1 km;

- The alternate highly damped system without gap sensors requires a transition length of ~4 km (2.5 miles) with an absolute damper filter frequency of 0.6 Hz;

- The alternate acceleration feedback system (also without gap sensors) requires a transition length of ~6.5 km (4 miles); and

- Improved vehicle dynamic behavior in a grade transition is possible for a system either with or without a gap sensor, if the amount of absolute damping is reduced during passage through the transition. The necessary signals can be obtained by wayside communication or by increasing the capacity of the onboard computer and using it, in conjunction with the existing accelerometers, as a simplified inertial navigator. This permits subtraction of the component of the rate signal due to the vertical curvature of the guideway, thus eliminating the damping forces which increase vehicle stroke relative to the guideway. Substantial reduction in transition length should be possible, particularly for the alternate concepts without gap sensors.

D.1.2.2 Ride Quality – Ride quality over a grade transition is not as good as on a level guideway. To meet the DOT ride-quality specifications based on power spectral density criteria, the following conclusions are drawn:

- The baseline position feedback system, without relative damping, requires a transition length of ~4 km (2.5 miles). For operation over the stroke-limited transition length of ~1 km (0.62 miles), the ride-quality specification limit would be exceeded for approximately 7.5 seconds;

- The alternate highly damped system without gap sensors requires a transition length of ~5 km (3 miles); and

- The alternate acceleration feedback system was not analyzed for ride quality during grade transition; however, it may be slightly better (shorter transition length) than the baseline position feedback system.

It appears that the PSD criteria for ride quality are inappropriate for short-time, infrequent events such as grade and turn transitions. If the DOT criteria on maximum sustained acceleration and rate of change of acceleration (jerk) are used, then all control schemes will show acceptable ride quality for transition lengths <<1 km.

D.1.3 Horizontal Curves (Turns)

Detailed analyses have not been performed to measure vehicle dynamic motion in horizontal turns. Preliminary linear multidegrees of freedom (DOF) analyses, however, indicate that turns can be negotiated, with the following observations:

- The baseline position feedback system can achieve acceptable dynamic behavior up to 10-degree banking, subject to appropriate gain-constant modification and damping reduction. Detailed studies are necessary to establish the concomitant effect of gain-constant modification on ride quality and stroke in a grade transition;

- The alternate acceleration feedback system shows somewhat better performance in a turn than the baseline system. The alternate highly damped system was not analyzed for horizontal turn negotiation; and

- Vehicle dynamic behavior, primarily stroke, in a horizontal turn can be improved, if desired, by reducing the amount of absolute damping provided during transit through the turn, as previously described for negotiating a grade transition.

D.1.4 Crosswinds

Preliminary multi-DOF dynamic analysis of vehicle response to a 20 m/s (45 mph) crosswind shows a maximum side sway (lateral motion of the c.g.) of about 8 cm (3.1 inches). Rolling motion also takes place and effectively reduces maximum lateral stroke to 2.6 cm (1.1 inches). Maximum vertical stroke (due solely to roll) is ~5 cm (2 inches). No serious problems are foreseen in withstanding crosswinds of 20 m/s (45 mph).

D.2 RECOMMENDATIONS

The Task I program developed multi-DOF computational techniques and associated computer programs for precise evaluation of MAGLEV vehicle dynamic response to a variety of input parameters and for various control system concepts/strategies. Recommended follow-up analyses include:

- Conduct multi-DOF analyses of vehicle transient and steady-state dynamic response to guideway gaps, grade transitions, horizontal curves, wind gusts and elevated guideway deformations. Nonlinear magnet force effects should be incorporated;

- Perform extensive, in-depth parametric investigations of control gain constant selection to optimize vehicle ride quality and dynamic response characteristics in horizontal curves;

- Perform comprehensive analyses of alternate control concepts (e.g., acceleration feedback and/or revised signal mixing and filtering schemes) to improve ride quality and dynamic response in curves and grade transitions; and

- Conduct multi-DOF analyses of vehicle dynamic behavior at speeds above and below 134.1 m/s and include response to wind gusts, guideway gaps, grade transitions and horizontal turns.

