11 - Advanced Systems

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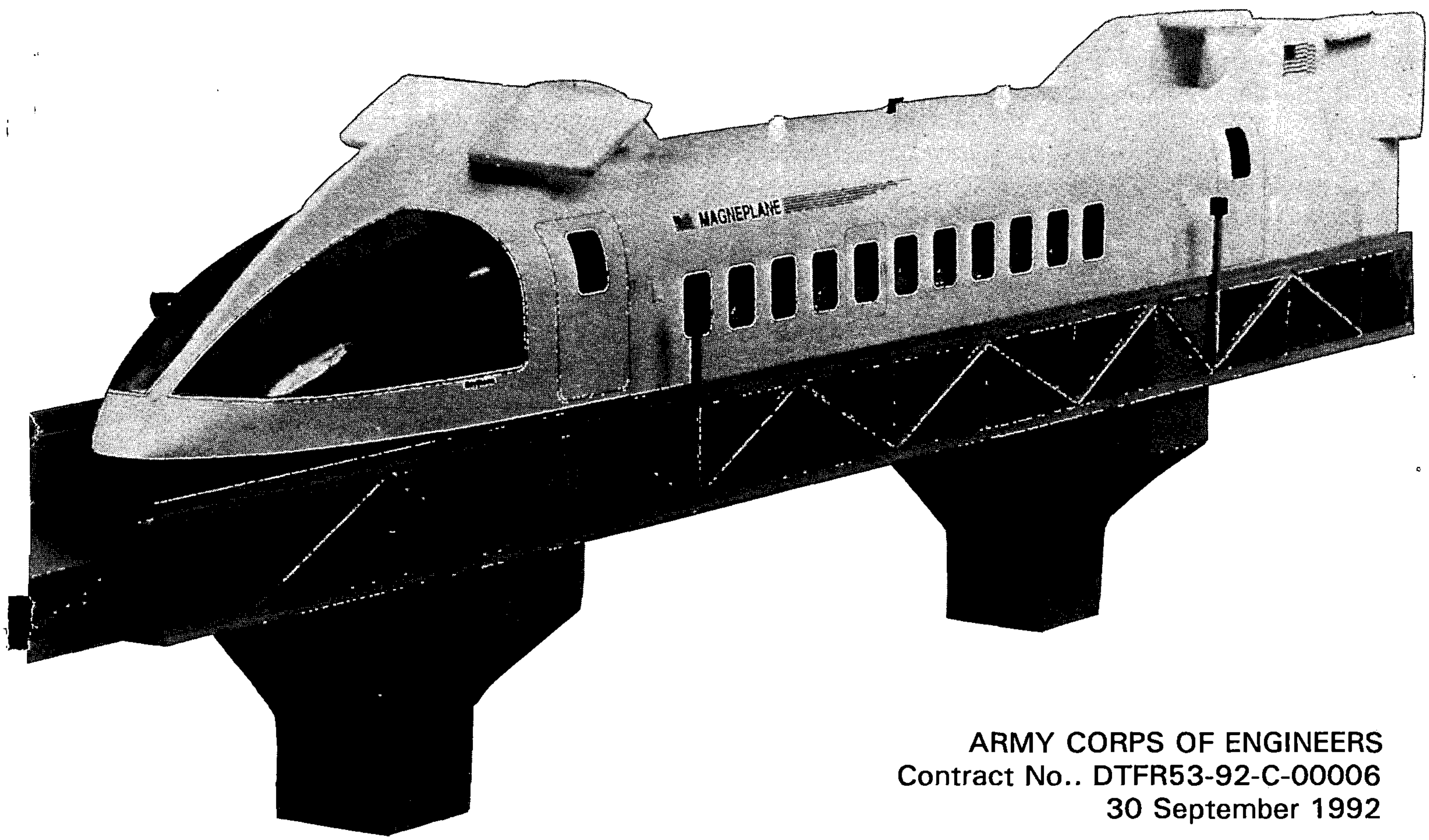
SYSTEM CONCEPT DEFINITION REPORT
for the
NATIONAL MAGLEV INITIATIVE

Volume 4



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PARAMETRIC PERFORMANCE REPORT

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5.3.3.1. INTRODUCTION

The parametric performance studies presented in this section vary a given parameter over a range and show the effects of the variation on costs other performance variables. The parameter must be one that can conceivably be varied; either in route design or route operation, but not in fundamental design.

These studies constitute a view of the system's performance sensitivity to various parameters. In most cases the performance variable is total system cost, broken into annual operations cost and annual levelized capital cost (in this case, payment on capital bonds at a 10.09% rate). A few other performance variables are used as well.

The most striking thing about the parametric results is that there is often nothing striking at all: total costs are insensitive to wide variation in many independent parameters. The parameters that are most noteworthy are maximum velocity and passenger throughput. Higher maximum velocities are significantly less expensive, even for a constant level of passenger throughput. This runs contrary to popular thought (that "faster is more expensive"), but nevertheless, it is true!

Passenger throughput is the most significant parameter of all.Tripling the throughput from 4,000 to 12,000 passengers per hour raises the total annual cost by about 60%, and consequently nearly halves the cost per passenger. ($40 tickets become $20 tickets, produce the same profit, and generate even more ridership.)

5.3.3.1.a. FORMAT OF THE STUDIES

Each study contains the following elements in this order:

1. PARAMETER. The parameter that is varied.

2. MOTIVATION. Why this parameter is important to study, and what it is.

3. VARIABLES. The range of variation of the parameter in question, and the performance variables that are affected and calculated.

4. CONSTANTS. Under what conditions the evaluations were made. Most studies refer to one of the two standard route configurations (STR or SEV) detailed in 5.3.3.1.b.

5. CONCLUSIONS. The positive conclusions that one can draw from the results.

6. NOTES. (1) *Negative* conclusions; ie what the results do not say; warnings against over-interpretation. (2) Anything else worth noting.

7. CALCULATIONS. The calculation methods, or references to other sources.

5.3.3.1.b. BASE CASE FOR CONSTANTS

The cases used for route constants, as noted in 5.3.3.1.a., item 4, are as follows. Both the "straight magway configuration" (STR) and the "realistic to severe magway configuration" (SEV) are given.

A. straight magway configuration **(STR)**
   1. magway structure
      a. dual (two directions)
      b. height: 5.2 m
      c. span length: 9.1 m
      d. material: all aluminum
   2. ancillary structures
      a. switches: none
      b. magports: none
   3. route
      a. straight and level, all elevated
      b. length: 160 km
   4. blocks
      a. block size: 2 km
      b. number of blocks in system: 160
      c. power converter station spacing: 8 km
      d. number of power converter stations: 20
      e. converter rating: 6 MW
      f. converters per station: 4
      g. number of converters in system: 80
   5. power substations
      a. separation: 53 km
      b. rating: 60 MVA
      c. number of substations in system: 3
   6. control
      a. global controllers: 1
      b. wayside controllers: 20

B. realistic to severe magway configuration **(SEV)**
   1. magway structure: see primary configuration
   2. ancillary structures: see primary configuration
   3. route
      a. first half of Severe Segment Test
      b. length: 400 km
   4. blocks: variable
   5. power substations: variable
   6. control
      a. global controllers: 3
      b. wayside controllers: variable

C. operating time
   1. per day: 18 hr

2. per year: 6570 hr
3. system life: 50 years (328,500 hr)

D. service and routes for various types of analyses
1. for reliability/safety studies (see specification list)
2. for economic tradeoffs and parametric studies
    a. route: depends on the study
    b. ride quality
        (1) BEST when using STR
        (2) MIN-B when using SEV
    c. vehicle mix: all large (140-passenger)
    d. throughput
        (1) 4,000 pas/hr = 1.11 pas/s
        (2) time between vehicles (headway): 126 s
        (3) lifetime throughput: 1.314×10^9 passengers
    e. velocity, when not otherwise calculated: 134 m/s

5.3.3.1.c. COST VARIATION ESTIMATION

Cost variations are made according to a baseline cost estimate. The baseline is presented in Figure 1. This was made according to a non-final cost estimate used internally during the final stages of the contract period, called "Rev. 1". There are a few differences between this estimate and the final values presented in the life cycle cost report, section 5.3.11. Any differences are due to schedule constraints that made it impossible to update the current values to reflect the greater accuracy of the life cycle cost report. None of the differences would change the results greatly.

Parameterized cost variation is achieved by using the spreadsheet shown in Figure 1, which was taken from section 5.3.11. To find the effect of a component cost change, the "mult" column is changed and the additions are recalculated. For example, if the parameter under study raises "121 total magway" costs by 20% in a given test, the "mult" column would be edited to read "1.20", and the spreadsheet recalculated. The results are tabulated in graphical form for each parametric performance study, but the printout of the spreadsheet is not duplicated for each study.

The most important fields in Figure 1 are "total capital/m" and "total operations/m"; these are the values graphed for each study. The "annual" column refers to levelized annual costs, which in all cases are 10.09% of capital expenditures. Justification of the levelizing function is given in section 5.3.11.

item	part cost	subtotal	%total	mult	annual
1211 magway contingency	$370,012,500		11.56	1	$37,334,261
1213 magway	$1,480,050,000		46.22	1	$149,337,045
121 total magway		$1,850,062,500	57.78		
151 electrical contingency	$131,210,000		4.10	1	$13,239,089
152 magway electrification	$656,057,000		20.49	1	$66,196,151
153 communication and control	$48,301,000		1.51	1	$4,873,571
15 total electrical/C3		$835,568,000	26.10		
18x vehicle (each)	$25,814,000				
18 total vehicle		$516,280,000	16.12	1	$52,092,652
total capital		**$3,201,910,500**	**100.00**		**$323,072,769**
total capital/m					**$2,019**
211 magway maintenance	$5,000,000		5.07	1	$5,000,000
212 vehicle maintenance	$6,570,000		6.66	1	$6,570,000
21 other maintenance	$12,636,000		12.80	1	$12,636,000
21 total maintenance		$24,206,000	24.52		
221 vehicle energy	$64,650,000		65.50	1	$64,650,000
222 fixed facility energy	$590,000		0.60	1	$590,000
22 total energy		$65,240,000	66.10		
23 on-board operations		$5,520,000	5.59	1	$5,520,000
24 other fixed facility operations		$3,738,000	3.79	1	$3,738,000
total operations		**$98,704,000**	**100.00**		**$98,704,000**
total operations/m					**$617**
total annual cost/m					**$2,636**
annual cost/pas-km					$0.0502

Figure 1 Spreadsheet used for cost variation estimation

5.3.3.2. EFFECTS OF SELECTED PARAMETERS

5.3.3.2.a. MAXIMUM VELOCITY

MOTIVATION. This study measures the effects of varying the maximum velocity allowed in a route holding all other variables constant. For higher maximum velocities, the trip time is lower, the energy cost is slightly higher, and the number of vehicles required for a given capacity is lower.

VARIABLES. The maximum velocity is varied over the range 25 - 175 m/s. Testing for velocities much higher than 175 m/s would be too inaccurate, since the technology is only designed for 150 m/s maximum. The performance variables are average velocity and cost.

CONSTANTS. The study uses the route configuration SEV. See 5.3.3.1.b.

CONCLUSIONS. Figure 2 and Figure 3 show the performance effects of variance of maximum velocity. For limits under 100 m/s, the cost goes up sharply due to the number of vehicles needed, but over 100 m/s, (on this particular route) cost effects are minimal.

NOTES

1. The conclusion points to the importance of the maximum velocity in all vehicle operations, not just in cruising. If the number of vehicles is to be held as low as possible, they must be loaded and inspected quickly and returned to use quickly.

2. One could increase the velocity limit of 134 m/s. This would have a negligible effect on performance on the parts of the Severe Segment Test used above, but would have a large effect for straighter routes. For straighter routes, the costs would continue to go down as the maximum velocity is increased. This indicates that a maximum velocity should only be limited by the safe use of the technology.

3. Although the amount of energy used changes for different velocity limits, the effect was not included here because it is small. Magneplane's drag curve is very flat over all velocities; ie. the drag and the energy usage doesn't change much as a function of speed.

CALCULATIONS. The calculations for average velocity were done using the automated route analysis tools as described in the Hypothetical Route Report. A separate model was created for each maximum velocity chosen. The costs were calculated as described in 5.3.3.1.c.

maximum velocity (m/s)	traversal time (s)	number of vehicles	vehicle multiplier	annual capital ($/m)	annual operations ($/m)	total annu-al ($/m)
25	16020	127	2.00	2345	692	3037
50	8010	64	1.00	2019	617	2636
100	4210	33	0.53	1866	581	2447
150	3478	28	0.43	1834	574	2408
175	3434	27	0.43	1834	574	2408

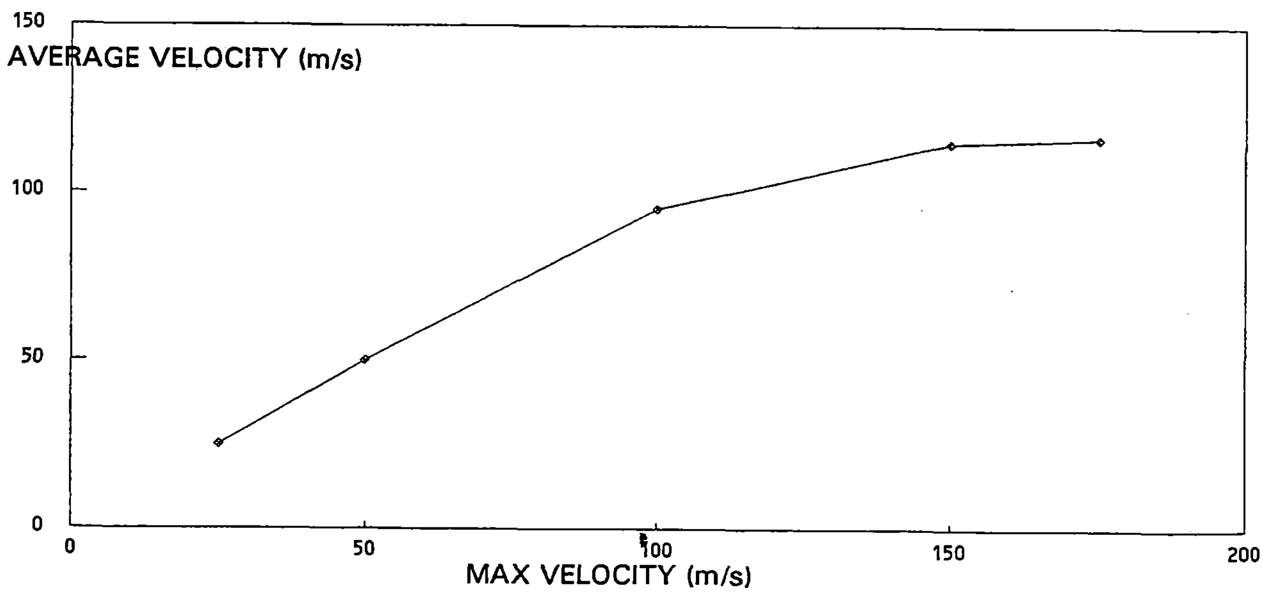


Figure 2 Effect of maximum velocity (values, graph)

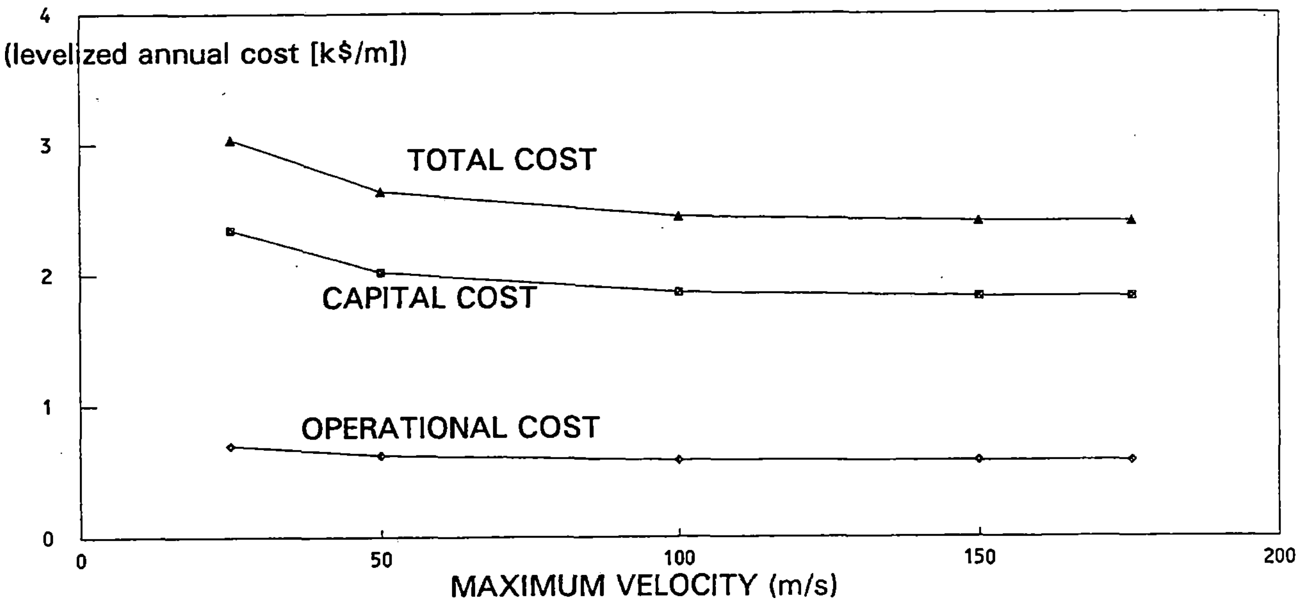


Figure 3 Effect of maximum velocity - continued

5.3.3.2.b. LONGITUDINAL ACCELERATION

MOTIVATION. This study measures the effects of varying the maximum longitudinal acceleration/deceleration allowed in a route holding all other variables constant. For higher accelerations, the average speed is higher, the energy cost is slightly higher, and the number of vehicles required for a given capacity is lower.

VARIABLES. The maximum allowed longitudinal acceleration is varied over the range 0.98 - 4.9 m/s^2 (0.1g - 0.5g). The performance variables are average velocity and cost.

CONSTANTS. The study uses the route configuration SEV. Ride Quality is assumed to be MIN-B ("Seated/Belted") as outlined in the contract. See 5.3.3.1.b.

CONCLUSIONS. Figure 4 and Figure 5 show the performance effects of variance of longitudinal acceleration. The cost and velocity effects over this range of variance are relatively small considering the large difference in ride quality experienced over the range.

NOTES. None.

CALCULATIONS. The calculations for longitudinal acceleration were done using the automated route analysis tools as described in the Hypothetical Route Report. A separate model was created for each maximum velocity chosen. The costs were calculated as described in 5.3.3.1.c. The cost inputs were the required number of vehicles and the energy use increase.

maximum acceleration (m/s^2)	traversal time (s)	number of vehicles	vehicle multiplier	energy use multiplier
0.98	4364	35	1.00	1.00
2.94	3654	29	0.84	1.04
4.90	3558	28	0.82	1.05

maximum acceleration (m/s^2)	annual capital ($/m)	annual operations ($/m)	total annual ($/m)
0.98	2019	617	2636
2.94	1967	621	2588
4.90	1961	624	2585

Figure 4 Effect of longitudinal acceleration (values)

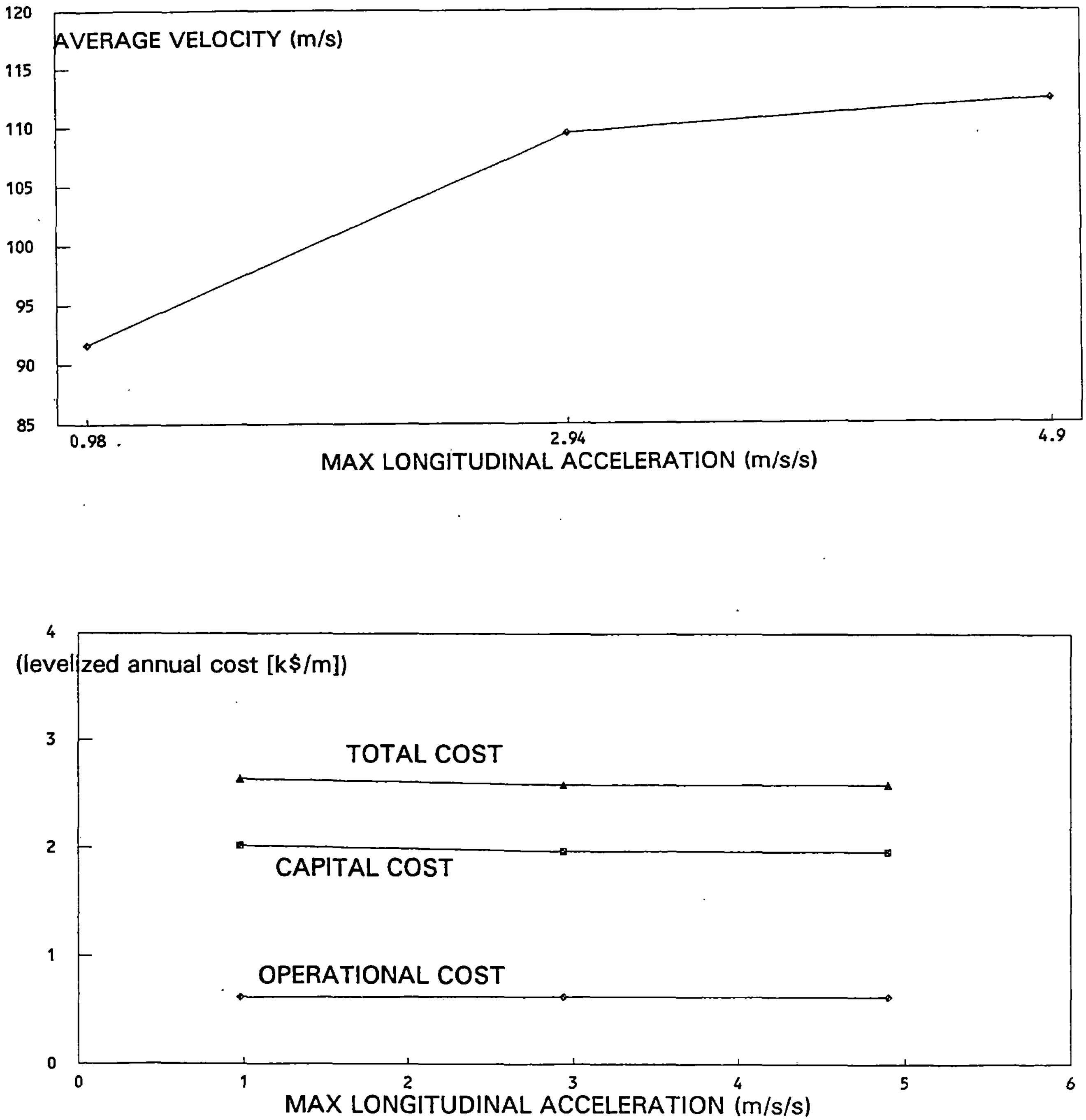


Figure 5 Effect of longitudinal acceleration (graphs)

5.3.3.2.c. ROLL ANGLE

MOTIVATION. This study measures the effects of varying the maximum roll angle allowed in a route holding all other variables constant.

