Under Contract
DTFR 53-92-C-00003

MAGLEV SYSTEM CONCEPT DEFINITION

HYPOTHETICAL ROUTE REPORT

Prepared for

**U.S. Department of Transportation
Federal Railroad Administration**

September 30, 1992

BECHTEL

HUGHES

GM
ELECTRO-MOTIVE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MENS ET MANUS
1861

DRAPER
LABORATORY

INTRODUCTION

The hypothetical route simulation is a computer program for simulating maglev on a benchmark guideway alignment for performance assessment of the maglev transportation system within the context of the current System Concept Definition contract. The total guideway distance of the hypothetical route from terminal #1 where it starts, to terminal #4 where it ends, is 800 km and consists of a number of horizontal curves with radii of curvature as small as 400 m, and elevation grades as steep as 10 percent. Terminal #2 is located at 400 km and terminal #3 is at 470 km. We are to assume that the vehicle only stops momentarily at these terminals. In addition, there is a 5 km tunnel beginning at 515 km from terminal #1. The route meanders horizontally and vertically until 475 km, at which point it is straight and level until terminal #4.

Our maglev simulation has adapted the hypothetical route alignment for determination of significant characteristic parameters for the Bechtel concept maglev. This simulation consists of programs that have been specifically tailored to allow analysis of the hypothetical route, and in fact these same programs are being used by the Government in its analysis of the performance characteristics of alternate SCD concepts for the National Maglev Initiative.

Inputs to the simulation include route alignment data, positions of stations, maximum line speed, maximum banking angle, kinematic parameter limits such as accelerations, jerks, and braking. Outputs include total trip time, velocity vs distance or time and acceleration vs distance or time. The distance and time increment resolution is adjustable. Total trip time is the total time for the vehicle to travel beginning to the end of the hypothetical route. The vehicle stops at stations only momentarily in the model. Vehicle velocity and acceleration profiles give the total velocity vs distance or time and acceleration vs distance or time, respectively, traveled by the vehicle at any given distance or time increment.

This report is organized to follow the contract requirements for the hypothetical route deliverable. Section 1 responds to contract section 4.2; Section 2 responds to contract section 4.3; and Section 3 responds to contract section 4.4. In addition, we have included under Section 4 discussion of two additional performance topics that we believe are of interest to the NMI regarding the hypothetical route.

1. PERFORMANCE CHARACTERISTICS

Three sets of performance parameters were simulated: US1 Design, Minimum Requirements, and Seat Belted. US1 Design parameters represent the current Bechtel concept baseline. Minimum Requirements and Seat Belted parameters represent the Department of transportation's maximum allowable values for ride comfort. Also simulated were judicious departures from the hypothetical route alignment using the US1 Design parameter set. These results are given in section 4.2. The parametric values for each performance set are given in Table 1-1.

Table 1-1
Performance Parameters

	US1 DESIGN	MINIMUM REQUIRE-MENTS	SEAT BELTED	MINIMUM REQUIRE-MENTS with ZERO TILT	
Line speed	134	134	134	134	meters/second
Maximum speed at maximum acceleration	120	120	120	120	meters/second
Total Banking angle	~~30~~ 24	30	45	15	degrees
Lateral acceleration limit	~~0.16~~ .10	0.16	0.20	0.16	g's
Lateral jerk limit	~~0.25~~ .07	0.25	0.25	0.25	g's/sec
Upward acceleration	~~0.10~~ .05	0.10	0.10	0.10	g's
Downward acceleration	~~0.30~~ .20	0.30	0.40	0.30	g's
Vertical jerk limit	~~0.30~~	0.3	0.30	0.3	g's/sec
Fore-aft acceleration	0.16	0.20	0.6	0.20	g's
Fore-aft jerk limit	~~0.25~~ .07	0.25	0.25	0.25	g's/sec
Braking limit	0.16	0.20	0.6	0.20	g's

1.1 TOTAL TRIP TIMES

The total trip times and average speeds for US1 Design, Minimum Requirements, Seat Belted, and Minimum Requirements with Zero Tilt parameter sets to travel from station #1 to station #4 on the hypothetical route is given in Table 1-2.

1.2 NUMBER AND SIZE OF VEHICLES

For the hypothetical route , only one vehicle at a time was simulated. Each vehicle has a passenger capacity of 120 people.

Table 1-2
Total Trip Times

	TOTAL TRIP TIME	AVERAGE SPEED	TRIP TIME DIFFERENCE from US1 Design	AVERAGE SPEED DIFFERENCE from US1 Design
US1 DESIGN	1h 59m 02s 7142 s	111.8 m/s 250 mi/hr		
MINIMUM REQUIREMENTS	1h 58m 24s 7104 s	112.4 m/sec 251 mi/hr	0m 38 38 s	0.6 m/s 1 mi/hr
SEAT BELTED	1h 45m 15s 6315 s	127 m/sec 284 mi/hr	13m 47s 827 s	15.2 m/s 34 mi/hr
MINIMUM REQUIREMENTS with Zero deg. TILT	2h 11m 11s 7871 s	102 m/s 228 mi/hr	-12m 09s -729 s	-9.8 m/s -21.9 mi/hr

1.3 VEHICLE VELOCITY PROFILE

The graphs shown in Figures 1-1 to 1-16 succinctly shows the vehicle velocity versus distance profile and includes all the data points generated during each simulation run. Note that the total guideway length indicated in the 600 to 800 km graph is slightly short of the 800 km of the hypothetical route alignment. This is because the actual lengths of the curves of the guideway were used instead of tangent approximations as is the case in the hypothetical route alignment.

1.4 RIDE COMFORT PROFILE

At the high operating speeds of maglev vehicles, any imperfections in the guideway and fluctuations in the winds impinging on the vehicle can result in significant suspension force variations, resulting in vehicle vibrations. Studies have shown that if sufficiently large, these vibrations can cause passenger discomfort and even motion sickness, resulting in dissatisfaction with the quality of the ride. The suspension force variations also produce dynamic stresses in the guideway and the suspension components mounted on the guideway, as well as in the vehicle. The guideway imperfections and wind fluctuations also cause variations in the clearance between

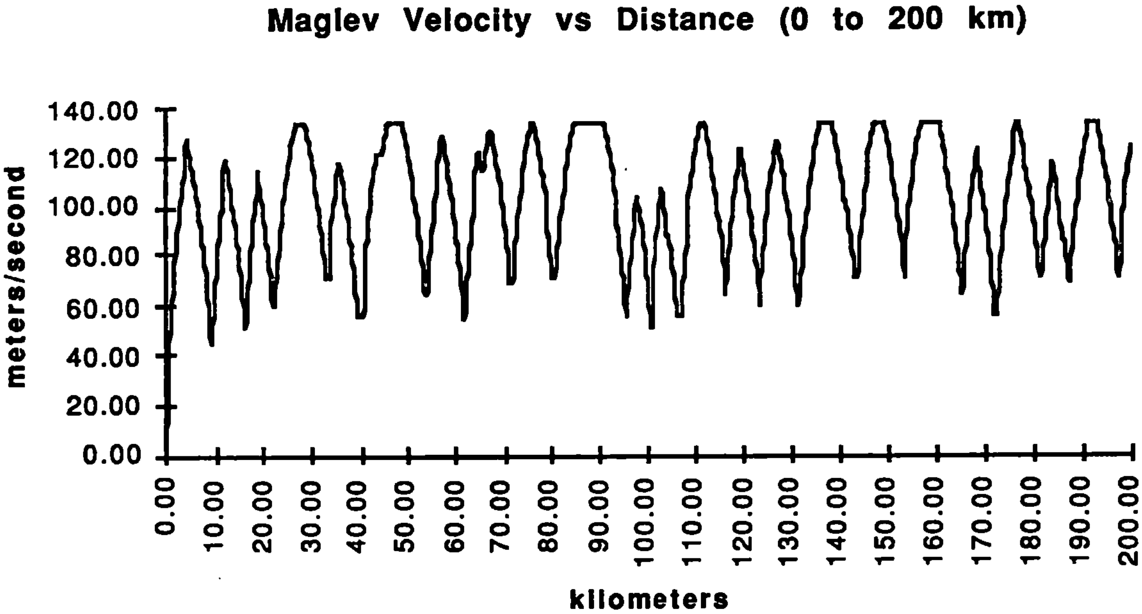


Figure 1-1 US1 Design Set - Zero to 200 km

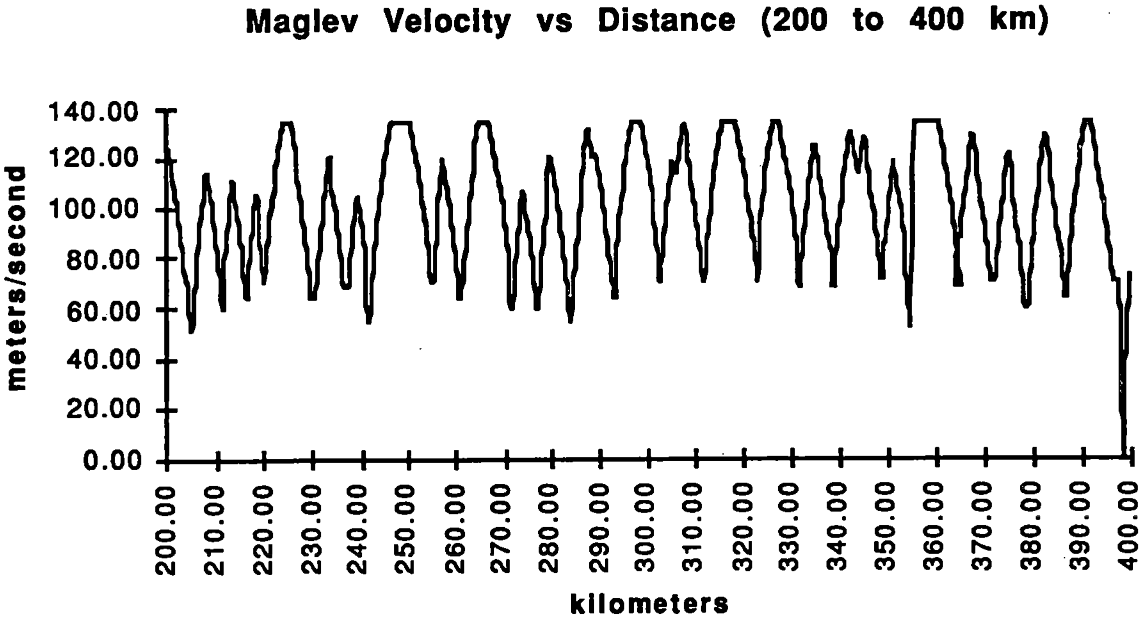


Figure 1-2 US1 Design Set - 200 to 400 km

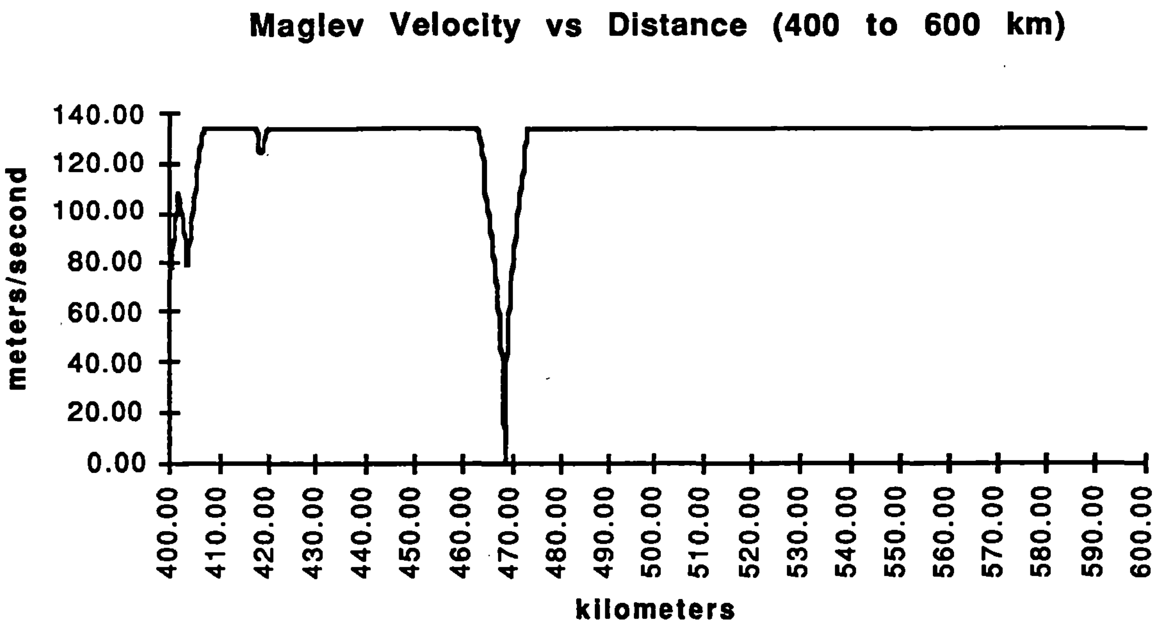


Figure 1-3 US1 Design Set - 400 to 600 km

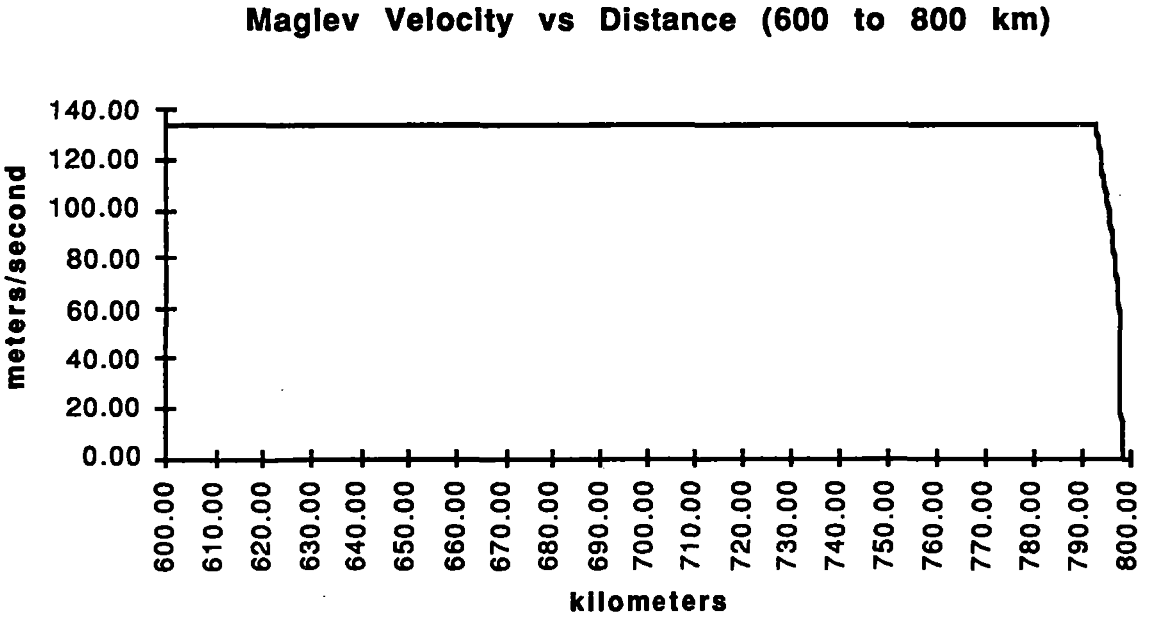


Figure 1-4 US1 Design Set - 600 to 800 km

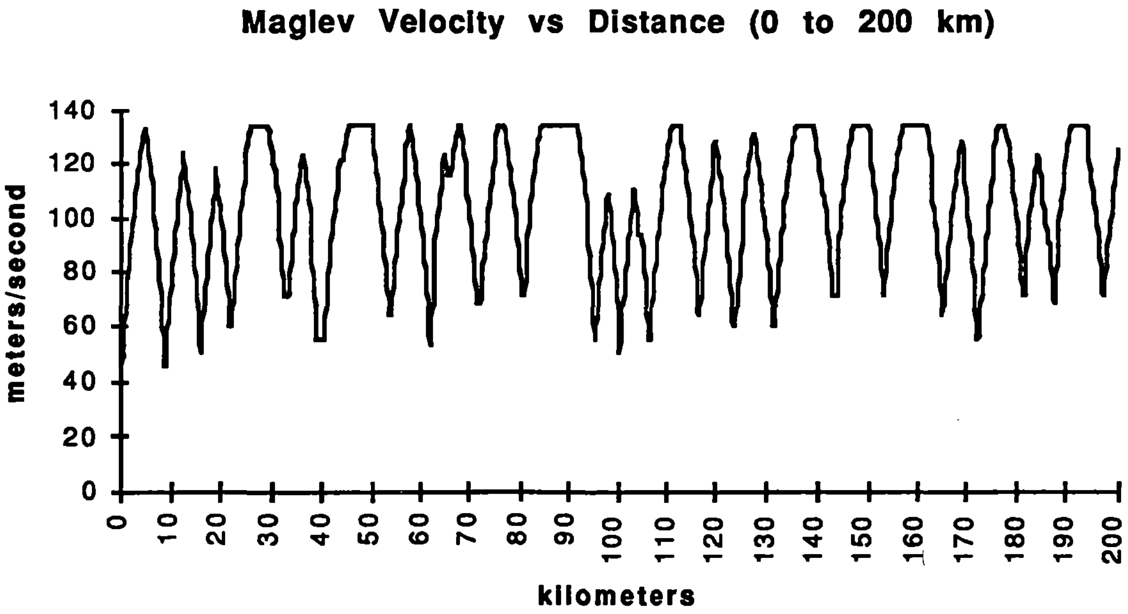


Figure 1-5 Minimum Requirements Set - Zero to 200 km

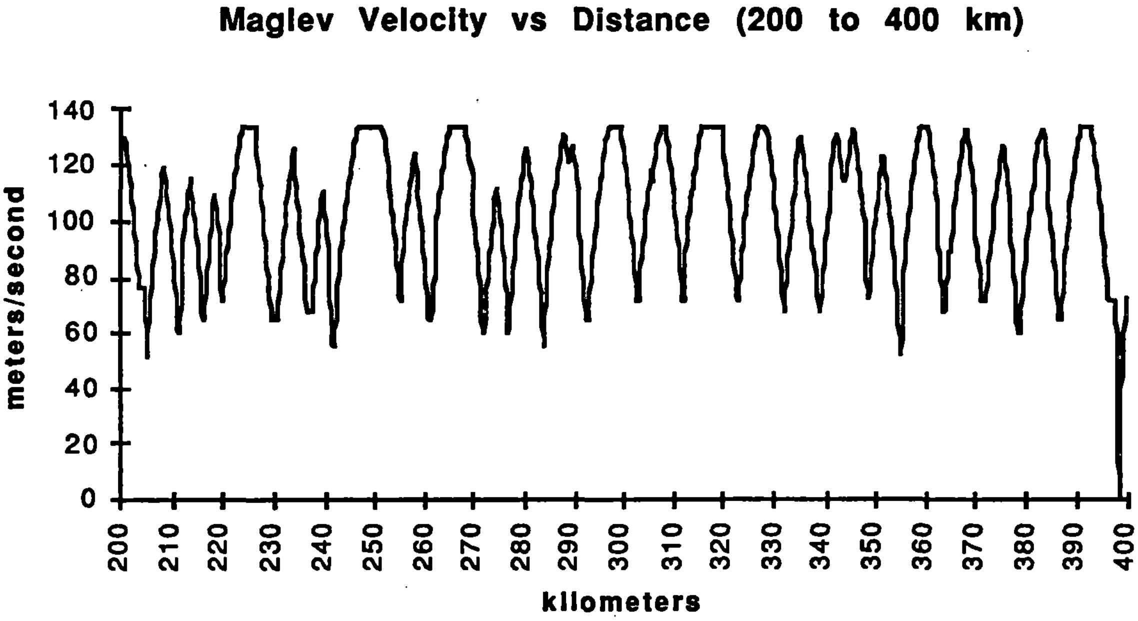


Figure 1-6 Minimum Requirements Set - 200 to 400 km

Maglev Velocity vs Distance (400 to 600 km)

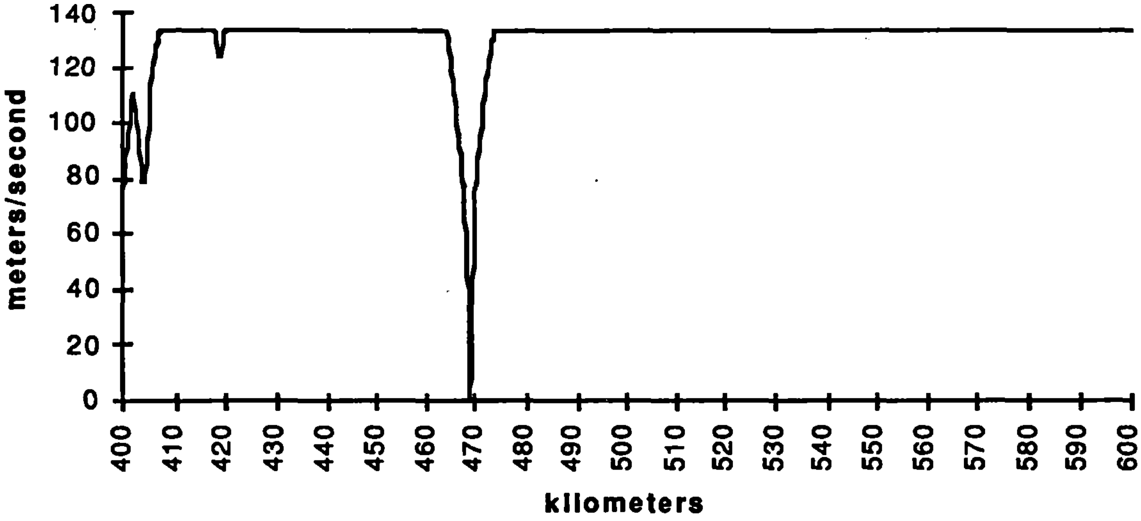


Figure 1-7 Minimum Requirements Set - 400 to 600 km

Maglev Velocity vs Distance (600 to 800 km)