D.3 CONTROL MAGNETS

Active control with control magnets is chosen over a secondary suspension because it allows more freedom in meeting the ride quality requirements, can be used on a rougher guideway, is simpler and likely to cost less, and requires a minor amount of control power under normal conditions. Previous work has shown that separate control coils are a necessity to allow persistent-mode operation of the levitation coils. The control coils can be cryogenically cooled or can be at ambient temperature. Ambient coils have been chosen for the conceptual design to simplify the driver interface and other aspects of the coil design. These magnets are most effective when mounted as close to the track as possible coaxial with the levitation magnets; however, it is more important to maximize the vehicle clearance above the track. Accordingly, the control magnets are located on the bottom of the dewar, coaxial with the levitation magnets. A control coil size approximately 5 cm high by 18 cm wide is provided.

Eight control coils are specified to provide redundancy, with each coil providing 50 percent of the total control force at the four levitation module locations. The windings of these coils will use aluminum tape interleaved with mylar or another suitable tape insulation to minimize weight and maximize heat transfer from the core of the coil. Heat generated in the coils will be dissipated by conduction through the insulating overwrap to the outside container of the magnet module, and by radiation and convection to the vehicle skin on the bottom of the module and hence to the ambient air. Provisions are also included in the conceptual design to circulate cooling air over the underside of the control coils for direct convective cooling, if required.

Electrically, each magnet must supply three percent of the levitation magnet ampere turns to meet ride quality requirements when gap sensors are used in the control loops, and 4.5 percent when they are not. The operating levels required are then 10,500 ampere turns and 15,800 ampere turns rms, respectively. The parameters of the baseline magnets for these two cases are listed in Table D-1.

Negotiation of grade transitions requires more net control force than for level conditions. A value of seven percent of the levitation magnet ampere turns or 24,600 ampere turns is specified for the baseline condition with gap sensors. This value is predicated on a transition distance of 4 km (2.5 miles) while still maintaining ride quality (i.e., higher values would provide shorter grade transitions, but ride quality requirements cannot be met). When gap sensors are not used, a control current ratio of about 10 percent to 11 percent is required to maintain ride quality over transition distances of ~10 km (6.2 miles). The grade transition control force requirement is a transient peak-loading effect with a low duty cycle. The extra thermal load imposed on the control coil due to grade transitions is a short-term condition and can be "heat-sinked" into the control coil and dissipated normally after the grade is negotiated. The impact of the added power for grade transitions will fall on the control coil drivers, which must be sized to provide the higher peak values.

D.4 BEYOND THE FORD STUDY

While the results of the Ford study are encouraging, guideway bank angles only up to 10 degrees were considered. As indicated in Section 6 of this report, combined guideway and vehicle banking angles up to 24 degrees may be most effective. This larger bank angle will impose greater side forces on the guideway, which may have a significant effect on vehicle performance and guideway cost. One approach for reducing guideway loading and costs using combined aerodynamic surfaces and magnetic control coils will be limited to vertical motions and will include guideway flexibilities, as well as factors such as guideway roughness, gap response, and vertical windshear. A block diagram of the proposed control system is shown in Fig. D-3.

Table D-1. Control Coil Parameters (Per Coil)[1]

Parameter	Ampere turn ratio	
	$\alpha = 0.03$	$\alpha = 0.045$
Material	Aluminum	Aluminum
Turn size, cm	5 x 0.0233	5 x 0.0233
Overall cross section, cm	5 x 18.4	5 x 18.4
Length (between centerlines), cm	150	150
Width (between centerlines), cm	50	50
Turns	750	750
Resistance (at 120°C), Ω	10	10
Inductance, H	1.6	1.6
Current density (RMS), A/mm^2	1.2	1.2
Current peak, A	20	30
RMS	14	21
Real power (peak[2]), kW	4	9
RMS	2	4.5

(1) Values for straight and level operation.

(2) The mechanical power delivered by each coil is <100 watts and is much less than the power required to supply the coil I^2R losses.