VARIABLES. The maximum allowed roll angle is varied over the range 5 - 60 °. The performance variables are average velocity and cost.

CONSTANTS. The study uses the route configuration SEV. See 5.3.3.1.b.

CONCLUSIONS. Figure 6 and Figure 7 show the performance effects of variance of maximum roll angle. The cost and velocity effects over this range of variance is relatively small for this particular route.

NOTES.

1. Energy use was assumed constant.

2. Even for small maximum roll angles, coordinated curves were assumed (ie. zero lateral acceleration). This was a source of error, since some lateral acceleration would be allowed in a real system.

CALCULATIONS. The calculations for roll angle were done using the automated route analysis tools as described in the Hypothetical Route Report. A separate model was created for each maximum velocity chosen. The costs were calculated as described in 5.3.3.1.c.

The cost inputs are the required number of vehicles and the cost increase for banked magway. Over the range studied, the cost of banked magway construction was approximated at 5% - 65% over the construction cost of straight magway. The capital cost increase for the whole magway assumed that the maximum bank cost was incurred over 10% of the total magway length.

The normalization point for the vehicle cost multiplier and the magway cost multiplier were chosen to be at 24° and 0° respectively.

maximum roll angle (°)	traversal time (s)	number of vehicles	vehicle multiplier	cost multiplier for bank	x 10% =
5	4715	37	1.22	1.04	1.004
10	4349	34	1.13	1.08	1.008
24	3851	31	1.00	1.32	1.032
30	3741	30	0.97	1.42	1.042
45	3580	28	0.93	1.50	1.050
60	3553	28	0.92	1.65	1.065

maximum roll angle (°)	annual capital ($/m)	annual operations ($/m)	total annual ($/m)
5	2091	634	2725
10	2073	637	2700
24	2054	617	2671
30	2056	615	2671
45	2055	612	2667
60	2075	611	2686

Figure 6 Effect of maximum roll angle (values)

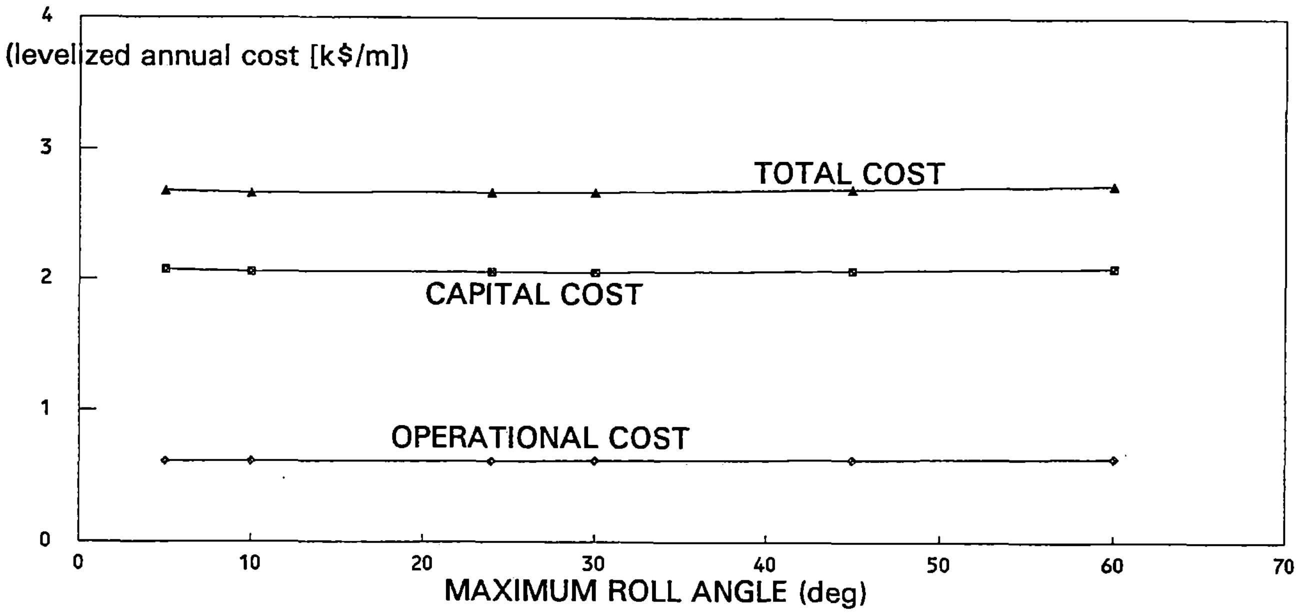


Figure 7 Effect of maximum roll angle (graph)

5.3.3.2.d. POWER SUPPLIED

MOTIVATION. This study measures the effects of varying the maximum available power in a route holding all other variables constant.

VARIABLES. The maximum available power is varied over the range 6 - 36 MW. Not every block requires the maximum level of power available. The performance variables are average velocity and cost.

CONSTANTS. The study uses the route configuration SEV. See 5.3.3.1.b.

CONCLUSIONS. Figure 8 and Figure 9 show the performance effects of variance of maximum power available. The cost effect over this range of variance is almost zero for this particular route. However, the effect on velocity is significant: going up from a 6 MW limit to a 36 MW limit saves 20% of travel time at no additional cost.

NOTES.

1. Energy use was assumed constant.

2. The mechanical energy limit actually used was assumed to be 85% less than the values given in Figure 8 to account for inefficiency.

CALCULATIONS. The calculations for power availability were done using the automated route analysis tools as described in the Hypothetical Route Report. A separate model was created for each power level chosen. The costs were calculated as described in 5.3.3.1.c.

The cost inputs are the required number of vehicles and the capital cost increase for installed power. The required number of vehicles changes because average velocity changes according to the available power.

The normalization points for the vehicle cost multiplier and the installed power cost multiplier were set at 6 MW.

The distribution of power levels of power converters was estimated, and shown in Figure 8 (top). The estimation was based on the actual usage levels on the Severe Segment Test. See the Hypothetical Route Report, section 2.1.7. for further clarification. The cost multiplier for power conversion equipment was estimated according to a linear cost-curve; ie. 12 MW converters were assumed to cost twice as much as 6 MW converters. This multiplier is listed in the second-to-last row in the table. The last row is the multiplier for total magway electrification, which is equal to the previous row times 7.9%. This percentage is derived thus:

power converter cost is 36% of power converter station cost (see 5.3.11.)
power converter station cost is 22% of magway electrification cost (see 5.3.11)
power converter cost is therefore 7.9% of magway electrification cost

The *last* row in Figure 8 (top) is used as the input to the cost spreadsheet as described in 5.3.3.1.c.

	The six alternate systems studied					
	6 MW limit	12 MW limit	18 MW limit	24 MW limit	30 MW limit	36 MW limit
Fraction 6 MW	1.00	0.25	0.13	0.09	0.08	0.07
Fraction 12 MW		0.75	0.37	0.26	0.24	0.22
Fraction 18 MW			0.50	0.35	0.32	0.30
Fraction 24 MW				0.30	0.27	0.26
Fraction 30 MW					0.10	0.10
Fraction 36 MW						0.05
Total	1.00	1.00	1.00	1.00	1.00	1.00
Cost mult.	1.00	1.75	2.38	2.86	3.08	3.22
Total elect. cost mult (x 7.9%)	1.00	1.06	1.11	1.15	1.16	1.18

power limit (MW)	traversal time (s)	number of vehicles	vehicle multiplier	electrical multiplier	annual capital ($/m)	annual operations ($/m)	total annual ($/m)
6	4376	34	1.00	1.00	2019	617	2636
12	3801	31	0.87	1.06	2006	607	2613
18	3637	29	0.83	1.11	2018	604	2622
24	3580	28	0.82	1.15	2034	603	2637
30	3567	28	0.82	1.16	2042	603	2645
36	3565	28	0.81	1.18	2045	603	2648

Figure 8 Effect of power supplied (values)

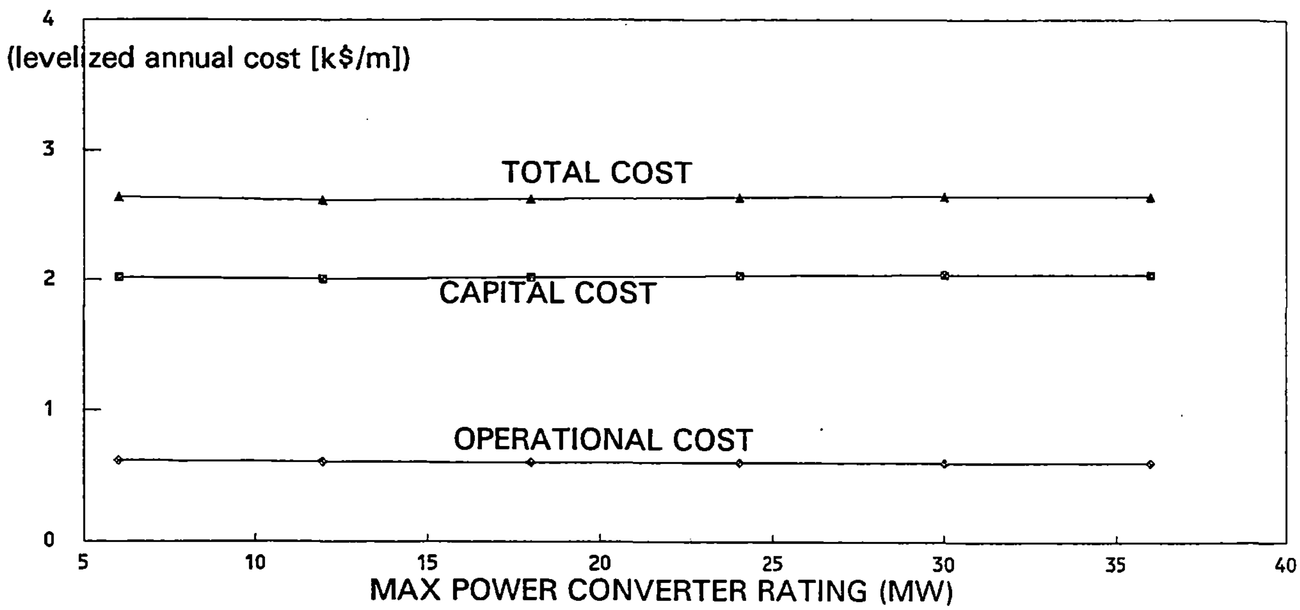


Figure 9 Effect of power supplied (graph)

5.3.3.2.e. RADIUS

MOTIVATION. This study measures the effects on velocity of varying the radius of a curve.

VARIABLES. The radius is varied over the range 0 - 5 km. The performance variable is maximum possible velocity. The performance is given for three maximum roll angles: 24, 35, and 45 °.

CONSTANTS. The study does not include information about any route.

CONCLUSIONS. Figure 10 shows the effect of variance of radius in a curve.

NOTES.

1. The performance indicated is correct for long curves. For curves that only change direction by a few degrees (for example, 10°) there may not be enough time to roll up to the maximum roll angle within the roll rate limit imposed by the ride quality standard. The performance given here does not take account of such cases.

2. This study assumes coordinated curves, ie. zero lateral acceleration.

3. A detailed study of a specific route is required to optimize radius decisions for each curve. For further discussion, see the tradeoff analysis on right-of-way deviation in horizontal curves.

CALCULATIONS. The velocity calculation is:

$$v=\sqrt{Rg\tan\theta}$$

where

v is the maximum possible velocity in the curve
R is the radius
g is the acceleration due to gravity
θ is the maximum roll angle

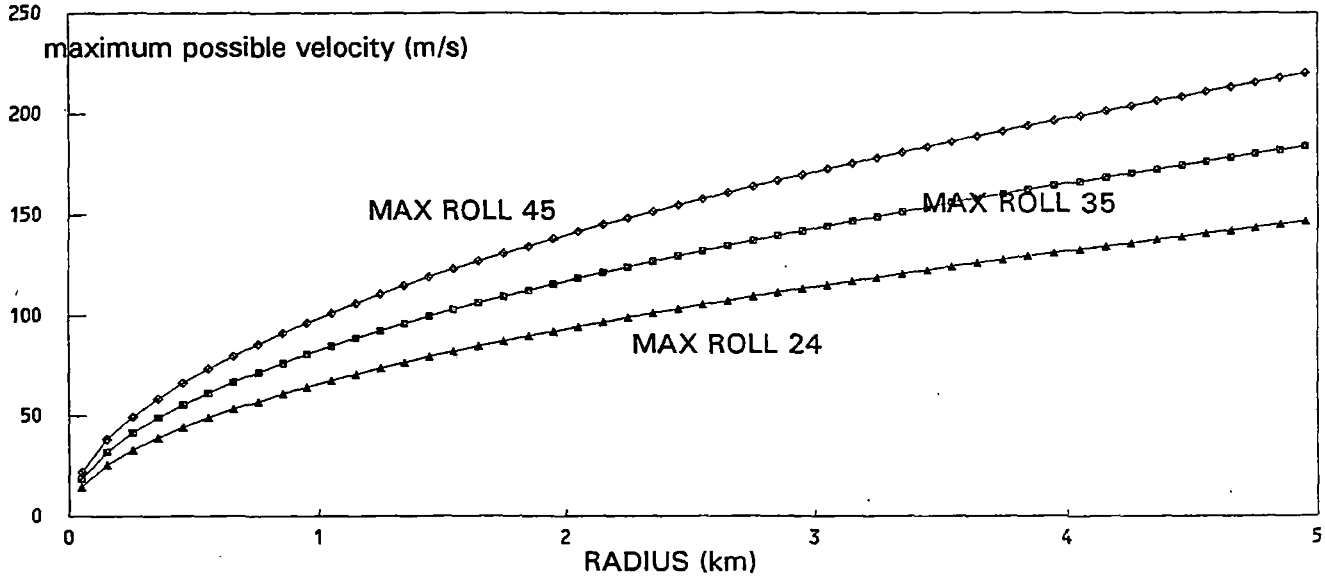


Figure 10 Effect of radius

5.3.3.2.f. PASSENGER THROUGHPUT

MOTIVATION. This study measures the effect of varying the passenger throughput.Both total cost and cost per passenger are shown. Throughput is a measure of the rate of passengers crossing a point in the magway. (The term "capacity", or *limit* of throughput, is technically a non-variable parameter of about 25,000 passengers per hour each way for the current system, but the term sometimes used synonymously with "throughput".)

VARIABLES. The passenger throughput is varied over the range 0 - 24,000 passengers per hour each way. The performance variable is cost.

CONSTANTS. The study uses the route configuration STR. See 5.3.3.1.b.

CONCLUSIONS. Figure 11 and Figure 12 show the performance effects of variance of passenger throughput. It can be seen from the levelized annual cost graph that the annual operational cost catches up with the levelized annual capital cost as the throughput increases. Total cost is driven more by operational cost than by capital. From the two pie graphs in Figure 11 it can be seen that operations and maintenance (less energy) remains almost at a constant 8% of total cost regardless of throughput, while the portion of cost allocated to energy increases dramatically with throughput, and the portion of cost allocated to capital decreases dramatically with throughput.

NOTES

1. The blip in the graphs in Figure 12 at 11,250 passengers per hour indicates the point below which the electrical system can be made in a leapfrogging mode. Above 11,250, no leapfrogging can be used.

2. The cost results are not meant to be taken as a capacity upgrade plan. Each cost level shown represents a separate hypothetical system built and operated at that particular capacity. If a route is built for low throughput and subsequently upgraded, the cost structure will be vastly different. For the Magneplane baseline upgrade plan, see section 3.2.3.j.

CALCULATIONS. The costs were calculated as described in 5.3.3.1.c. The inputs to the cost spreadsheet were the throughput multiplier and the electrification multiplier.

The electrification multiplier was 1.00 for all throughput levels below 11,250, and 1.22 for all throughput levels above 11,250. The baseline system uses leapfrogged power converter scheme. This is applicable until vehicles run closer than 6 km apart. At closer spacing, which corresponds with throughput levels of 11,250 or more, leapfrogging is not an option. Since power converter stations account for 22% of total magway electrification costs (see section 5.3.11.), and it is assumed that a high-throughput, non-leapfrogging system would require twice the number of converter stations as a leapfrogging system, 122% of the baseline total magway electrification costs are assumed for a non-leapfrogging system.

The throughput multiplier, as listed in Figure 11, is equal to the fraction of 4,000 passengers per hour in the system in question. For example, the throughput multiplier is 6 for the 24,000 passengers per hour system. The throughput multiplier is used in the cost spreadsheet for all inputs that are proportional to

through-put (pas/hr)	through-put multi-plier	annual capital ($/m)	annual operations ($/m)	total annual ($/m)	passengers per year	pas. cost ($/pas-km)
0	0	1694	137	1831	0	
2000	0.5	1865	337	2202	2.6×10^7	0.084
4000	1	2019	617	2636	5.3×10^7	0.050
8000	2	2345	1097	3442	1.1×10^8	0.033
12000	3	2780	1576	4356	1.6×10^8	0.028
16000	4	3105	2056	5161	2.1×10^8	0.025
20000	5	3431	2535	5966	2.6×10^8	0.023
24000	6	3756	3015	6771	3.2×10^8	0.021

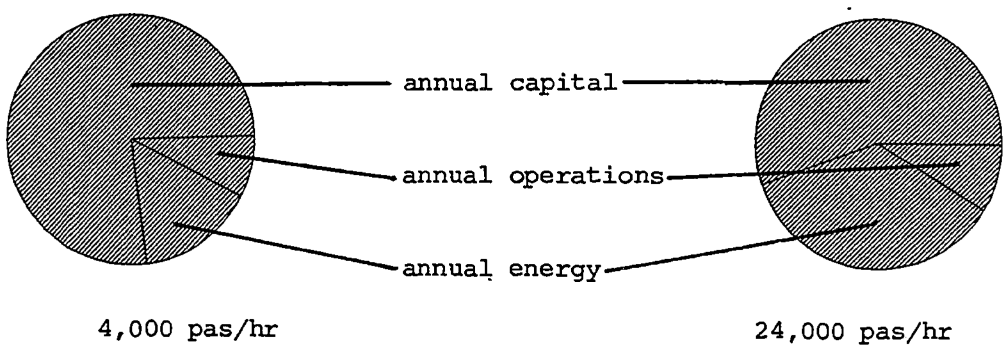
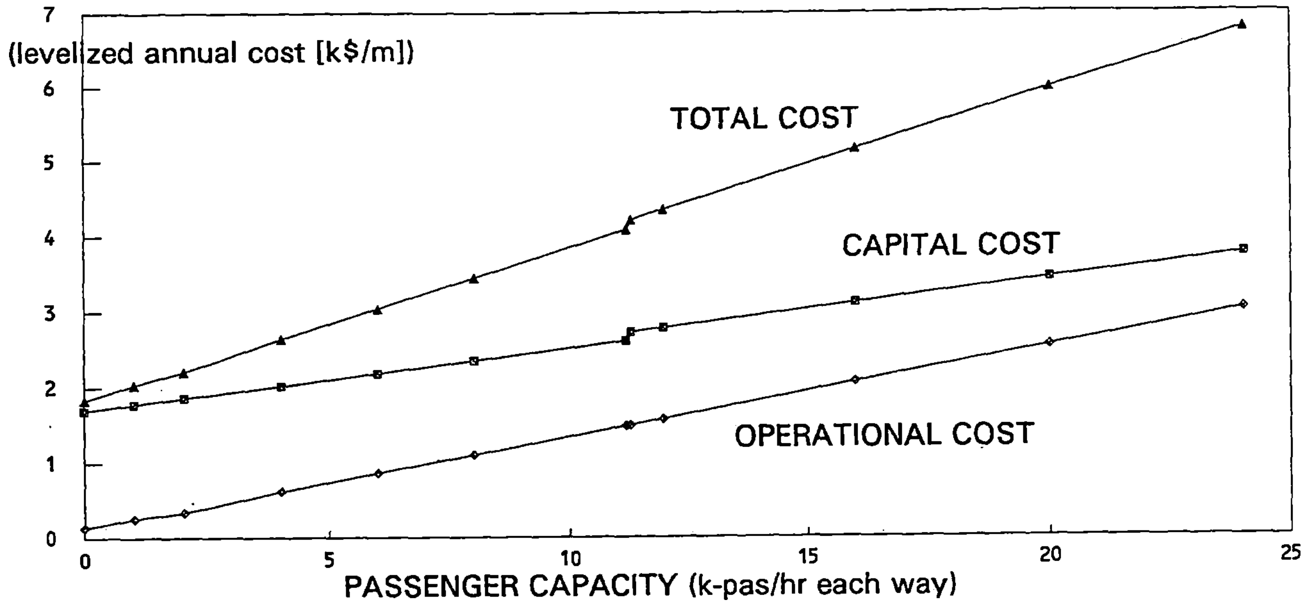


Figure 11 Effect of passenger throughput (values)

throughput. The principal ones are vehicles (capital), vehicle maintenance, and vehicle energy.