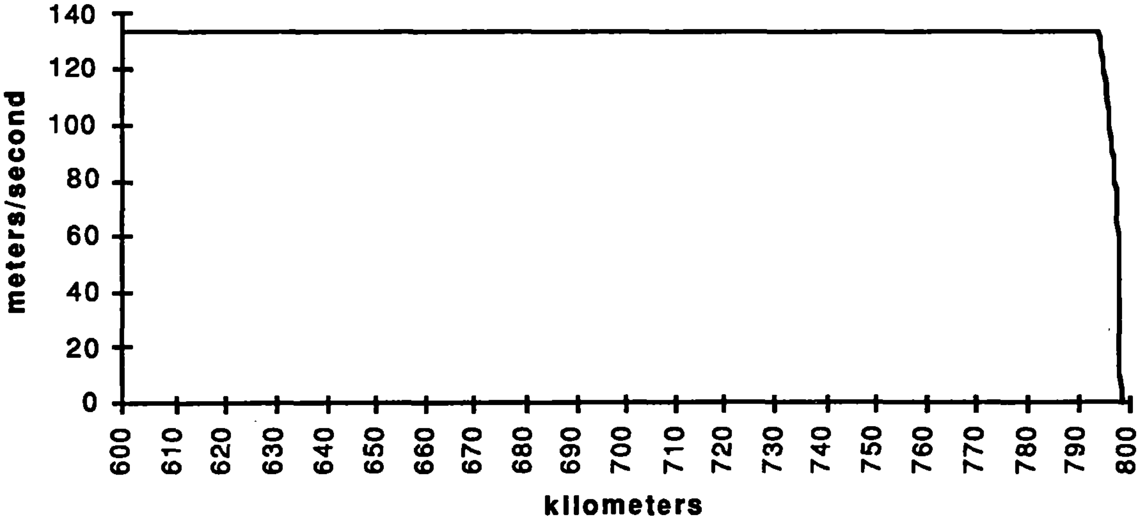


Figure 1-8 Minimum Requirements Set - 600 to 800 km

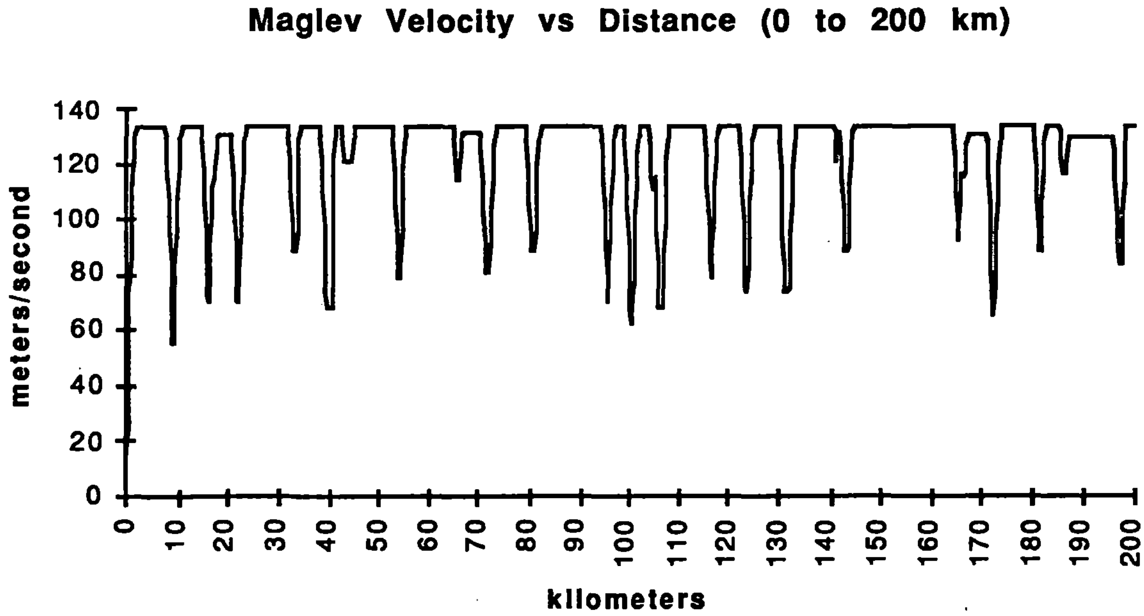


Figure 1-9 Seat Belted Set - Zero to 200 km

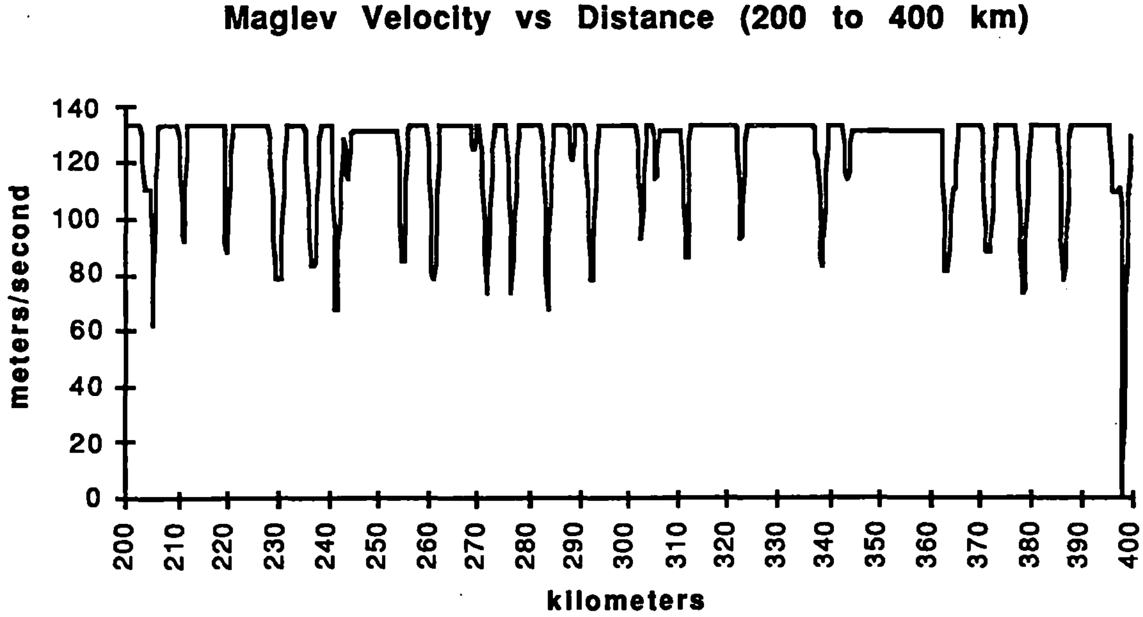


Figure 1-10 Seat Belted Set - 200 to 400 km

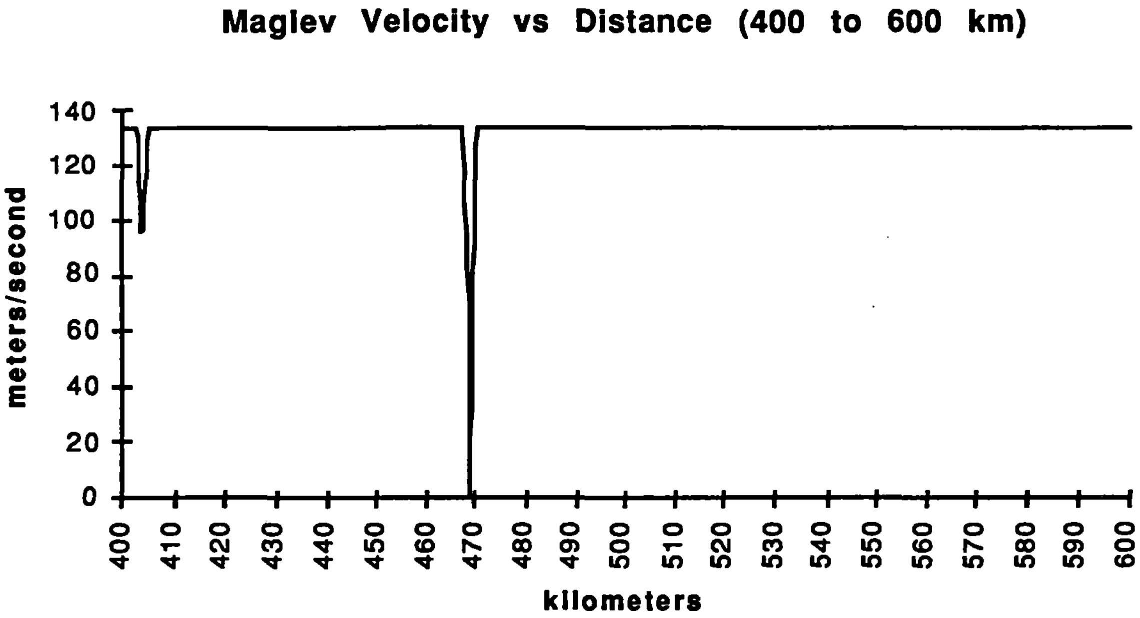


Figure 1-11 Seat Belted Set - 400 to 600 km

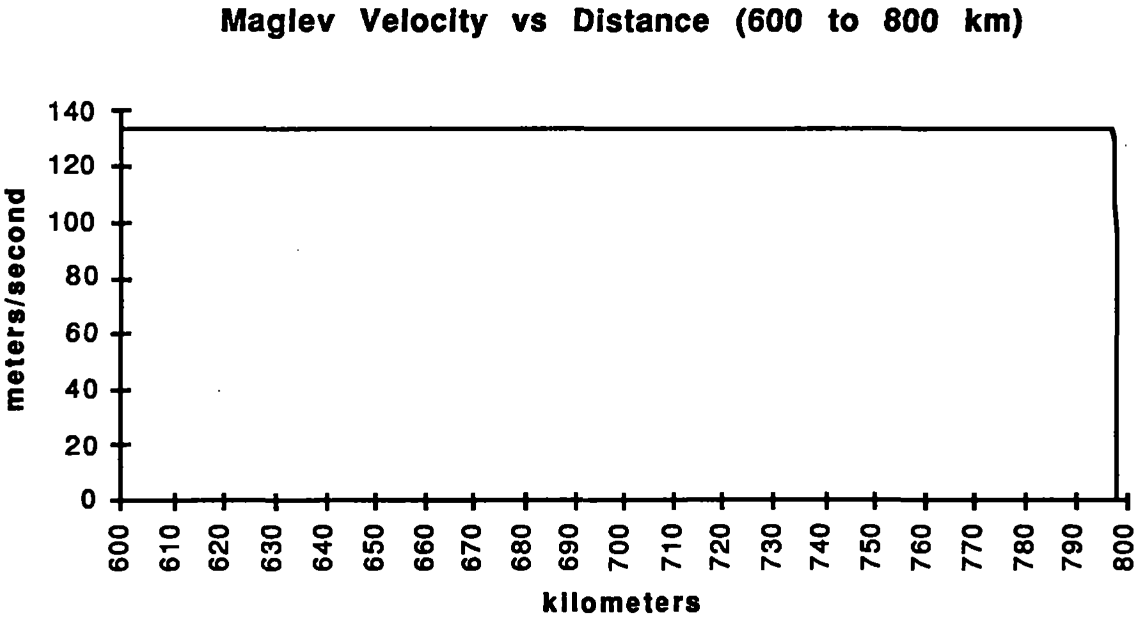


Figure 1-12 Seat Belted Set - 600 to 800 km

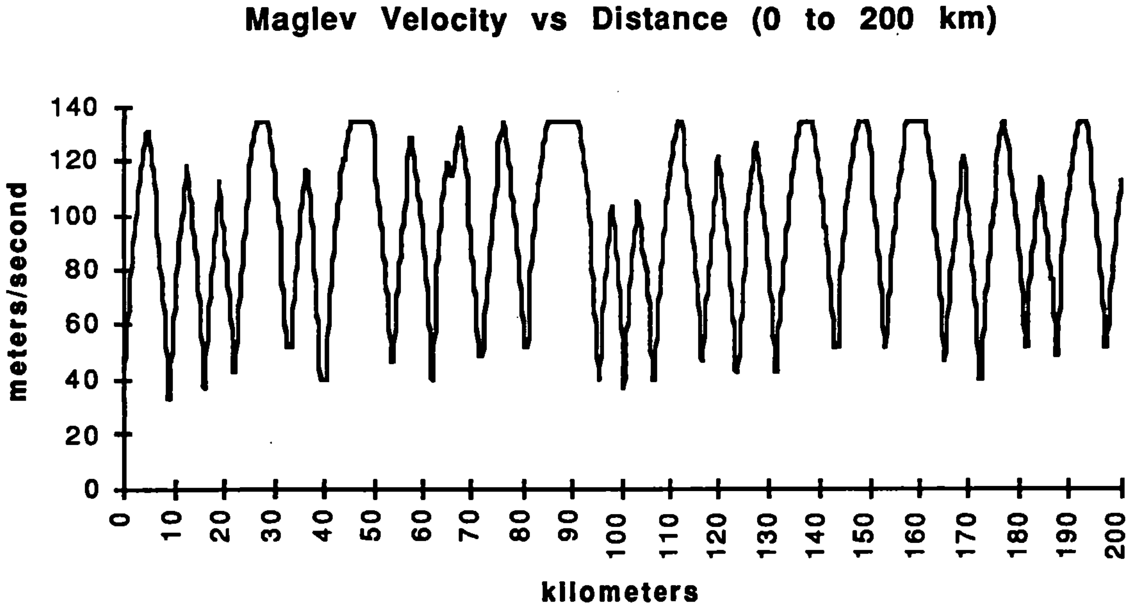


Figure 1-13 Zero Tilt Set - Zero to 200 km

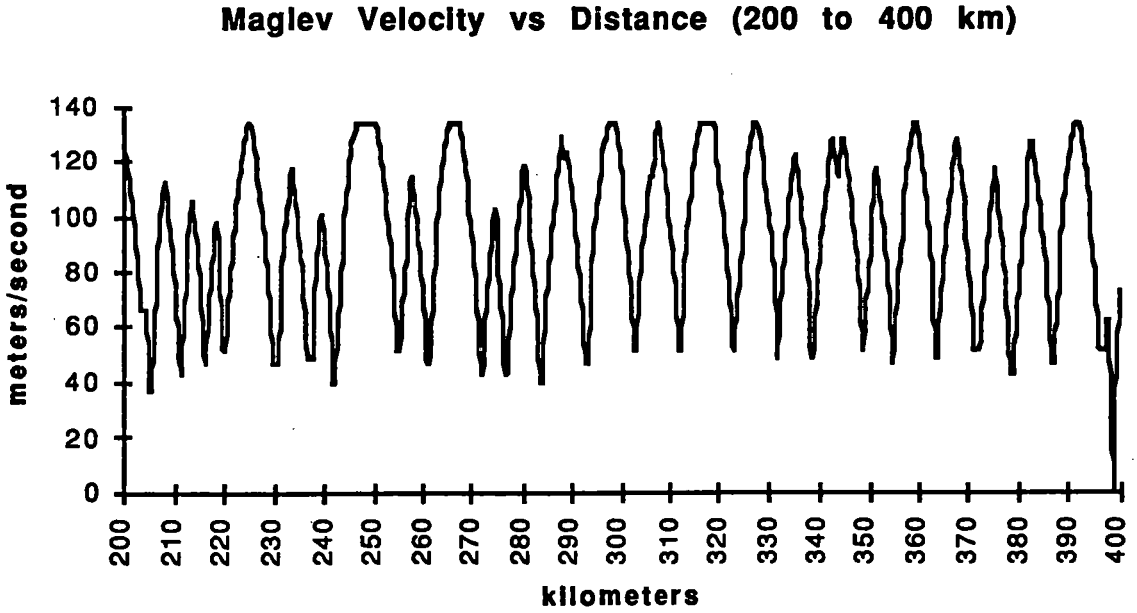


Figure 1-14 Zero Tilt Set - 200 to 400 km

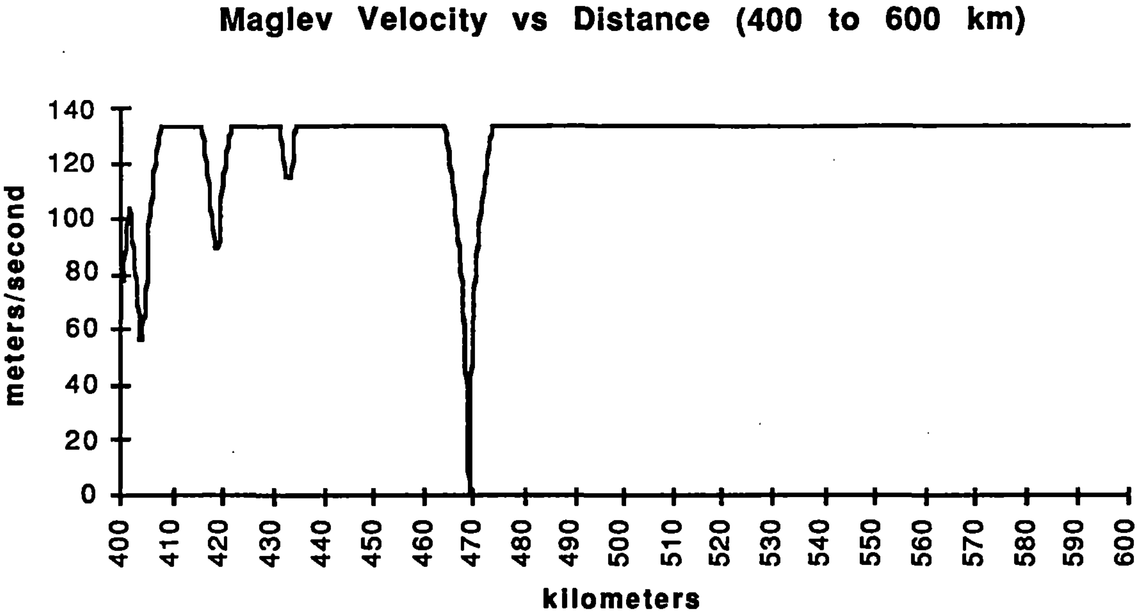


Figure 1-15 Zero Tilt Set - 400 to 600 km

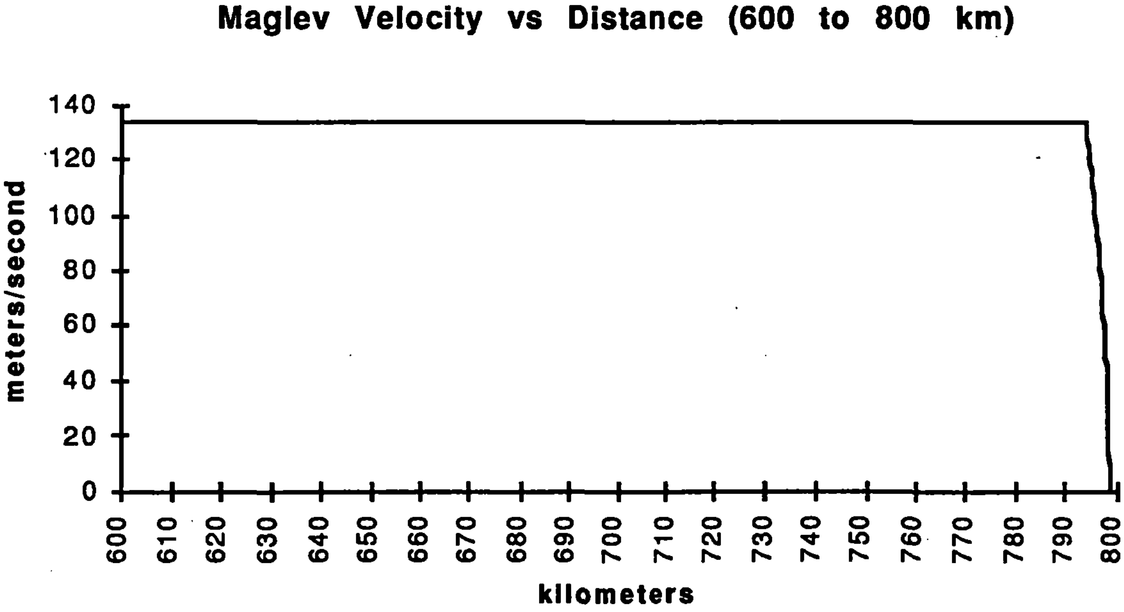


Figure 1-16 Zero Tilt Set - 600 to 800 km

the vehicle and the guideway; if sufficiently large, these variations can result in vehicle-to-guideway contact which can result in damage. The cost of constructing a guideway without these minor imperfections and in such a way as to shield the vehicle from wind would be prohibitive. For this reason, the discomfort resulting from guideway roughness and wind fluctuations is minimized in our baseline vehicle concept by the use of an actively controlled secondary suspension.

Studies have developed criteria and standards for evaluating ride quality [References 1,2]. It is thus necessary to evaluate the passenger accelerations, secondary suspension actuator strokes and primary suspension air gap variations of the vehicle/active secondary suspension controller/guideway combination to determine an satisfactory design and establish that it provides adequate ride comfort. Generally, there is a trade-off between the conflicting requirements of minimizing passenger accelerations, maintaining adequate vehicle-guideway clearances and providing reasonable actuator strokes.

1.4.1 Approach

Dynamic models of vehicle suspensions and guideways have been developed at MIT and Draper and have been applied to our vehicle, suspension and guideway design to determine ride comfort along the hypothetical route provided by DOT/FRA and as specified in Contract Modification 0002. Ride comfort in the vibration regime was determined both by calculating the Peplar index in the 1.0 to 25 Hz frequency band for a passenger located at the roll center of the vehicle and by comparison of the vertical and lateral accelerations (in the local coordinate system) at the worst passenger seat in the vehicle (for the baseline vehicle, this is a window seat at the front of the vehicle) with the ISO 1 hour reduced comfort curves over the 0.1 to 80 Hz frequency band. Ride comfort in the Motion Sickness regime (0.1 to 1.0 Hz) was determined by comparing the vertical acceleration with the extended ISO 1 hour reduced comfort curve set forth in Figure 2 of the contract modification.

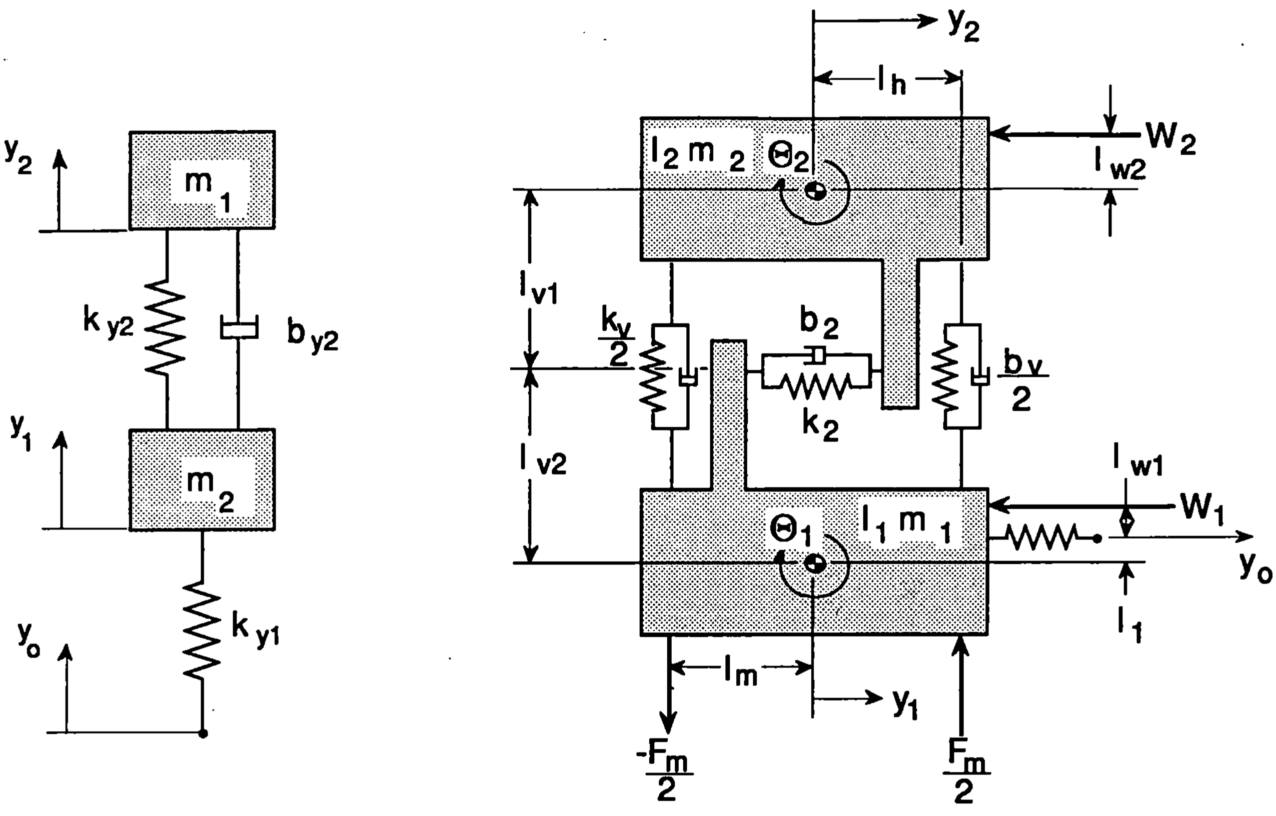
Ride comfort in the curving regime was to be determined by comparing the vertical, lateral and longitudinal accelerations and jerk and/or jolt with the design goal values set forth in the contract modification. However, in our simulations of vehicle performance over the hypothetical route, the vehicle was constrained to observe these limits at all times; hence, it was unnecessary to compare these parameters with the desired values, since they were guaranteed to be observed. These simulations were performed by Hughes using the Maglev Performance Simulator program. The simulations provided a vehicle velocity profile for the entire hypothetical route; the velocities through the specified ride comfort evaluation segments of the route were examined and the maximum velocity was determined to be 134 m/s through segment #4, both on a straight section and around a 1 km radius curve. Ride comfort parameters for this report were evaluated for a maximum vehicle speed of 134 m/s.