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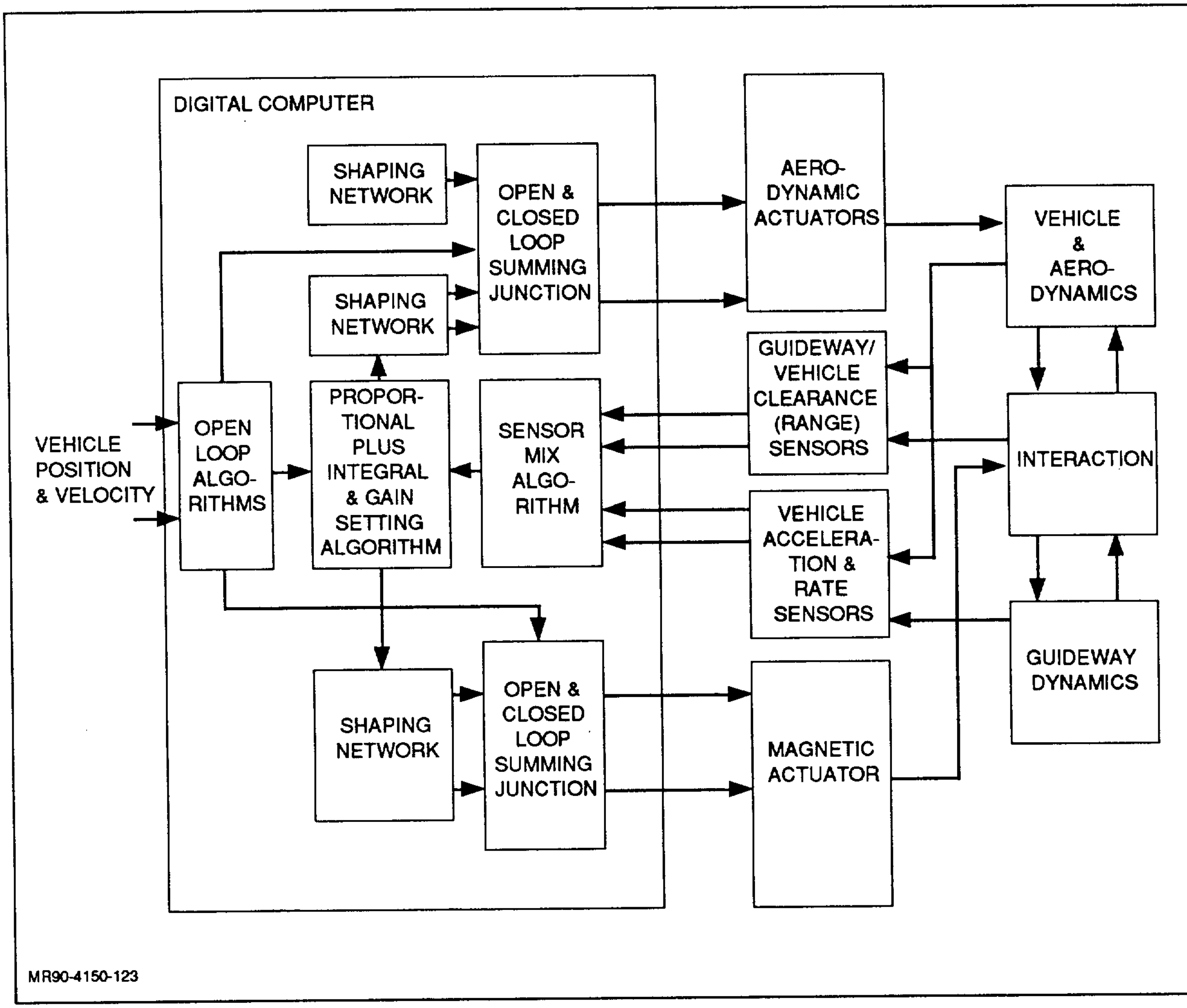

Fig. D-3 Aeromagnetic Guidance, Control & Load Alleviation System – Block Diagram

D.5 MAGNET FAILURE

A potential problem is loss of the magnetic field at one of the vehicle's corners. The likelihood of failure is small but must be considered. A failure would be a function of the magnet and cryogenic design (i.e., the choice of superconducting current density, the stability of the coil in response to changes in the magnetic field, the loss of refrigerant, and/or loss of vacuum). While the magnets can be designed with excess copper and superconductor to minimize the probability of failure, the degree of "excess" is a judgment that must be determined by experiments during the magnet development program. In addition, the use of monofilament wire to minimize the heat generated by ac losses must be balanced against the stability obtained with multifilament twisted superconducting composites.