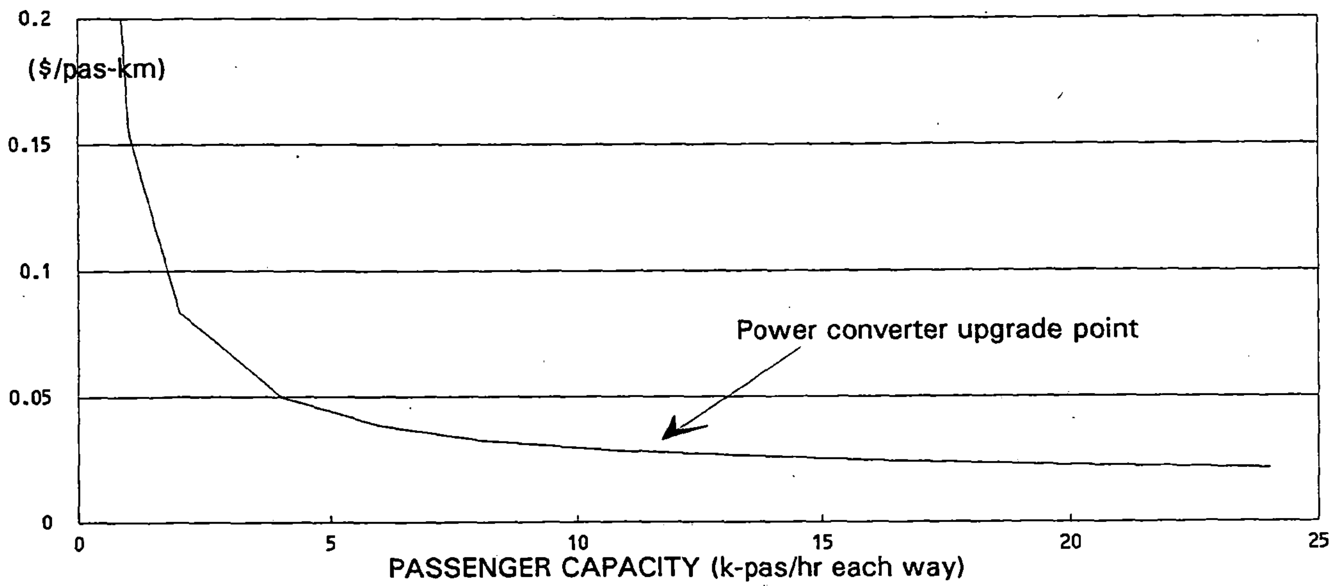


Figure 12 Effect of passenger throughput (graphs)

5.3.3.2.g. BLOCK LENGTH

MOTIVATION. This study measures the effects of varying the block length holding all other variables constant.

VARIABLES. The block length is varied over the range 0.1 - 10.0 km. This changes both the amount of energy used and the spacing (quantity) and rating of converter stations. The performance variable is cost.

CONSTANTS. The study uses the route configuration STR. See 5.3.3.1.b.

CONCLUSIONS. Figure 13 and Figure 14 show the performance effects of varying the block length. The cost effect is quite large for small blocks (due to the quantity of converters) but has less effect for longer blocks. The optimal range is 1 - 2 km.

NOTES. None.

CALCULATIONS. The cost inputs are the capital cost increase for installed power and the cost of energy. The normalization points for both inputs were set at 2 km block lengths.

In Figure 13, the column "Power converter rating" is based on a standard value plus extra power needed for magway losses that depend on block length. The column "sum of converter ratings" is the power converter rating times the number of converters, which is half the number of blocks. The converter cost multiplier assumes that the installed power equipment cost is linear versus power; ie. that a 12 MW converter costs twice as much as a 6 MW converter. The electrical cost multiplier is 7.9% of the increase indicated by the converter cost multiplier, justified as follows:

power converter cost is 36% of power converter station cost (see 5.3.11.)
power converter station cost is 22% of magway electrification cost (see 5.3.11)
power converter cost is therefore 7.9% of magway electrification cost

The energy used represents one vehicle traversal of the route configuration STR. The specific values used in this study are:

system length: 160 km
operating current: 770 A
vehicle power: 4.8 MW
LSM winding resistance: 0.0001 Ω/phase/m

block length (m)	number of blocks	power converter rating (MW)	sum of converter ratings (MW)	converter cost multiplier	electrical cost multiplier	energy used (10^{17} J)	energy use multiplier
100	3200	4.8	7680	18.46	2.38	1.13	0.93
500	640	4.9	1568	3.77	1.22	1.15	0.95
1000	320	5.0	800	1.92	1.07	1.17	0.97
2000	160	5.2	416	1.00	1.00	1.21	1.00
3000	107	5.3	283	0.68	0.97	1.26	1.04
4000	80	5.5	220	0.53	0.96	1.29	1.07
5000	64	5.7	182	0.44	0.96	1.34	1.11
7500	43	6.1	130	0.31	0.95	1.44	1.19
10000	32	6.6	105	0.25	0.94	1.45	1.28

block length (m)	electrical cost multiplier	energy use multiplier	annual capital ($/m)	annual operations ($/m)	total annual ($/m)
100	2.38	0.93	2590	589	3179
500	1.22	0.95	2110	597	2707
1000	1.07	0.97	2048	605	2653
2000	1.00	1.00	2019	617	2636
3000	0.97	1.04	2007	633	2640
4000	0.96	1.07	2003	645	2648
5000	0.96	1.11	2003	661	2664
7500	0.95	1.19	1999	694	2693
10000	0.94	1.28	1994	730	2724

Figure 13 Effect of block length (values)

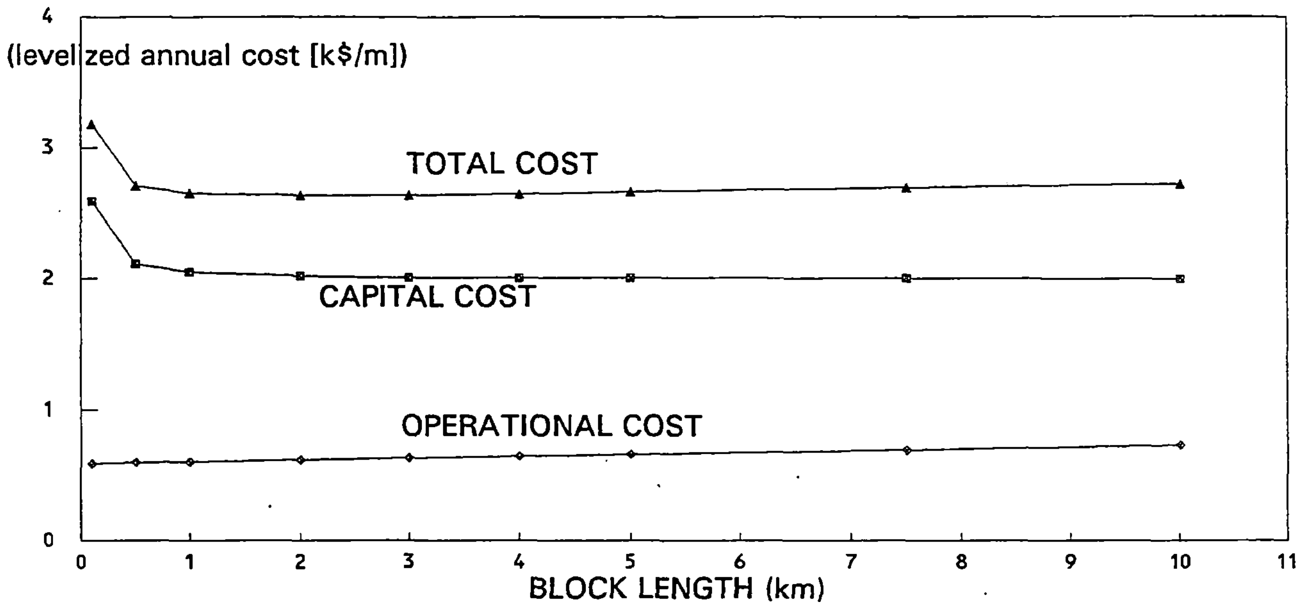


Figure 14 Effect of block length (graph)

5.3.3.2.h. TUNNEL SIZE

MOTIVATION. This study measures the cost effect of varying the diameter of a tunnel.

VARIABLES. The tunnel diameter is varied over the range 10 - 14 m. The performance variable is cost.

CONSTANTS. The study uses the route configuration STR. See 5.3.3.1.b.

CONCLUSIONS. Figure 15 shows the performance effects of variance of tunnel diameter. There is a very slight savings in operational costs due to reduction in drag associated with larger tunnels, but the main component of cost variance is in the tunnel excavation. This study indicates that the use of the smallest possible tunnel is the most cost effective.

NOTES

1. The effect of tunnels on ride quality is not considered in this parametric study because there is not necessarily any effect. In general it is assumed that a vehicle will slow down in a tunnel or at least experience a jolt on entry. In practice, the power supplied to the LSM can be increased in the tunnel to maintain a constant velocity, and the entry jolt can probably be eliminated through propulsion control. This depends on prototype testing and tunnel entry shape as discussed in section 3.2.3.c.

2. The actual diameter of tunnels used for Magneplane systems will probably be smaller than 10 m, which was the smallest tunnel size studied. The ultimate decision will be a tradeoff between capital cost and allowed entry jolt; energy cost will have no role in the decision because it is insignificant.

CALCULATIONS. The costs were calculated as described in 5.3.3.1.c. The inputs to the cost spreadsheet were the vehicle energy multiplier and an adder to total capital cost.

The vehicle energy multiplier is proportional to the total drag increase due to aerodynamic drag increase. Aerodynamic drag was assumed to be 46% of total drag, and total drag was calculated to first order by

$$\frac{\Delta D}{D} = \frac{1}{(1-A)^2-1}$$

where

D is aerodynamic drag
A is the ratio of vehicle frontal area to tunnel cross-sectional area

Drag calculations are given in more detail in section 3.2.2.k. The capital costs given in 5.3.11. were multiplied by the levelizing function (10.09%) to arrive at the annual costs presented in Figure 15.

diameter (m)	aerodynamic drag multiplier	vehicle energy multiplier	annual capital cost for tunnel ($/m)	annual capital ($/m)	annual operations ($/m)	total annual ($/m)
10	1.28	1.13	2481	4500	669	5169
12	1.16	1.07	3585	5602	647	6249
14	1.11	1.05	4747	6766	637	7403

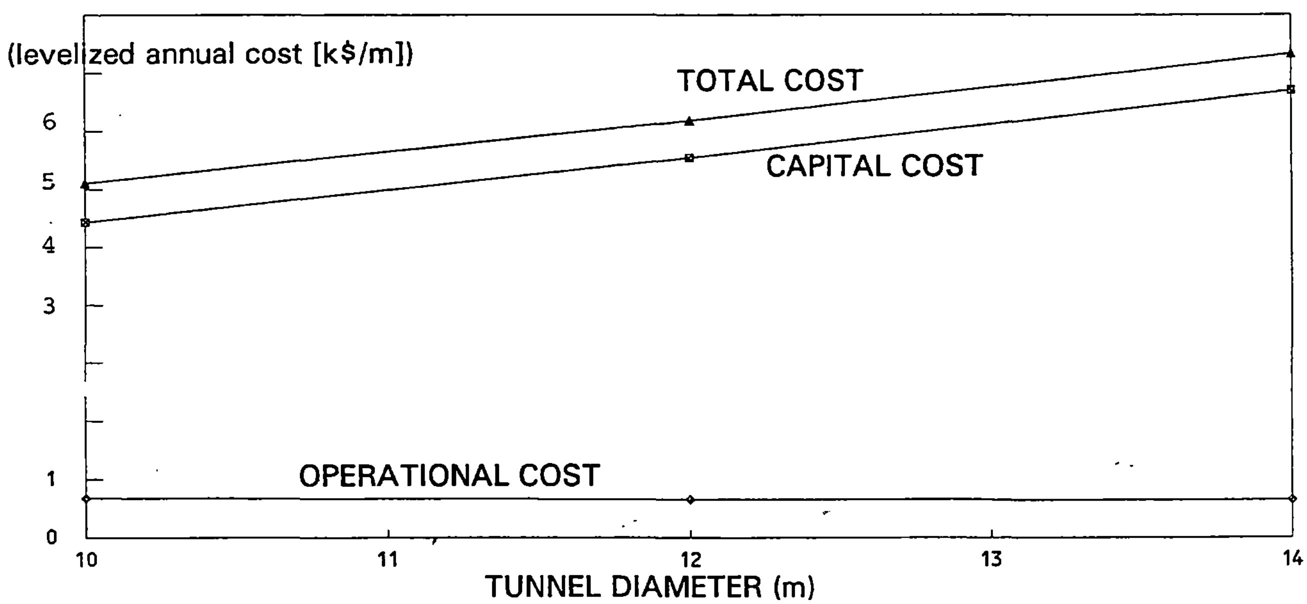


Figure 15 Effect of tunnel diameter (values, graph)

5.3.3.2.i. VELOCITY IN SWITCH

MOTIVATION. This study measures the effects of varying the velocity used in a switch. For higher velocities, the switch is longer and more expensive, but there are fewer operations limitations. Lower velocities in switches allow shorter switches but the system speed and capacity are reduced.

VARIABLES. The velocity in switches is varied over the range 65 - 134 m/s. Two ride quality standards are shown: BEST and MIN-B. The performance variable is the incremental cost of switch section over the displaced magway.

CONSTANTS. No route information is included in the study.

CONCLUSIONS. Figure 16 and Figure 17 show the incremental cost of a switch for various velocities during the turn-out maneuver and for two ride quality standards. The configuration of a switch should be carefully analyzed versus the operational constraint imposed by the switch velocity, for each locale.

NOTES

1. Velocity in a switch when the vehicle is continuing *straight* through is not limited as discussed above. The extra switch cost, which is incurred only due to the radius of the turn-out, is a function of the turn-out velocity only. Higher straight-through velocities do not add any cost to the system.

CALCULATIONS. Switches of various lengths were costed as described in supplement C. The costs in Figure 16 include civil structure only, not the electrical and controls costs that are associated with switches. The switch length required is a simple function of the turn-out radius. Radius is limited by the lateral acceleration limit imposed by the ride quality standard. While Magneplane normally self-banks in curves, significant banking cannot be done in switches. Therefore lateral acceleration will occur. Ride quality parameters are given in section 3.1.

Ride quality standard	Velocity (m/s)	Length (m) (including 150 m transition at each end)	Incremental cost of switch (k$)
BEST	65	533	2973
BEST	100	659	3702
BEST	134	781	4408
MIN-B	65	457	2529
MIN-B	100	541	3017
MIN-B	134	623	3492

Figure 16 Effect of velocity in switch (values)

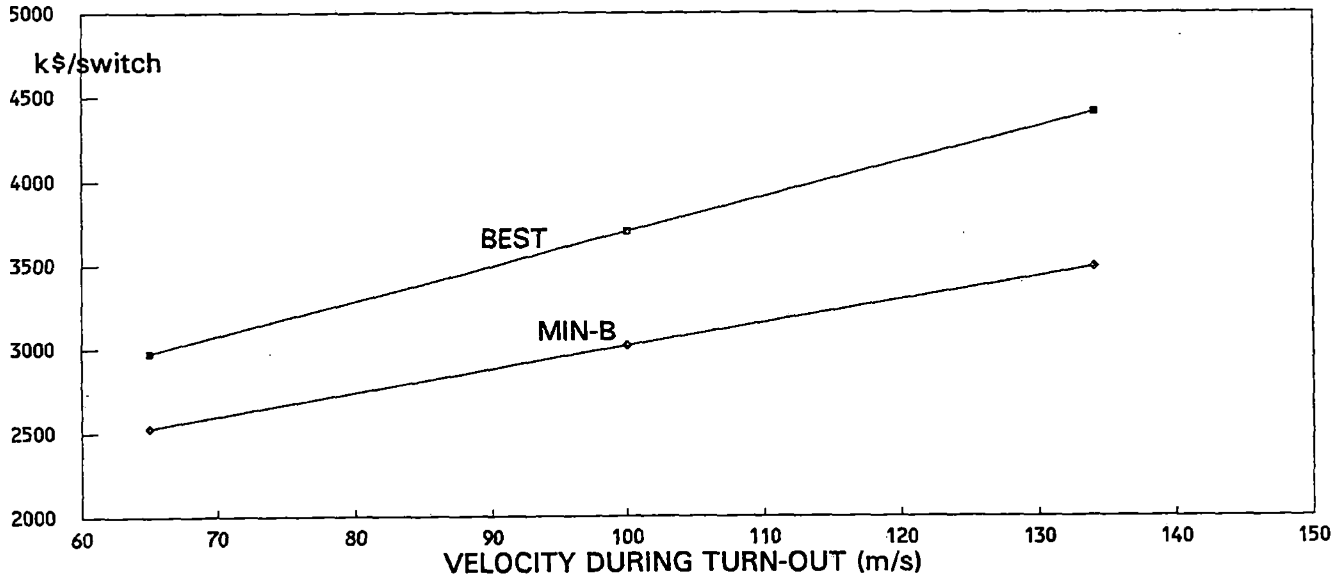


Figure 17 Effect of velocity in switch (graph)

5.3.3.2.j. SPAN LENGTH

MOTIVATION. This study measures the cost effect of varying the span length.

VARIABLES. The span length is varied over the range 4.6 m - 36.6 m. The construction material used also varies, according to the optimal material to use for each span length. For example, at 10 m, aluminum is the less expensive material. The performance variable is cost.

CONSTANTS. The study uses no route information. The span height is held constant at 5.18 m.

CONCLUSIONS. Figure 18 shows the performance effects of variance of span length. There is a minimum cost which occurs at about 9 m. For shorter spans, the number of piers tends to drive costs up, while for longer spans, the span bulk tends to drive costs up. Naturally a real route would have many different span lengths in it, according to the land.

NOTES

1. The minimum shown is only valid for 5.18 m heights. For taller magway structures, the optimal span length is longer. For shorter magway structures, the optimal span length is shorter. Figure 18 gives the general shape of the curve and an indication of the cost sensitivity of the system to span length in the general case.

2. See section 5.3.2.25. and 5.3.2.26. for additional information on magways at different heights.

CALCULATIONS. The costs were calculated as described in 5.3.3.1.c. The input to the cost spreadsheet was a magway multiplier, which was calculated according to the span costs as listed in the "magway cost" column of the table. The normalization point for costs is 9 m spans.

Span cost calculations may be found in 5.3.2.23.

span length (m)	optimal material for this length	magway civil cost ($/m)	magway capital cost multiplier	annual capital ($/m)	annual operations ($/m)	total annual ($/m)
4.57	aluminum	9695	1.05	2078	617	2695
9.14	aluminum	9235	1.00	2019	617	2636
13.72	aluminum	10473	1.13	2171	617	2788
22.86	steel	11395	1.23	2288	617	2905
36.58	steel	14058	1.52	2626	617	3243

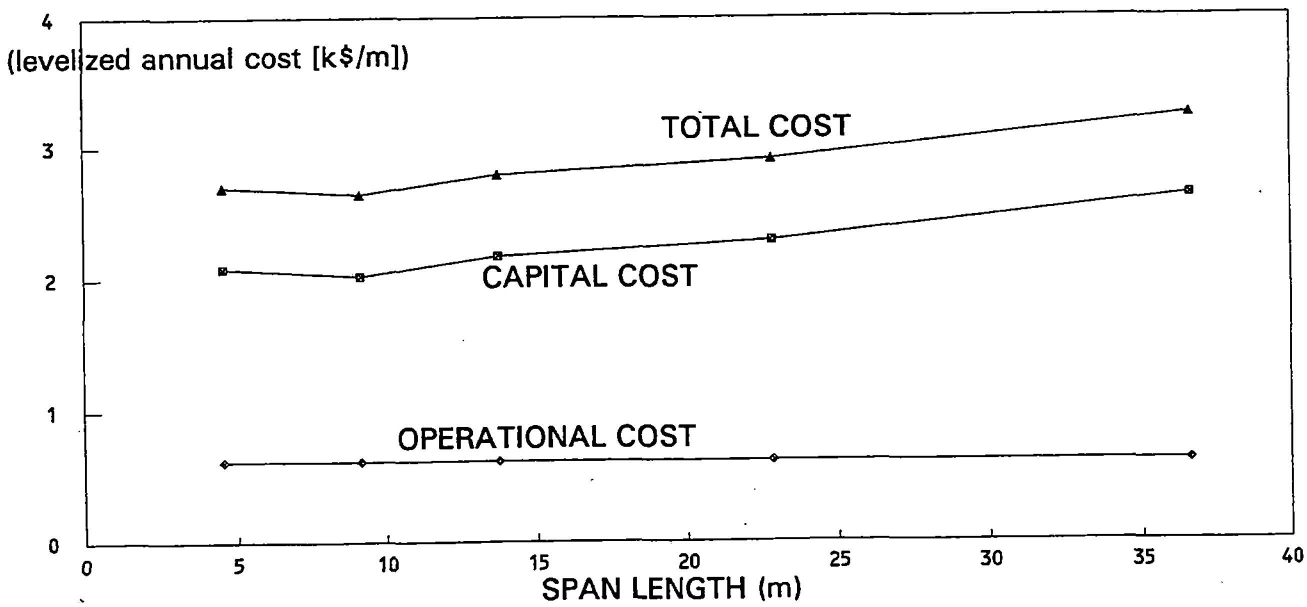


Figure 18 Effect of span length (values, graph)

5.3.3.3. RESPONSE TO THE STATEMENT OF WORK

The relevant portion of the Statement of Work is reproduced here for reference:

- Parametric Performance Report. The contractor shall provide analysis supporting the choice of performance limits embodied in the system concept. The contractor shall provide a parametric study of the following issues contained in Section C, paragraph: 3.1.1a; 3.1.2a; 3.1.3a,g; 3.2.1a-c,e,h; 3.2.2a-f; 3.2.3 b,c,g, as a minimum.

Our interpretation of the above paragraph is that the requirement is for a series of studies of the *performance* effects of variance of some specified *parameters*. Unfortunately, we were unable to identify a specific parameter that could reasonably be studied quantitatively in a number of the issues referenced in the paragraph. Each of the issues referenced is listed below with discussion.

We are providing "analysis supporting the choice of performance limits" but **not** in the sense of a tradeoff analysis. We did not provide justification for system parameters; we only showed how variation of those parameters affects cost or other performance variables. That is the nature of the work: first, we designed the system parameters (creatively and iteratively), then we costed the complete system, then we measured the effect of parameter variation. The tradeoff analyses, by contrast, were done *early* in the research, and were done in a completely different fashion, although they cover many of the same topics. (See section 5.3.2.)

What follows (5.3.3.3.a. - 5.3.3.3.r.) is a list of the parameters and issues that were required for study with discussion, notes, or references for each.

5.3.3.3.a. SPEED (ref. 3.1.1.a.)