Although the ride comfort and air gap variations generally tend to be poorer at the highest vehicle speeds, the vehicle inputs from guideway roughness and wind variations do depend upon the vehicle speed, and the primary suspension stiffnesses and drag also are speed dependent. Accordingly, the ride comfort and air gap variations were also evaluated at a selected lower speed to ensure that satisfactory ride comfort was maintained over the range of operating speeds. Since the lower speeds through the ride comfort evaluation sections of the hypothetical route occurred during curve negotiation, the quasi-static lateral accelerations of the vehicle due to centrifugal force were included in the calculation of air gap variations. The reduced speeds were 72 m/s in ride quality evaluation segment 1, while negotiating a 1 km radius curve, and 65 m/s in segment 2 while negotiating an 800 m radius curve (the centrifugal force on the vehicle was the same in both cases).

In the calculation of the Pepler ride comfort index, the vehicle interior noise was estimated as 65 db(A) (a noise level of 65 db(A) or lower does not affect the value of the Pepler index). Although the Proposal stated that ride comfort would be evaluated for entrance to/exit from tunnels, the ride comfort evaluation zones of the hypothetical route do not include the single tunnel on the route, so these the effect of these inputs were not evaluated. The vehicle accelerations resulting from passing trains also was not included in this study. It should be noted that, whereas the contract specified that the Pepler index be calculated using RMS accelerations in a 1 Hz to 25 Hz bandwidth, the values presented here were calculated over a very wide frequency range; this was inherent in the calculation method and results in slightly pessimistic Pepler index values.

1.4.2 Ride Comfort Models

A number of models have been developed for assessing the impact on ride quality of vehicle vibrations resulting from guideway roughness and wind forces. These range from simple single degree of freedom heave models [Reference 3 and 4] to more complex models incorporating multiple degrees of freedom and a multiplicity of primary suspension modules [References 5 and 3, respectively]. Figure 1-17 depicts several of the simple models [4] and Figure 1-18 shows a



Heave Model

Lateral/Roll Model

Figure 1-17 Draper simple dynamic models

more complicated model which, while analyzing only two degrees of freedom of the passenger compartment (heave and pitch), incorporates a larger number of suspension modules like our baseline vehicle concept.

The results presented in this report were all obtained from an improved model, the Five-Degree-of-Freedom model, which was completed at Draper during this study under an internally funded Corporate Sponsored Research project. This model is more comprehensive than any appearing in the open literature to date and, in simulating inputs from guideway roughness, addresses the real world situations in which both the front and rear bogies pass sequentially over the same guideway imperfections and roll effects due to unequal inputs from the left and right sides of the guideway. Inputs to the vehicle from impinging wind forces are simulated, including both vibrational inputs due to fluctuations and the effects of the destabilizing yaw moments resulting from the aerodynamic forces acting on the vehicle. Importantly, the model contains the capability to

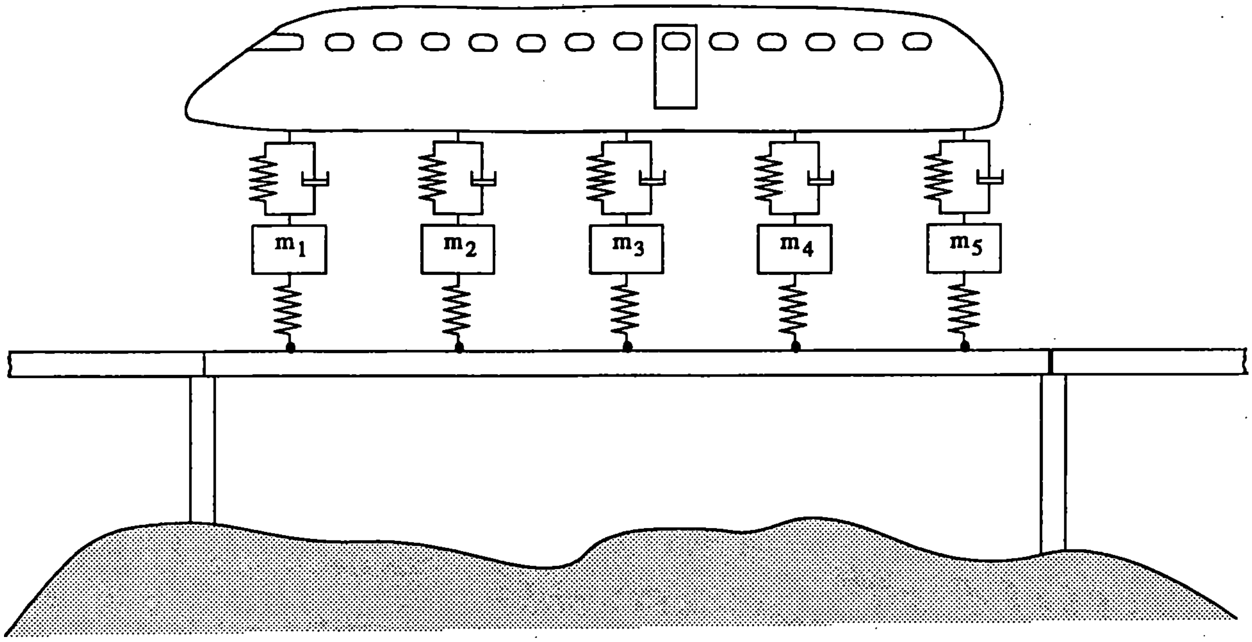


Figure 1-18 MIT multi-bogie dynamic model

implement an optimal active control strategy to minimize passenger accelerations while at the same time constraining vehicle-to-guideway clearance variations within acceptable values. The model is fully described in Part C, Section 6.1 of the Final Report.

Many of the existing models simulate guideway roughness and fluctuating wind inputs by driving the system transfer function with a temporal Power Spectral Density function obtained from a guideway roughness spatial PSD and vehicle velocity. The resulting passenger compartment vertical and lateral acceleration PSDs are then used in one of two ways, depending upon whether the performance is being compared with the ISO standards or the Peplar index. In the former case, the output PSD is used to calculate RMS vibration amplitudes in one-third octave wide bands, while in the latter the RMS vibration over the entire applicable frequency range is calculated. The Draper five-degree-of-freedom model uses a somewhat different approach, as described in Part C, Section 6 of the Final Report.

Recent work [Reference 6] addresses the dynamic interaction between the vehicle, its suspensions and the guideway structure as the moving vehicle passes over it. While it provides many valuable insights into the effects of these interactions, its generality and consideration of only simple passive secondary suspensions prevents its use here in making meaningful quantitative assessments of the behavior the vehicle defined in this concept study. In this study, the assessment of the dynamic guideway interaction effects on passenger accelerations and gap variations was limited to inclusion of the effects of the vehicle passing over the dynamically deflected guideway. This was done by multiplying the transfer function (relating acceleration or gap variation to guideway disturbance magnitude) by the dynamic guideway deflection caused by the passage of the vehicle over the guideway described by Wormley, et al.

1.4.3 Results

As mentioned above, the passenger accelerations and gap variations were calculated for a vehicle speed of 134 m/s, corresponding to the highest speed attained over the ride comfort evaluation zones of the hypothetical route. Passenger accelerations resulting from curve negotiation and cresting and bottoming of hills were not included, since the specified values were guaranteed not to be exceeded by the constraints placed on the simulation; these constraints were the Design Goal values for the results presented here.

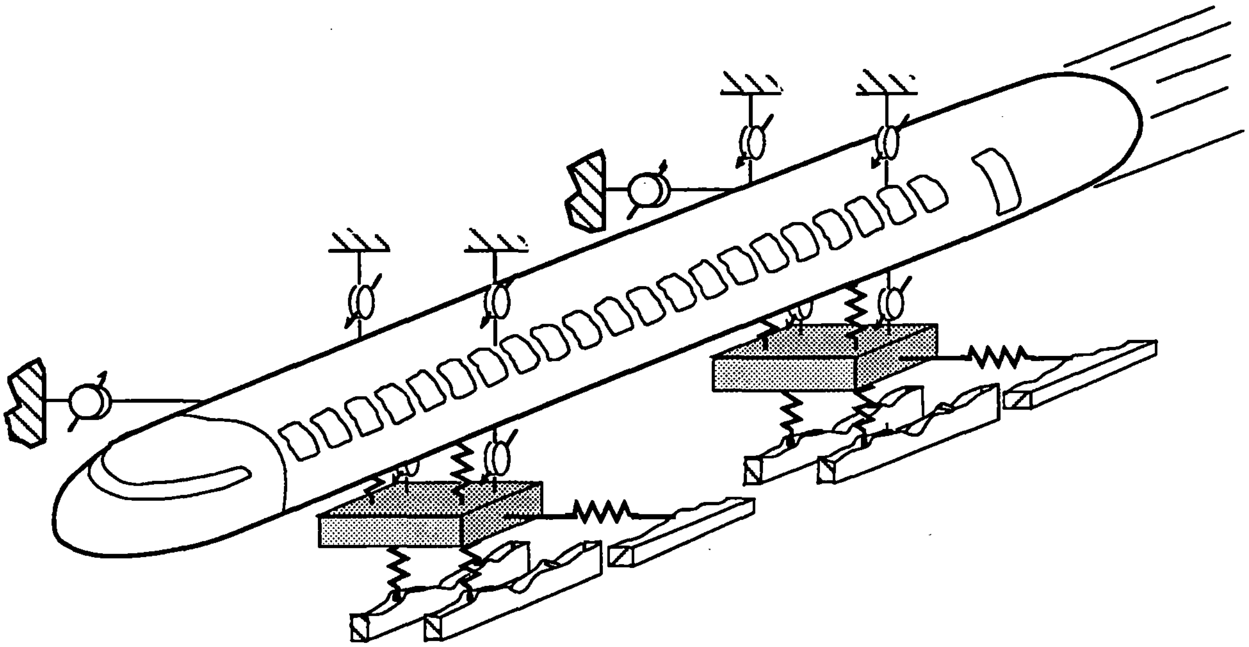


Figure 1-19 Draper 5-degree of freedom dynamic model

Of the many cases analyzed in this study, results from only two are presented here; these are for an optimized passive secondary suspension system and for the baseline configuration consisting of an active secondary suspension system with optimal controller and horizontal aerodynamic control surfaces. The data presented are for the vehicle location with the highest values; generally this is at the front of the vehicle, while the values in the rear are smaller than in the front and values in the center of the vehicle are lowest of all. For a two-bogie vehicle, Wormley, et al [3,6] have shown that the vertical passenger accelerations and air gap variations are generally higher in the front of the vehicle than in the rear; their results show that for a six-bogie vehicle the accelerations are lower overall than for the two bogie vehicle and are slightly larger in the rear than in the front, with lowest values also in the center of the vehicle.

1.4.4 Passive Secondary Suspension

Table 1-3 shows the Pepler index and passenger compartment accelerations in both the vertical and lateral directions which result from guideway roughness, interaction with the guideway dynamic deflection (vertical only) and wind fluctuations for the baseline vehicle with an optimized passive secondary suspension.

Table 1-3
Passenger Accelerations, Passive Secondary Suspension

Speed	Guideway Roughness		Wind Fluctuations		G/W Interac	Total			Pepler Index
	vertical	lateral	vertical	lateral	vertical	vertical	lateral	Roll	
(m/s)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(°/s)	
134	0.0658	0.0673	0.1126	0.0336	0.0006	0.1304	0.0752	2.12	5.56
90	0.0438	0.0408	0.0827	0.0324	0.0008	0.0936	0.0521	1.66	4.31

Note that the Pepler index values are quite high, in the somewhat uncomfortable range of 5 to 6 for the maximum speed of 134 m/s. Even at the lower speed of 90 m/s the ride quality is in the neutral range between 4 and 5. As can be seen from the table, the major contributors to the poor ride quality are the large vertical acceleration due to the wind fluctuation input and, to a lesser extent, the large roll rate. Throughout the results reported here, it will be noted that there are substantial vertical responses from the horizontal winds; this is a result of the location of the effective point of application of the wind forces, which is somewhat above the primary suspension and fairly near the front of the vehicle so that horizontal wind forces produce roll moments which must be reacted by the vertical suspension. A further aerodynamic contributor to large accelerations at the front of the vehicle is the yaw moment which results when the relative wind (vector sum of the mean crosswind and vehicle velocity) is not parallel to the longitudinal axis of the vehicle. The magnitude of this yaw moment increases with increasing yaw angle and has the effect of a negative (unstable) spring stiffness for yaw motions which has the undesirable effect of increasing the yaw responses to applied forces.

Figure 1-20 depicts the horizontal (lateral) accelerations at the front, center and rear of the vehicle in comparison to the ISO one hour reduced comfort profile. The accelerations at the front and rear of the vehicle are noticeably above the ISO profile and the center not very much below it. The effect of the aerodynamic effects to increase accelerations at the front are clearly evident.

Figure 1-21 shows the vertical accelerations at the front, center and rear of the vehicle in comparison to the ISO one hour reduced comfort profile. The accelerations at all locations in the vehicle are slightly above the ISO profile and the effect of the aerodynamic effects in increasing accelerations at the front of the vehicle are not nearly as pronounced as for the lateral direction.

Table 1-4 shows the maximum air gap variations resulting from guideway roughness, wind steady and fluctuating wind components, and centrifugal force due to curve negotiation for the optimized passive secondary suspension. Values for the four most severe conditions occurring in the four ride comfort evaluation zones of the hypothetical route are shown. Although only the maximum values calculated are included, it is noted that the largest values for all but centrifugal force occur at the front suspension bogie of the vehicle. Note that the RMS variations and steady wind values are those calculated for 90 m/s and are thus somewhat conservative. The last two columns show the maximum expected gap variations expressed as a fraction of the nominal suspension physical gaps (0.1 m for the vertical suspension and 0.05 m for the lateral suspension). These totals include five times the standard deviation (RMS for a Gaussian distribution) of the variations due to guideway roughness and wind fluctuations; the probability of exceeding 5σ is 2.87×10^{-7}. It can be seen that, in spite of penalizing poor ride comfort in the optimization, the air gap variations are unsatisfactory in the lateral direction, although for the vertical primary suspension they are quite satisfactory. Various factors, discussed in the conclusions, render the predicted gap variations quite pessimistic and the indicated variations may not in fact be unacceptable. Also discussed later are simple vehicle design modifications which can minimize, or eliminate, the previously mentioned deleterious aerodynamic effects and this could make even these pessimistic predictions acceptable.

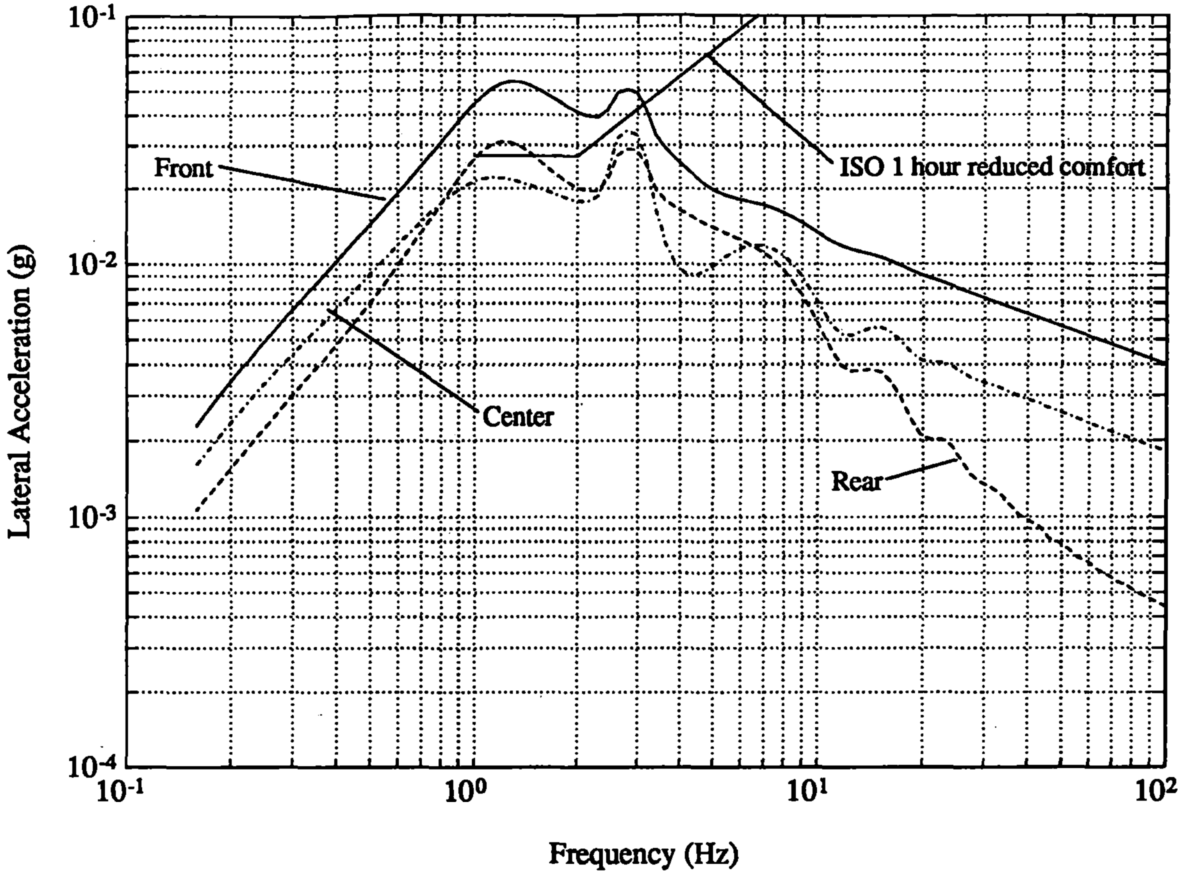


Figure 1-20 Lateral accelerations, optimized passive secondary suspension

1.4.5 Fully Active Secondary Suspension With Aerodynamic Control Surfaces

Table 1-5 shows the Pepler index and passenger compartment accelerations in both the vertical and lateral directions which result from guideway roughness, interaction with the guideway dynamic deflection (vertical only) and wind fluctuations for the baseline configuration consisting of fully active secondary suspension with optimal controller and aerodynamic control surfaces. The benefits to ride comfort of this configuration, as compared to the passive secondary suspension, are dramatically evident; the value of the Pepler index is reduced from 5.56 to 1.88 at 134 m/s, and is now in the very comfortable to comfortable range. At 90 m/s, the ride comfort is slightly better still. (It should be remembered that the Pepler index is 1.0 for zero accelerations, zero roll rate and noise below 65 db(A)).

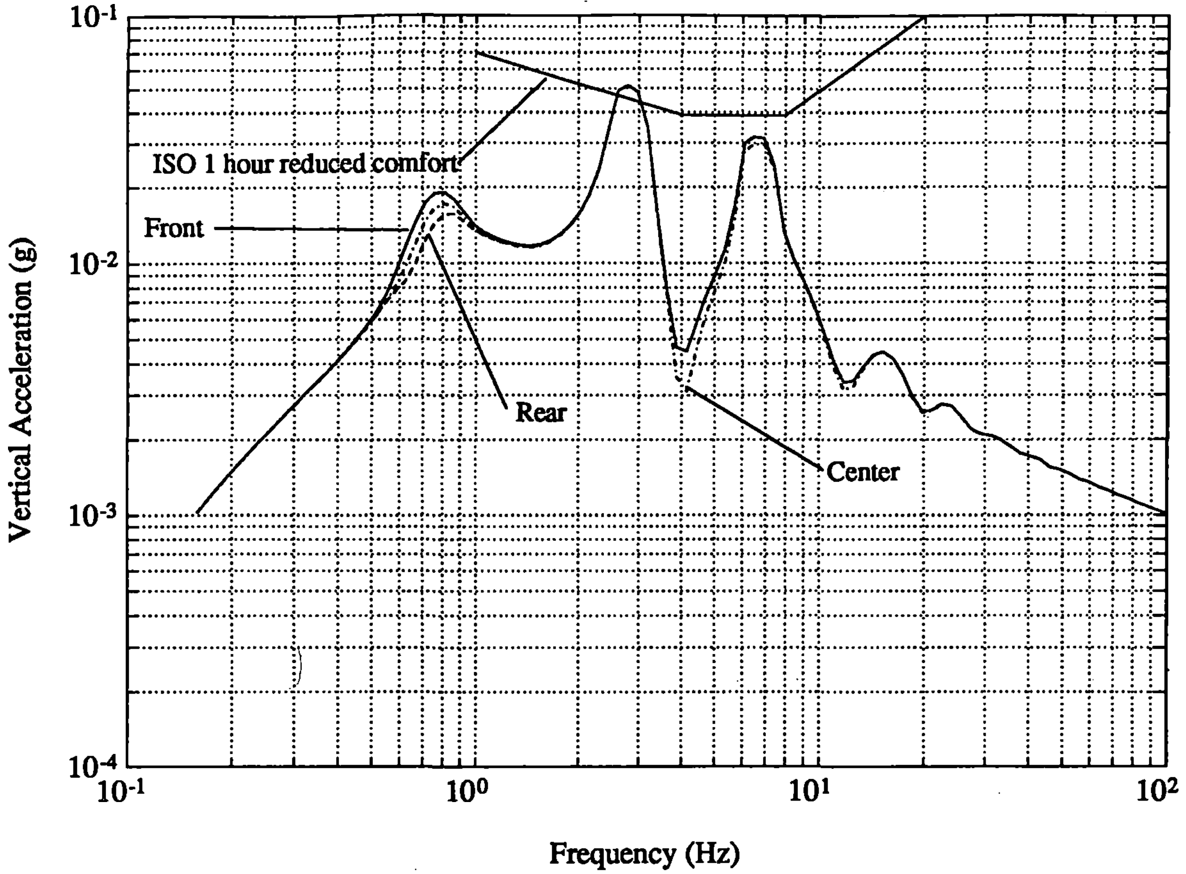


Figure 1-21 Vertical accelerations, optimized passive secondary suspension

Table 1-4
Gap Variations, Passive Secondary Suspension

Speed	Curve Radius	Centrifugal Force		RMS Roughness & Wind Variation		Dyn. G/W Interac	DC Wind		Total, w/5s wind& roughness	
		Vertical	Lateral	Vertical	Lateral	Vertical	Vertical	Lateral	Vertical	Lateral
(m/s)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(% gap)	(% gap)
65	800	.0084	.0122	.0052	.0095	.0011	.0017	.0060	36%	131%
72	1,000	.0084	.0122	.0052	.0095	.0011	.0017	.0060	36%	131%
129	•	.0000	.0000	.0065	.0124	.0006	.0021	.0083	35%	141%
134	8,000	.0004	.0000	.0065	.0124	.0006	.0021	.0083	35%	141%

Table 1-5
Passenger Accelerations, Active Secondary Suspension with Aerodynamic Control Surfaces

Speed	Guideway Roughness		Wind Fluctuations		G/W Interac	Total			Pepler Index
	vertical	lateral	vertical	lateral	vertical	vertical	lateral	Roll	
(m/s)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(°/s)	
134	0.0185	0.0439	0.0272	0.0492	0.0013	0.0292	0.0659	0.55	1.88
90	0.0154	0.0078	0.0187	0.0050	0.0013	0.0242	0.0093	0.45	1.79

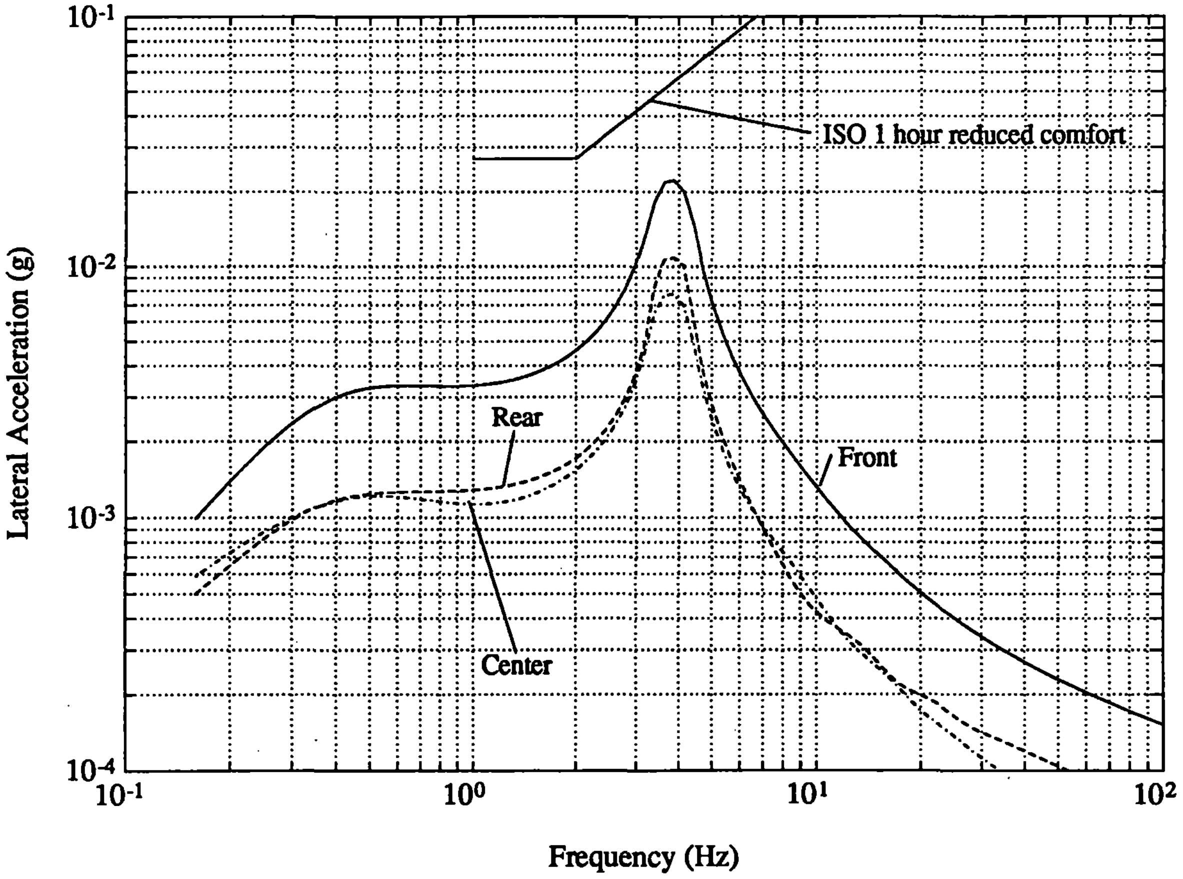


Figure 1-22 Lateral accelerations, active secondary suspension with aerodynamic actuators

Figure 1-22 depicts the horizontal (lateral) accelerations at the front, center and rear of the vehicle in comparison to the ISO one hour reduced comfort profile. In contrast to the passive secondary suspension, the accelerations at all locations in the vehicle are noticeably below the ISO one hour reduced comfort profile, indicating a very comfortable ride by that standard. The action of the aerodynamic effects to increase accelerations at the front are still clearly evident.