Magnet failure can be caused by loss of vacuum and/or loss of refrigeration. Loss of vacuum will cause rapid loss of superconductivity due to sudden large heat inputs. For this reason, each of the redundant magnets has a separate cryostat. Loss of vacuum during normal operation is considered a low probability since industry has successfully used vacuum containers. A protective shroud encloses the magnet, thereby minimizing the possibility of dewar puncture. Loss of refrigeration through compressor failure is considered a higher risk because the compressor seals cannot be lubricated to avoid contaminating the helium. Normal replacement of these seals minimizes the possibility of failure, but to guard against it, two redundant features are added. First, a storage container of 16-liter capacity is placed in each cryostat, and finally a second compressor is placed on the vehicle.

Although magnet failure and loss of lift can still occur, redundant magnets in the corners of the vehicle tend to minimize the risk since the vehicle corner can be supported by the remaining magnet. The wheels required for low-speed operation form a back-up system to prevent impact with the guideway. The dedicated guideway provides confinement surfaces on which the vehicle will coast to low speeds on wheels in the event of complete loss of magnetic field at one of the corners.

An analysis, made in Ref. 4.1, assumed the failure of one magnet of two in one corner. Table D-2 summarizes the results using the correct image calculations for a corner guideway for the 0.5 x 1.5 m magnet before and after failure. The results show the new suspension height (h) and the lateral guidance distance (h') due to a failure of one of the two magnets at position 1 (see Fig. D-4). The normal equilibrium values for these parameters are h = h' = 30 cm (11.8 inches), and $F_G = 0.36\ F_{LAvg}$. After failure, the remaining operational magnet in the damaged module, position 1, drops 5.5 cm (2.2 inches) and moves 5.8 cm (2.3 inches) closer to the vertical surface to increase both the lift and the guidance force that was lost. The adjacent support magnet module (position 2) also drops slightly (1.3 cm, 0.5 inch) and moves away from the vertical 5.8 cm so that the guidance force at these positions is now $0.23\ F_{LAvg}$ instead of the normal operating value of $0.36\ F_{LAvg}$.

The assumption of a rigid vehicle structure leads to the magnet forces and positions for magnets 3 and 4 listed in Table D-2; however, an actual vehicle ~30 m (100 ft) long is expected to have some flexibility, and the magnets at positions 3 and 4 will have force and position values between those listed in Table D-2 and the equilibrium values for normal operation.

The maximum dynamic excursion (minimum position) can also be obtained, assuming the failure of one magnet at position 1 to be catastrophic (i.e., instantaneous). These values for position 1 are h = 20.9 cm and h' = 20.2 cm. Should magnet failure occur over a finite time (i.e., several seconds) the equilibrium values listed in Table D-2 will be reached with no overshoot.

Table D-2. Magnet Equilibria Positions After Failure of One of the Eight Levitation/Guidance Magnets (See Fig. D-4)

Magnet position	Lift force, F_L (fraction of normal value)	Guidance force, F_G (fraction of normal $F_{L_{AVG}}$)	Suspension height, h (cm)	Lateral distance, h' (cm)
1	0.83	0.23	24.5	24.2
2	1.17	0.23	28.7	35.8
3	0.83	0.36	32.6	30.5
4	1.17	0.36	28.0	29.5