This has been completed. See 5.3.3.2.a.

5.3.3.3.b. CAPACITY (ref. 3.1.2.a.)

This has been completed. See 5.3.3.2.f.

5.3.3.3.c. STRUCTURAL INTEGRITY (ref. 3.1.3.a.)

From the SOW:

> *Structural Integrity - (MR) Civil structure (foundation and structure supporting the guideway) shall have a minimum 50-year life. Consideration shall be given to structural integrity under earthquake and high-wind conditions.*

Design life and structural integrity of the civil structures were not studied in a parametric analysis.

Design Life: It is apparent in the life cycle cost analysis of the system that the amortization of the system capital cost dominates the life cycle cost. We do not believe that significant structural cost savings are obtained by shortening the design life. In fact, many of the important loading conditions obtain from occasional environmental conditions, such as high winds and earthquake and emergency operating conditions, and are not reduced by shortening the life span. However, large maintenance and replacement costs would be incurred if the design life is shortened.

Thus the most cost effective design life is as long as is consistent with the projected life of the technology. In other words, the system should be designed to last as long as possible, but not so long that the system gets replaced by newer technology before it has worn out.

Structural Integrity: Structural integrity requirements for earthquakes and high-wind conditions are developed to be consistent with applicable national building codes and are not subject to parametric analysis.

5.3.3.3.d. POWER SYSTEMS (ref. 3.1.3.g.)

From the SOW:

> *Power Systems - (DG) Power systems should be sized to provide vehicle acceleration and braking capacity for all operating conditions and should be capable of meeting requirements for system capacity. Guideway power systems should be capable of sustaining vehicles at full cruising speed up sustained grades of 3.5:100, and provide vehicle propulsion at reduced speeds up a maximum grade of 10:100.*

Power Systems Sizing: The power supplied was studied parametrically; see 5.3.3.2.d. The baseline power system is sized to meet the stated design goals. The vehicle can accelerate, brake, sustain speeds on grades and sustain speeds with headwinds with the proposed power system plan. Adequate electrification is proposed for the passenger carrying capacity specified, and an upgrade plan is included for increases in system capacity.

Acceleration and Braking Capacity: The ability to accelerate and brake cannot be compromised, although some trade-off of cost versus acceleration and deceleration rates can be observed. A parametric study of acceleration is given in 5.3.3.2.b. Acceleration was also implicitly taken into account in the study on power supplied (5.3.3.2.d.).

In the Hypothetical Route Report we analyzed the average velocity vs. ride quality standard, and found a 20% change in the average velocity between BEST and MIN-B ride quality standards. Thus 17% fewer vehicles are required to achieve the same route capacity using MIN-B as compared to BEST. The reduced cost of vehicles negates the additional electrification cost necessary to achieve the higher acceleration rates.

We conclude that the acceleration and braking requirements are set largely by the acceptance of ride quality and safety considerations rather than by the life cycle cost.

Capacity: Passenger throughput was studied; see 5.3.2.2.f.

Grade Capability: Change of the grade performance goal has little impact on the overall life cycle cost of the system. Grade performance requirements are locally determined by terrain. Magway propulsion capacity is installed as needed.

5.3.3.3.e. LEVITATION AND GUIDANCE SYSTEMS (ref. 3.2.1.a.)

From the SOW:

> *Levitation and guidance systems including magnet design and configuration, cooling, control system requirements, power requirements, and failure modes.*

The fundamental levitation and guidance concept of the Magneplane system was not studied formally in a parametric analysis.

Levitation and Guidance: The fundamental operation of the system relies on the cooperation of various elements including the magway shape and magnet placement. These items cannot be meaningfully varied for any analytic purpose. Any variance in these parameters would have a snowball effect: many other subsystems would have to be redesigned and recosted to maintain operability, and there is no indication that a study of this sort is worthwhile.

Magnet Design and Configuration, Cooling: Trade studies were performed looking at various choices in this area, but no meaningful parametric study can be done (see Levitation and guidance, above). Tradeoff analyses are referenced here:

levitation height, ref. 5.3.2.1;
separation between on-board magnets and concrete reinforcing, ref. 5.3.2.7;
superconducting coil charging procedure, ref. 5.3.2.8;
type of superconducting wire, ref.5.3.2.9;
distribution of levitation modules, ref. 5.3.2.10;
choice of dipole vs. quadruple levitation modules, ref. 5.3.2.11
temperature of the superconducting wire, ref.5.3.2.12;
magway levitation structures (sheets vs. coils vs. ladders), ref 5.3.2.13;
levitation sheet thickness and joints, ref. 5.3.2.14;
number of superconducting magnet modules, ref. 5.3.2.15;

cryogenic cooling and shielding methods, ref. 5.3.2. (subsection number not available at publication time).

Control System Requirements: The on-board superconducting magnets are not actively controlled under normal operating circumstances. They are steady-state magnets.

Power Requirements: The on-board superconducting magnets are unpowered with the exception of the cryogenic refrigerator which is described in section 3.2.1.a.2.

Failure Modes: Failure modes analysis of the on-board superconducting magnets and cryogenic system is described in the safety plan.

5.3.3.3.f. PROPULSION SYSTEM (ref. 3.2.1.b.)

From the SOW:

> *Propulsion system, including motor design, power factor, energy requirements and abnormal speed considerations.*

The fundamental propulsion concept of the Magneplane system was not studied formally in a parametric analysis; ie. we did not specify system cost and performance for other methods of propulsion.

Motor Design: Trade studies were performed for various aspects of the motor design, referenced as follows:

LSM winding pitch, ref. 5.3.2.18;
LSM propulsion coil current, ref. 5.3.2.19;
propulsion configuration in curves, ref. 5.3.2.21;

Power Factor: The system power factor can be adjusted to near unity by installation of power factor correcting capacitors. Detailed trades for installation of said devices can be performed based on local utility needs.

Energy Requirements: The LSM was designed to produce maximum coupling efficiency between the magway and vehicle consistent with the levitation gap. Small changes to the gap have a small effect on the motor efficiency while producing significant effects on many fundamental design parameters. See section 5.3.2.1 for further discussion.

Abnormal Speed Considerations: The LSM has been designed to produce adequate propulsion and braking for vehicle operation at any speed up to the local design velocity. See 3.2.1.b. This is a design requirement and is not meaningful as a parametric performance analysis.

5.3.3.3.g. STRUCTURAL DESIGN CONSIDERATIONS (ref. 3.2.1.c.)

From the SOW:

> *Structural design considerations, including weight and crashworthiness considerations.*

Vehicle structural design considerations were not studied formally in a parametric analysis. Structural considerations are dictated by applicable FRA and possibly FAA regulations and by the design considerations for vehicle levitation and propulsion. Much of the structural requirement comes from the vehicle stiffness needed to keep the natural frequency of the vehicle body above the control band for aerodynamic and LSM motion damping.

Weight: The vehicle weight was minimized consistent with meeting the structural requirements.

Crashworthiness: The SOW crashworthiness requirement is minimal. The vehicle has been designed to comply and has included protection against bird strikes. These requirements have not been studied vs. vehicle cost and performance.

5.3.3.3.h. ACTIVE AND/OR PASSIVE BANKING (ref. 3.2.1.e.)

From the SOW:

> *Active and/or passive banking, including the minimum horizontal and vertical radii of curvature as a function of vehicle velocity.*

Magneplane vehicle banking for curves is accomplished by natural banking of the vehicle in curves and by the design detail of the magway in curves. There is no physical banking mechanism. No meaningful parameter for formal study can be identified. Related parametric performance studies are 5.3.2.2.c. (roll angle) and 5.3.2.2.e. (radius).

5.3.3.3.i. SUSPENSION SYSTEM APPROACH (ref. 3.2.1.h.)

From the SOW:

> *Suspension system approach to meet ride comfort requirements, including primary and secondary, active and passive systems.*

The Magneplane has no secondary suspension. Vibration and disturbance damping is achieved by the use of the LSM with supplementary control by aerodynamic surfaces.

The damping method is not meaningfully subject to parametric performance analysis. The damping tools are required to enable operation of the vehicle. Changes to the acceptable ride quality standards have little effect on the cost of the damping system.

5.3.3.3.j. CIVIL STRUCTURAL ELEMENTS (ref. 3.2.2.a.)

From the SOW:

> *Civil structural elements, including piers, footings, columns, spans and materials used and adjustability of structure to maintain required alignment.*

Civil structural elements were not studied formally in parametric analyses. However, extensive trade studies were performed looking at various choices for the structure, referenced as follows:

magway structural system, ref. 5.3.2.23.
magway height, ref. 5.3.2.25.
span length, ref. 5.3.2.26. and 5.3.3.2.j.
magway foundations, ref. 3.2.2.a.5.

Adjustability: The Magneplane system is designed to operate with good ride quality with magway misalignments of 10 mm at joints and can operate without compromising safety with magway misalignments of up to 50 mm. Magway settlements of 100 mm can be negotiated without hazard.

Magway alignment and realignment is accomplished with simple surveying and shimming methods and are not a significant cost factor.

5.3.3.3.k. MAGLEV ACTIVE/PASSIVE ELEMENTS (ref. 3.2.2.b.)

From the SOW:

> *Maglev active/passive elements, including propulsion, guidance and levitation system components, mounting and means of alignment adjustment, and optimum material properties.*

Maglev active/passive elements were not studied formally in a parametric analysis. However, trade studies for propulsion and leviation elements were performed, referenced as follows:

levitation height, ref. 5.3.2.1;
separation between on-board magnets and concrete reinforcing, ref. 5.3.2.7;
superconducting coil charging procedure, ref. 5.3.2.8;
type of superconducting wire, ref.5.3.2.9;
distribution of levitation modules, ref. 5.3.2.10;
choice of dipole vs. quadruple levitation modules, ref. 5.3.2.11.
temperature of the superconducting wire, ref.5.3.2.12;
magway levitation structures (sheets vs. coils vs. ladders), ref 5.3.2.13;
levitation sheet thickness and joints, ref. 5.3.2.14;
number of superconducting magnet modules, ref. 5.3.2.15;

cryogenic cooling and shielding methods, ref. 5.3.2. (Subsection number not available at publication time).
LSM winding pitch, ref. 5.3.2.18;
LSM propulsion coil current, ref. 5.3.2.19;
propulsion configuration in curves, ref. 5.3.2.21.
magway structural system, ref. 5.3.2.23.

Mounting and Means of Alignment: Mounting and alignment of levitation and suspension elements is done through standard construction methods.

Material Properties: The primary material for magway levitation and propulsion elements is aluminum. Copper as an alternate material was considered but quickly discarded due to weight and cost considerations.

Specific aluminum alloys for the levitation plate and LSM remain to be specified. Conventional alloys (e.g. 6061-T6 for levitation plate) are applicable.

5.3.3.3.el. ALIGNMENT TOLERANCES (ref. 3.2.2.c.)

From the SOW:

> *Alignment tolerances, and sources of disturbances (expansion gaps, thermal distortion, warpage, differential settlement of substructure, wear, etc.)*

Alignment tolerances and sources of disturbances were not studied formally in parametric analyses. The Magneplane system has specified alignment, deflection and settlement tolerances that are consistent with maintaining adequate ride quality using the control authority available through LSM and aero-dynamic damping. One of the demonstrated benefits of the Magneplane system is the ability to build the system with conventional fabrication and installation techniques.

The deflection tolerance specified is L/2000 and the end/gap alignment requirement is 10 mm. Settlements of 20 mm can be accommodated without adjustment. (See section 3.2. for final accurate values of these tolerances, in case of reporting schedule limitations.)

Considerable effort has gone into the costing exercise for the system proposal; however, we have not developed estimations for the costs associated with constructing magways with higher or lower tolerances or with maintaining higher or lower tolerances through maintenance. The extra costs of a smoother alignment would definitely not be justified since there is no significant benefit.

Parametric study of construction tolerance is more appropriate for maglev systems that propose extremely smooth alignments.

5.3.3.3.m. ENTRY/EXIT METHOD (ref. 3.2.2.d.)

This has been completed. See 5.3.3.2.i.

5.3.3.3.n. CONSTRUCTION AND FABRICATION TECHNIQUE (ref. 3.2.2.e.)

From the SOW:

> *Construction and fabrication techniques, with approaches to minimize costs.*

Construction and fabrication techniques were not studied formally in a parametric study. The Magneplane system has been designed and costed using standard construction and fabrication methods. Some cost benefits can be realized through the development of specialized tooling and fixtures. In addition, special methods will be developed for sensitive areas, such as wetlands.

5.3.3.3.o. POWER REQUIREMENTS... (ref. 3.2.2.f.)

From the SOW:

> *Power requirements, proposed distribution method, lightning protection and grounding.*

Power requirements: The power supplied was studied parametrically; see 5.3.3.2.d.

Distribution method: The distribution voltages, bus structures and substation sizing and spacing are done with standard methods. No meaningful parametric analysis can be done.

Lightening Protection and Grounding: Lightening protection and grounding for the distribution system is consistent with accepted codes and practices. No meaningful parametric analysis can be done.

5.3.3.3.p. CLIMATIC EFFECTS (ref. 3.2.3.b.)

From the SOW:

> *Climatic effects including the impact of adverse weather, such as wind blown dust and debris, ice, snow, rain, wind, fog, thermal cycling.*

Climatic effects were not studied formally in a parametric analysis. Discussion of the system operation and projected weather effects is included in section 3.2.3.b. It is projected that most adverse weather will not effect system operation. Ice and snow will melt due to heating of the magway and LSM from drag and propulsion losses. Accumulation of debris is inhibited by the passage of high speed vehicles. Rain, wind, and fog have no direct effects with the exception of the note below. The magway has been designed to function within a broad range of temperatures. For these reasons, no meaningful parametric analysis can be done.

Note: An important issue remains as to whether the efficacy of the emergency brakes is altered by rain, dust, etc. If so the stopping distances must be altered accordingly. It is not possible to quantitatively determine this factor without testing the brake materials in a realistic manner. This work is part of the test and development effort.

5.3.3.3.q. SPECIAL EFFECTS (ref. 3.2.3.c.)

From the SOW:

> *Effects of entering and exiting tunnels and passing other vehicles.*

The effects of entering tunnels and passing other vehicles were not studied formally in parametric analyses.

Tunnel Entry: Tunnel entrances will be tapered to reduce the drag pulse felt by the vehicle while making the transition to the higher-drag environment of the tunnel. It is also possible to adjust the propulsion of the LSM to compensate for the drag change. These options were not pursued in detail for this concept definition study. A trade study will eventually be performed on the costs of shaping the tunnel portals vs. costs associated with giving a boost to the LSM thrust. This will occur when prototype testing data is available.

Passing Other Vehicles: A similar situation pertains to the passing of other vehicles. A study of the drag change in passing other vehicles has been included in section 3.2.2.g.

Due to the reasons indicated in the above, no meaningful parameters could be identified for the purposes of a formal parametric analysis.

5.3.3.3.r. POWER DISTRIBUTION AND CONTROL (ref. 3.2.3.g.)

From the SOW:

> *Power distribution and control, including substation spacing and sizing, voltages and frequencies, block size, and distribution method.*

Power Supply, substations, voltages, and frequencies: Specifications for power supply, substation size and spacing, distribution voltage, bus structure are done according to standard utility methods. The frequency for the distribution system is 60 Hz. No meaningful parameter for formal parametric analysis can be identified.

Power Control: Two methods of power control were studied for conversion of utility power to the LSM supply frequency and voltage. See section 5.3.2.

Block Size and Distribution Method: A parametric study of block size is given in 5.3.3.2.g. In addition, a tradeoff analysis was performed to study the optimal block length and distribution method between the power converter and magway LSM. See section 5.3.2.17.

5.3.4. ENERGY ANALYSIS

CONTENTS

FIGURES

5.3.4.1. ENERGY DEFINITIONS

This report shows the energy usage of the Magneplane system under various ideal conditions, and the energy one could expect to use on a real route.

Mechanical energy, in this report, means the energy used towards the following:

- acceleration/deceleration (positive or negative)
- climbing grades (positive or negative)
- aerodynamic drag
- electromagnetic drag
- landing gear drag
- on-board power

"Mechanical energy" has a general common definition, but here we use this specific definition for the term. There is also energy used, which is not included where the term "mechanical energy" appears. This, which we will call *utility energy* consists of:

- total mechanical energy
- resistive loss in LSM winding
- resistive loss in power conversion and local distribution

The reason for distinguishing formally between mechanical energy and utility energy is that mechanical energy is a function of dynamic properties of the vehicle, while utility energy is a function of mechanical energy and magway properties. In particular, utility energy is sensitive to block length while mechanical energy is not.

Mechanical energy will be used for a large part of the analysis in order to avoid the complexity of the extra variable of block length. Where actual energy projections are made with associated costs, utility (real) energy is used.

5.3.4.2. ENERGY FLOW

5.3.4.2.a. MAIN ENERGY FLOW PATH

The sole energy source and flow considered in this section (5.3.4.) is that which comes from the utility grid, flows through the Magneplane distribution line, power converters, LSM winding, and vehicle electrical system. There are other energy paths, such as the energy used for maintenance and magport operation, and the energy stored in the superconducting coils. These are not included here, because they are independent circuits and are topics for separate, future study.

The energy flow for a single vehicle is diagramed in Figure 1. There is a single-line flow from the source to the LSM winding through the distribution mechanisms.

Although each electrically isolated LSM winding (up to 2 km in length) is powered for its full length, most of the energy is taken up at the location where the vehicle is, and only a minority is lost in the rest of the LSM length. About 80% $\pm$ 10% is efficiently transferred to the vehicle and the rest is lost in magway heating, depending on a large number of variables.

Of the energy transferred to the vehicle, about 0.25 MJ/s (250 kW) is used for on-board operations, and the remainder (up to 20 or 30 MJ/s depending on route design and local conditions) is used for propulsion.

Propulsion energy flows into three areas: aerodynamic drag, landing gear drag, and electromagnetic drag. (Levitation is a passive effect, which occurs at the expense of electromagnetic drag on the propulsion system.)

The final form of all electrical input energy is heat energy. Over the course of normal daily vehicle operation, about half ($\pm$20%) of the input energy is converted to heat in the magway structure, and the other half in converted into heat in the air and vehicle skin due to air friction.

5.3.4.2.b. TEMPORARY ENERGY EFFECTS

The main energy flow path described in 5.3.4.2.a. exhibits continuous exceptions due to energy storage effects. Over the course of an operating day, all input energy is converted into heat energy as stated; however, the vehicle stores energy either as kinetic energy or gravitational potential energy during its route traversal.

Gravitational potential energy is one form of energy storage. During a grade climb, the system energy input is not all converted into heat, but is used to lift the vehicle vertically. On the down-hill side, the gravitational potential energy is re-gained.

Vehicle kinetic energy is the other form of energy storage. During acceleration, the system energy input is not all converted into heat, but is converted into vehicle kinetic energy. During deceleration, that energy is then re-gained.

The results of these temporary energy effects are:

1. The net energy demand for a vehicle fluctuates widely in short time periods. For example, it may accelerate and draw 24 MW, then coast down a hill a minute later and draw only 2 MW at cruising speed, and so on.

2. Despite the fluctuation in vehicle energy draw, the typical power converter must supply only a small power range in normal operations. For example, a converter supplying a straight magway block might supply 5 MW $\pm$ 1 MW. A converter supplying an entry ramp might supply 20 MW $\pm$ 4 MW.

3. Gravitational potential energy and kinetic energy must be reconverted into electrical energy at times when the net energy demand for the vehicle is negative. This occurs on steep down grades and during deceleration (on exit ramps and in blocks before curves).

4. The Magneplane distribution line, which generally runs alongside the magway and supplies all the power converters, experiences a variable energy flow. A large amount of energy may be removed from the line by one converter station, while another converter station may supply power to the line at all times. The situation may change at another time of the day.

5. Despite the erratic pattern on the Magneplane distribution line, the utility grid experiences an almost constant draw from a Magneplane system, due to the averaging effect of many vehicles.

Note that the temporary energy storage effects do *not* result in conversion of usable stored energy into waste heat. *Magway and air heating remain about constant under all speeds, grades, and other conditions.*

5.3.4.2.c. ENERGY FLOW ON SYSTEM HALT

During a system halt, which may only happen in extreme emergencies, the combined kinetic energy of all vehicles on the system must be converted either into magway heat via emergency brakes or into electric energy in the utility grid. This is an exception to section 5.3.4.2.b., items 2 and 5.

The choice of conversion to electrical energy or heat energy depends on the local utility grid and the emergency at hand. Both methods are available for redundancy.

5.3.4.3. ENERGY CALCULATIONS

The energy use calculations for the Magneplane system are described in the Hypothetical Route Report, sections 3.5., 3.7., and appendix B.

In addition, the calculations for the components of drag are presented in this report, section 3.2.1.b. Software that calculates energy usage for the Magneplane system appears in Supplement G.

The energy use calculations in the Hypothetical Route Report are made in the context of the analysis of a route. Therefore, it is essential to refer to that source to understand the analysis.

A brief description of the energy calculations follows:

1. Divide the route into segments, and for each segment, calculate the relevant current conditions (acceleration, grade, radius of curvature, etc.). See the Hypothetical Route Report for details.

2. Calculate the thrust required to meet the demanded conditions. The total thrust is equal to the sum of the following forces:

    - force due to electromagnetic drag
    - force due to aerodynamic drag
    - force due to landing gear drag
    - force required to go up or down hill
    - force required to accelerate/decelerate

Drag force details are found in section 3.2.1.b.

3. Calculate the mechanical energy used by the vehicle when traversing the segment (thrust times distance) and mechanical power (mechanical energy per time).

4. Calculate the magway current and resistance, which are required to project LSM heating.

5. Calculate the LSM heating (P_{loss}) at each point:

$$P_{loss}=3I^2R$$

The factor of 3 is due to the three phases in the winding.

6. Calculate utility power:

$$P_{util}=e(P+P_{loss})+P_v$$

where

e = efficiency factor of power equipment and feeder cables (1.07)
P = mechanical power demand
P_v = loss due to on-board power drawn by vehicle (250 kW)

Note: In the case that there is regenerative power, the variable e is the *regenerative* efficiency factor (0.931), and P is negative.