Figure 1-23 shows the vertical accelerations at the front, center and rear of the vehicle in comparison to the ISO one hour reduced comfort profile. The accelerations at all locations in the vehicle are more than an order of magnitude below the ISO profile indicating, like the lateral plot, a very comfortable ride by the ISO standards as well as by the Pepler index. In this case, the influence of the aerodynamic effects in increasing accelerations at the front of the vehicle are barely perceptible. The contribution to vertical acceleration of the disturbance resulting from the dynamic guideway deformation due to the passage of the vehicle is not included in the ISO plot; it is sufficiently small in magnitude that its effect would be barely perceptible on the plot.

The motion sickness limits in the region of 0.1 to 1.0 Hz, added to the ISO one hour reduced comfort standard by the contract modification, are not shown on this plot, but it is obvious that the vertical accelerations in that frequency range are more than an order of magnitude below the minimum value (≈0.035 g at ≈0.2 Hz) of that added segment.

Table 1-6 shows the vertical and lateral air gap variations which result from guideway roughness, steady wind and wind fluctuations for the baseline configuration consisting of active secondary suspension with optimal controller and aerodynamic control surfaces. These results indicate that, in spite of the dramatically improved ride comfort provided by the active secondary suspension and aerodynamic control surfaces, the air gap variations are not significantly improved from the passive suspension case. A major reason for this is that the aerodynamic control surfaces cannot provide any lateral forces with which to reduce the lateral air gap variations, while the concentration of the lateral wind force at the front of the vehicle and the effect of the unstable aerodynamic yaw moment cannot be adequately counteracted by trading off increased lateral acceleration (i.e., reduced ride comfort) for reduced gap variations. It is again emphasized that the projections presented here, as in the case of the passive suspension, are very conservative and this predicted worst case lateral air gap variation of ≈140 percent may not in fact be unacceptable. This point is further discussed in the summary.

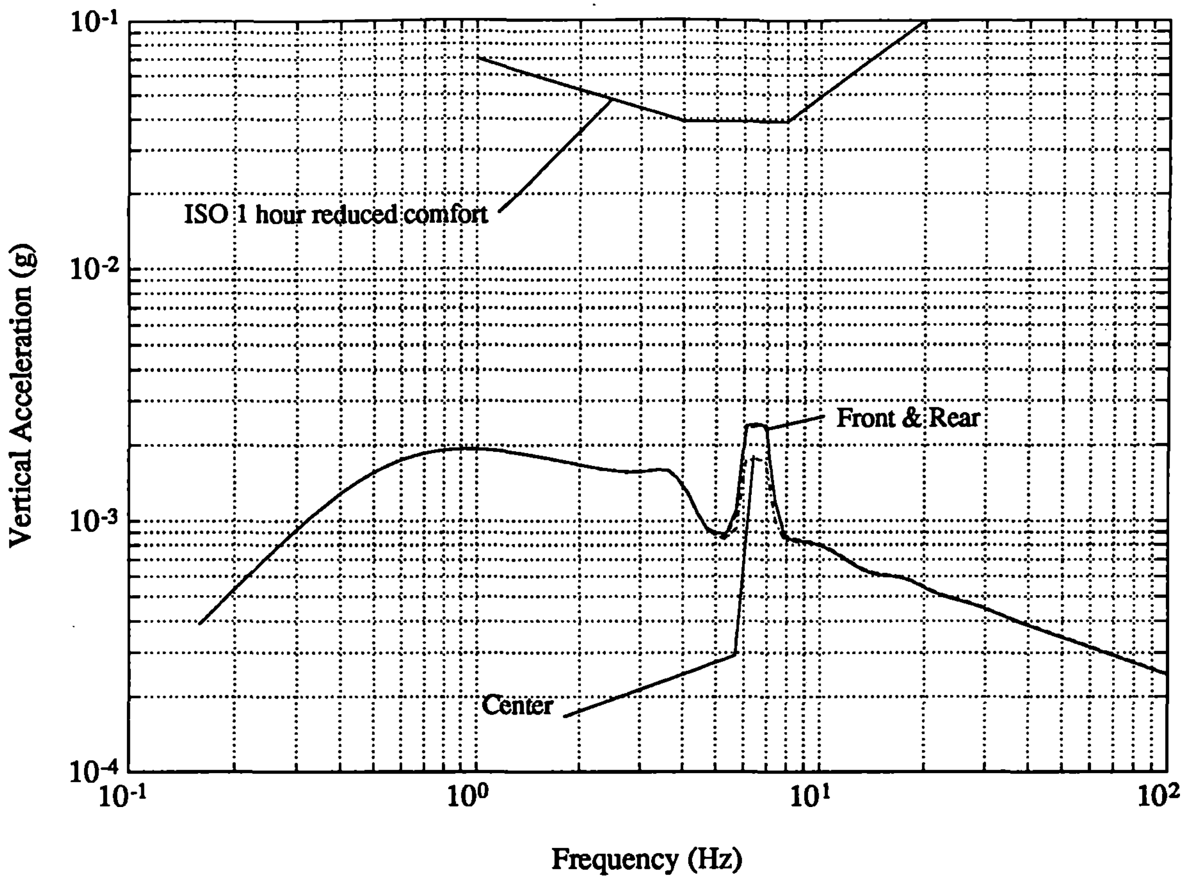


Figure 1-23 Vertical accelerations, active secondary suspension with aerodynamic actuators

Table 1-6
Gap Variations, Active Secondary Suspension with Aerodynamic Control Surfaces

Speed	Curve Radius	Centrifugal Force		RMS Roughness & Wind Variation		Dyn. G/W Interac	DC Wind		Total, w/5σ wind& roughness	
		Vertical	Lateral	Vertical	Lateral	Vertical	Vertical	Lateral	Vertical	Lateral
(m/s)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(% gap)	(% gap)
65	800	.0084	.0122	.0132	.0096	.0058	.0017	.0060	79%	132%
72	1,000	.0084	.0122	.0132	.0096	.0058	.0017	.0060	79%	132%
129	∞	.0000	.0000	.0127	.0122	.0063	.0021	.0083	69%	139%
134	8,000	.0004	.0000	.0127	.0122	.0063	.0021	.0083	70%	139%

1.4.6 Summary

These results have shown that the baseline vehicle concept should be capable of providing a very comfortable ride to passengers. To achieve this comfortable ride required the use of a fully active secondary suspension with an optimal controller and aerodynamic control surfaces, because the optimized passive secondary suspension could not provide an acceptable comfortable ride quality.

Although the results indicate substantial likelihood of guideway-suspension contact, a number of considerations suggest strongly that this is not likely to be a problem in an actual vehicle of this design. These considerations are described in the following:

First, the primary suspension was assumed to be strictly linear; in fact the suspension forces increase more rapidly with larger displacements, tending to reduce the maximum air gap variations, compared with those predicted using the linear assumption.

Second, the active controller was assumed to be perfectly linear, without any provision for applying more control effort when the primary suspension approached contact with the guideway. If necessary, such provisions could be made, further reducing the probability of contact.

Third, the baseline system configuration envisions post-installation alignment of the guideway suspension components to a tolerance of approximately ±0.5mm. If this were implemented, the magnitude of the guideway roughness with spatial wavelengths of between 0.33 ms and 25 m (1 span length) could be reduced below that of the assumed welded steel rail values. This would reduce the vehicle excitation by the guideway in this bandwidth, reducing both the passenger accelerations and air gap variations (note, however, that this alone may not provide adequate relief since, in the lateral direction at 134 m/s, the contribution of wind variations to gap variation is more than twice that of the guideway roughness).

Fourth, the baseline vehicle has six primary suspension bogies, whereas the five-degree-of-freedom model which provided the performance estimates has two bogies. Wormley, et al [3,6] have shown that, for the range of parameter values they studied, a six-bogie vehicle exhibits lower passenger accelerations with smaller air gap variations than a two-bogie vehicle. In the case of guideway roughness excitations, the RMS accelerations at front and rear of a six-bogie vehicle were from 35 to 45 percent of those of a comparable two-bogie vehicle. In the case of vehicle motions resulting from dynamic vehicle-guideway interactions, the air gap variations of a six-bogie vehicle were ≈55 percent of those of a two-bogie vehicle for a span crossing frequency ratio of 0.75 (134 meters/second for our vehicle) and ≈80 percent for a span crossing frequency ratio of 0.4 (90 m/s for our vehicle). Passenger accelerations for a six-bogie vehicle were 25-30 percent of those for a two bogie vehicle at a crossing frequency ratio of 0.75 and 40-70 percent for a crossing frequency ratio of 0.4.

Fifth, it was assumed in the five-degree-of-freedom dynamic model that the damping in the primary suspension is zero; this is the assumption commonly made for electrodynamic suspensions and is undoubtedly reasonable for image flux configurations such as Magneplane. However, it appears that this assumption may not be strictly correct for the suspension configuration used in our concept and approximate calculations have been made which indicate the possibility of significant damping. Further work will be required to accurately quantify the level of damping present, but it is clear that even a small amount of damping can substantially decrease the passenger accelerations and air gap variations resulting from guideway roughness and, probably from wind fluctuations as well. Figure 1-24 shows the substantial improvement a small amount of damping produces in the vertical accelerations and air gap variations caused by guideway roughness; the data is from the Draper simple heave model shown in Figure 1-17 having a 1 Hz, $\zeta=0.25$ passive secondary suspension with other parameters corresponding to our baseline vehicle concept.

Finally, it was mentioned earlier that the concentration of the aerodynamic force from crosswinds at the front of the vehicle and the unstable yaw moment due to aerodynamic forces both result in larger passenger accelerations and primary suspension air gap variations at the front of the vehicle than would otherwise be the case. As a result, although excellent ride comfort is available from the baseline vehicle with active secondary suspension, the air gap variations calculated at the front of the vehicle are larger than would be desirable. Both of these deleterious effects can be very substantially reduced, or perhaps even eliminated, by the simple addition of a vertical aerodynamic surface at the rear of the vehicle to bring the center of pressure nearer to the center of the vehicle (note that the baseline vehicle already has actively controlled horizontal aerodynamic surfaces at both the front and rear). Still further improvement in the air gap variation/passenger acceleration tradeoff can be obtained by actively controlling such a vertical surface. This can be very advantageous because the forces required to decrease passenger accelerations can then be applied directly to the vehicle where they are most effective. By contrast, with a hydraulic actuator in an active secondary suspension, these forces are accompanied by equal and opposite forces on the bogie which tends to increase the air gap variations. Moreover, to the extent permitted by available control force capability, the aero actuator forces can be made to counteract hydraulic actuator forces intended to reduce gap variations so that, overall, increased passenger accelerations are not traded for reduction of gap variations. This simple design addition can potentially, in itself, reduce the lateral air gap variations to a satisfactory level while retaining the excellent ride comfort provided by the baseline vehicle concept.

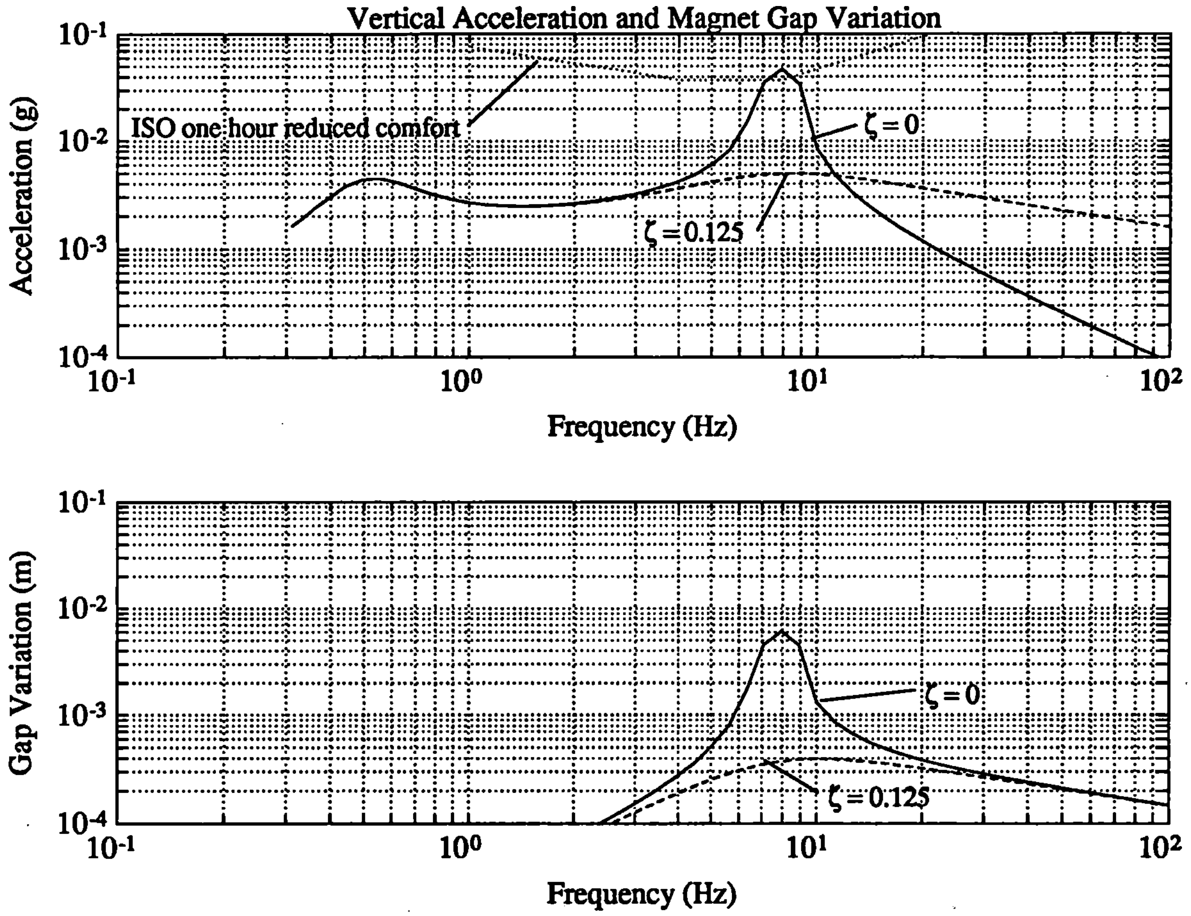


Figure 1-24 Vertical accelerations and air gap variations Draper simple heave model with passive secondary suspension

References

1. Peplar, R.D., et al, "Development of Techniques and Data for Evaluating Ride Quality, Vol. II: Ride Quality Research", Report No. DOT-TSC-RSPD-77-1, II.

2. "Guide for the Evaluation of Human Exposure to Wholebody Vibration," ISO Standard 2631/1, International Organization for Standardization, 1985.

3. "Magnetic Levitation Vehicle-Suspension Guideway Interaction," D. N. Wormley, R. D. Thornton, S.-H. Yu and S. Cheng, Technical Memorandum No. TBD, Center for Transportation Studies, Massachusetts Institute of Technology, January, 1992.

4. "Final Report, Comparison of Major Parameters in Electrodynamic and Electromagnetic Levitation Transportation Systems," (Maglev BAA #24), S. Brown, C. R. Dauwalter, F. Heger and M. Weinberg, Report R-2420, Charles S. Draper Laboratory, Inc., July, 1992.

5. "Title TBD," D. C. McCallum, et al, Report C-TBD, Charles S. Draper Laboratory, Inc., TBD, 1992.

6. "Interactions Between Magnetically Levitated Vehicles and Elevated Guideway Structures," D. N. Wormley, R. D. Thornton, S.-H. Yu and S. Cheng, Draft Final Report (Maglev BAA #204), Center for Transportation Studies, Massachusetts Institute of Technology, July, 1992.

1.5 REQUIRED VEHICLE HEADWAY

Required headway was calculated for three cases given in Tables 1-7, 1-8 and 1-9: These are respectively, Case I Safety/Brickwall Distance Capacity Analysis, Case II Equal Distance System Capacity Analysis where distance headway is equal to 4,000 m, and Case III Equal Time System Capacity Analysis where time headway is not allowed to be less than 40 seconds.

Safety/Brickwall is the case where the headway is determined from the necessary time or distance required to stop the vehicle based on its speed. Equal Distance is the case where a constant distance is maintained between vehicles. Equal Time is the case where a minimum time headway is maintained between vehicles for block limited headways that are less than the minimum time headway.

The required capacity of 12,000 passengers per hour per direction can be achieved using a 3 m/s/s braking for Brickwall and Equal Distance cases, but not for the Equal Time case.

Each of the Headings in Tables 1-7 through 1-9 have the following meaning:.

Speed is the vehicle average speed.

Braking Rate is the deceleration rate used in an emergency stop.

Time to Stop is the required time to bring the vehicle to a full stop.

Minimum Stopping Distance is the minimum distance required to stop the vehicle.

Minimum Headway is the calculated smallest distance or time separation between vehicles allowed.

System Headway is the actual operating headway, and differs from Minimum Headway only in case III (for time).

Vehicles per Hr is the number of vehicles that can traverse the route each hour.

System Capacity is the total capacity of the line in passengers per hour per direction (pphpd).

Calculations were made as follows: Time to stop is Speed divided by Braking Rate. Minimum Stopping Distance is reaction distance plus braking distance plus 80 m; reaction distance is Speed times 1 second reaction time (computer/electronic/system), braking distance is the Speed squared divided by twice the Braking Rate, and 80 m represents the length of the vehicle plus a safety factor. Minimum Headway (seconds) equals Minimum Headway (meters) divided by Speed. Vehicles Per Hr is equal to 3,600 seconds (1 hour) divided by the System Headway. System Capacity is equal to 120 passengers per vehicle times Vehicles per Hr.

Table 1-7

Case I Safety/Brickwall Distance Capacity Analysis

Speed m/sec	Braking Rate m/s^2	Time to Stop seconds	Minimum Stop Dist. meters	Minimum Headway meters	Minimum Headway seconds	**System Headway seconds**	Vehicles Per Hr	**System Capacity pphpd**
28	3.00	9.3	236	2000	72.0	**72.0**	50	**6000**
56	3.00	18.5	650	2000	36.0	**36.0**	100	**12000**
83	3.00	27.8	1321	2000	24.0	**24.0**	150	**18000**
111	3.00	37.0	2249	4000	36.0	**36.0**	100	**12000**
139	3.00	46.3	3434	4000	28.8	**28.8**	125	**15000**

Table 1-8

Case II Equal Distance-Headway >= 4000 Meters

Speed m/sec	Braking Rate m/s^2	Time to Stop seconds	Minimum Stop Dist. meters	Minimum Headway meters	Minimum Headway seconds	**System Headway seconds**	Vehicles Per Hr	**System Capacity pphpd**
28	3.00	9.3	236	4000	144.0	**144.0**	25	**3000**
56	3.00	18.5	650	4000	72.0	**72.0**	50	**6000**
83	3.00	27.8	1321	4000	48.0	**48.0**	75	**9000**
111	3.00	37.0	2249	4000	36.0	**36.0**	100	**12000**
139	3.00	46.3	3434	4000	28.8	**28.8**	125	**15000**

Table 1-9

Case III Equal Time-Headway >= 40 Seconds

Speed m/sec	Braking Rate m/s^2	Time to Stop seconds	Minimum Stop Dist. meters	Minimum Headway meters	Minimum Headway seconds	**System Headway seconds**	Vehicles Per Hr	**System Capacity pphpd**
28	3.00	9.3	236	2000	72.0	**72.0**	50	**6000**
56	3.00	18.5	650	2000	36.0	**40.0**	90	**10800**
83	3.00	27.8	1321	4000	48.0	**48.0**	75	**9000**
111	3.00	37.0	2249	4000	36.0	**40.0**	90	**10800**
139	3.00	46.3	3434	4000	28.8	**40.0**	90	**10800**

1.6 ENERGY DEMAND PROFILE

The energy consumption for one vehicle to traverse the hypothetical route in the forward direction from Terminal 1 to Terminal 4 is given in Table 1-10. The US1 Design parameter set was used to determine the energy values. The top row represents the baseline, and the succeeding rows of the table shows the increase in energy requirements as the acceleration and braking parameters are increased. If 400 vehicles were to be put into operation (200 each way) for the hypothetical route (800 km) to provide 12,000 passengers per hour per direction, the total energy for a 2-hour period would be 26.46144×10^{12} J (7,350 MWhr). This is 3,675 MW average continuous power and is equivalent to the output of two or three average sized power generating stations, an average station producing between 1,000 and 2,000 MW (per Southern California Edison).

Figures 1-25 through 1-28 show the power profile for the vehicle from zero to 800 km. The worst case condition for US1 Design was used (0.2 g's used for both acceleration and braking). The left y-axis scale is for the upper curve representing velocity, and the right y-axis scale is for the lower curve representing instantaneous power. Note that the maximum required power for the vehicle is about 26 MW, even though the average required power per vehicle is only about 9.1 MW, and the straight and level power requirement is 7.8 MW. The reason why the average is so much lower than the 26 MW peak is because very little or no power is used when slowing down to negotiate the next curve in the route. Thus, in effect, the vehicle coasts through a significant portion of the hypothetical route making the overall average required power significantly less than the maximum required.

The average power required per vehicle during the first 400 km (containing most of the curves) was about 10.1 MW whereas the last 400 km (mostly straight and level) was 8.3 MW. Thus it can be seen that the actual power requirements do not vary much (about 20 percent) between a route with many tight curves, and a straight and level route, however, a price is paid in terms of reduced trip time for the route of many curves.

In addition, any operational route with many vehicles will cause the total demand power to be equal to the average power times the number of vehicles, assuming the vehicles to be randomly distributed along the route. It would be sufficient to specify a power grid capable of maintaining the average total power requirement plus or minus three standard deviations. For n independent data sets all with the same standard deviation, the standard deviation of the sum of the elements of all the sets is equal to the standard deviation of one set times the square root of n. For the hypothetical route with one vehicle, the power mean was 9.1 MW with a standard deviation of

7.8 MW. Thus the hypothetical route the total power required would 3,650 MW with a standard deviation of 156 MW. Three standard deviations would be equal to 468 MW representing a reserve power difference of only 12.8 percent. This is considered to be a worst case condition, since total random variable independence was assumed. For instance, if the 400 vehicles were in lock step from point to point along the hypothetical route, the vehicles would cancel any variances from the mean except for the variance of one vehicle divided by the square root of n. This would give a standard deviation for the total power of only 0.5 MW, a best case condition. Obviously, the vehicles will not be in lock step, but shall vary from point to point in a quasi-random fashion, being constrained by such things as block length and minimum headway. The actual standard deviation will therefore be somewhere between 0.5 MW and 156 MW, dependent upon how much independence each power random variable is allowed to have.