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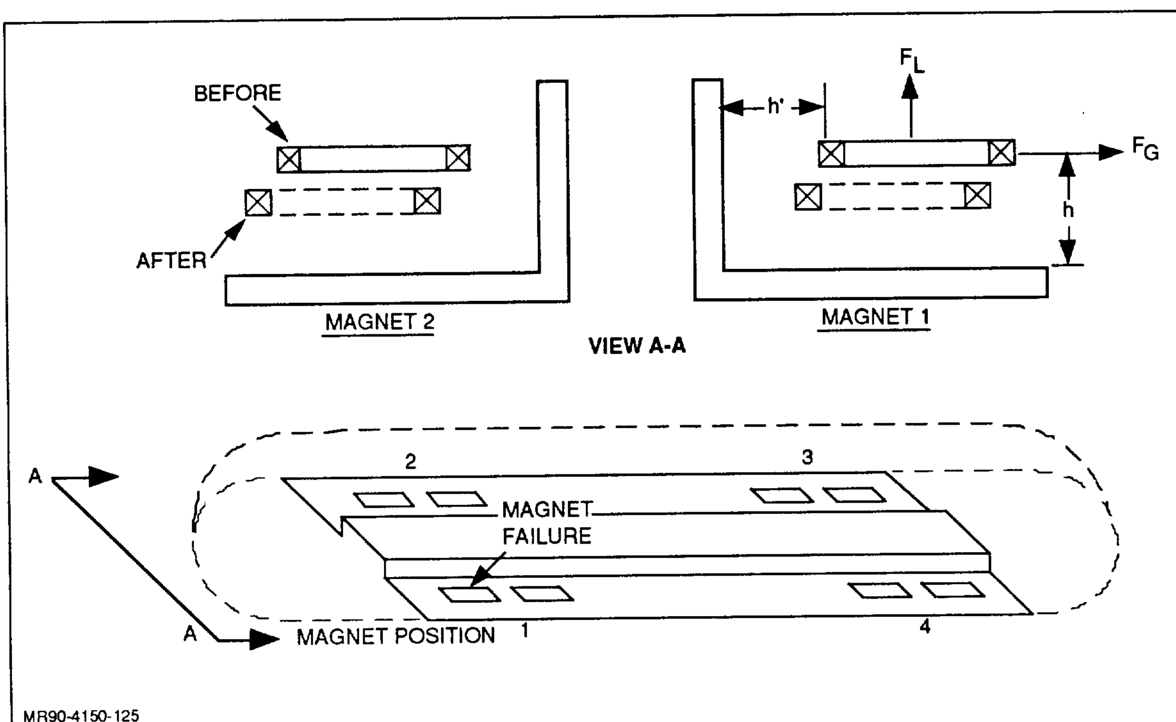

Fig. D-4 Magnet Failure Mode – Schematic Diagram

Other factors that will influence the new equilibrium position and the transient behavior are aerodynamics, propulsion, and the feedback control system for the control coils. A magnet field probe can be used to detect magnet failure, and the characteristics of the control system can be changed to minimize the effect of the loss.

D.6 DYNAMIC SIMULATION

It is evident that there is no clear understanding at the present time as to what can be considered acceptable motions to the passengers on a MAGLEV vehicle travelling 35 ft above the ground making a coordinated turn every few miles. A flight simulator, similar to those available at aerospace companies, should be used to simulate the visual, audio and physical cues of a typical MAGLEV trip in terrain similar to those found in candidate New York State rights-of-way.

Simulations (Fig. D-5) are conducted in Grumman's Schwendler Development Center Systems/Simulation Development Laboratory (SSDL), a new facility. The SSDL is a complex of interconnected centers operating independently or as part of a centralized full mission simulator. Each of these task management centers is staffed by analysts, engineers, and programmers who concentrate on particular aspects of simulation, including flight characteristics, threat descriptions, displays, and other related disciplines.

Simulation can be a form of aircraft prototyping since the simulation replicates the design specifications of the objective aircraft system. Virtually all design engineering factors can be examined in a mission simulator (MS) environment. The more exotic and innovative the aircraft system technology, the more valuable the MS will be in developing effective, economical programs.

The out-the-window scene in the projection dome is detailed enough to create the visual cues of low-level flight, including foliage, roads, railroads, power lines, and ground structures. Illumination intensity and visibility in the visual scene are variables that are immediately adjustable from the control console, allowing the effects of weather and ambient light level to be evaluated. Cloud decks with realistic scud representations are added for in-flight realism.