By completing the above steps, the demands of each of the energy destinations and types of storage over a whole route traversal are calculated. These energy destinations and types of storage are:

- levitation sheet heating via electromagnetic drag
- air heating via aerodynamic drag
- magway/pad heating due to landing gear friction
- on-board electric components
- LSM winding resistive heating
- power distribution/conversion component heating
- vehicle kinetic energy
- gravitational potential energy

The energy demand for each of these items are combined and the total demand in each route segment is summed over all route segments. The result is the total energy demand for a route traversal.

Block length is an important factor in the energy calculation. See section 5.3.2.16. for a tradeoff study on block length, which was used for each individual block of the routes studied in the Hypothetical Route Report. Also see section 5.3.3.2.g. for the life-cycle cost effects of variation in block length.

5.3.4.4. ENERGY SENSITIVITY TO VELOCITIES AND GRADES

Figure 2 shows the mechanical power and energy demand for the large vehicle at a variety of speeds and grades. The mechanical power for each speed listed at zero grade is as follows:

20 m/s: 0.61 MW
60 m/s: 2.27 MW
100 m/s: 3.20 MW
134 m/s: 4.79 MW

Note that on the mechanical power graph, the lines almost cross at the same point on the axis. This is anti-intuitive, but it does in fact mean that a magplane could coast down a hill of about 8% grade at any speed and nearly maintain that speed without any input power. This is unlike other forms of transportation. (See below.) The reason for this is that the total drag experienced by the vehicle is almost constant over the whole velocity range (see 3.2.1.b.).

The mechanical energy graph illustrates this point even better. The mechanical energy use per vehicle-metre is about 34 kJ/m ± 3 kJ/m regardless of velocity.

In summary, energy use is almost totally insensitive to velocity, and varies linearly with grade.

5.3.4.5. ENERGY REQUIREMENTS FOR VARIOUS THROUGHPUT LEVELS

Energy use varies linearly with passenger throughput, assuming equal vehicle load. Thus by simple multiplication:

Assuming 6 MW per large vehicle = 43 kW/passenger
and trip time = 1 hr, then E = 43 kW-hrs/passenger-trip

4,000 pas/hr: 172 MW (172,000 kW-hrs/hr)
8,000 pas/hr: 344 MW (344,000 kW-hrs/hr)
12,000 pas/hr: 516 MW (516,000 kW-hrs/hr)
25,000 pas/hr: 1075 MW (1,075,000 kW-hrs/hr)

These values are for one-way travel only.

5.3.4.6. REAL PROJECTED ENERGY USE

The Severe Segment Test (See US Army Corps of Engineers "Maglev Hypothetical Route Plan & Profile" 1992) is an adequate route for the purpose of energy use projection. Although it is not realistic in the sense of curve density and placement, the total traversal energy is probably consistent with real routes.

Naturally, straighter routes will require less energy than curvy routes. For section 5.3.4.6., the Severe Segment Test energy results are used. This section uses kw-hrs instead of SI units for easy conversion to costs.

Note that the energy use reflected in the Life Cycle Cost Report is different because it reflects the energy use on a somewhat idealized route.

As stated in the Hypothetical Route Report, section 2, the energy required for one large vehicle to traverse the 800 km route is:

BEST ride quality: 9,622 kW-hrs
MIN-S ride quality: 10,311 kW-hrs
MIN-B ride quality: 10,494 kW-hrs

Since the ride quality standard has not yet been established for maglev, we assume 10,100 kW-hrs as a rounded average. This indicates 12.6 kW-hrs/km for the large vehicle.

The energy requirements for the small vehicle are about 60% of those for the large vehicle. Since they carry 45 passengers instead of 140 (32%). The energy cost per passenger of running small vehicles is therefore 1.88 times the cost of running large vehicles (60%/32%).

At $0.0852/kW-hr *(large vehicle)*:

12.6 kW-hrs/vehicle-km (1.07 $/vehicle-km)
0.0902 kW-hrs/pas-km (0.00769 $/pas-km)

Converting to the *small vehicle* at 60%:

7.56 kW-hrs/vehicle-km (0.644 $/vehicle-km)
0.169 kW-hrs/pas-km (0.0144 $/pas-km)

5.3.4.7. COMPARISON TO OTHER FORMS OF TRANSPORTATION

5.3.4.7.a. DISCUSSION

The main differences in energy flow and usage between Magneplane and previous forms of transportation are:

1. Magneplane (like an electric train) requires conversion of original fuels into electrical energy, which is then shared throughout the system. Cars and airplanes deliver the original fuel directly to the vehicle, where it is burned inefficiently and causes undue pollution.

2. Magneplane can achieve a higher load factor in normal operation than automobiles, trains, or planes. The incentive for underloading automobiles is high; the scheduling practices of trains and planes causes underloading. The Magneplane system, when operated for profit, will have the

incentive to load to capacity, and it has the *capability* to load nearer to capacity due to small dynamically-scheduled vehicles. Load factor has a large effect on energy usage.

3. The *drag curve* is strikingly different for Magneplane versus other forms of transportation. The drag curve refers to the plot of drag levels over the velocity range. Magneplane's drag curve is approximately flat, ie. the drag is always about the same. See section 3.2.1.b. for the exact plot. Intuition dictates that drag ought to increase with speed, which is what happens with cars, planes, and trains, and also with aerodynamic drag for Magneplane. However, electromagnetic (EM) drag is the opposite: the power input to the levitation system (in the form of EM drag) is higher at lower speeds. The sum of EM drag and aerodynamic drag is about constant.

4. As a result of the drag curve, the cost of energy does not go up with speed. For other transportation systems, it generally costs more to go faster; for Magneplane, it costs less to go faster. See section 5.3.3.2.a. for the specific cost information.

5.3.4.7.b. QUANTITATIVE COMPARISON

Figure 3 shows the energy intensity of cars, busses, trains, planes, and magplanes. The figure only shows the cost of *propulsion energy* for the different systems. There are many other cost differences, such as Magneplane's low maintenance requirements as compared with all other systems. See sections 5.3.7. and 5.3.11. for further discussion. Note that for the liquid-fueled modes, most of the energy use is on-site, while for the electric modes, most is used in the delivery.

5.3.4.8. OTHER FACTORS

Discussion of other energy-related factors such as power conditioning, switching transients, harmonics, and power factors can be found in section 3.2. Here is a list of the main sub-sections covering energy-related topics:

- 3.2.1.b. PROPULSION AND BRAKING SYSTEM
- 3.2.1.j. POWER PICK-UP SYSTEM
- 3.2.2.f. POWER
- 3.2.3.g. POWER DISTRIBUTION AND CONTROL
- 5.3.7.a. ADVANTAGES AND DISADVANTAGES
  - (5.3.7.a.14. MAGNEPLANE IS ENERGY EFFICIENT)

Refer to the index to find more specific topics.

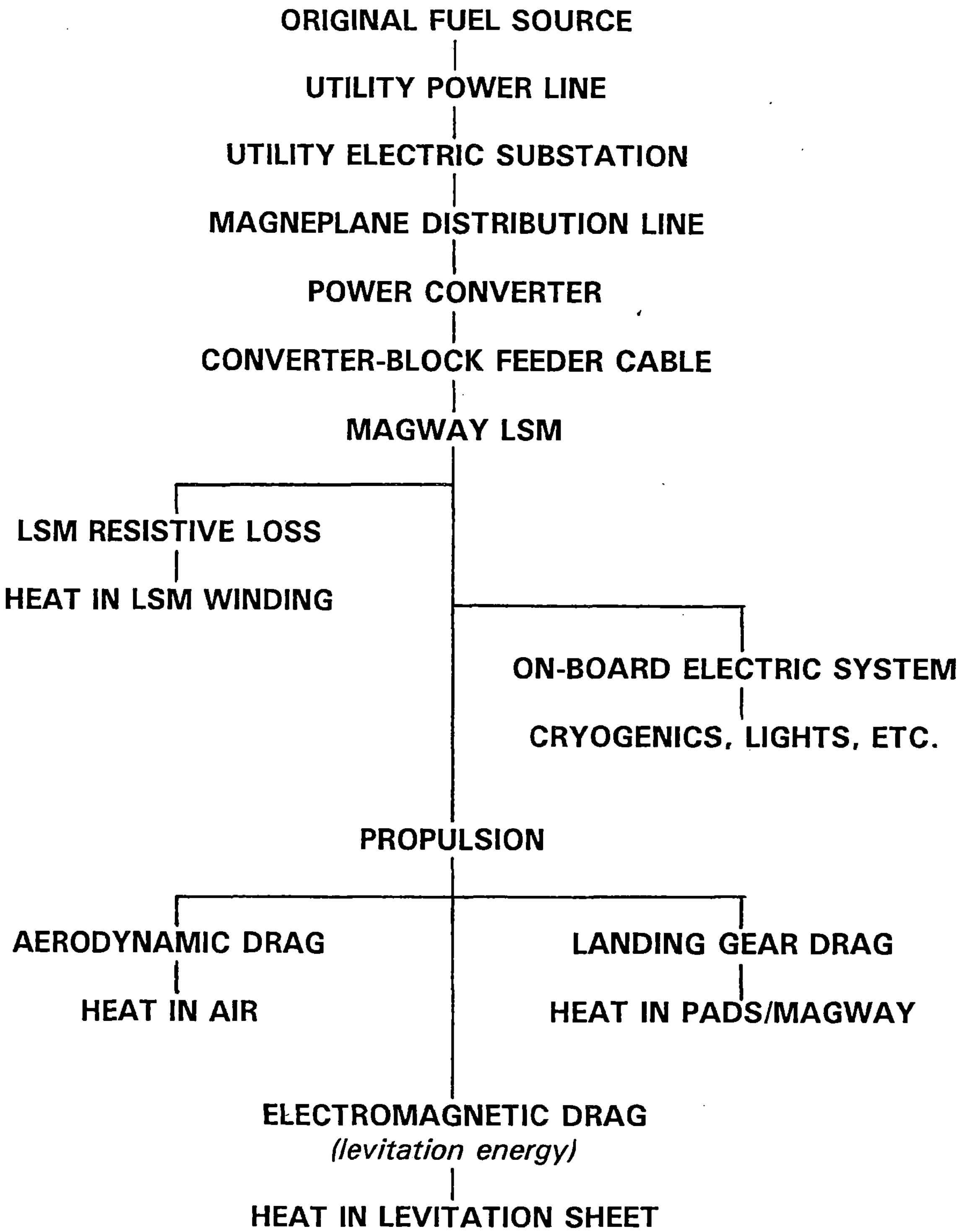


Figure 1 Energy flow diagram for the Magneplane system

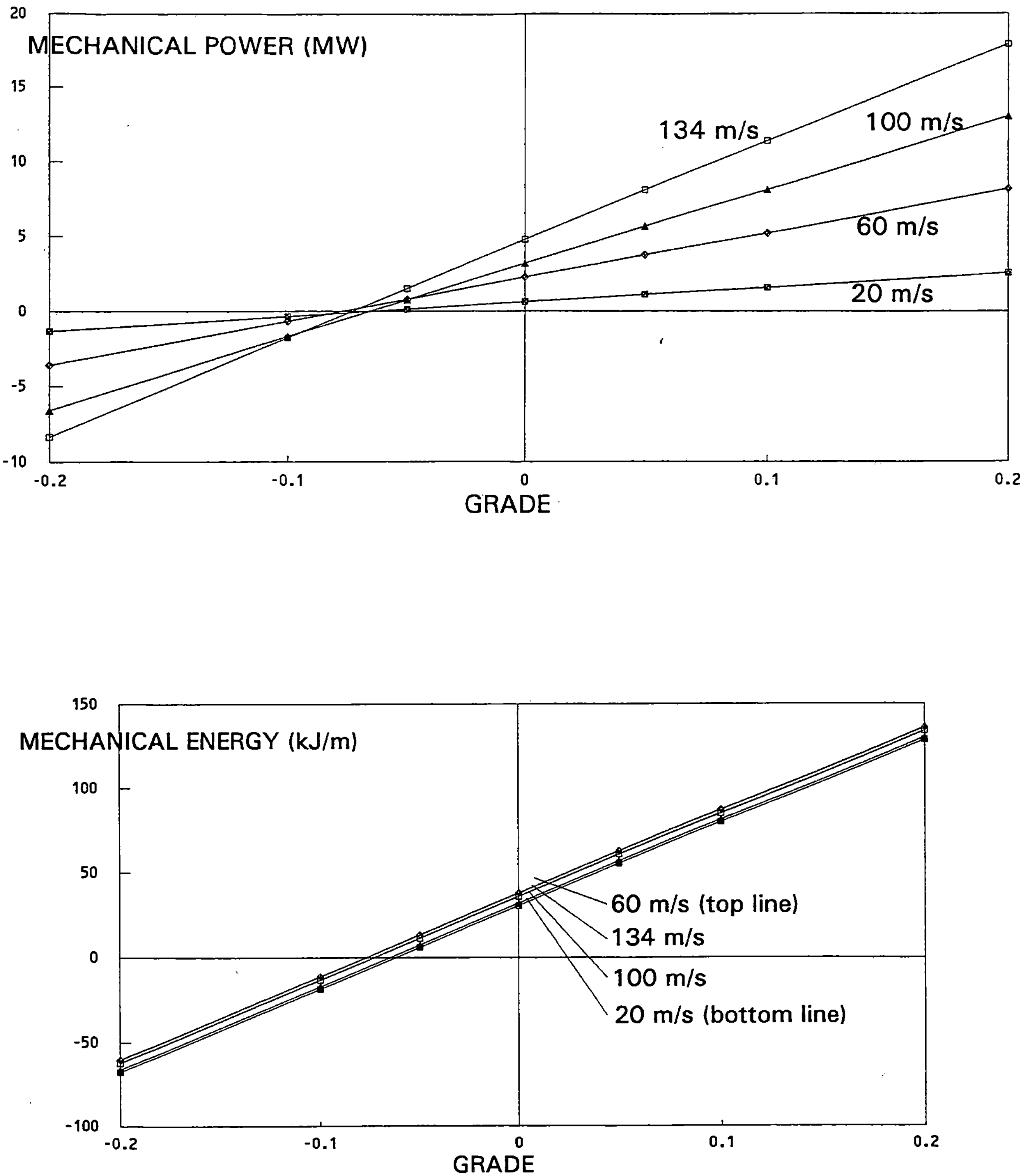
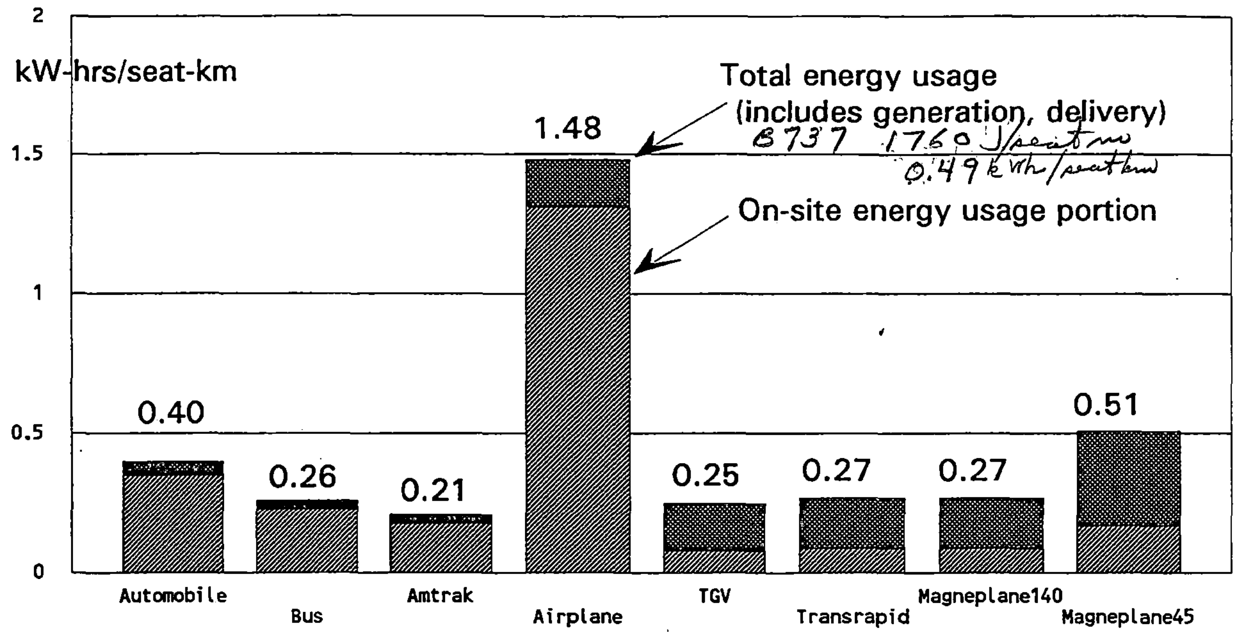


Figure 2 Mechanical power and energy requirements for various grades and velocities



ASSUMPTIONS FOR THIS GRAPH:

Automobile (gasoline): 2 pas/vehicle, 32.3 miles/gallon
Bus (diesel): Unknown assumptions
Amtrak (diesel): 100% load
Airplane (jet fuel): 100% load, 0-200 mile trip
TGV (electric): 100% load
Transrapid TR07 (electric): 100% load
Magneplane (electric): 100% load, both size vehicles given, see section 5.3.4.6.

Electricity generation is at 33% efficiency
Liquid fuel refining and transportation is at 89% efficiency

SOURCE: Center for Transportation Research, Argonne National Laboratory, "Maglev vehicles and superconductor technology: Integration of high-speed gound transportation into the air travel system", Publication ANL/CSNV-67

Figure 3 Comparison of energy usage of forms of transportation

5.3.5. MAINTENANCE PLAN

Elements of the maintenance plan have been identified and costed by system element, using conventional estimating techniques. Maintenance of the vehicle was assumed to take 1 man-hour per operating hour as is consistent with commercial aircraft practice. This includes labor required for cleaning and maintaining the vehicle body; testing and repairing control surfaces, actuators, controls and communications (devices similar to aircraft controls); and care and maintenance of the cryogenic refrigeration and superconducting magnet systems.

The magway maintenance plan is viewed as standard maintenance consistent with the size of the capital installation. Specific maintenance estimates were made of the magway physical structure, power distribution lines, power substation and power converter, LSM, global controls, and wayside communications and control systems.

The following thirteen pages list the maintenance cost elements and give estimated costs for each. Also see section 3.2.3.i., Operations and Maintenance.

MAGLEV COST ESTIMATION | SYSTEM CONCEPT DEFINITION

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS | SHEET 1

SUMMARY

COST ELEMENTS WBS NO.	DESCRIPTION	AVERAGE ANNUAL COSTS PER MILE	PER KM	TOTAL ANNUAL COSTS 100 MI/160 KM
21	MAINTENANCE COSTS			
211	GUIDEWAY MAINTENANCE COSTS	$50,000	$31,300	$5,000,000
212	VEHICLE MAINTENANCE COSTS	65,700	41,100	6,570,000
213	OTHER FIXED FACILITY MAINTENANCE COSTS			
2131	OVERHEAD DISTRIBUTION LINE COSTS	4,500	2,800	450,000
2132	POWER SUBSTATION & CONVERTER STATION COSTS	40,900	25,600	4,089,000
2136	LSM WINDING COSTS	53,800	33,600	5,376,000
2137	CENTRAL CONTROL FACILITY COSTS	1,800	1,100	178,000
2138	GUIDEWAY COMMUNICATIONS COMMAND AND CONTROL SYSTEMS COSTS	17,900	11,200	1,790,000
	TOTAL OTHER FIXED FACILITY MAINTENANCE COSTS	118,900	74,300	11,883,000
	TOTAL MAINTENANCE COSTS	234,600	146,700	23,453,000

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS SHEET 2

SUMMARY

COST ELEMENTS

WBS NO.	DESCRIPTION	AVERAGE ANNUAL COSTS PER MILE	PER KM	TOTAL ANNUAL COSTS 100 MI/160 KM
23	ON-BOARD OPERATING COSTS			
231	ON-BOARD PERSONNEL COSTS	$55,200	$34,500	$5,520,000
	TOTAL ON-BOARD OPERATING COSTS	55,200	34,500	5,520,000
24	OTHER FIXED FACILITY OPERATING COSTS			
241	TRAFFIC CONTROL COSTS	9,600	6,000	964,000
	TOTAL OTHER FIXED FACILITY OPERATING COSTS	9,600	6,000	964,000
	TOTAL ANNUAL OPERATING AND MAINTENANCE COSTS	$948,000	$592,600	$94,800,000

NOTE THE FOLLOWING:

1. THE WBS BREAKDOWN BASED ON INFORMATION IN THE CAPITAL COST ESTIMATION INTERIM REPORT, JANUARY 1992, PAGES 2-15 THROUGH 2-19.
2. ESTIMATE EXCLUDES RIGHT OF WAY COSTS.
3. ESTIMATE EXCLUDES GENERAL SALES AND ADMINISTRATIVE COSTS, INCLUDING SALES/MARKETING COSTS, INSURANCE COSTS AND ADMINISTRATION COSTS.