Table 1-10
Total Energy per Vehicle per Trip

Forward Acceleration Limit	Braking Limit	megajoules	kilowatt-hours
0.16 g	0.16 g	66,153	18,376
0.20 g	0.16 g	66,838	18,566
0.16 g	0.20 g	69,253	19,237
0.20 g	0.20 g	69,984	19,440

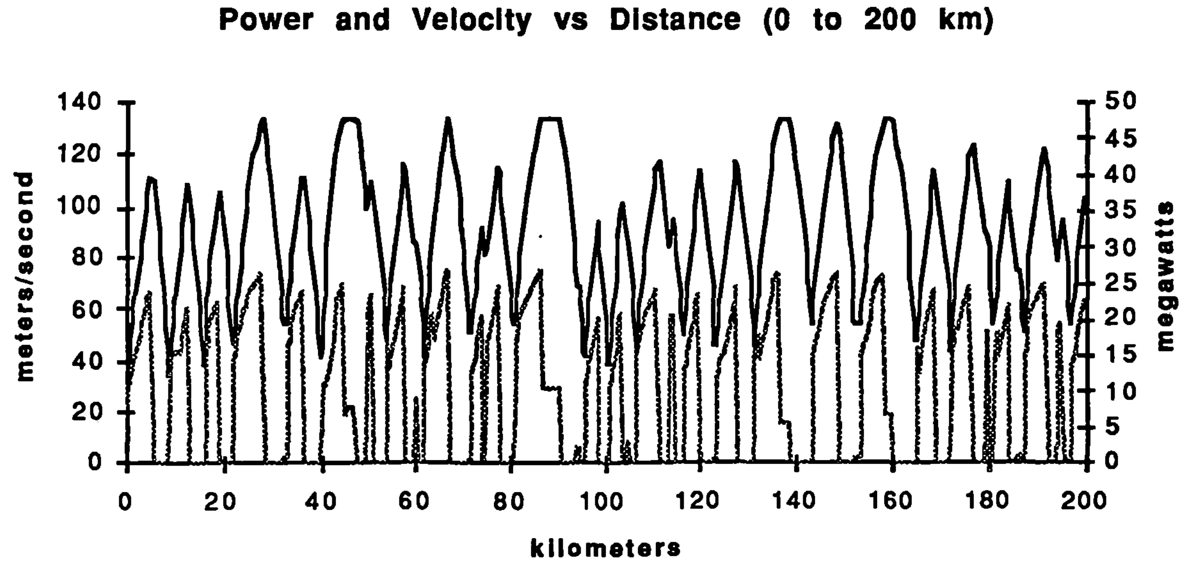


Figure 1-25 Power profile- zero to 200 km

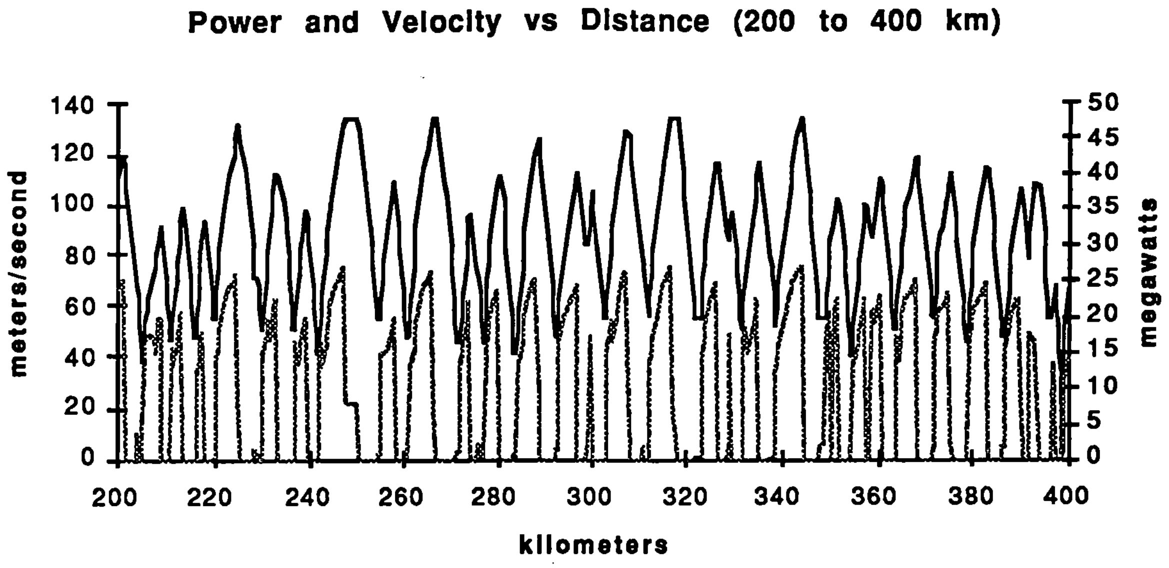


Figure 1-26 Power profile- 200 to 400 km

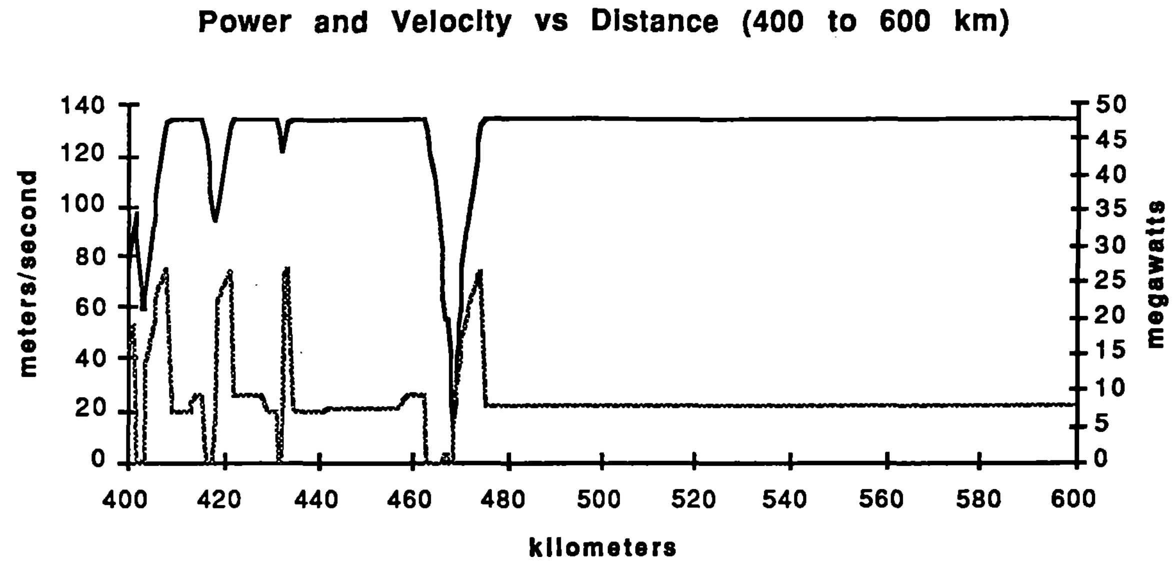


Figure 1-27 Power profile- 400 to 600 km

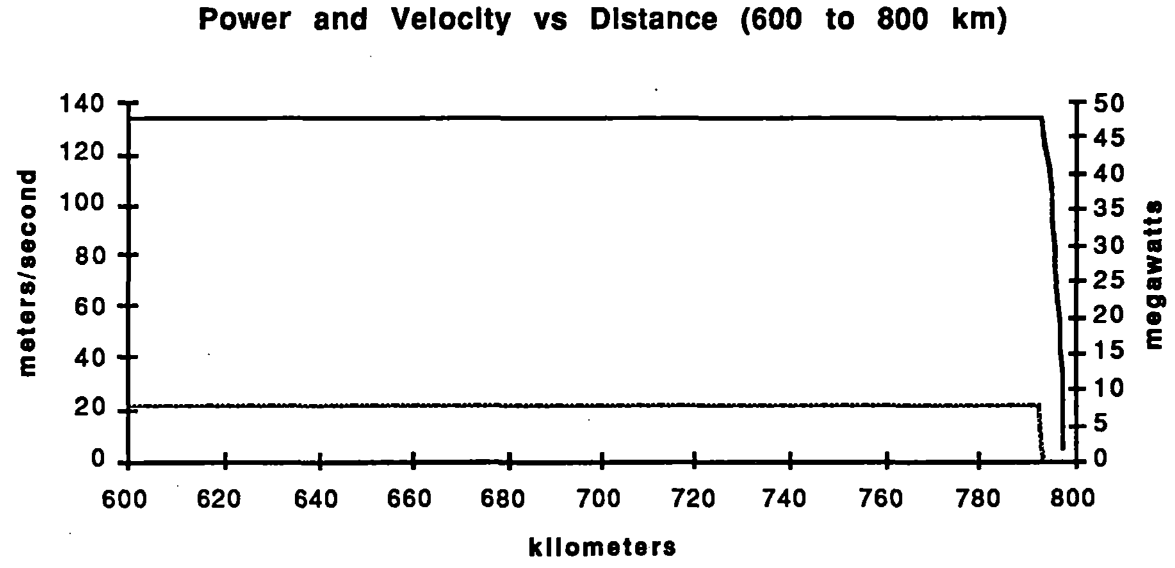


Figure 1-28 Power profile- 600 to 800 km

$$\frac{8{,}3\text{MW}}{134\text{m/s}\ 120\text{pass}} = 516\ \text{J/seat m}$$

$$= 143\ \text{Wh/seat km}$$

2. DRAWINGS

2.1 AT-GRADE DUAL GUIDEWAY SECTION, INCLUDING VEHICLES

This drawing is provided at the end of Section 2.

2.2 ELEVATED DUAL GUIDEWAY SECTION, INCLUDING VEHICLES, WITH SINGLE SPAN PROFILE

2.3 SCALED TURNOUT DRAWING

This drawing is provided at the end of Section 2.

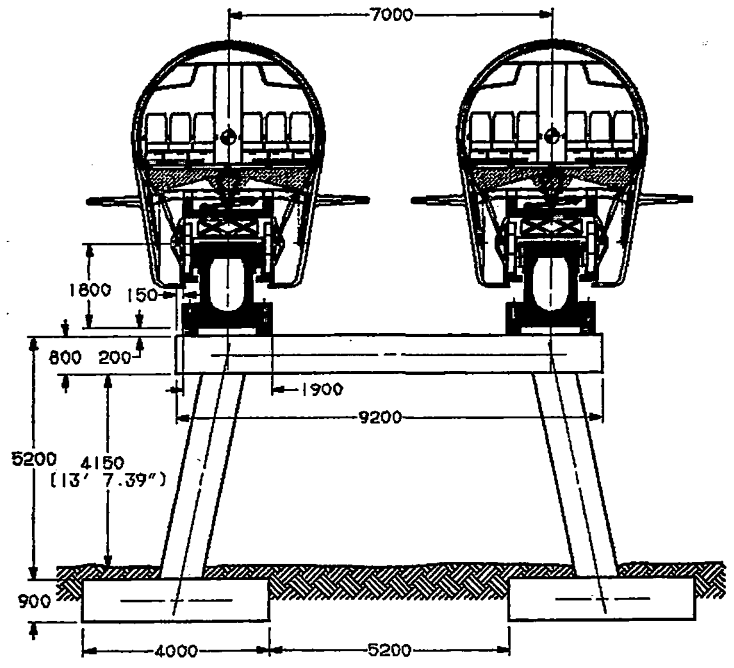
Switching concept requirements for the hypothetical route exercise were deleted by the Government, per discussions and correspondence in January and February of 1992. Descriptions of our baseline switch concept and alternate switch concepts were provided in the Draft System Concept Definition Report and are expanded in the Final System Concept Definition Report. Both drawings of the baseline concept switch and a separate discussion with drawings of the proposed alternate passive switch as developed on behalf of the team by Draper Laboratories are provided in the deliverable, Final System Concept Definition Drawings which is being provided to the Government at the same time as this report.

2.4 SCALED SUPERELEVATED DUAL GUIDEWAY SECTION

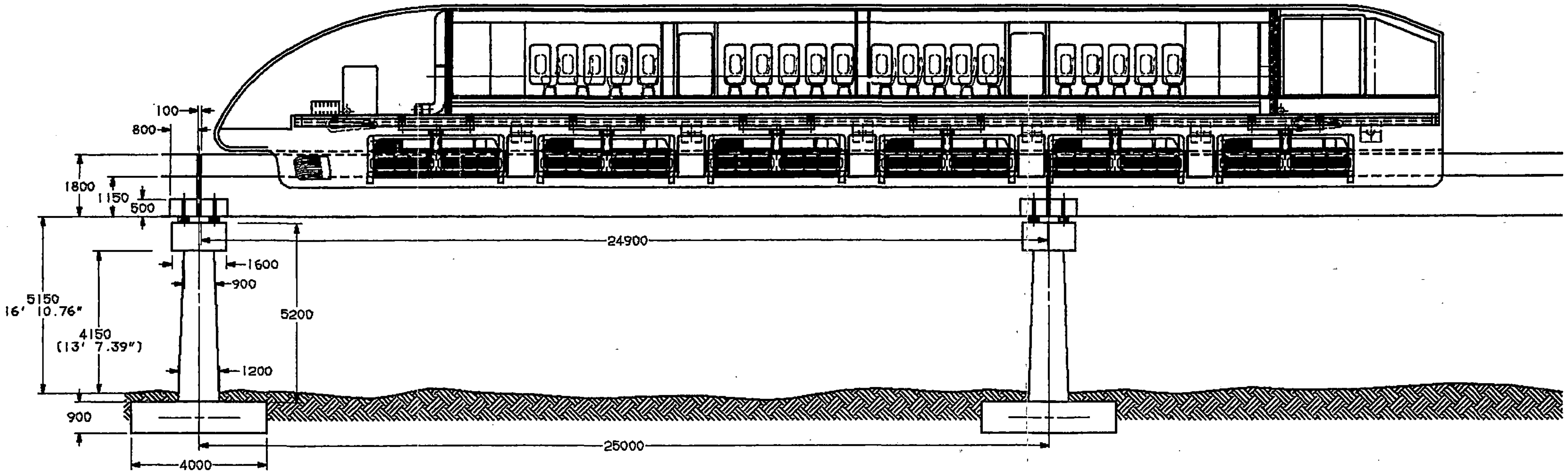
This drawing is provided at the end of Section 2.

MGLV0107

RFC NO	REV LET	REVISION	DATE	BY	APVD



GUIDEWAY CROSS-SECTION
ON GIRDERS



ELEVATED GUIDEWAY-SIDE VIEW
(25 METER SECTION)