In addition to the fixed-base simulator described above, Grumman has moving-base simulators. Figure D-6 shows the Grumman 20-ft-diameter projection dome with six-degrees-of-freedom motion and a visual system that could be modified to perform testing for the MAGLEV program. Some of the characteristics of this simulator are:

- Low-friction teflon composition bearings at cross-axis universal joints;

- Computer-designed actuator cushions and abort valve spools;

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Fig. D-5 ACAS Cockpit & Dome Simulator

- Servo valves unbalanced to compensate for actuator extend and retract piston areas;
- Internally mounted, infinite resolution, noise-free magnetostrictive actuator position feedbacks;
- Hydrodynamic rod bushings and split-ring pistons provide minimum friction (50-lb maximum breakaway at operating pressure);
- Total moving load of 24.6 klb with payload of 19 klb;

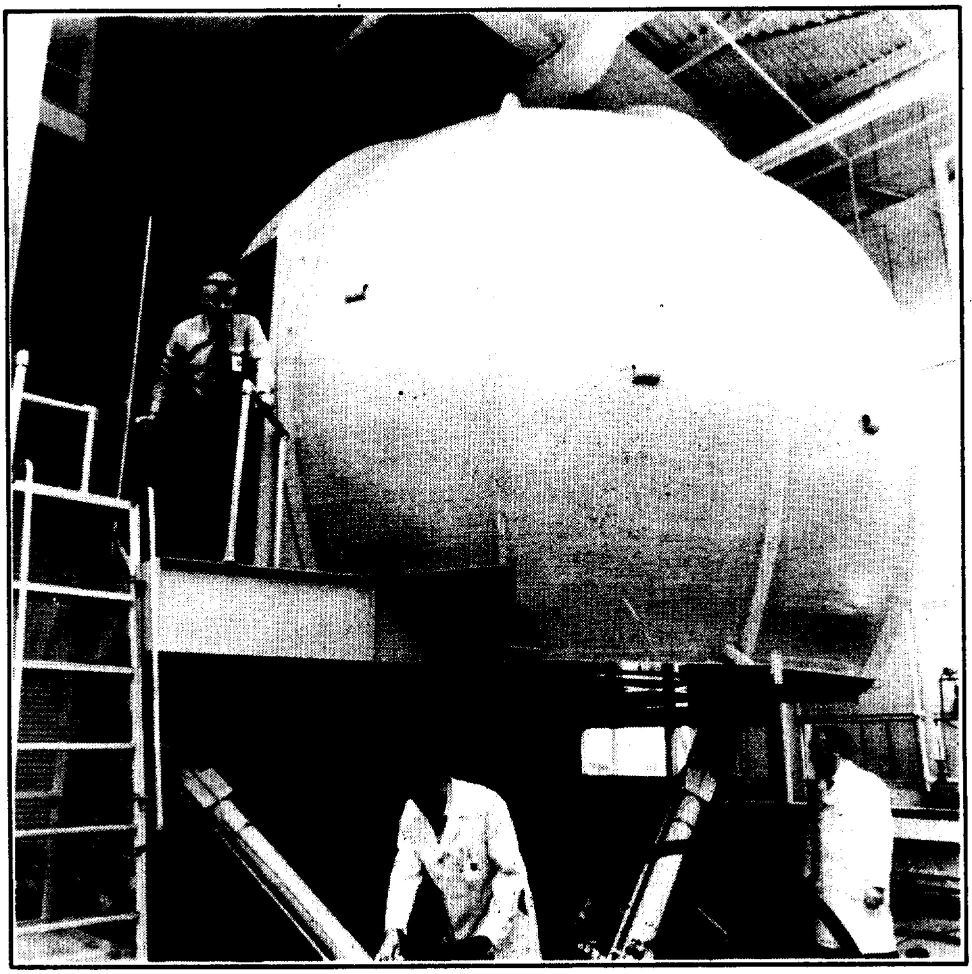

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Fig. D-6 Simulator Cockpit within a 20-ft-Diameter Dome at Grumman has a Six-Degrees-of-Freedom Motion System and a Visual System.

- Static accuracy better than 0.5 percent for all actuators – MIL-STD-1558 specifies 1.0 percent;
- System overshoot is 1.4-percent longitudinal axis with other axes negligible; MIL-STD-1558, as modified by the B-52/C-130 requirements, specifies two percent maximum;
- Transport lag for step input is 0.03-second maximum; MIL-STD-1558 specifies 0.05 second; and
- Resonant frequency of structures exceeds 15 Hz; MIL-STD-1558 specifies greater than 5 Hz.

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