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS SHEET 3

OPERATING AND MAINTENANCE COST ELEMENT: WBS NO. 211 - GUIDEWAY MAINTENANCE COSTS

COST ELEMENTS

DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
LABOR TO MAINTAIN GUIDEWAY ANNUAL AVERAGE OF 4 MEN @ 200 FT/DAY (32 HR/200 FT = .16 HR/FT) DIRECT LABOR PER MILE = 5,280 FT X .16 = 845 HR ALLOW SUPERVISION LABOR @ 10% = 85 HR ALLOW MISC. SUPPORT LABOR @ 8% = 70 HR TOTAL LABOR PER MILE = 1,000 HR	HR	1,000	$30.00	$30,000
EQUIPMENT AND TOOLS PER LABOR HOUR TO MAINTAIN GUIDEWAY EQUIPMENT, TOOLS, VEHICLES, OPERATING EXPENSES, ETC. $10,000 COST PER MILE/1000 HRS. = $10.00/HR (5 WEEKS @ $2,000/WEEK = $10,000)	HR	1,000	$10.00	$10,000
MATERIAL COSTS ESTIMATE MATERIAL COST @ $10.00 PER HOUR OF LABOR	HR	1,000	$10.00	$10,000
TOTAL ESTIMATED ANNUAL MAINTENANCE COST PER MILE	HR	1,000	$50.00	$50,000
X NUMBER OF MILES			X	100
TOTAL ESTIMATED ANNUAL GUIDEWAY MAINTENANCE COST PER THE BASELINE PARAMETERS				$5,000,000 TOTAL

THE AVERAGE ANNUAL GUIDEWAY MAINTENANCE COST PER MILE OF THE BASELINE PARAMETERS — $50,000 PER MILE

OR

THE AVERAGE ANNUAL GUIDEWAY MAINTENANCE COST PER KM OF THE BASELINE PARAMETERS — $31,300 PER KM

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS SHEET 4

OPERATING AND MAINTENANCE COST ELEMENT: WBS NO. 212 - VEHICLE MAINTENANCE COSTS

COST ELEMENTS

DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
ORDINARY MAINTENANCE REQUIREMENTS ANNUAL AVERAGE COST PER VEHICLE BASED ON ONE HOUR OF MAINTENANCE PER HOUR OF OPERATIONS 18 HR/DAY X 365 DAYS/YR = 6,570 HR/YEAR PER VEHICLE (NOTE: $50.00/HR AVERAGE HOURLY RATE INCLUDES ALL LABOR, MATERIAL AND EQUIPMENT COSTS REQUIRED FOR ORDINARY MAINTENANCE)	HR	6,570	$50.00	$328,500

TOTAL ANNUAL AVERAGE MAINTENANCE COST PER VEHICLE BASED ON 6,570 OPERATING HOURS PER YEAR		$328,500 PER VEHICLE
X NUMBER OF VEHICLES	X	20
TOTAL ESTIMATED ANNUAL VEHICLE MAINTENANCE COST PER THE BASELINE PARAMETERS		$6,570,000 TOTAL
THE AVERAGE ANNUAL VEHICLE MAINTENANCE COST PER MILE OF THE BASELINE PARAMETERS		$65,700 PER MILE
OR		
THE AVERAGE ANNUAL VEHICLE MAINTENANCE COST PER KM OF THE BASELINE PARAMETERS		$41,100 PER KM

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS

SHEET 5

OPERATING AND MAINTENANCE COST ELEMENT: WBS NO. 2131 - OVERHEAD DISTRIBUTION LINE MAINTENANCE COSTS

COST ELEMENTS

DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
ORDINARY MAINTENANCE REQUIREMENTS ANNUAL AVERAGE COST BASED ON HISTORICAL COST DATA FOR SIMILAR DISTRIBUTION PLANT FACILITIES AS A % OF CAPITAL COST:	LS	1	$450,000	450,000

CAPITAL COST ESTIMATE	$15,000,000 TOTAL
X % OF CAPITAL COST	3%
= MAINTENANCE ESTIMATE	$450,000 TOTAL

TOTAL ESTIMATED ANNUAL MAINTENANCE COST PER THE BASELINE PARAMETERS	$450,000 TOTAL
THE AVERAGE ANNUAL MAINTENANCE COST PER MILE OF THE BASELINE PARAMETERS	$4,500 PER MILE
OR	
THE AVERAGE ANNUAL MAINTENANCE COST PER KM OF THE BASELINE PARAMETERS	$2,800 PER KM

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS SHEET 6

OPERATING AND MAINTENANCE COST ELEMENT: WBS NO. 2132 - POWER SUBSTATION & CONVERTER STATION MAINTENANCE COSTS

COST ELEMENTS

DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
ORDINARY MAINTENANCE REQUIREMENTS ANNUAL AVERAGE COST BASED ON HISTORICAL COST DATA FOR SIMILAR DISTRIBUTION PLANT FACILITIES AS A % OF CAPITAL COST:	LS	1	$4,089,000	4,089,000

CAPITAL COST ESTIMATE	$136,309,000 TOTAL
X % OF CAPITAL COST	3%
= MAINTENANCE ESTIMATE	$4,089,000 TOTAL

TOTAL ESTIMATED ANNUAL MAINTENANCE COST PER THE BASELINE PARAMETERS — $4,089,000 TOTAL

THE AVERAGE ANNUAL MAINTENANCE COST PER MILE OF THE BASELINE PARAMETERS — $40,900 PER MILE

OR

THE AVERAGE ANNUAL MAINTENANCE COST PER KM OF THE BASELINE PARAMETERS — $25,600 PER KM

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS SHEET 7

OPERATING AND MAINTENANCE COST ELEMENT: WBS NO. 2136 - LSM WINDING MAINTENANCE COSTS

COST ELEMENTS / DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
1. PERIODIC TESTING AND REPAIRS				
LABOR COST PER LSM WINDING BLOCK IN THE SYSTEM PERIODIC TESTING = 192 HOURS (24 MAN DAYS/YEAR) PERIODIC REPAIR = 192 HOURS (24 MAN DAYS/YEAR) TOTAL = 384 HOURS (48 MAN DAYS/YEAR)	HR	384	$30.00	$11,520
AVERAGE COST OF EQUIPMENT, TOOLS, VEHICLES, OPERATING EXPENSES, ETC. PER LABOR HOUR ESTIMATE COST @ $10.00 PER HOUR OF LABOR	HR	384	$10.00	$3,840
MATERIAL COST TO MAKE MINOR REPAIRS TO THE LSM WINDING BLOCK AS REQUIRED AS PART OF THE PERIODIC TESTING & REPAIRS. ESTIMATE COST @ $10.00 PER HOUR OF LABOR	HR	384	$10.00	$3,840
TOTAL PERIODIC TESTING AND REPAIRS	HR	384	$50.00	$19,200
2. PERIODIC REPLACEMENT OF LSM WINDINGS				
ALLOW AVERAGE REPLACEMENT OF ONE LSM WINDING SECTION PER WINDING BLOCK PER YEAR				
LABOR COST PER LSM WINDING BLOCK TO REMOVE EXISTING SECTION AND INSTALL NEW SECTION	HR	16	$30.00	$480
AVERAGE COST OF EQUIPMENT, TOOLS, VEHICLES, OPERATING EXPENSES, ETC. PER LABOR HOUR	HR	16	$10.00	$160
MATERIAL COST OF NEW LSM WINDING SECTION AT LENGTH OF 8 METERS	EA	1	$13,790	$13,790
TOTAL PERIODIC REPLACEMENT OF LSM WINDINGS				$14,400
TOTAL ESTIMATED ANNUAL MAINTENANCE COST PER LSM WINDING BLOCK				$33,600 PER BLOCK
X NUMBER OF LSM WINDING BLOCKS			X	160
TOTAL ESTIMATED ANNUAL MAINTENANCE COST PER THE BASELINE PARAMETERS				$5,376,000 TOTAL
THE AVERAGE ANNUAL MAINTENANCE COST PER MILE OF THE BASELINE PARAMETERS				$53,800 PER MILE
OR				
THE AVERAGE ANNUAL MAINTENANCE COST PER KM OF THE BASELINE PARAMETERS				$33,600 PER KM

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS SHEET 8

OPERATING AND MAINTENANCE COST ELEMENT: WBS NO. 2137 - CENTRAL CONTROL FACILITY MAINTENANCE COSTS

COST ELEMENTS

DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
ANNUAL AVERAGE MAINTENANCE COSTS				
GLOBAL CONTROL CENTER EQUIPMENT UNIT				
CAMERA/MONITOR	LS	1	$36,600	$36,600
FDDI	LS	1	1,000	1,000
WORKSTATION	LS	1	140,300	140,300

TOTAL ESTIMATED ANNUAL MAINTENANCE COST PER THE BASELINE PARAMETERS — $178,000 TOTAL

THE AVERAGE ANNUAL MAINTENANCE COST PER MILE OF THE BASELINE PARAMETERS — $1,800 PER MILE

OR

THE AVERAGE ANNUAL MAINTENANCE COST PER KM OF THE BASELINE PARAMETERS — $1,100 PER KM

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS SHEET 9

OPERATING AND MAINTENANCE COST ELEMENT: WBS NO. 2138 - GUIDEWAY COMMUNICATIONS COMMAND & CONTROL SYSTEMS MAINT. COSTS

COST ELEMENTS

DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
ANNUAL AVERAGE MAINTENANCE COSTS				
WAYSIDE CONTROL AND COMMUNICATION EQUIPMENT UNITS				
CAMERA/MONITOR	LS	1	$36,600	$36,600
FDDI	LS	1	1,000	1,000
POSITION SENSOR	LS	1	91,000	91,000
TELEPHONE	LS	1	1,661,400	1,661,400

TOTAL ESTIMATED ANNUAL MAINTENANCE COST PER THE BASELINE PARAMETERS $1,790,000 TOTAL

THE AVERAGE ANNUAL MAINTENANCE COST PER MILE OF THE BASELINE PARAMETERS $17,900 PER MILE

OR

THE AVERAGE ANNUAL MAINTENANCE COST PER KM OF THE BASELINE PARAMETERS $11,200 PER KM

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS SHEET 10

OPERATING AND MAINTENANCE COST ELEMENT: WBS NO. 221 - COST FOR VEHICLE ENERGY

COST ELEMENTS

DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
THE VEHICLE ENERGY REQUIRED FOR THE 100 STRAIGHT MILES OF THE BASELINE PARAMETERS IS 5,775 KW PER VEHICLE.	KWH	758,835,000	$0.0852	$64,652,740

20 VEHICLES X 5,775 KW = 115,500 KW PER HOUR

OPERATING HOURS = 18 X 365 = 6,570 HOURS PER YEAR

TOTAL ANNUAL ENERGY = 758,835,000 KWH PER YEAR

TOTAL ESTIMATED ANNUAL VEHICLE ENERGY COST PER THE BASELINE PARAMETERS	$64,652,740 USE $64,653,000 TOTAL
THE AVERAGE ANNUAL VEHICLE ENERGY COST PER MILE OF THE BASELINE PARAMETERS	$646,500 PER MILE
OR	
THE AVERAGE ANNUAL VEHICLE ENERGY COST PER KM OF THE BASELINE PARAMETERS	$404,100 PER KM

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS SHEET 11

OPERATING AND MAINTENANCE COST ELEMENT: WBS NO. 222 - COST FOR FIXED FACILITY ENERGY

COST ELEMENTS

DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
1. GLOBAL CONTROL CENTER FACILITY	KWH	147,168	$0.0852	$12,540
840 SF X 20 W = 17 KW PER HOUR				
24 X 365 = 8,760 HOURS PER YEAR				
TOTAL ANNUAL ENERGY = 147,168 KWH PER YEAR				
2. ENERGY FOR WAYSIDE CONTROL & COMMUN. EQUIP. UNITS	KWH	2,277,600	$0.0852	$194,050
20 EA X 13 KW PER HR = 260 KW PER HOUR				
24 X 365 = 8,760 HOURS PER YEAR				
TOTAL ANNUAL ENERGY = 2,277,600 KWH PER YEAR				
TOTAL ESTIMATED ANNUAL FIXED FACILITY ENERGY COST PER THE BASELINE PARAMETERS				$206,590 USE $210,000 TOTAL
THE AVERAGE ANNUAL FIXED FACILITY ENERGY COST PER MILE OF THE BASELINE PARAMETERS				$2,100 PER MILE
OR				
THE AVERAGE ANNUAL FIXED FACILITY ENERGY COST PER KM OF THE BASELINE PARAMETERS				$1,300 PER KM

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS SHEET 12

OPERATING AND MAINTENANCE COST ELEMENT: WBS NO. 231 - ON-BOARD PERSONNEL COSTS

COST ELEMENTS

DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
ON-BOARD PERSONNEL REQUIRMENTS	HR	175,200	$30.00	$5,256,000

BASED ON THE FOLLOWING CRITERIA:
AVERAGE TRIP LENGTH OF 3 HOURS
TOTAL OF 20 VEHICLES FOR 100 MILES
1 OPERATOR/ATTENDANT PER VEHICLE TRIP
3 LABOR SHIFTS AT 8 HOURS EACH

1 OPERATOR/ATTENDANT X 3 SHIFTS = 24 HOURS PER VEHICLE DAY
20 VEHICLES X 24 HOURS/DAY X 365 DAYS = 175,200

DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
SUPERVISION & SUPPORT LABOR FOR ON-BOARD PERSONNEL	HR	8,760	$30.00	$262,800

ALLOW 5% OF ON BOARD PERSONNEL = 8,760

TOTAL ESTIMATED ANNUAL ON-BOARD PERSONNEL COST PER THE BASELINE PARAMETERS — $5,518,800
USE
$5,520,000
TOTAL

THE AVERAGE ANNUAL ON-BOARD PERSONNEL COST PER MILE OF THE BASELINE PARAMETERS — $55,200
PER MILE

OR

THE AVERAGE ANNUAL ON-BOARD PERSONNEL COST PER KM OF THE BASELINE PARAMETERS — $34,500
PER KM

TOTAL ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST PER BASELINE PARAMETERS SHEET 13

OPERATING AND MAINTENANCE COST ELEMENT: WBS NO. 241 - TRAFFIC CONTROL COSTS

COST ELEMENTS

DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL
TRAFFIC CONTROL CENTER OPERATIONS	HR	32,120	$30.00	$964,000

BASED ON THE FOLLOWING LABOR REQUIREMENTS:

1 OPERATIONS SUPV. PER SHIFT X 3 SHIFTS	24 HRS/DAY
2 CONTROLLERS PER SHIFT X 3 SHIFTS	48 HRS/DAY
1 MAINTENANCE SUPV. PER DAY	8 HRS/DAY
1 MAINTENANCE PERSON PER DAY	8 HRS/DAY
DAILY TOTAL	88 HRS/DAY
	X 365 DAYS/YR
ANNUAL TOTAL	32,120 HRS/YEAR

TOTAL ESTIMATED ANNUAL OPERATING COST PER THE BASELINE PARAMETERS — $964,000 TOTAL

THE AVERAGE ANNUAL OPERATING COST PER MILE OF THE BASELINE PARAMETERS — $9,600 PER MILE

OR

THE AVERAGE ANNUAL OPERATING COST PER KM OF THE BASELINE PARAMETERS — $6,000 PER KM

5.3.6. MAGNETIC FIELD ANALYSIS

CONTENTS

FIGURES

Condition	static limit (DC)	max. alternating field (AC)
A	5 mT (50 gauss)	0.1 mT (1 gauss)
B	0.5 mT (5 gauss)	0.1 mT (1 gauss)
C	0.1 mT (1 gauss)	0.01 mT (0.1 gauss)

Figure 1 Magnetic field limit cases specified in SOW

5.3.6.1. INTRODUCTION

There are number of magnetic field sources associated with the Magneplane concept. This report discusses the major sources and presents the computed field levels in and around the Magneplane baseline vehicle and magway.

The field limits of particular interest were specified in the Statement of Work for this study. There are three limit cases (A, B, and C). The actual limit case imposed on the technology by government regulation has not been determined at this time, so three cases are studied in order to cover three possible scenarios of actual future regulation. Figure 1 shows the three limit cases.

5.3.6.1.a. SUMMARY OF RESULTS

The major sources of DC fields in the vehicle are the superconducting coils in the levitation and propulsion windings. Their impact is mitigated by locating them in bogies that are isolated from the passenger area and by tailoring specific features of their design. This includes the use of the natural magnetic field cancellation character of multipole coil configurations and by using a non-uniform distribution of ampere turns in the propulsion coils. The stray field levels have also been reduced by using an active set of shielding windings using aluminum conductor.

The primary source of AC fields is the LSM winding in the magway and the two components of current that it carries. It is a 3 phase winding carrying about 1075 A rms at 100 Hz for the thrust interaction with the vehicle and about 400 A rms at ~400 Hz for inductive transfer of power to the vehicle for on-board services.

The baseline vehicle and magway design achieves condition B throughout the passenger compartment. It can achieve the static part of condition C with virtually no modification. The AC part of condition C can be achieved in the vehicle by the addition of an aluminum sheet for shielding the AC field from the LSM. This approach is not, however, part of the present baseline.

5.3.6.1.b. MAGNEPLANE BASELINE CONFIGURATION & FIELD SOURCES

The major field sources in the vehicle are the superconducting coils that are used for levitation and propulsion. They are located in bogies, one at each end of the vehicle. A cross-sectional sketch of the vehicle, together with the levitation and propulsion coil modules, is shown in Figure 7. Each bogie has two levitation coil modules of two coils each and one propulsion module with six coils in it. The relative position of the levitation and propulsion coils has been designed to partially reduce stray field effects.

The operating clearance between the vehicle and magway at the design point of 150 m/s is 0.15 m. The magway aluminum sheets are each nominally 1.5 m wide and 0.02 m thick. The sheets are electrically passive, but interact with the moving levitation coils on the vehicle to create the required lift. The fields from the levitation coils are DC (Static) in the reference frame of the vehicle and moving with the speed of the vehicle relative to the earth.

The space around the centerline of the magway, between the aluminum sheets, is for the linear synchronous motor (LSM) windings. These are the primary source of AC fields in the system. The LSM is a three phase winding that creates a magnetic field that couples with the superconducting propulsion coils on the vehicle to generate the required thrust on the vehicle. The fields from the superconducting propulsion coils and from the LSM, are DC in the reference frame of the vehicle and moving with the vehicle speed relative to the earth.

The LSM winding is also excited with a second, three phase current at a frequency that is different from the frequency of the current component that is used for thrust. The second current is used to inductively transfer power to pick-up coils that are on the vehicle. This component of the LSM current will create a field that is AC in both the reference frames of the vehicle and of the earth, but with different frequencies.

The approximate dimensions for the 140 passenger vehicle are shown in Figure 8. Passengers are in a central cabin and two levitation/propulsion bogies are used. Figure 9 is a similar sketch for a 45 passenger vehicle. It also uses bogies at each end and has superconducting coils of identical dimensions, but with fewer ampere turns because the required lift and thrust are reduced. As a result the stray fields due to the coils in the 45 passenger vehicle will be less. Consequently, this report will concentrate on the parameters for the 140 passenger vehicle.

A schematic of the baseline dimensions for coils in a bogie, together with the amp-turns required for the 140 passenger vehicle are shown in Figure 10. The levitation coils are excited with opposing polarity so that each levitation module of two coils forms a quadrupole to help reduce the stray fields. This sketch represents the forward bogie, which has the propulsion coils shifted forward of the levitation coils to help reduce the stray fields in the passenger section of the vehicle. The rear bogie is identical, but rotated 180 degrees so that the propulsion coils "trail" the levitation coils, again to reduce the stray fields in the passenger section.

Figure 11 is an isometric view that outlines the superconducting coils in a single bogie. They consist of two pairs of levitation coils and a set of six propulsion coils. The propulsion coils carry considerably more amp-turns than the levitation coils (see Figure 10) and are, therefore, somewhat more difficult to shield. The distribution of the amp-turns among the six coils is non-uniform, having been tailored to aid the natural decay of the magnetic field in space.

The idealized current distribution for the shielding coils can be found by first specifying planes on which the coils are to be located. Figure 12 shows a set of planes which overlay on the coils and coordinate system in Figure 11. Shielding coils in these planes would be located beneath the floor and in the walls of the bogie section of the vehicle, and would decrease the fields experienced by the passengers. The planes are located so as to allow a walkway that is 1.2 m wide over the bogie. Personnel access through the walkway would be restricted & passenger access would be prohibited.

Figure 13 shows an isometric view of an ideal shielding coil winding distribution on the selected planes for the baseline case of 2.42E+05 amp turns in each levitation coil, 7.8E+05 amp turns in the central four propulsion coils and 3.9E+05 amp turns in the end coils of the propulsion coil set. The contours are drawn such that the shielding coils should be wound with 1E+04 amp-turns between contours. A plan view of the ideal coil pattern is shown in Figure 14.

5.3.6.2. STATIC FIELDS IN THE VEHICLE

The static magnetic fields inside the vehicle come from two distinct sources:

(1) the on-board superconducting magnets that comprise the levitation and propulsion systems; and

(2) the fields in the cabin produced by the thrust component of current in the LSM windings in the magway, which appear as a static field in the vehicle frame of reference.

The superconducting magnets in the bogies produce the largest of the fields in the cabin, but satisfy the 1 gauss limit at floor level around the passengers because of the isolated location of the bogies and the use of active shield coils. The static field levels in the passenger space from the LSM are within the 1 gauss limit with no shield for the LSM.

5.3.6.2.a. BOGIE LEVITATION AND LSM PROPULSION WINDINGS

The superconducting magnets that produce the levitation and propulsion forces also produce high magnetic fields in the neighborhood of the bogies. In order to reduce the fields in passenger space, the baseline design includes a shield. The shield is active, which means there are additional windings that are so placed as to reduce the total field in the vehicle. The design and impact of the shield are discussed in the next section. The effect of no shield is included in section 5.3.6.2.a.2. as a fault condition - ie., the bogie magnets are at full current and the shield windings are at zero current.

5.3.6.2.a.1. ACTIVE SHIELD

The contours of the total magnetic flux density magnitude produced by the magnets and shield windings are shown in Figure 15 superimposed on an elevation view of the 140 passenger vehicle. Only the 1, 5, and 50 gauss contours are shown. These field magnitudes do not include the effect of eddy currents produced in the magway by the vehicle motion. Therefore, these fields correspond to a zero speed situation. They are conservative because the polarity of the induced fields for a moving vehicle are such that a reduction in stray field intensity would occur, relative to the zero speed case.

Limiting Field Level (G)	50	5	1
Distance from Magnets (m)	0.2	1.2	1.7
Number of Excluded Seats	0	0	5

Figure 2 Extent of limiting fields

The distances to the various field levels of interest at floor level, measured from the end plane of the bogie along the vehicle long axis, are shown in Figure 15 and listed in Figure 2. The impact on the number of passenger seats of achieving the listed field limits are also included in the figure.

As can be seen, the 50 gauss limit is met by merely limiting access in the region within 0.2 m of the bogies. In the baseline design, the entire bogie area is planned to be off limits to passengers and used for storage or for field insensitive equipment. Hence, such an exclusion limit has essentially no impact.

The 5 gauss limit requires an exclusion zone of the region within 1.2 m of the bogie. No seats need be excluded to meet this specification. Access to the region over the bogies must be restricted as planned and described earlier.

The 1 gauss requirement is met by excluding a region within 1.7 m of the bogie. Such an exclusion has the impact of excluding 5 seats from the vehicle. Alternatively, the vehicle could be lengthened by 0.81 m. These changes are very small and the baseline is expected to be able to meet the 1 gauss requirement with no change in seating or length by a future alteration in the shielding coil arrangement.