PROPRIETARY

GENERAL MOTORS
LOCOMOTIVE GROUP

PART NAME
MGLV-VEHICLE/GUIDEWAY

BY JORGE PAEZ, DHN
DATE 22JL92

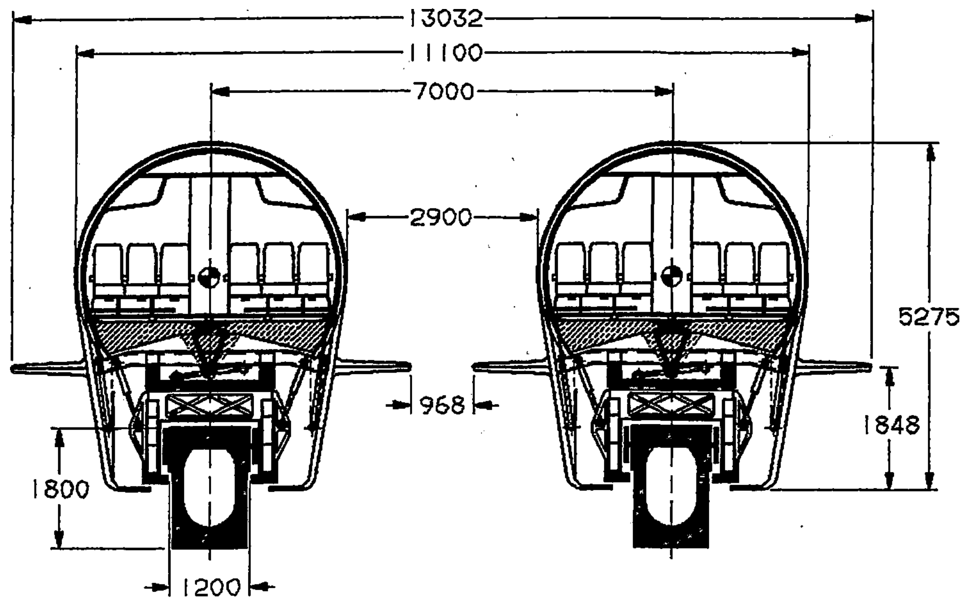
FIRST USED ON
MAGLEV
95068

PART NO
MGLV0107

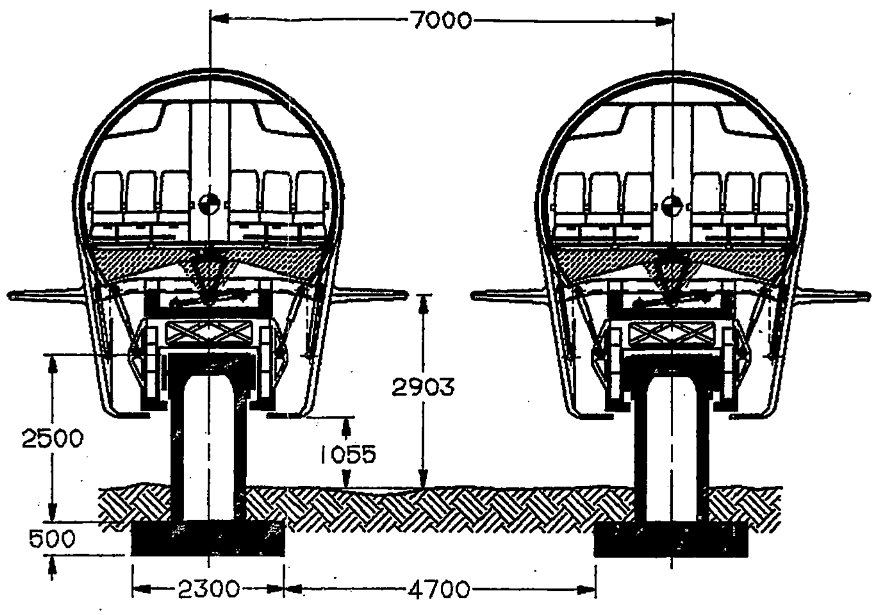
SHEET 1 OF 1

MGLV0107

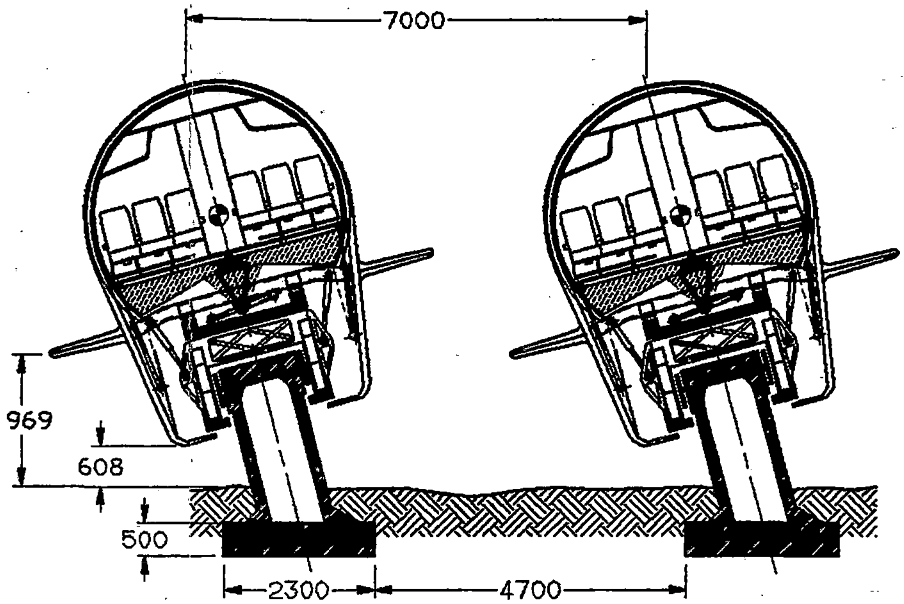
RFC NO	REV LET	REVISION	DATE	BY	APVD



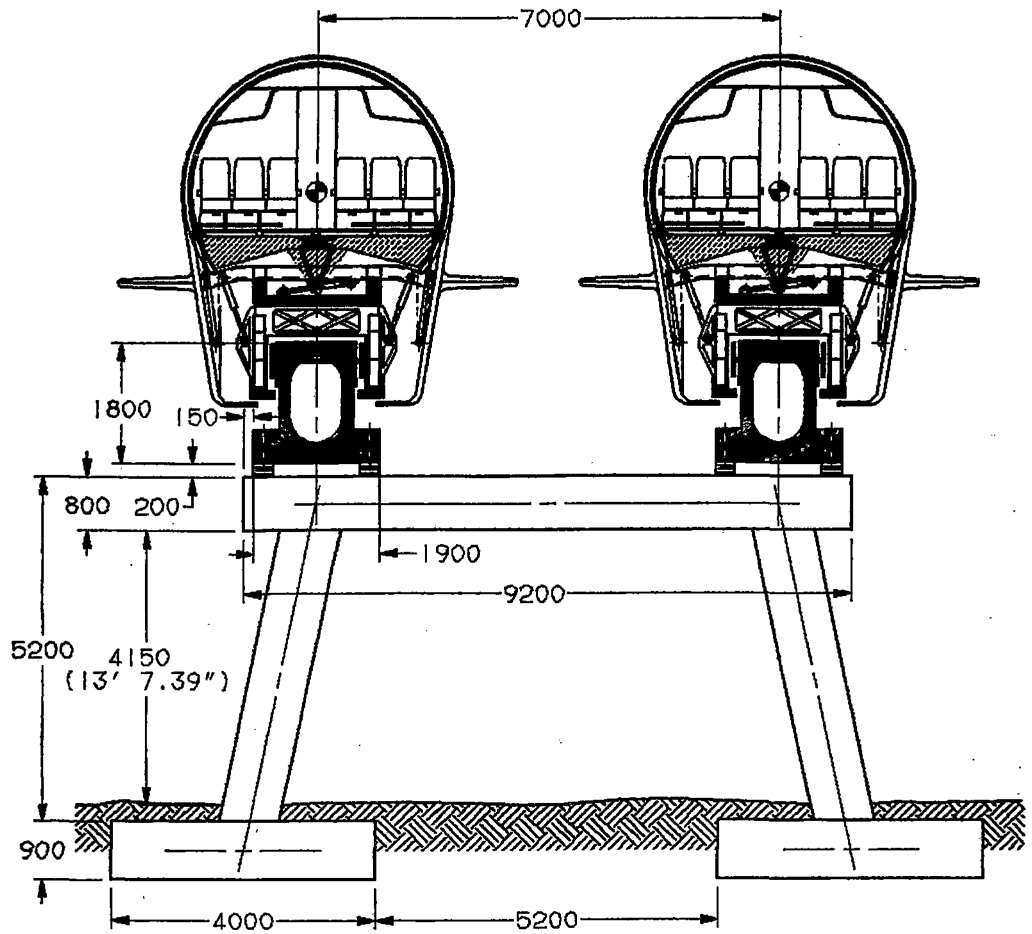
GUIDEWAY CROSS-SECTION
BETWEEN GIRDERS



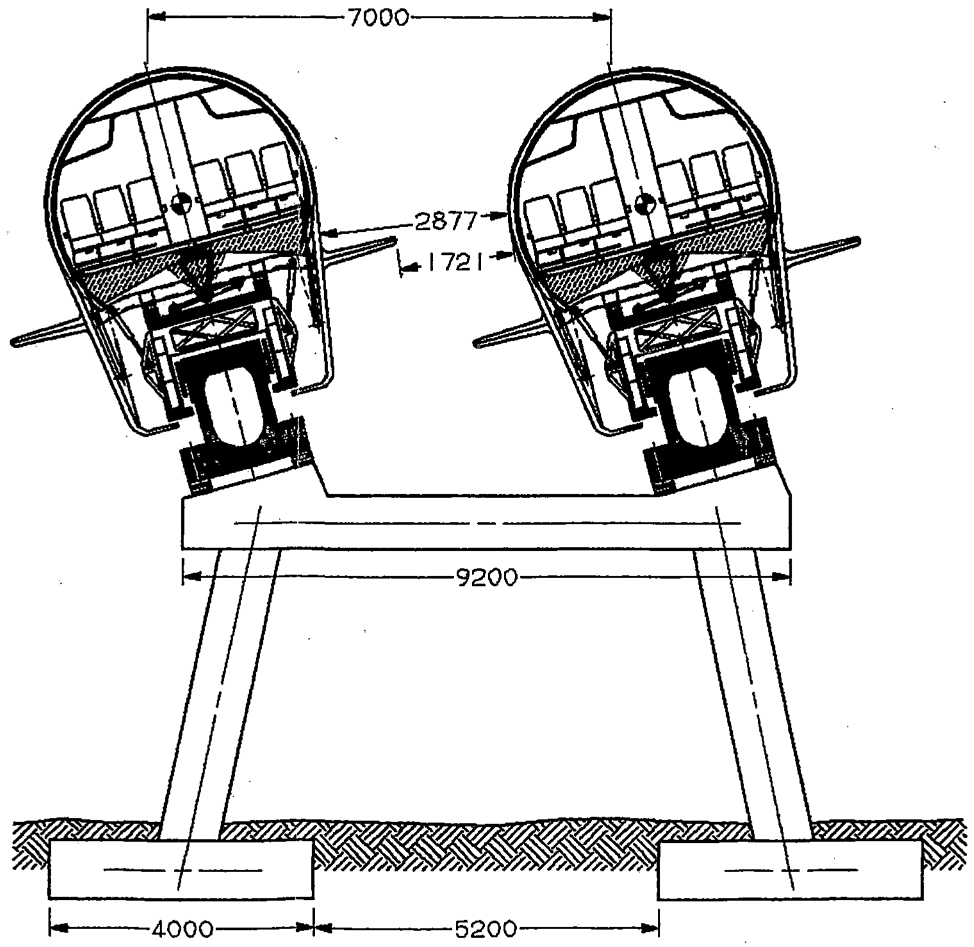
GUIDEWAY CROSS-SECTION
AT GRADE LEVEL



GUIDEWAY CROSS-SECTION
AT GRADE LEVEL WITH 15° TILT



GUIDEWAY CROSS-SECTION
ON GIRDERS



GUIDEWAY CROSS-SECTION
ON GIRDERS WITH 15° TILT

PROPRIETARY

GENERAL MOTORS
LOCOMOTIVE GROUP
LA GRANGE, IL. 60525, U.S.A.
LONDON, ONT. N5A 4N5, CANADA

PART NAME
MGLV-VEHICLE/GUIDEWAY

DR JORGE PAEZ
DATE 08JL92

FIRST USED ON
MAGLEV
95068

PART NO
MGLV0107

SHEET 1 OF 1

34-B

3. COSTS

3.1 VEHICLE CAPITAL COST

Our baseline concept system related to the hypothetical route uses a single vehicle and therefore no graphical data is necessary to depict costs. The charts on the following pages show the latest capital cost information for the baseline vehicle. Costing information was obtained by various means including expert estimate, comparison cost to existing hardware, and verbal cost estimate by part vendors. Depending on the estimation methodology, confidence percentages are given for cost items.

Total vehicle cost includes assembly labor cost at $150/hour. This would represent a high burden factory with higher than average wages. However, to allow for adjustments in labor rate, labor hours are detailed and included in the costing estimates. As a general rule, most items were costed as purchased assemblies with minimal final assembly needed. It was felt that this method would result in a more realistic final vehicle cost. Since part costs vary widely with production rates it was assumed at all times that maglev represented high volume large scale production (hundreds of vehicles per year) and used production techniques similar to aircraft and rail locomotives.

SINGLE VEHICLE

DESCRIPTION	COST EACH	PURCHASED ASSEMBLY TOTAL COST	INDIVIDUAL ASSEMBLY LABOR HOURS	AGGREGATE ASSEMBLY LABOR HOURS	AGGREGATE ASSEMBLY LABOR COST
ASSEMBLED VEHICLE TOTAL		$3,946,382		799	$119,820
PAINTING		$5,000			
VEHICLE ASSEMBLY COMPLETE	0	$0	0		
BASIC BODY	187,425	$187,425	0		
AERODYNAMIC BRAKES	22050	$176,400	20		
HYDRAULICS SYSTEM	10,000	$10,000	40		
AIR COMPRESSOR FOR AIR SUSPENSION	5,000	$5,000	4		
AIR PIPING FOR AIR SUSPENSION	4	$525	80		
CARGO DOORS, BOTH SIDES	1,000	$4,000	16		
EMERGENCY COUPLER	11,025	$11,025	20		
EMERGENCY PARACHUTE	1,000	$1,000	1		
EMERGENCY EVACUATION SLIDES	5,000	$20,000	1		
INSULATION—SPRAY ON	8,000	$8,000	40		
WINDOWS	250	$10,000	20		
FIRE EXTINGUISHER SYSTEM					
FIRE EXTINGUISHING AGENT SPHERES	4,500	$27,000	20		
FIRE EXTINGUISHER PIPING	100	$100			
SMOKE AND FIRE DETECTORS	1,500	$6,000			
CO2 & HALON PORTABLE EXTINGUISHERS	75	$900			
GUIDANCE CONTROL SURFACE	1,000	$2,000	8		
LEVITATION CONTROL SURFACE	2,000	$8,000	16		
ENVIRONMENTAL CONTROL SYSTEM	50,000	$50,000	12		
INNER COACH	99,225	$99,225	0		
SEATS—COACH CLASS	3,500	$105,000	30		
SEATS—BUSINESS CLASS	8,500	$68,000	8		
WINDOWS	100	$4,000	20		
GALLEY	70,000	$140,000	24		
GALLEY CART	1,000	$6,000	2		
LAVATORY	65,000	$130,000	24		
WATER SUPPLY TANK	500	$1,000	4		
WASTE WATER STORAGE TANK	500	$500	4		
PASSENGER COMMUNICATIONS & ENTERTAINMENT SYSTEM	200	$21,200	40		
LIGHTING	27	$1,188	40		
VEHICLE CONTROL SUBYSYSTEM			40		
COMMUNICATIONS SET	41,000	$41,000	0		
COMPUTER SUITE & MANUAL CONTROL SUBSYSTEM	41,000	$41,000	0		
CONTROL SENSORS	20,000	$20,000	0		
INTERFACE CABLING	15,000	$15,000	0		
SECONDARY SUSPENSION SUBSYSTEM			8		
LATERAL ACTUATORS & SENSORS	5,000	$30,000	0		
VERTICAL ACTUATORS, SENSORS & POWER SUPPLY	5,000	$120,000	0		
BOGIE LINKS	13,061	$78,363	0		
TILTING MECHANISM	10,000	$10,000	0		
MAGNET BOGIE SUSPENSION SUBSYSTEM	20,000	$120,000	96		
AIR LEVITATION SYSTEM	6,000	$36,000	0		
SUPERCONDUCTING MAGNET SUBSYSTEM	187,000	$2,244,000	0		
MECHANICAL BRAKING SUBSYSTEM			24		
BRAKING ACTUATOR SUBSYSTEM	2,721	$65,306	0		
BRAKE PADS	218	$5,224	0		
WHEELS	500	$12,000	0		
CRYROGENIC REFRIGERATION SUBSYSTEM			20		
HELIUM & STORAGE DEWAR	17,300	$17,300	0		
CRYOGENIC PUMP	1,000	$1,000	0		
COOLANT DISTRIBUTION LINES	20,000	$640,000	0		
FUSELAGE ELECTRICAL POWER SUBSYSTEM			116		
BATTERY	4,000	$4,000	0		
UNINTERUPTABLE POWER SUPPLY	400	$800	0		
POWER DISTRIBUTION & CONTROL EQUIPMENT	10,000	$10,000	0		
FUEL CELL SYSTEM	10,000	$10,000	0		
VARIABLE FACTORS	NA		NA		
PASSENGER LOAD	NA		NA		
PASSENGER SERVICE PERSONNEL LOAD	NA		NA		
WATER	NA		NA		
FOOD	NA		NA		
Misc. CONSUMABLES	NA		NA		
CARRY ON BAGGAGE	NA		NA		
BAGGAGE CONTAINERS	500	$2,000	1	1	
CHECKED BAGGAGE	NA		NA		

TOTALS=> $3,946,382 Vehicle Material Cost
$119,820 Vehicle Labor Cost
============
$4,066,202 Vehicle Total Cost

RLP 9/11/92

MULTIPLE VEHICLE
PASSENGER CAR

DESCRIPTION	COST EACH	PURCHASED ASSEMBLY TOTAL COST	INDIVIDUAL ASSEMBLY LABOR HOURS	AGGREGATE ASSEMBLY LABOR HOURS	AGGREGATE ASSEMBLY LABOR COST
ASSEMBLED VEHICLE TOTAL		$3,714,382		758	$113,670
PAINTING		$5,000			
VEHICLE ASSEMBLY COMPLETE	0	$0	0		
BASIC BODY	187,425	$187,425	0		
AERODYNAMIC BRAKES	22050	$176,400	20		
HYDRAULICS SYSTEM	10,000	$10,000	40		
AIR COMPRESSOR FOR AIR SUSPENSION	5,000	$5,000	4		
AIR PIPING FOR AIR SUSPENSION	4	$525	80		
CARGO DOORS, BOTH SIDES	1,000	$4,000	16		
EMERGENCY COUPLER	11,025	$11,025	20		
EMERGENCY PARACHUTE	1,000	$1,000	1		
EMERGENCY EVACUATION SLIDES	5,000	$20,000	1		
INSULATION–SPRAY ON	8,000	$8,000	40		
WINDOWS	250	$10,000	20		
FIRE EXTINGUISHER SYSTEM					
FIRE EXTINGUISHING AGENT SPHERES	4,500	$27,000	20		
FIRE EXTINGUISHER PIPING	100	$100			
SMOKE AND FIRE DETECTORS	1,500	$6,000			
CO2 & HALON PORTABLE EXTINGUISHERS	75	$900			
GUIDANCE CONTROL SURFACE	1,000	$2,000	8		
LEVITATION CONTROL SURFACE	2,000	$8,000	16		
ENVIRONMENTAL CONTROL SYSTEM	50,000	$50,000	12		
INNER COACH	99,225	$99,225	0		
SEATS–COACH CLASS	3,500	$105,000	30		
SEATS–BUSINESS CLASS	8,500	$68,000	8		
WINDOWS	100	$4,000	20		
GALLEY	70,000	$140,000	24		
GALLEY CART	1,000	$6,000	2		
LAVATORY	65,000	$130,000	24		
WATER SUPPLY TANK	500	$1,000	4		
WASTE WATER STORAGE TANK	500	$500	4		
PASSENGER COMMUNICATIONS & ENTERTAINMENT SYSTEM	200	$21,200	40		
LIGHTING	27	$1,188	40		
VEHICLE CONTROL SUBYSYSTEM					
COMMUNICATIONS SET	41,000				
COMPUTER SUITE & MANUAL CONTROL SUBSYSTEM	41,000				
CONTROL SENSORS	20,000				
INTERFACE CABLING	15,000				
SECONDARY SUSPENSION SUBSYSTEM			8		
LATERAL ACTUATORS & SENSORS	5,000	$30,000	0		
VERTICAL ACTUATORS, SENSORS & POWER SUPPLY	5,000	$5,000	0		
BOGIE LINKS	13,061	$78,363	0		
TILTING MECHANISM	10,000	$10,000	0		
MAGNET BOGIE SUSPENSION SUBSYSTEM	20,000	$120,000	96		
AIR LEVITATION SYSTEM	6,000	$36,000	0		
SUPERCONDUCTING MAGNET SUBSYSTEM	187,000	$2,244,000	0		
MECHANICAL BRAKING SUBSYSTEM			24		
BRAKING ACTUATOR SUBSYSTEM	2,721	$65,306	0		
BRAKE PADS	218	$5,224	0		
WHEELS	500	$12,000	0		
CRYROGENIC REFRIGERATION SUBSYSTEM			20		
HELIUM & STORAGE DEWAR	17,300	$17,300	0		
CRYOGENIC PUMP	1,000	$1,000	0		
COOLANT DISTRIBUTION LINES	20,000	$640,000	0		
FUSELAGE ELECTRICAL POWER SUBSYSTEM			116		
BATTERY	4,000	$4,000	0		
UNINTERUPTABLE POWER SUPPLY	400	$800	0		
POWER DISTRIBUTION & CONTROL EQUIPMENT	10,000	$10,000	0		
FUEL CELL SYSTEM	10,000	$10,000	0		
VARIABLE FACTORS	NA		NA		
PASSENGER LOAD	NA		NA		
PASSENGER SERVICE PERSONNEL LOAD	NA		NA		
WATER	NA		NA		
FOOD	NA		NA		
Misc. CONSUMABLES	NA		NA		
CARRY ON BAGGAGE	NA		NA		
BAGGAGE CONTAINERS	500				
CHECKED BAGGAGE	NA		NA		

TOTALS=>
$3,714,382 Vehicle Material Cost
$113,670 Vehicle Labor Cost
$3,828,052 Vehicle Total Cost

RLP 9/11/92

EMPTY CARGO VEHICLE

DESCRIPTION	COST EACH	PURCHASED ASSEMBLY TOTAL COST	INDIVIDUAL ASSEMBLY LABOR HOURS	AGGREGATE ASSEMBLY LABOR HOURS	AGGREGATE ASSEMBLY LABOR COST
ASSEMBLED VEHICLE TOTAL		$2,978,869		485	$72,750
PAINTING		$5,000			
VEHICLE ASSEMBLY COMPLETE	0	$0	0		
BASIC BODY	187,425	$187,425	0		
AERODYNAMIC BRAKES	22050				
HYDRAULICS SYSTEM	10,000				
AIR COMPRESSOR FOR AIR SUSPENSION	5,000	$5,000	4		
AIR PIPING FOR AIR SUSPENSION	4	$525	80		
CARGO DOORS, BOTH SIDES	1,000	$4,000	16		
EMERGENCY COUPLER	11,025	$11,025	20		
EMERGENCY PARACHUTE	1,000	$1,000	1		
EMERGENCY EVACUATION SLIDES	5,000				
INSULATION—SPRAY ON	8,000	$8,000	40		
WINDOWS	250				
FIRE EXTINGUISHER SYSTEM					
FIRE EXTINGUISHING AGENT SPHERES	4,500	$27,000	20		
FIRE EXTINGUISHER PIPING	100	$100			
SMOKE AND FIRE DETECTORS	1,500	$6,000			
CO2 & HALON PORTABLE EXTINGUISHERS	75	$900			
GUIDANCE CONTROL SURFACE	1,000				
LEVITATION CONTROL SURFACE	2,000				
ENVIRONMENTAL CONTROL SYSTEM	50,000				
INNER COACH	99,225				
SEATS—COACH CLASS	3,500				
SEATS—BUSINESS CLASS	8,500				
WINDOWS	100				
GALLEY	70,000				
GALLEY CART	1,000				
LAVATORY	65,000				
WATER SUPPLY TANK	500				
WASTE WATER STORAGE TANK	500				
PASSENGER COMMUNICATIONS & ENTERTAINMENT SYSTEM	200				
LIGHTING	27				
VEHICLE CONTROL SUBYSYSTEM			40		
COMMUNICATIONS SET	41,000	$41,000	0		
COMPUTER SUITE & MANUAL CONTROL SUBSYSTEM	41,000	$41,000	0		
CONTROL SENSORS	20,000	$20,000	0		
INTERFACE CABLING	15,000	$15,000	0		
SECONDARY SUSPENSION SUBSYSTEM			8		
LATERAL ACTUATORS & SENSORS	5,000	$30,000	0		
VERTICAL ACTUATORS, SENSORS & POWER SUPPLY	5,000	$5,000	0		
BOGIE LINKS	13,061	$78,363	0		
TILTING MECHANISM	10,000	$10,000	0		
MAGNET BOGIE SUSPENSION SUBSYSTEM	20,000	$120,000	96		
AIR LEVITATION SYSTEM	6,000	$36,000	0		
SUPERCONDUCTING MAGNET SUBSYSTEM	187,000	$2,244,000	0		
MECHANICAL BRAKING SUBSYSTEM			24		
BRAKING ACTUATOR SUBSYSTEM	2,721	$65,306	0		
BRAKE PADS	218	$5,224	0		
WHEELS	500	$12,000	0		
CRYROGENIC REFRIGERATION SUBSYSTEM			20		
HELIUM & STORAGE DEWAR	17,300	$17,300	0		
CRYOGENIC PUMP	1,000	$1,000	0		
COOLANT DISTRIBUTION LINES	20,000	$640,000	0		
FUSELAGE ELECTRICAL POWER SUBSYSTEM			116		
BATTERY	4,000	$4,000	0		
UNINTERUPTABLE POWER SUPPLY	400	$800	0		
POWER DISTRIBUTION & CONTROL EQUIPMENT	10,000	$10,000	0		
FUEL CELL SYSTEM	10,000	$10,000	0		
VARIABLE FACTORS	NA		NA		
PASSENGER LOAD	NA		NA		
PASSENGER SERVICE PERSONNEL LOAD	NA		NA		
WATER	NA		NA		
FOOD	NA		NA		
Misc. CONSUMABLES	NA		NA		
CARRY ON BAGGAGE	NA		NA		
BAGGAGE CONTAINERS	500				
CHECKED BAGGAGE	NA		NA		

TOTALS=> $2,978,869 Vehicle Material Cost

$72,750 Vehicle Labor Cost

============

$3,051,619 Vehicle Total Cost

RLP 9/11/92

MULTIPLE VEHICLE
BAGGAGE/CONTROL CAR

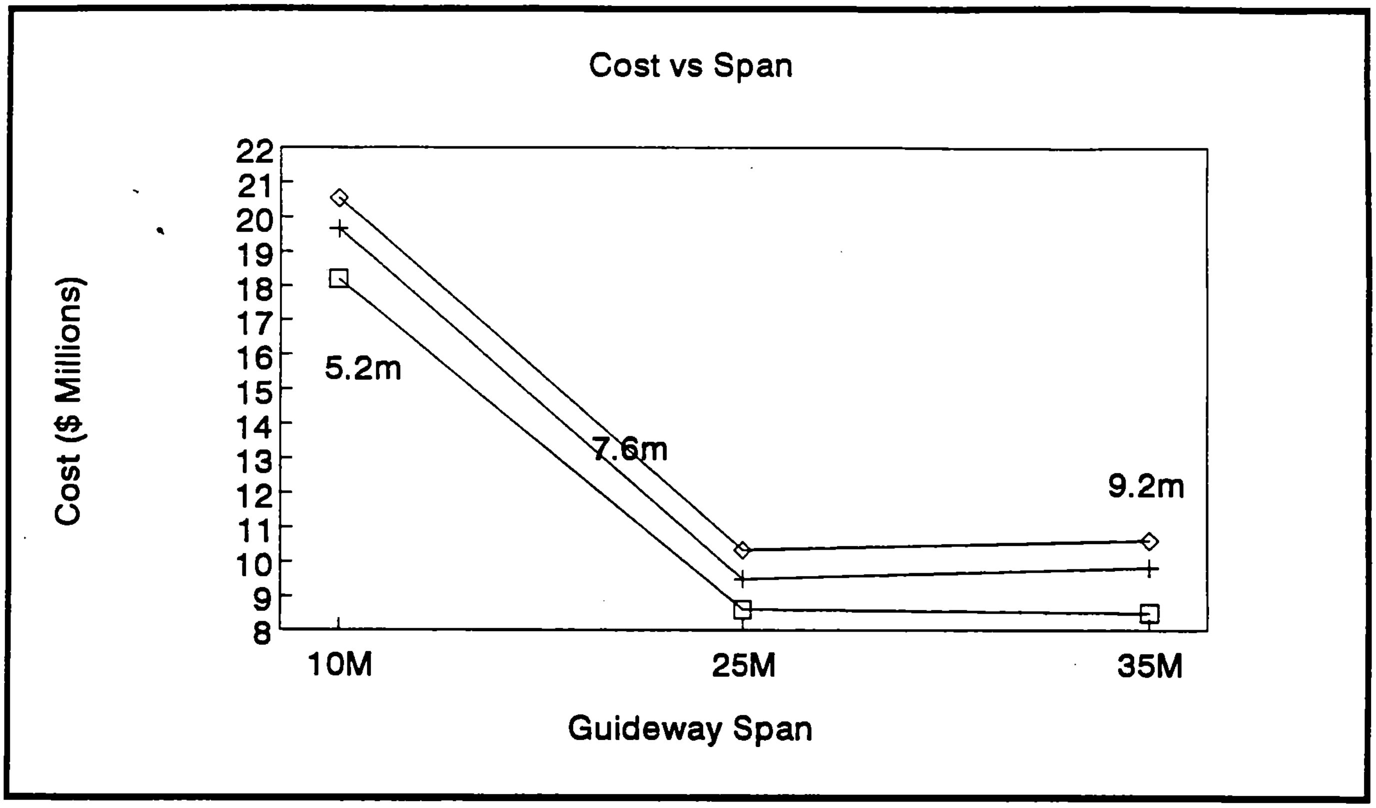
DESCRIPTION	COST EACH	PURCHASED ASSEMBLY TOTAL COST	INDIVIDUAL ASSEMBLY LABOR HOURS	AGGREGATE ASSEMBLY LABOR HOURS	AGGREGATE ASSEMBLY LABOR COST
ASSEMBLED VEHICLE TOTAL		$3,351,457		642	$96,300
PAINTING		$5,000			
VEHICLE ASSEMBLY COMPLETE	0	$0	0		
BASIC BODY	187,425	$187,425	0		
AERODYNAMIC BRAKES	22050	$176,400	20		
HYDRAULICS SYSTEM	10,000	$10,000	40		
AIR COMPRESSOR FOR AIR SUSPENSION	5,000	$5,000	4		
AIR PIPING FOR AIR SUSPENSION	4	$525	80		
CARGO DOORS, BOTH SIDES	1,000	$4,000	16		
EMERGENCY COUPLER	11,025	$11,025	20		
EMERGENCY PARACHUTE	1,000	$1,000	1		
EMERGENCY EVACUATION SLIDES	5,000				
INSULATION—SPRAY ON	8,000	$8,000	40		
WINDOWS	250	$10,000	20		
FIRE EXTINGUISHER SYSTEM					
FIRE EXTINGUISHING AGENT SPHERES	4,500	$27,000	20		
FIRE EXTINGUISHER PIPING	100	$100			
SMOKE AND FIRE DETECTORS	1,500	$6,000			
CO2 & HALON PORTABLE EXTINGUISHERS	75	$900			
GUIDANCE CONTROL SURFACE	1,000	$2,000	8		
LEVITATION CONTROL SURFACE	2,000	$8,000	16		
ENVIRONMENTAL CONTROL SYSTEM	50,000	$50,000	12		
INNER COACH	99,225				
SEATS—COACH CLASS	3,500				
SEATS—BUSINESS CLASS	8,500				
WINDOWS	100				
GALLEY	70,000				
GALLEY CART	1,000				
LAVATORY	65,000				
WATER SUPPLY TANK	500				
WASTE WATER STORAGE TANK	500				
PASSENGER COMMUNICATIONS & ENTERTAINMENT SYSTEM	200				
LIGHTING	27	$1,188	40		
VEHICLE CONTROL SUBYSYSTEM			40		
COMMUNICATIONS SET	41,000	$41,000	0		
COMPUTER SUITE & MANUAL CONTROL SUBSYSTEM	41,000	$41,000	0		
CONTROL SENSORS	20,000	$20,000	0		
INTERFACE CABLING	15,000	$15,000	0		
SECONDARY SUSPENSION SUBSYSTEM			8		
LATERAL ACTUATORS & SENSORS	5,000	$30,000	0		
VERTICAL ACTUATORS, SENSORS & POWER SUPPLY	5,000	$120,000	0		
BOGIE LINKS	13,061	$78,363	0		
TILTING MECHANISM	10,000	$10,000	0		
MAGNET BOGIE SUSPENSION SUBSYSTEM	20,000	$120,000	96		
AIR LEVITATION SYSTEM	6,000	$36,000	0		
SUPERCONDUCTING MAGNET SUBSYSTEM	187,000	$2,244,000	0		
MECHANICAL BRAKING SUBSYSTEM			24		
BRAKING ACTUATOR SUBSYSTEM	2,721	$65,306	0		
BRAKE PADS	218	$5,224	0		
WHEELS	500	$12,000	0		
CRYROGENIC REFRIGERATION SUBSYSTEM			20		
HELIUM & STORAGE DEWAR	17,300	$17,300	0		
CRYOGENIC PUMP	1,000	$1,000	0		
COOLANT DISTRIBUTION LINES	20,000	$640,000	0		
FUSELAGE ELECTRICAL POWER SUBSYSTEM			116		
BATTERY	4,000	$4,000	0		
UNINTERUPTABLE POWER SUPPLY	400	$800	0		
POWER DISTRIBUTION & CONTROL EQUIPMENT	10,000	$10,000	0		
FUEL CELL SYSTEM	10,000	$10,000	0		
VARIABLE FACTORS	NA		NA		
PASSENGER LOAD	NA		NA		
PASSENGER SERVICE PERSONNEL LOAD	NA		NA		
WATER	NA		NA		
FOOD	NA		NA		
Misc. CONSUMABLES	NA		NA		
CARRY ON BAGGAGE	NA		NA		
BAGGAGE CONTAINERS	500	$2,000	1	1	
CHECKED BAGGAGE	NA		NA		

TOTALS=> $3,351,457 Vehicle Material Cost
$96,300 Vehicle Labor Cost
============
$3,447,757 Vehicle Total Cost

RLP 9/11/92

3.2 DUAL GUIDEWAY SUPERSTRUCTURE CAPITAL COST

The chart on the following page provides the requested data, rounded to the nearest $000. Our baseline concept of 25 m column spacing with 5.2 m clearance has a capital cost for the civil structure only (i.e., without attachments) of approximately $9.1 million per mile, slightly higher than the cost estimated in the Draft Hypothetical Route Report.



Totals per Mile:

Column Height	Guideway Span 10M	25M	35M
5.2 m	$18,189,000	$8,611,000	$8,502,000
7.6 m	$19,650,000	$9,486,000	$9,819,000
9.2 m	$20,540,000	$10,333,000	$10,610,000

3.3 COMMAND, CONTROL AND COMMUNICATIONS SYSTEM CAPITAL COSTS

Hughes has developed a spreadsheet model from the capital cost elements of the *Maglev Cost Estimation: Capital Cost Elements* report developed by Parsons Brinkerhoff Quade & Douglas, Inc. The model has been enhanced by the addition of missing command and control factors such as software elements, station control centers and technology specific factors. The model is based on an Excel spreadsheet and can be modified to accommodate alternative technologies and varying route characteristics.

Total cost per kilometer for the Command Control and Communications system as applied to the Hypothetical route is as follows.

Cable network	$275 K
Sensor suites	150 K
Software engineering effort	75 K
Controller/workstation requirements	123 K
Integration effort (15% of above costs)	82 K
TOTAL	$ 690 K per kilometer (dual guideway)

For an hypothetical route of 800 km, the total capital cost is $560 M. In addition, we assume a Central Control Facility costing $40 M and additional C3 costs of $2.5 M per station or $10 M for a route having four stops. Also another $30 M expenditure will be needed as a capital expenditure for software development. This brings the total C3 capital cost for the hypothetical route to $630 million.

3.4 OTHER GUIDEWAY RELATED CAPITAL COSTS

Costs to be reported for Section 3.4 are of two types:

- Costs of features physically attached to the guideway, namely, propulsion coil windings, levitation system attachments, guidance system attachments, mounting brackets, and cover plates; and

- Linear synchronous motor capital costs (utility interface, inverter and control electronics, power distribution.

The cost table on the following page provides required data on the first costs type.

MAGLEV SYSTEM CONCEPT DEFINITION

01-Oct-92
11:09

Job: 21705-000

PLG

ORDER OF MAGNITUDE ESTIMATE

Propulsion, Levitation and Guidance systems:

(per single guideway)

	Per meter of Beam				Cost	
	Qty	Unit	Unit Cost	Cost per m	per 25m Beam	Cost per km
1. **Propulsion System:** 2 each 6 phase windings per side, with 300mm crossovers every 1000mm for a total of 15.6 meters of cable per Meter on each side or 31.2 meters of cable per meter of beam.	31.2	m	$13.12	$409.34	$10,234	$409,344
2. **Levitation System:** 1 each aluminum levitation ladder per side, 40 mm x 400 mm @ 43.4 Kg per meter each side or 86.8 kg per meter of beam	86.8	kg/m	$11.88	$1,031.18	$25,780	$1,031,184
3. **Guidance System:** one guidance coil per side, 600mm x 600mm, or 3 each per meter of beam length.	3	Each	$70.00	$210.00	$5,250	$210,000
FG frames	6	Each	$24.67	$148.00	$3,700	$147,996
4. **Mounting Brackets:** 3 brackets every meter per side or 6 each per meter of beam length (includes installation of brackets & coils)	6	Each	$30.00	$180.00	$4,500	$180,000
5. **FG Covers:** 1 cover every meter per side or 2 each per meter of beam length	2	Each	$63.50	$127.00	$3,175	$127,000
				Totals:	$53,000	$2,106,000
				For double guideways	$106,000	$4,212,000

The electrification capital cost will be analyzed in three sections:

- Utility substations and rectifiers
- Underground dc power distribution
- Electronic power conversion and control

This discussion is taken from Part K, Section 9 of the Final System Concept Definition Report.

Utility Substations and Rectifiers

The baseline design calls for a utility substation every 20 to 30 km depending on the terrain and availability of nearby utility transmission lines with suitable capacity. Each substation is capable of delivering 75 MW of dc power at 30 kV. Items covered in the cost estimate include:

- AC circuit breakers to isolate the maglev system from the utility system
- 2 50 MVA transformers with associated 12 pulse rectifiers to deliver 30 kV dc power
- A pair of dc circuit breakers for isolating sections of the dc bus as necessary for fault clearing
- Land area for the substation
- Extensions of available utility lines as necessary to bring power to the substations

A detailed study was done on behalf of the Bechtel Team by Southern California Edison (SCE) for the nearly 1,000 km route from San Diego to Sacramento by way of Los Angeles and San Francisco. This study was based on an original design using 24 kV dc distribution and a substation spacing of precisely 20 km. SCE estimated the substation cost at $1,700,000 per km.

The results of this study showed a higher than expected cost for the substations so we changed the baseline design to use 30 kV and 20 to 30 km spacing with greater consideration of the availability of nearby transmission lines so as to reduce the cost of line extension. The higher voltage allows dc distribution over the greater distance without the need for heavier cable. We then extrapolated the data in the SCE study and concluded that for the revised design the substation cost would be $1,500,000 per km.

Underground DC Power Distribution

Southern California Edison did a study of the cost of underground dc power distribution and recommended a design with the following design for 2,500 amperes at +15 kV and -15 kV:

- 2 2000 kcm stranded copper PILC per pole
- 1 1033 kcm stranded aluminum ground wire
- Splice vaults every 67 m

Their estimate for the cost of materials and installation was $900,000 per km.

Electronic Power Conversion and Control

Our baseline design calls for an inverter station every 4 km. Each station contains four 11 MW inverters, one for each side of each guideway, assuming a two-way system. The port and starboard inverters are constructed as entirely separate systems in order to achieve high fault tolerance. There is, of course, communication between the two inverters in order to achieve smooth control.

In Part B of the Final System Concept Definition Report, we provided data on the cost of complete inverters and also on individual thyristors. GTOs and their gate drive cost about three times as much as a thyristor but do not require commutating capacitors. Our initial estimate was an inverter cost of about $100 per kW of inverter output power. We have now done a more detailed estimate of the cost of key components and typical manufacturer's costing strategy and believe it is possible to reduce cost somewhat.

The modular nature of our design means that a production run of only 100 inverters for 100 km of guideway there would be more than 1,000 individual modules of most subcircuits, so there is a possibility of production economies never before realized at these power levels. Table K-6 provides a breakdown of the cost of various categories and subcategories of the components required for a complete 11 MW power control system. It also gives a total cost based on typical electronic manufacturing overhead costs. Based on this analysis we now estimate the cost at $800,000 per km.

Estimated Component and System Cost for Power Control

	Quantity	Cost each	Total cost	Subtotals
Inverter, 4 3-phase bridges, 11 MW				$38,400
GTO, 2.5 kV, 1300 A rms	24	$1,000	$24,000	
Gate drive for GTO	24	300	7,200	
Diode, 2.5 kV, 1300 A rms	24	100	2,400	
Snubber	24	100	2,400	
Heat removal components, 5 kW	24	100	2,400	
Chopper, 2 phase, 2 quadrant, 15 kV, 700 A				36,000
GTOs, 4 kV, 800 A rms	24	1,000	24,000	
Gate drive for GTO	24	250	6,000	
Diodes, 3 kV, 650 A rms	24	50	1,200	
Snubbers	24	100	2,400	
Heat removal components, 5 kW	24	100	2,400	
Inductors, air core, 800 A rms				8,400
0.05 h, 0.1 ohm, 560 kg	2	3,400	6,800	
Heat removal equipment, 64 kW	2	800	1,600	
Braking resistors				6,000
1 Mw	12	400	4,800	
Heat removal equipment	12	100	1,200	
Block switching				19,200
Thyristor, 3.2 kV 1300 A rms	24	600	14,400	
Gate drive	24	100	24,00	
Heat removal components, 5 kW	24	100	2,400	
Sensing and control electronics				38,800
Embedded control microprocessors	12	200	2,400	
Communication facilities	1	10,000	10,000	
Zone control computer	1	20,000	20,000	
Position sensing	1	2,000	2,000	
Battery backup	1	2,000	2,000	
Disconnect switches	12	200	2,400	
Miscellaneous				65,000
Building space, square meters	40	1,000	40,000	
Mounting racks, furniture	1	5,000	5,000	
Shipping and installation	1	20,000	20,000	
Total component cost				211,800
Spares			10%	21,180
G&A, sales, manufac., eng'g			200%	465,960
Contingency			10%	69,894
Total cost				768,834

3.5 ANNUAL OPERATING COSTS

Electric power is the only fuel of use and the government-provided value of 8.52 cents per kilowatt hour was used. From the data described elsewhere, power consumption is seen to be approximately 0.11 kWh per passenger-kilometer, for a total cost of approximately 0.94 cents per passenger-kilometer, or $7.52 per passenger for a 800 km trip. Annual operating costs for electric power obviously depend upon total system use over any given year.

Annualized train operations and vehicle maintenance activities are estimated to require 266 and 69 man-years respectively for a full system. Actual labor rates depend heavily on assumptions regarding whether union or non-union labor is used. For a typical mixed labor rate of $45,000 annually which would include overhead/benefits, train operations would require a budget of approximately $12 million and vehicle maintenance would require a budget of approximately $3 million annually in terms of personnel costs. Non-personnel related costs for vehicle maintenance for a 500 vehicle fleet are assumed from GM/EMD experience to range between 2 and 3 percent of total vehicle costs. Given the capital cost of approximately $4 million per vehicle as reported above, a mid-range estimate for vehicle maintenance for the hypothetical route would be approximately $50 million. Added together, total vehicle maintenance costs are therefore $53 million annually.

Command and control operating costs for the hypothetical route are composed of two elements: (i) material replacement and repair; and (ii) manpower. For material replacement and repair, assume $9,200 per mile for double guideway, or roughly $4.6 M annually for a 800 km hypothetical route. For manpower requirements for C3 (command/control/communications), assume a personnel requirement of 27 man-years per annum for the hypothetical route. In addition, each of the four stations along the route would have six people assigned to C3 operations, for an additional 24 man-year requirement. Therefore, 51 man-years at $40,000 requires a budget of roughly $2 million per annum. The total command/control/communications operating costs for the hypothetical route are therefore assumed as approximately $6.6 million per annum.

The manpower required for maintenance of the guideway is estimated to be 0.4 man-years per km per year or $12,800,000 per year for the entire hypothetical route (assuming $40,000 per man-year). Maintenance material for repair and replacement of the guideway is estimated to be $5,800 per km per year or $4,640,000 for the entire route.

Backup data supporting our operating costs are described in the Final System Concept Definition Report.

4. ADDITIONAL TOPICS

4.1 BI-DIRECTIONAL ANALYSIS

A simulation was performed showing the differences between trip times in the forward and reverse directions as shown in Table 4-1. The traversing of the hypothetical route in the reverse direction results in only a small difference in total trip time.

The velocity profile is given in Figures 4-1 through 4-4, and should be compared with the US1 Design Set figures in Section 1, Figures 1-1 through 1-4.

Table 4-1
Reverse Direction Trip Time

	TOTAL TRIP TIME	AVERAGE SPEED	Time Difference	Speed Difference
US1 DESIGN	1h 59m 02s 7142 seconds	111.8 m/s 250 mph		
REVERSE DIRECTION	1h 59m 56s 7196 seconds	111.4 m/s 249 mph	54 secs	0.4 m/s 1 mph

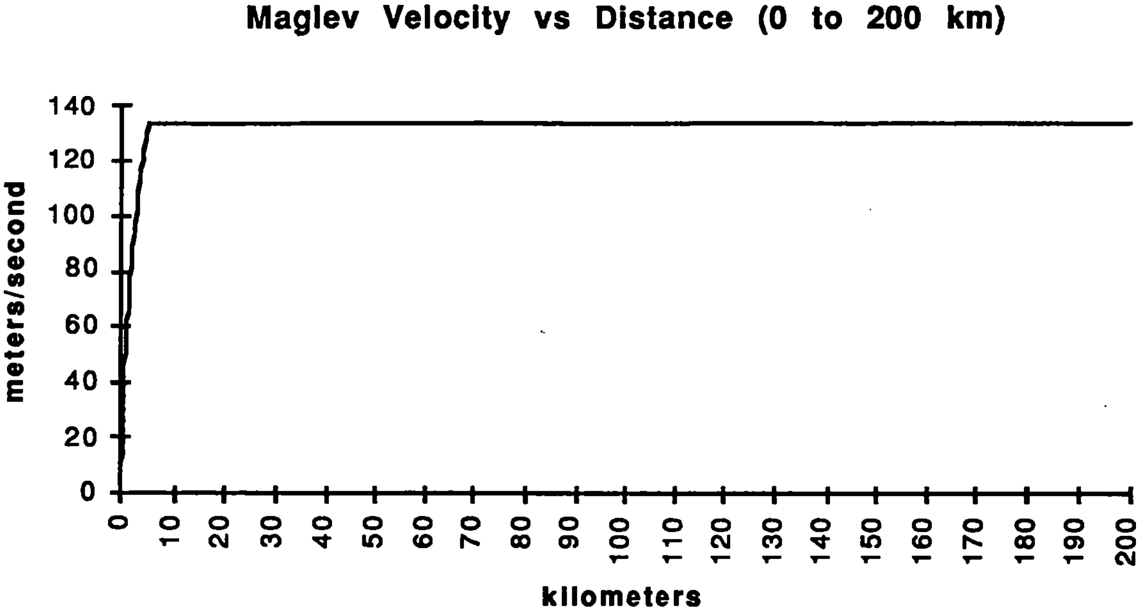


Figure 4-1 Reverse direction – zero to 200 km

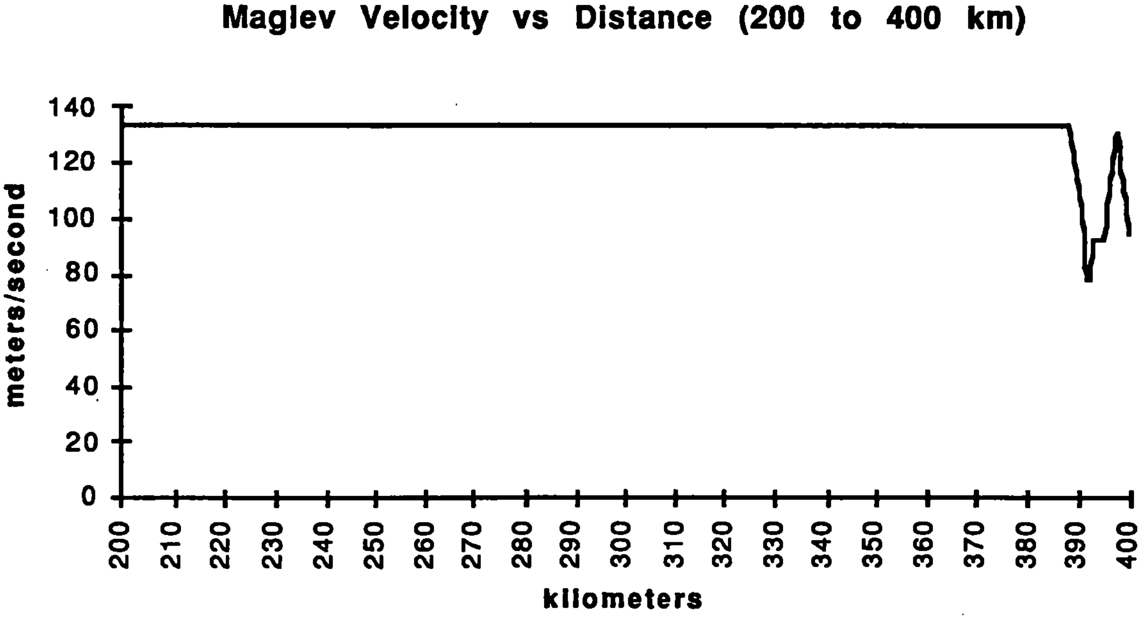


Figure 4-2 Reverse direction - 200 to 400 km

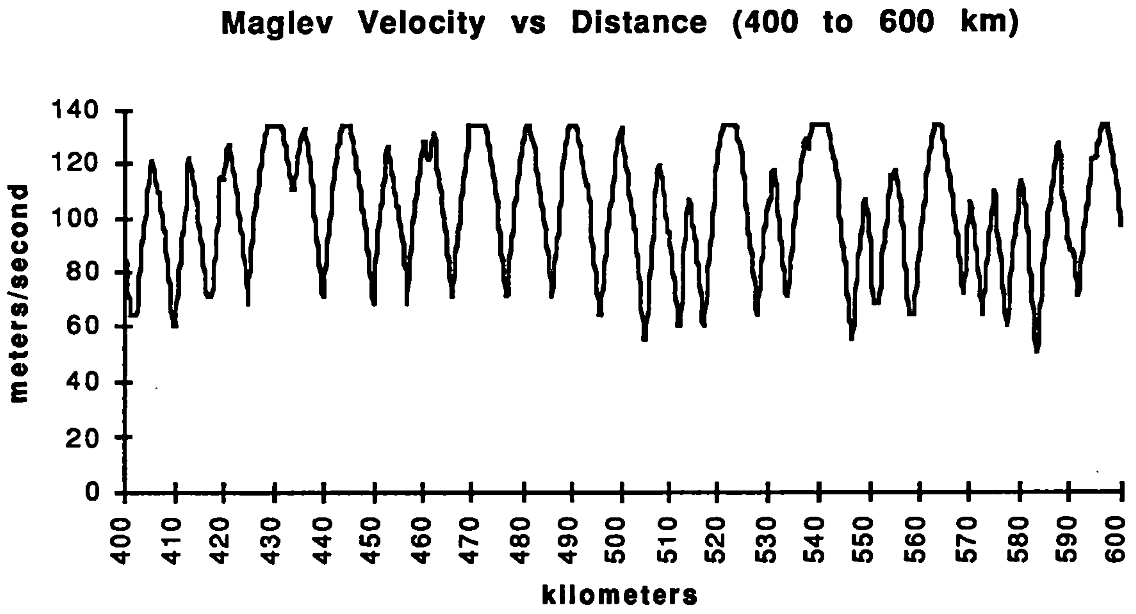


Figure 4-3 Reverse direction - 400 to 600 km

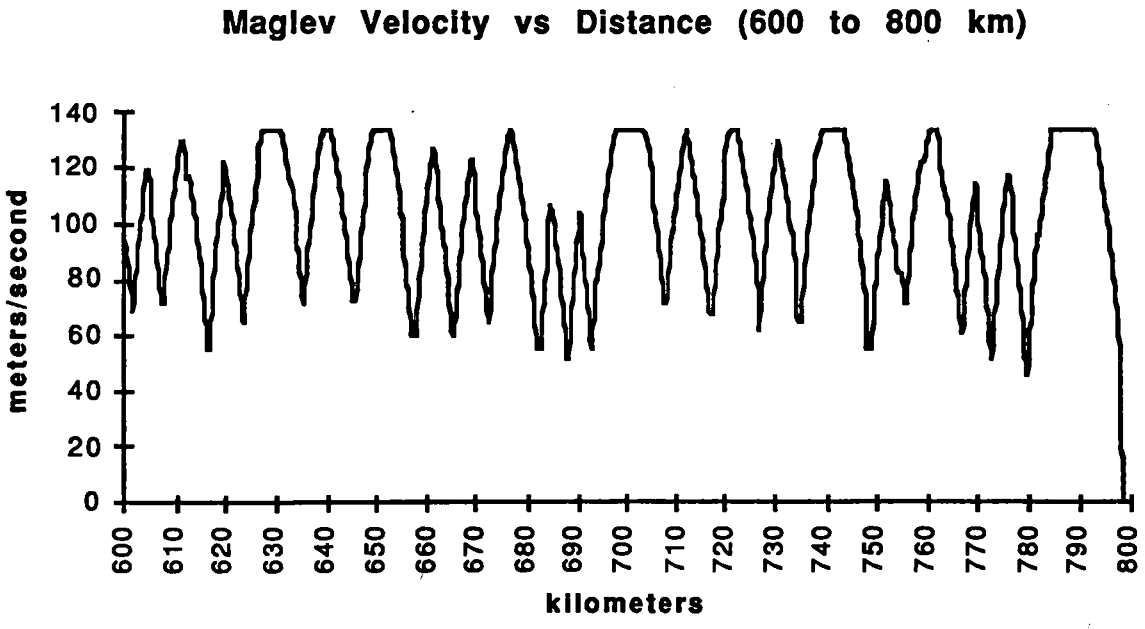


Figure 4-4 Reverse direction - 600 to 800 km

4.2 "JUDICIOUS DEPARTURE" SCENARIOS

Two simulations were run after making the radii of curvature not less than 1,000 m and not less than 3,000 m, respectively. Table 4-2 shows the total trip time of the redesigned routes compared to the standard route. Standard and redesigned routes used the minimum requirements parameter set. Figures 4-5 through 4-8 show the velocity profile of this new route for radii of curvature not less than 1,000 m and figures 4-9 through 4-12 show the velocity profile for radii of curvature not less than 3,000 m. The 3,000 m minimum radii of curvature is especially significant, since increasing this value a little to 3,120 m would allow geometric chords to be used in the guideway construction rather than curved beams. Not having to build any bends into the beams would reduce the cost of the guideway.