Contours of constant field magnitude over the vehicle cross-section in a typical plane containing the bogie are shown in Figure 16. Contours are labeled and indicate that the bulk of the volume within the vehicle is below 50 gauss. However, this will be a restricted area with no passenger access and will be used for storage or as a location for selected items of equipment.

The shield windings are made of aluminum conductor. The ideal shield requirements for the two vehicles are listed in Figure 3.

The actual powers and weights for the shield coils are carried in the Magneplane budget at levels 50% higher than those in Figure 3 to allow for adjustments in future design iterations and for the special shielding requirements for local areas.

5.3.6.2.a.2. NO SHIELD -- FAULT CONDITION

If the shield windings in the baseline vehicle were discharged because of a loss of power, the magnetic flux density in the vehicle would increase from the values present with a working shield. Figure 17 shows

Passenger Configuration	140	45
Shield Weight (kg)	2400	1600
Shield Power (kW)	23	16

Figure 3 Ideal shield weights and powers

the elevation view of the vehicle with the flux density contours of 1, 5, and 50 gauss with the bogie coils active, but with the shield coils discharged. A comparison with Figure 15 shows that the 1 gauss line has moved into the cabin and is now 3.9 m from the bogie end. The 5 gauss line is at 2.4 m; and the 50 gauss line at 1 m. This is not a usual operating condition, but still effects only a small portion of the passenger cabin.

Depending on field exposure level criteria, the loss of power to the shield windings could require moving passengers from the seats close to the bogies. Figure 4 illustrates the number of passengers seats that would have to be vacated for each of the specified field levels under this fault condition.

5.3.6.2.b. LSM PROPULSION WINDING

The LSM windings in the magway produce a static magnetic field in the vehicle frame of reference. This field distribution appears as a sinusoidal distribution in space along the vehicle length.

Figure 18 shows a transverse section of the vehicle with flux density contours superimposed. The contours correspond to levels at the peak of the standing wave. Other sections would see lower flux density magnitudes. As can be seen from the figure, the maximum density at the floor level is approximately 0.6 gauss. This is a DC field and is below even the most stringent requirement of 1 gauss.

5.3.6.3. AC FIELDS IN THE VEHICLE DUE TO ON-BOARD POWER TRANSFER

The baseline design calls for the pick-up of power from a higher frequency component of current in the LSM. The expected current is 400 A rms at a frequency of about 400 Hz. Pick up coils in the vehicle will be a three-phase meander winding running the length of the vehicle between the magnet bogies.

Both the LSM and the pick-up coils will produce an AC component of the magnetic field in the cabin. Only the LSM source is considered because the superposition of the field from the pick-up coils may be expected to cause some cancellation, and, hence, produce somewhat lower fields.

Flux Density Level (g)	50	5	1
Distance from Magnets (m)	1.0	2.4	3.9
Number of Affected Seats	0	15	35

Figure 4 Fault condition

The LSM windings will have a higher frequency component of current superimposed on the nominal 1075 A rms current at 100 Hz for thrust. It is expected that the power pick-up component will be at 400 A and at -400 Hz. Therefore the slip frequency in the vehicle frame of reference for the power pick-up component is 500 Hz.

Figure 19 shows the contours of magnetic flux density due to a 400 A current in the LSM. As can be seen, the maximum value at the floor is just under 0.2 gauss. This satisfies the AC field limit cases A and B (see Figure 1), but is slightly above the 0.1 gauss specification. The 0.1 gauss line is approximately 0.07 m above the floor. If necessary, this could be passively shielded from the cabin by a thin sheet of aluminum, because of the high frequency.

Such an aluminum shield would be 3 m wide by 18 m long and have the characteristics shown in Figure 5 depending on the field level and frequency.

Therefore, the most stringent of field limit of 0.1 gauss at 250 Hz would impose a 1760 kg weight penalty.

This shield is not presently part of the baseline, hence vehicle fields are as shown in Figure 19.

5.3.6.4. FIELDS NEAR THE MAGWAY

The various types of magnetic field sources generate alternating and static magnetic fields not only in the vehicle, but also in the surrounding space. The distribution of these fields is described below.

5.3.6.4.a. STATIC FIELDS

Unless the vehicle is at rest, there are no static fields associated with the vehicle or magway. The static field distribution from a vehicle at zero speed is discussed for magport environments in section 5.3.6.5.a.

5.3.6.4.b. AC FIELDS

Frequency (Hz)	250	250	500	500
Field Limit (gauss)	1.0	0.1	1.0	0.1
Sheet Thickness (cm)	3.0	11.5	8.0	2.0
Sheet Weight (kg)	460	1760	310	1220

Figure 5 Aluminum pick-up coil shield characteristics

The alternating currents from the LSM winding and the on-board power transfer windings produce AC fields. In addition, the field from the bogies that are DC in the vehicle reference frame appear as a transient field to an observer stationary with respect to the magway as a vehicle passes.

5.3.6.4.b.1. LSM PROPULSION WINDINGS

The LSM windings in the magway are energized in blocks. Each phase of the three-phase windings carries 1075 A rms. The frequency of the LSM is approximately 100 Hz. The field distribution from the LSM is shown in Figure 20 as contours of constant maximum magnetic field amplitude. The vehicle outline is superimposed for scale, but it does not generate this field.

The figure represents both the spatial and temporal distribution and was generated in the following manner. The flux density components from the LSM windings were calculated over a three-dimensional mesh at a fixed instant of time. For each point in the yz plane, the peak flux density was found by searching in the x-direction (the direction of motion of the vehicle). These values were then contoured. Therefore, the section does not represent the flux density distribution at any fixed instant of time. For example, every point on the 1 gauss contour will experience a 1 gauss field at some time, but the points will not experience the 1 gauss at the same instant.

As can be seen, the fields decay very rapidly with distance from the magway. Note that the 0.1 gauss line does not extend beyond the magway envelope.

5.3.6.4.b.2. AC FIELDS DUE TO THE POWER TRANSFER CURRENTS

In addition to the 1075 A rms current at 100 Hz, the LSM carries a another current component of 400 A at -400 Hz. Since the excitation is at 400 A rms, the Figure 20 contours can be used for this case with the flux density contour values scaled by 400/1075. Hence, field values for the power transfer current component will be less than 40% of the already small values for the propulsion current component. Furthermore, they will be at 500 Hz as opposed to 100 Hz.

5.3.6.4.c. MAGNETIC FIELDS FROM PASSING BOGIES

Limiting Field Level (gauss)	Distance from Centerline (m)
50	2.9
5	4.6
1	6.5

Figure 6 Distance from bogie at which field levels are reached in magport environment

Even though the superconducting magnets on the vehicle are operating in a DC condition, a transient field is seen in the magway frame of reference as the vehicle passes. The repetition rate depends on the vehicle speed and headway between vehicles.

Figure 21 shows a transverse view of the vehicle and magway and the fringe field magnitude from the on-board propulsion and levitation magnets of one bogie. As can be seen, the 1.0 gauss line falls within what might be expected as a right of way boundary. The 0.1 gauss lines extends radially about 4 vehicle diameters from the centerline. This is a transient associated with the vehicle passage and is not AC in the usual sinusoidal sense. It also has limited extent along the vehicle body as can be inferred from Figure 15.

5.3.6.5. FIELDS IN MAGPORTS

In magports, the contour plots discussed in previous sections are equally valid. The magnetic fields from the magnets in the vehicle bogies will produce DC fields and the LSM can be turned off so that the AC fields are not an issue except during arrival and departure.

5.3.6.5.a. STATIC FIELDS FROM THE BOGIES

Figure 16 shows the transverse section of the vehicle and the extent of the field at floor level as, for example, for the magport gate. This particular section is one through the middle of the levitation windings and represents a "worst case" situation. Everywhere else along the length of the vehicle, the field magnitudes will be lower as implied by Figure 15.

Figure 6 summarizes the distance in the transverse plane of the bogie in Figure 16 from the vehicle centerline to the field level listed as measured at vehicle floor level.

Depending on field exposure criteria to be applied in magports, Figure 16 indicates the area swept by the vehicle bogie fields as it enters a magport and the area to have restricted access until the vehicle is stopped. Once stopped, these areas, which are only located near the bogies, could have no access or could be actively shielded by coils in the msgport.

5.3.6.5.b. AC FIELDS

Section 5.3.6.4.b. described the AC fields associated with the LSM propulsion winding, the LSM power pickup component and the on-board power pick-up. The plots in those sections are also appropriate when interpreted in or near magports.

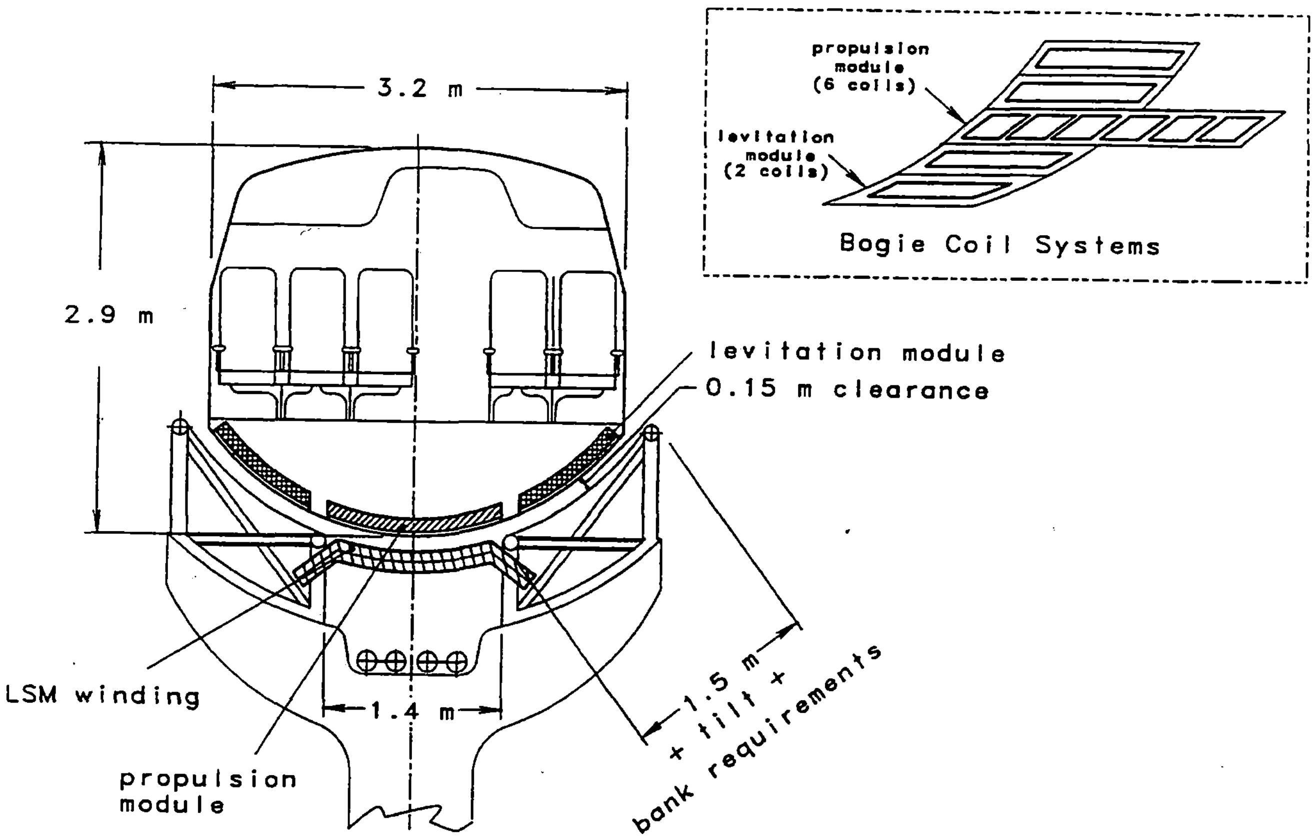


Figure 7 Vehicle cross-section sketch (dimensions approximate)