Table 4-3
Redesigned Route Alignment Trip Time

	TOTAL TRIP TIME	AVERAGE SPEED	Time Difference	Speed Difference
STANDARD ALIGNMENT USING MINIMUM REQUIREMENTS	1h 59m 02s 7142 seconds	111.8 m/s 250 mph		
REDESIGNED ALIGNMENT WITH NO RADII OF CURVATURE LESS THAN 1000 METERS	1h 55m 55s 6955 seconds	114.8 m/s 256.6 mph	0h 3m 07s 187 secs	3 m/s 6.6 mph
REDESIGNED ALIGNMENT WITH NO RADII OF CURVATURE LESS THAN 3000 METERS	1h 42m 09s 6129 seconds	130.3 m/s 291.3 mph	0h 16m 53s 1013 secs	18.5 m/s 41.3 mph

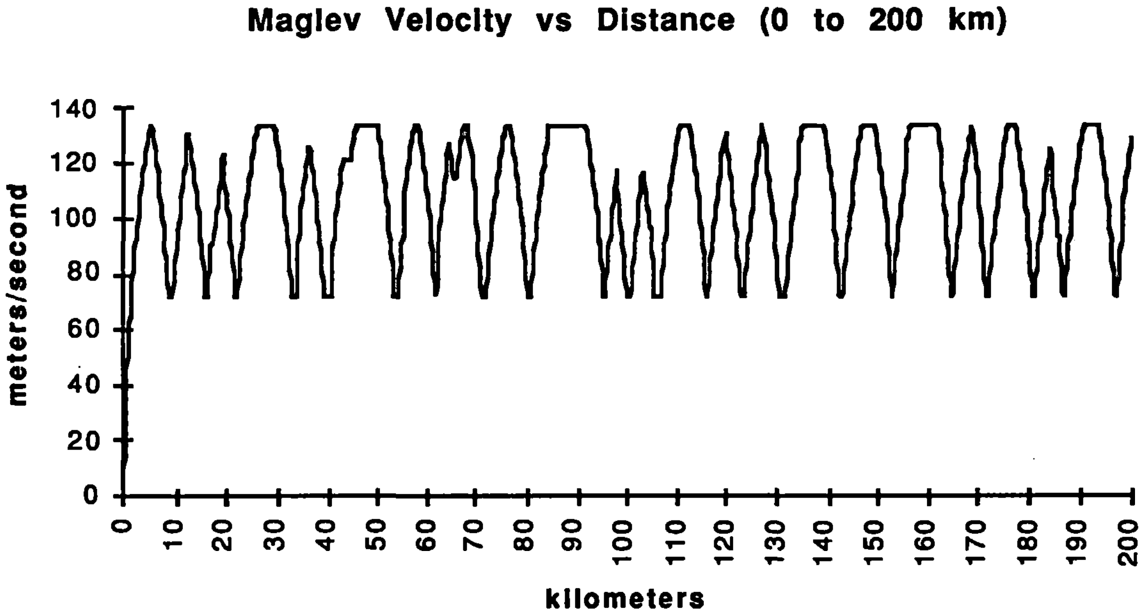


Figure 4-5 No radii less than 1,000 m – zero to 200 km

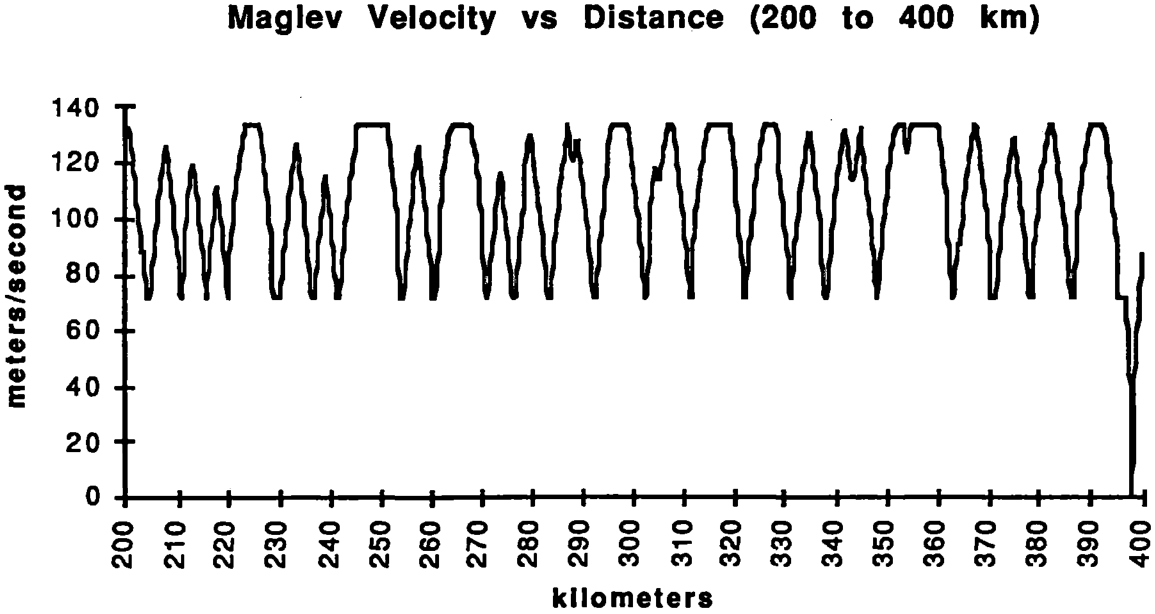


Figure 4-6 No radii less than 1,000 m – 200 to 400 km

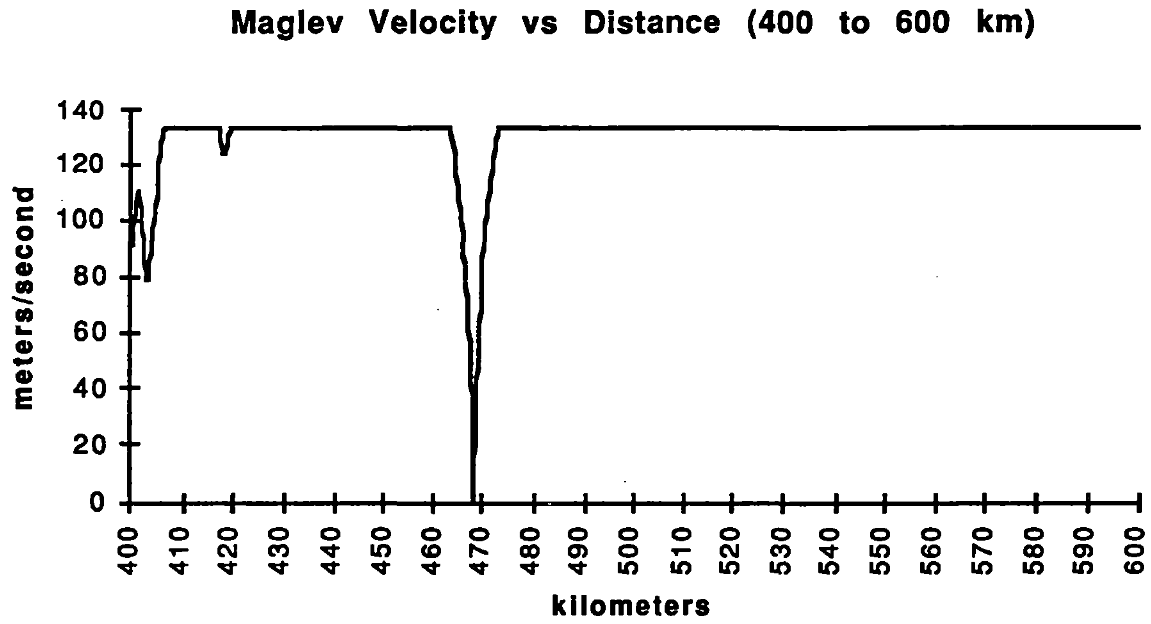


Figure 4-7 No radii less than 1,000 m – 400 to 600 km

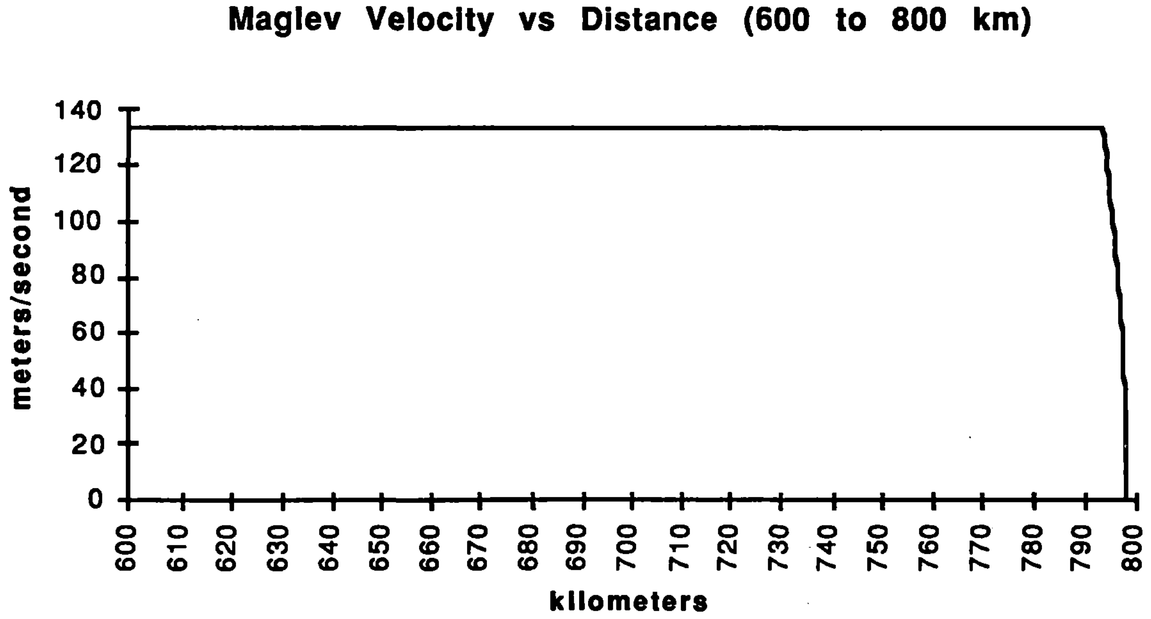


Figure 4-8 No radii less than 1,000 m – 600 to 800 km

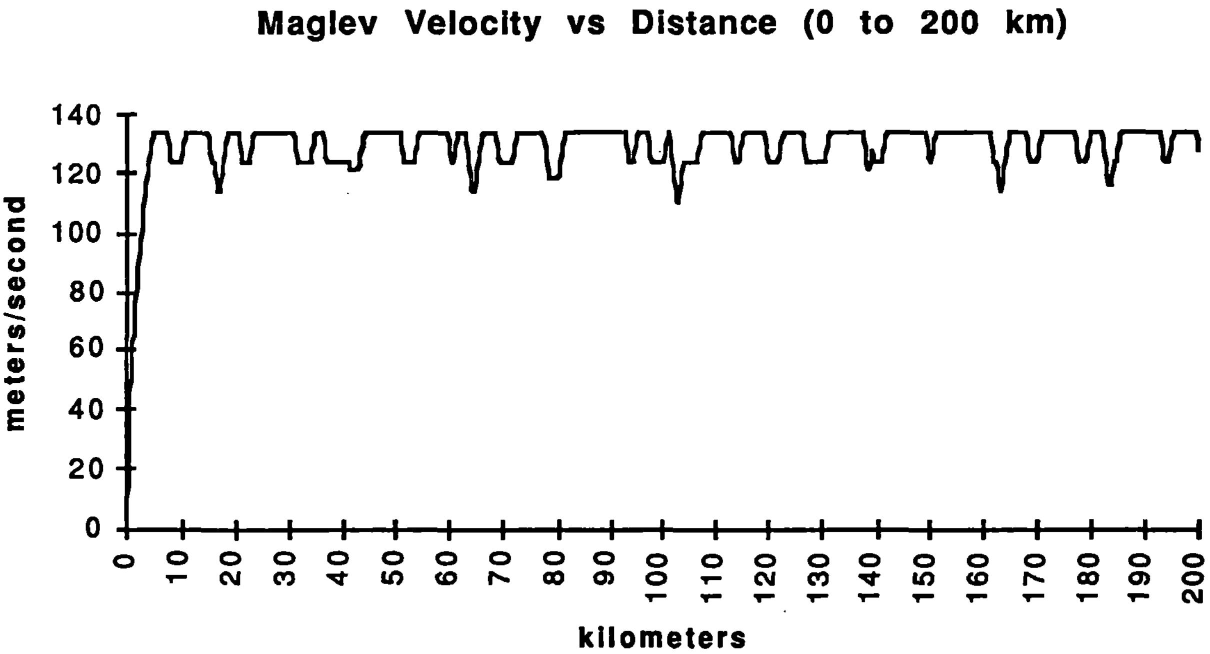


Figure 4-9 No radii less than 3,000 m – zero to 200 km

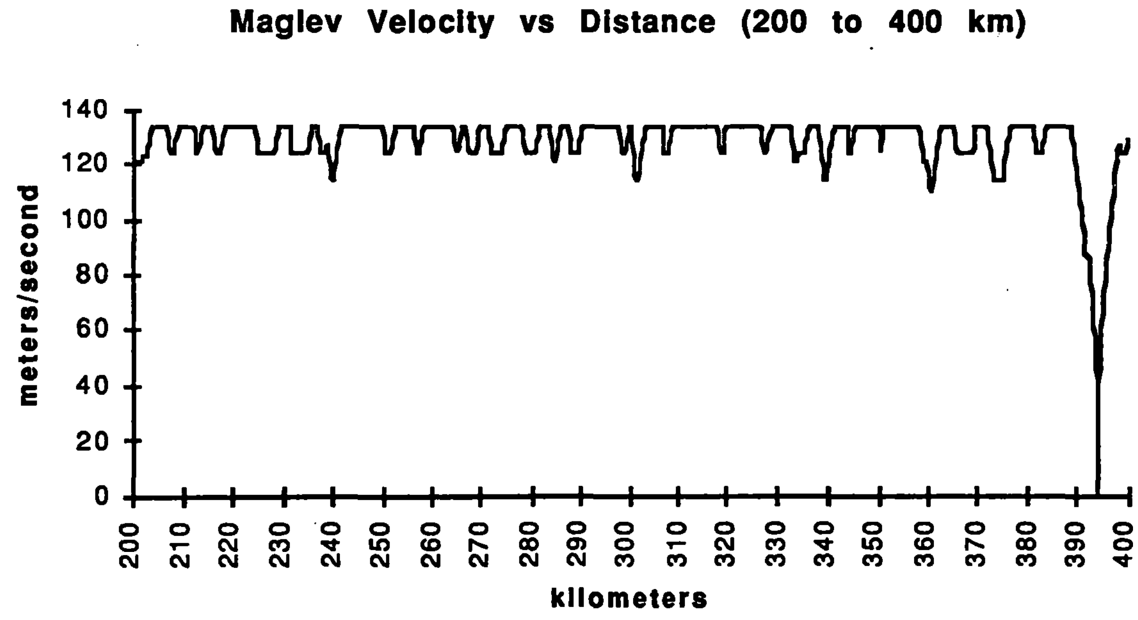


Figure 4-10 No radii less than 3,000 m – 200 to 400 km

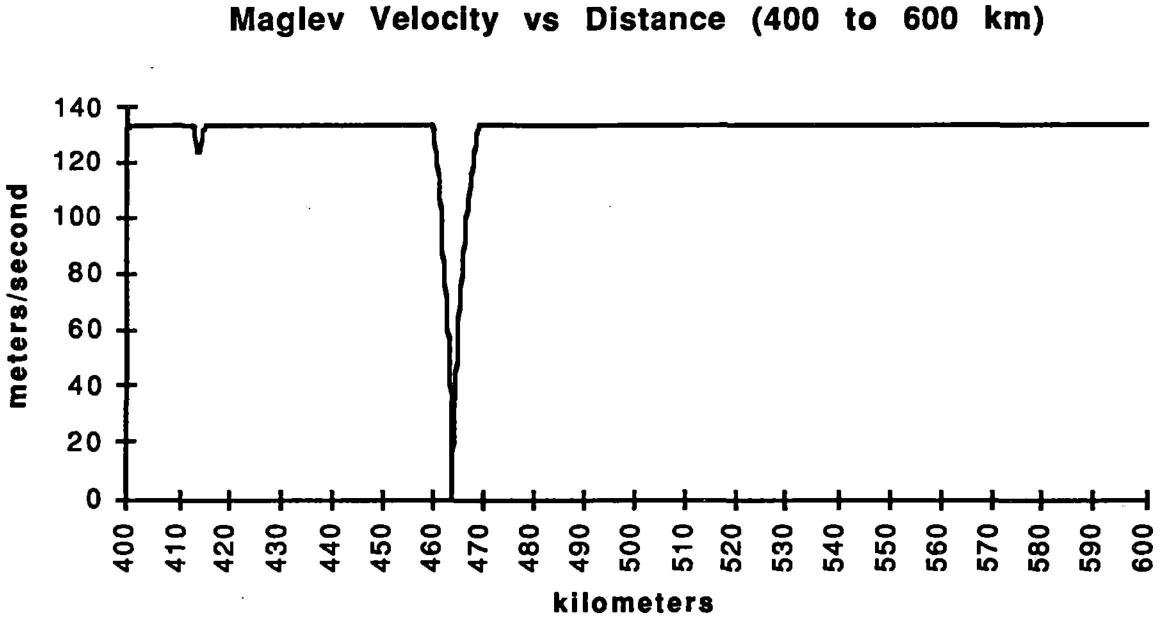


Figure 4-11 No radii less than 3,000 m – 400 to 600 km

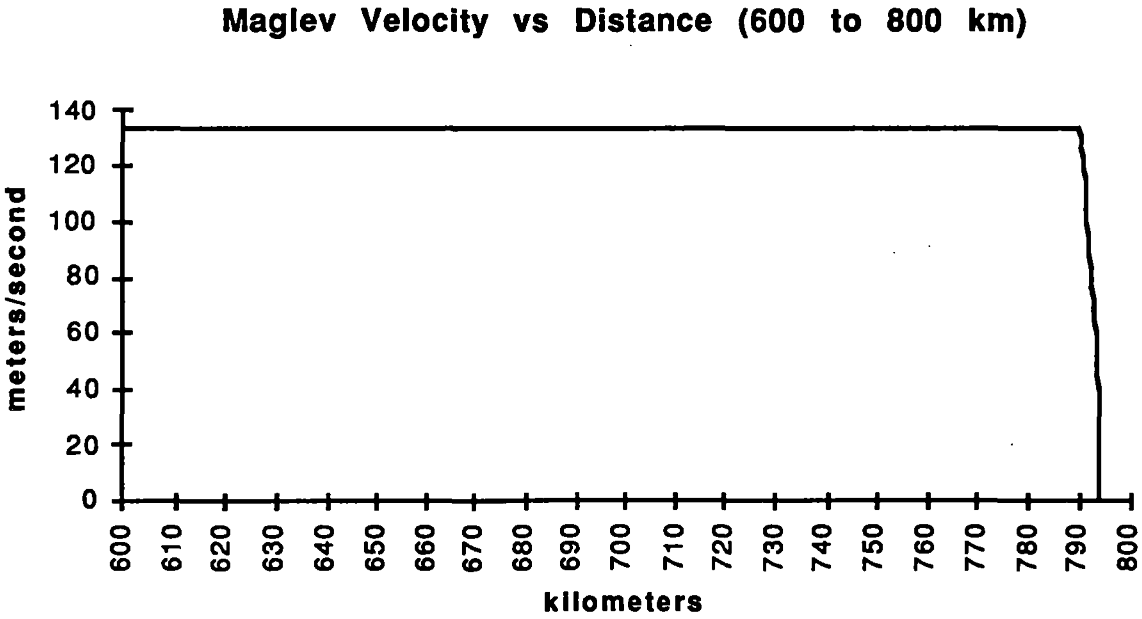


Figure 4-12 No radii less than 3,000 m – 600 to 800 km

Appendix A – Copies of Formal Correspondence Regarding Hypothetical Route

(Reader Note: USDOT letter was received in the manner presented here without letterhead on first page)

High Speed Ground Transportation Special Program Office

Subject: Hypothetical Route for MAGLEV System Concept Definition Contract, DTFR53-92-C-00003

If you believe that the technical direction contained herein constitutes work out of the scope of your contract, do not proceed with performance. Instead, formally notify the contracting officer of the basis of your position and await instructions. The contracting officer will evaluate the alleged change and (1) confirm that it is a change and direct the mode of further performance; (2) countermand the alleged change; or (3) notify your firm that no change is considered to have occurred. Proceeding with performance without first notifying the contracting officer of your position will be at your risk.

Should you have any questions or comments, please contact me at 617 494-2087.

Sincerely,

Geogre Anagnostopoulos
Contracting Officer's Technical Representative

Enclosure

U.S. Department of Transportation
Research and Special Programs Administration

Transportation Systems Center

Kendall Square
Cambridge, Massachusetts 02142

[illegible] Gary McA.

January 28, 1992 RECEIVED 2/5/92

High Speed Ground Transportation Special Program Office

Subject: Hypothetical Route for MAGLEV System Concept Definition Contract, DTFR53-92-C-00003

Bechtel Corporation
ATTN: Ms. Diane A. Benstein
P.O. Box 193965
San Francisco, CA 94119-3965

Dear Ms. Benstein,

Enclosed you will find two copies of the hypothetical route. This route is to be used in accordance with Section C, Paragraph 4.0 (HYPOTHETICAL ROUTE) of the subject contract. The enclosed route is not intended to represent a probable existing route but is intended to provide a diverse guideway configuration that will allow the Government to evaluate your system concept.

The hypothetical route shown is 800 kilometers in length and consists of three distinctly configured guideway segments separated by terminals. The terminals are assumed to be on-line, negating the need for the vehicle to leave the main guideway.

The segment between terminals 1 and 2 incorporates 400 to 1000 meter radii horizontal curves with grades varying between plus or minus 10%. The segment between terminals 2 and 3 has 1200 to 10,000 meter radii horizontal curves with grades varying between plus or minus 1%. The segment between terminals 3 and 4 is comprised of straight tangent guideway without horizontal or vertical curvature and includes a 5 kilometer tunnel.

Paragraph 4.0 identifies data to be furnished by the Government to facilitate the hypothetical route analysis. The required data referenced to the contract subparagraph number are provided as follows:

1. Hypothetical route (subpara. 4.1) - enclosed.

2. Passenger load and profile (subpara. 4.1) - The system should be designed to carry a peak load of 9600 passengers per hour in each direction.

3. Height and length of elevated guideway section and single span profile (subpara. 4.3(b)) - The details shown shall be for a dual guideway elevated 5 meters and the contractor's typical span.

4. Guideway degree of curve and speed of vehicle for superelevated guideway section (subpara/ 4/3(c)) - The detail shown should be at the maximum degree of curve (i.e. minimum horizontal radius of curvature) at maximum design operational speed for the contractor's system vehicle.

5. Location factors and cost growth indices for cost estimates (subpara. 4.4) - The location factor shall be 1.0 and the cost growth index shall be zero. The estimated costs and breakdown shall be based upon the national average per the 1991 Means Catalogue.

6. Electric power or other fuel charges (subpara. 4.4(e)(i)) - Electric power charges will be based on 8.52 cents per kilowatt hour. Charges for other fuels shall be assumed by the contractor and the assumptions should be explicitly stated in the cost estimate.

In addition to the above, subparagraph 4.4(b) requires a graphic representation of dual guideway superstructure capital cost versus guideway elevation and guideway span between piers. At a minimum, the graphs shall represent dual guideway superstructure capital costs from at-grade to 20 meters in height and 10 to 35 meter spans.

The design of the guideway structure should be based on the following geotechnical data:

1. **Seismic zone - 2**
2. **Foundation type - shallow foundations**
3. **Allowable net bearing capacity - 150 kN/m^2**
4. **Allowable settlement - 0.025 m**
5. **Minimum foundation width - 1 m**
6. **Maximum frost penetration - 1 m**

Bechtel

50 Beale Street
San Francisco, CA 94105-1895
Mailing address: P.O. Box 193965
San Francisco, CA 94119-3965

March 3, 1992

U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Kendall Square
Cambridge, Massachusetts 02142

Attention: Mr. George Anagnostopoulos
Contracting Officer's Technical Representative

Subject: Contract DTFR 53-92-C00003
Maglev System Concept Definition
Your letter of 28 January 1992
Hypothetical Route

Dear George:

Based on our discussions during the February 27 in-progress review meeting, we suggest the following information be added to the third paragraph under item #6 of your letter. We suggest this information follow in the current numerical order as indicated:

Item 1. "Seismic zone 2" should include a "baseline" soil acceleration spectrum, chosen by the NMI team.

Item 4. Typical soil data information should be furnished as required to perform these calculations.

We also understand that the NMI team had no objection to deleting the text of the second paragraph under Item #6 in order to clarify the requirement.

Very truly yours,

JCP

Joseph C. Perkowski, Ph. D.
Program Manager
System Concept Definition Study

cc: Contracting Officer
Diane Benstein, Bechtel R&D Contracts

Bechtel Corporation