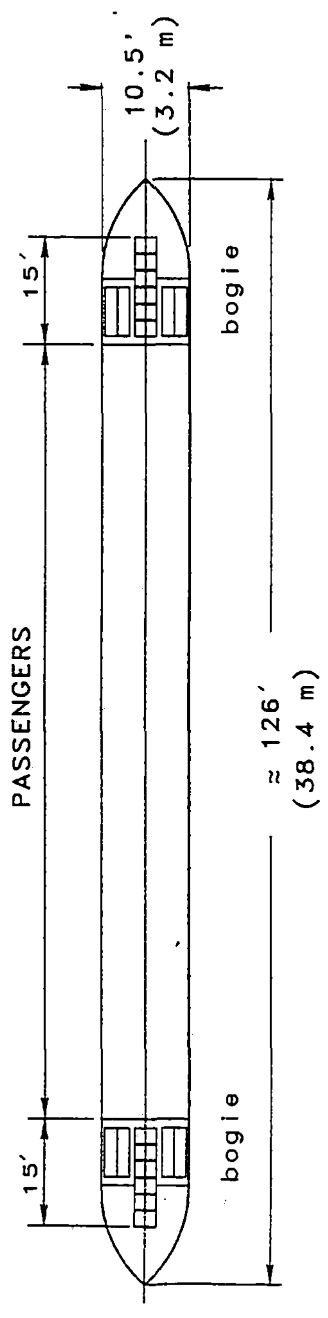


Figure 8 Baseline vehicle outline - 140 passengers

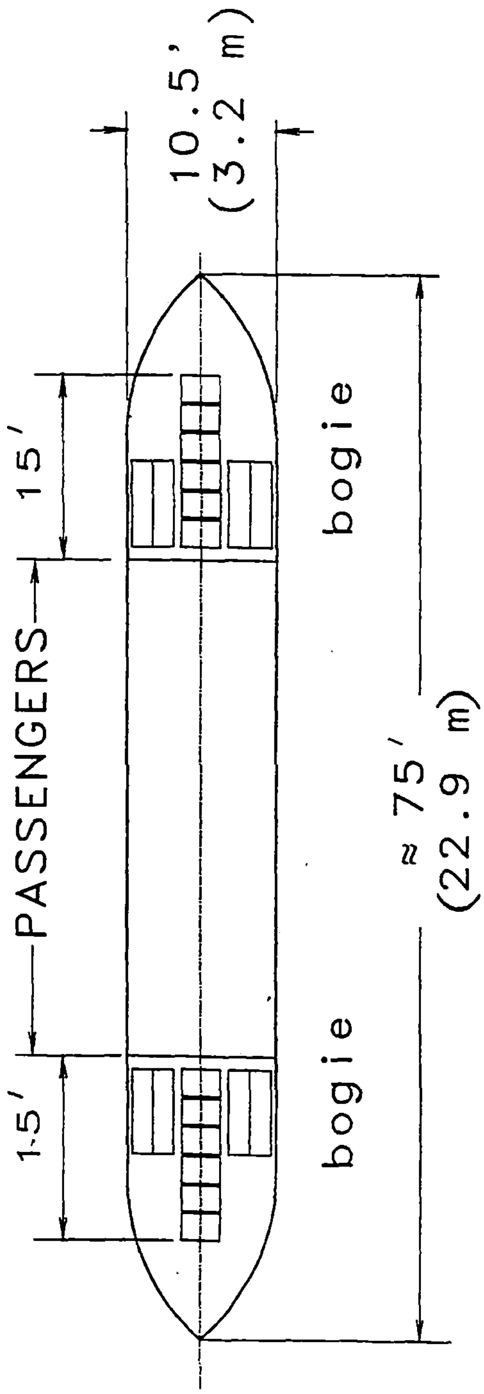


Figure 9 Baseline vehicle outline - 45 passengers

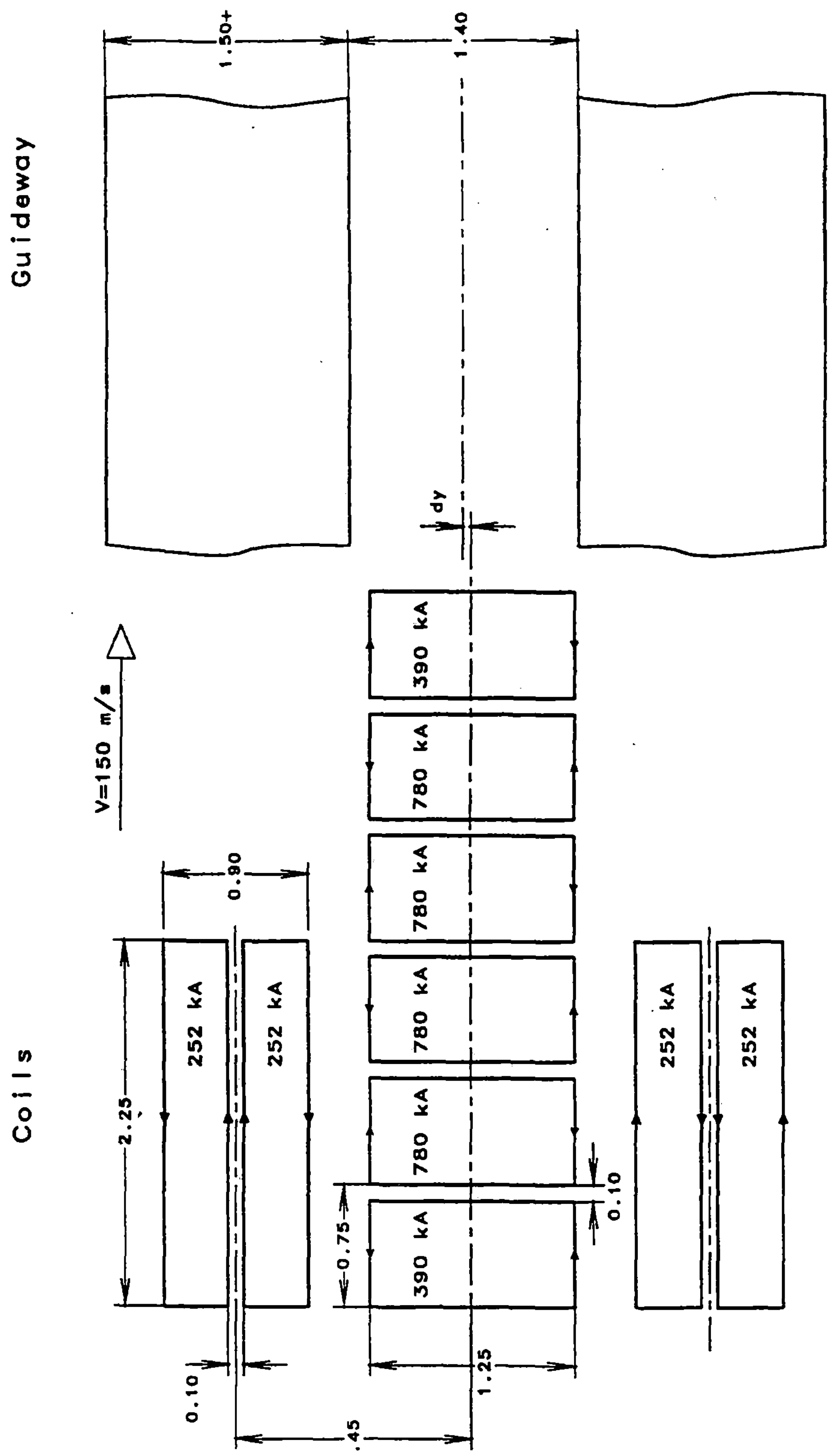


Figure 10 Schematic of coil and magway for forward bogie

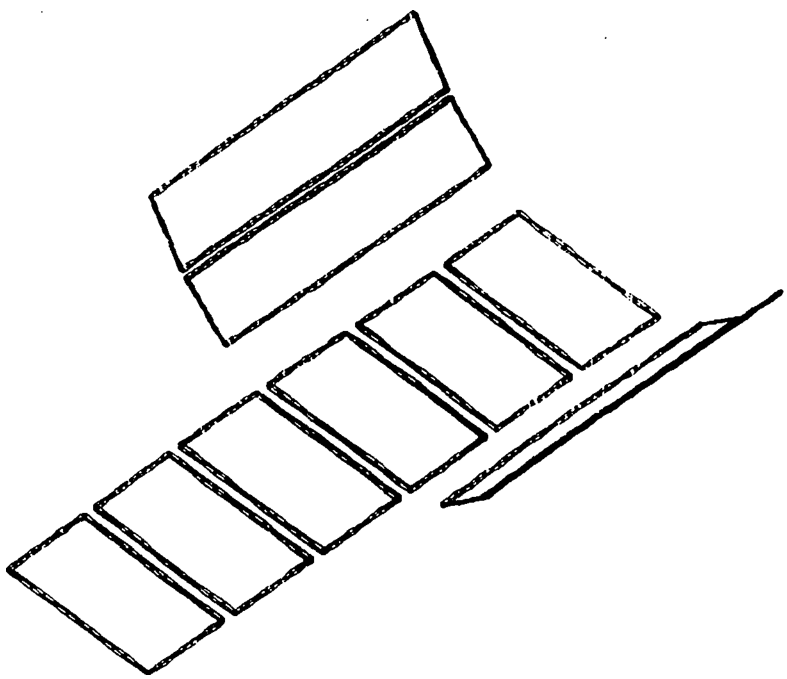


Figure 11 Outline of propulsion and levitation coils in one bogie

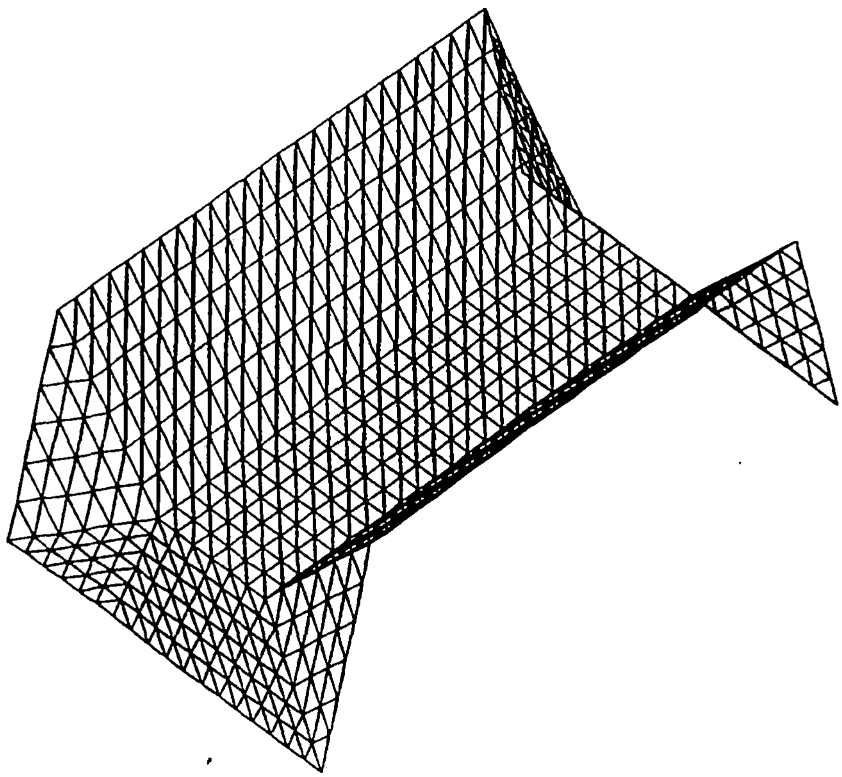


Figure 12 Surface in bogie region on which shielding coils are to be located

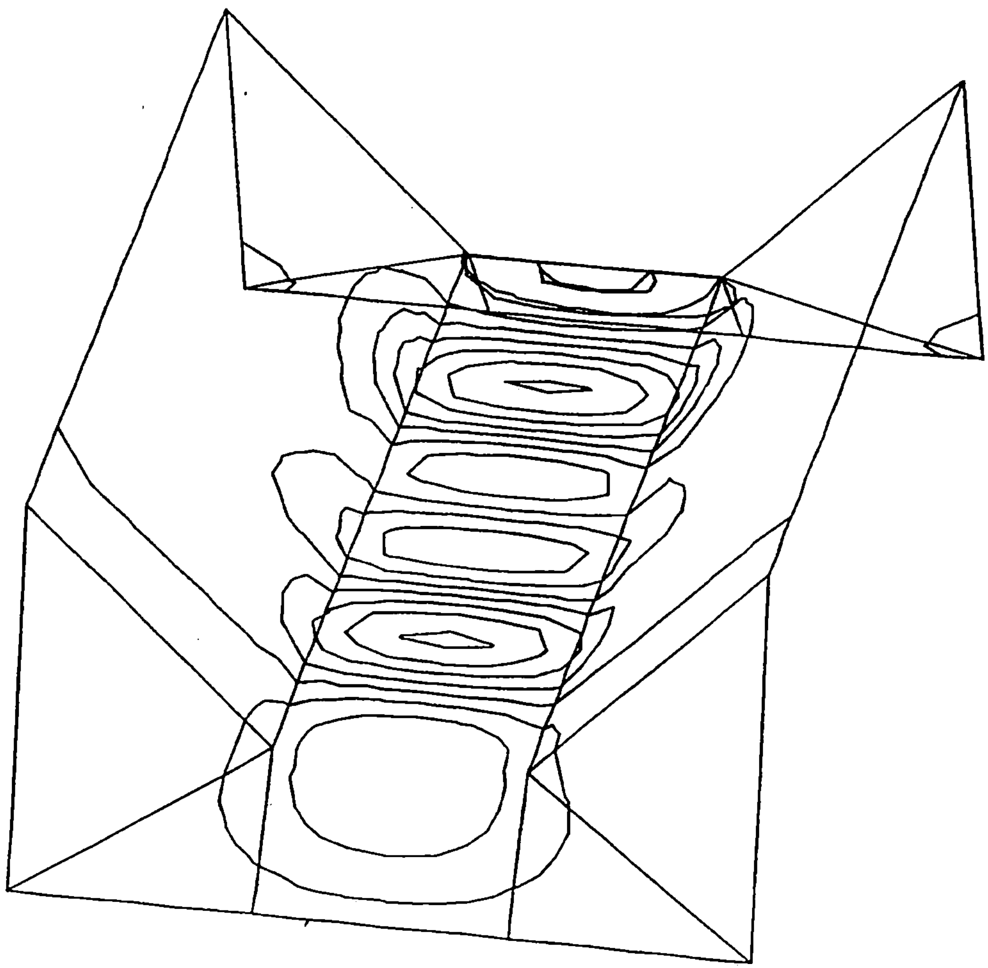


Figure 13 Isometric view of ideal current pattern for shield coils

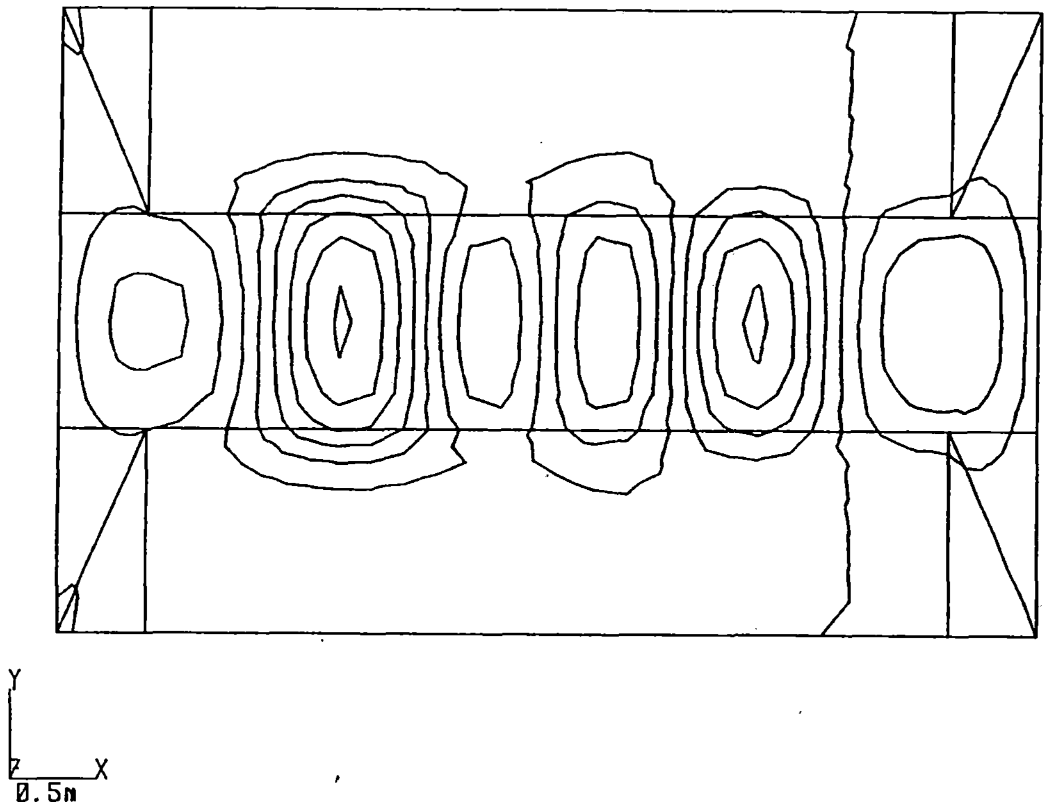


Figure 14 Plan view of ideal current pattern for shield coils

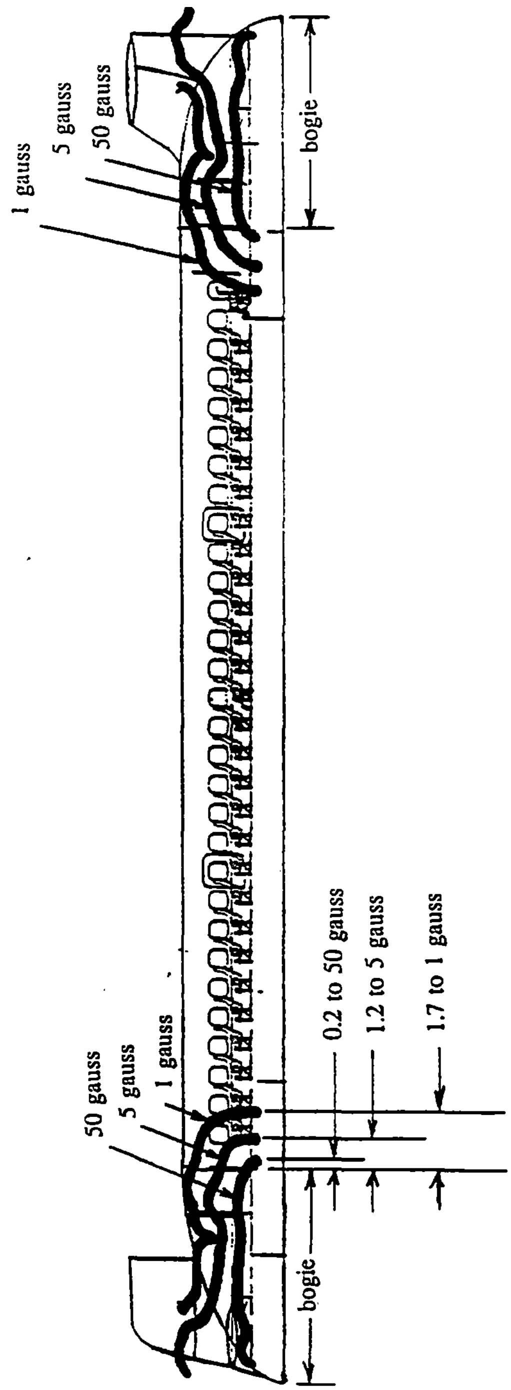


Figure 15 Magnetic field contour for 1, 5, and 50 gauss for the baseline 140-passenger vehicle with active shielding coils near bogies (M07)

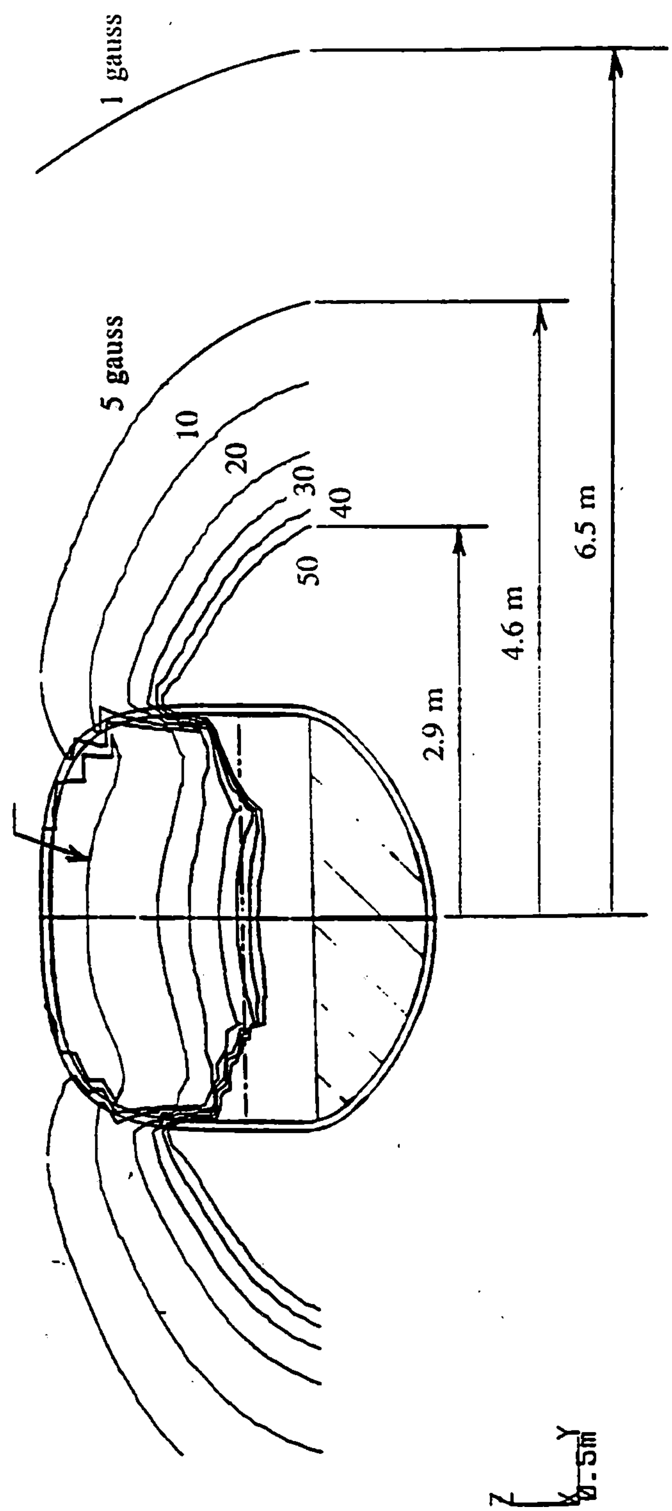


Figure 16 Contours of constant field magnitude in transverse plane over bogie with shields active (M07)

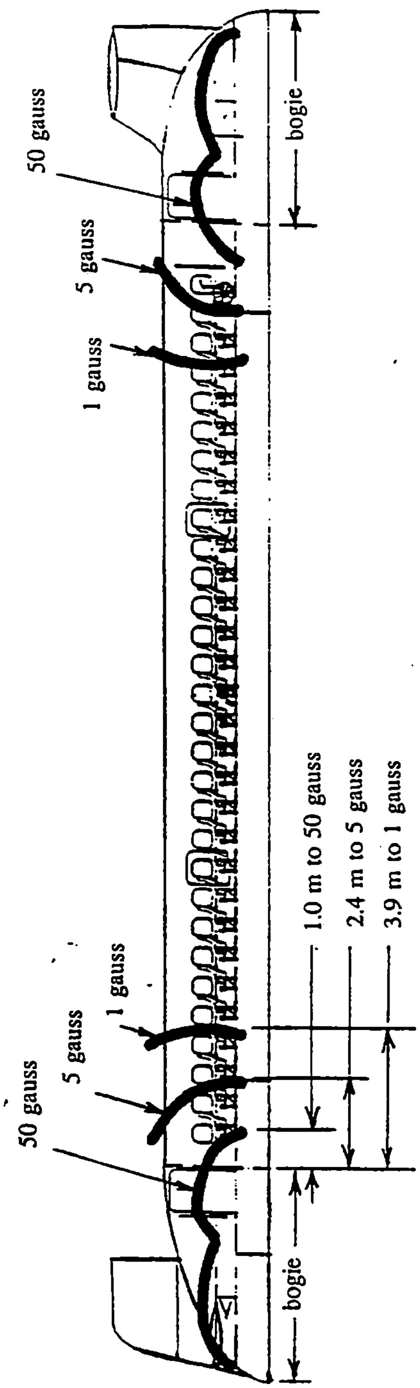


Figure 17 Magnetic field contours for 1, 5, and 50 gauss for the baseline 140-passenger vehicle with no active shield coils

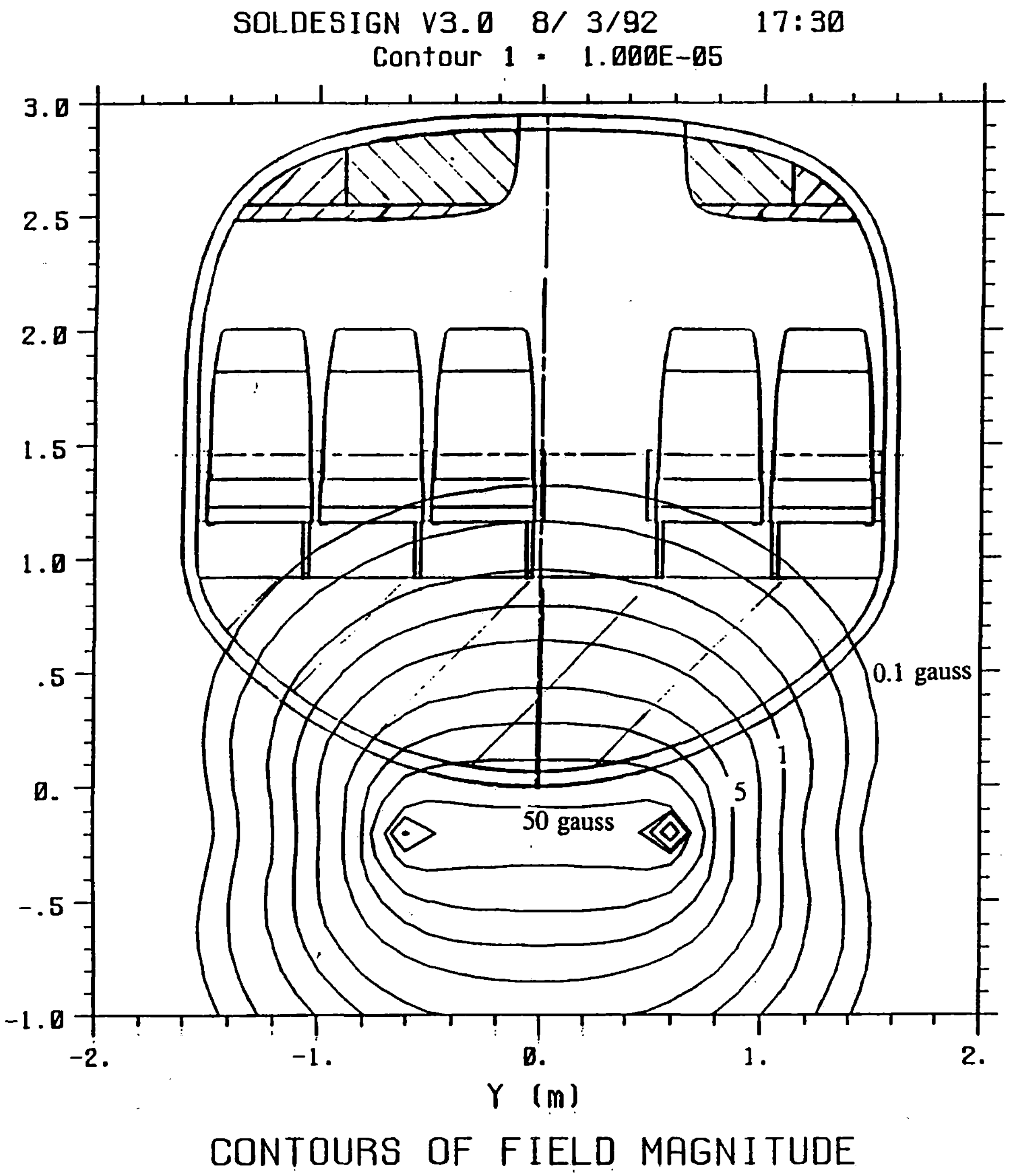


Figure 18 Contours of maximum magnetic field from LSM (max field at cabin floor is 0.6 gauss)

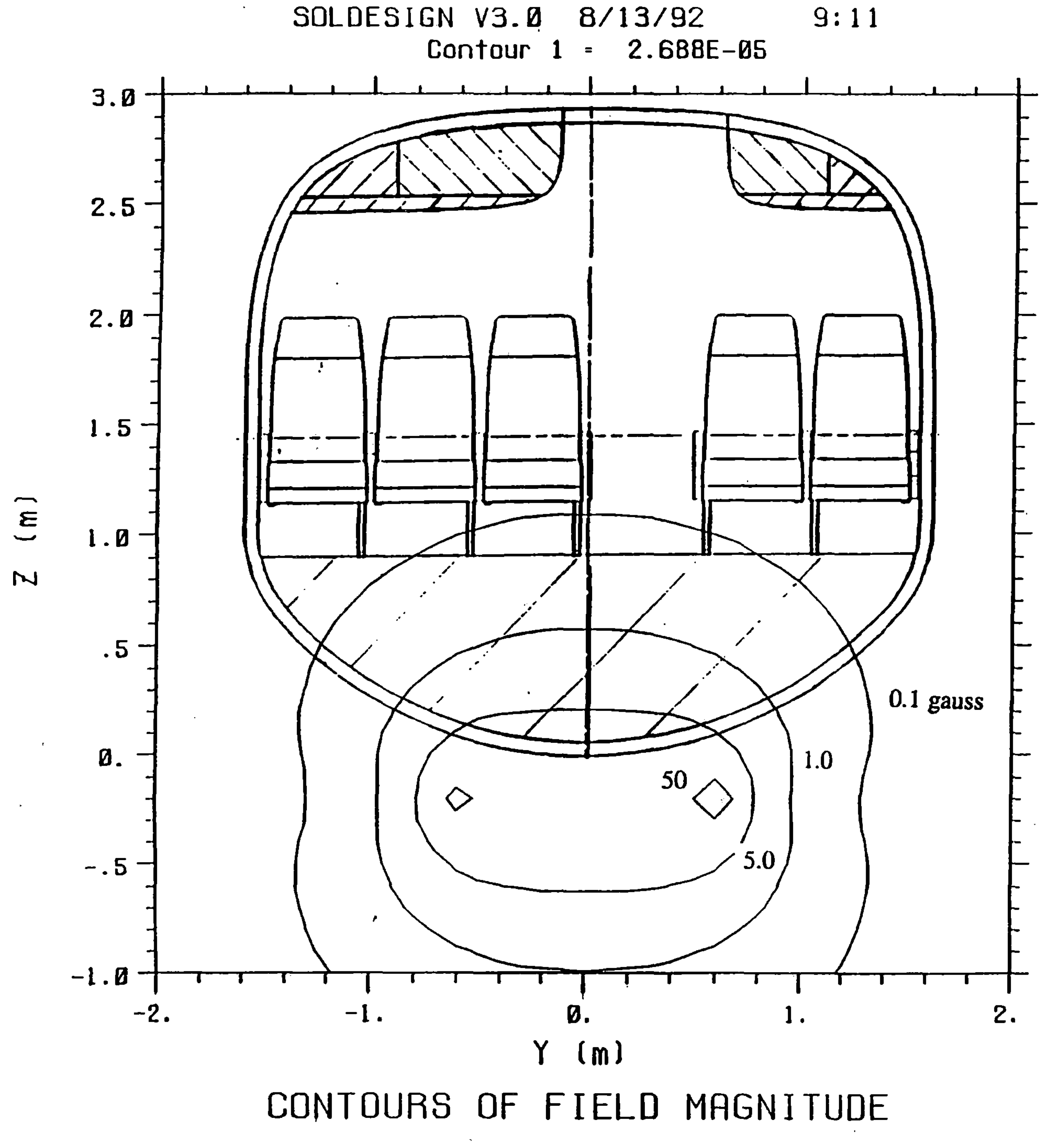


Figure 19 Contours of maximum flux density from 400 A current in LSM for on-board power transfer (produces 0.2 gauss at cabin floor)

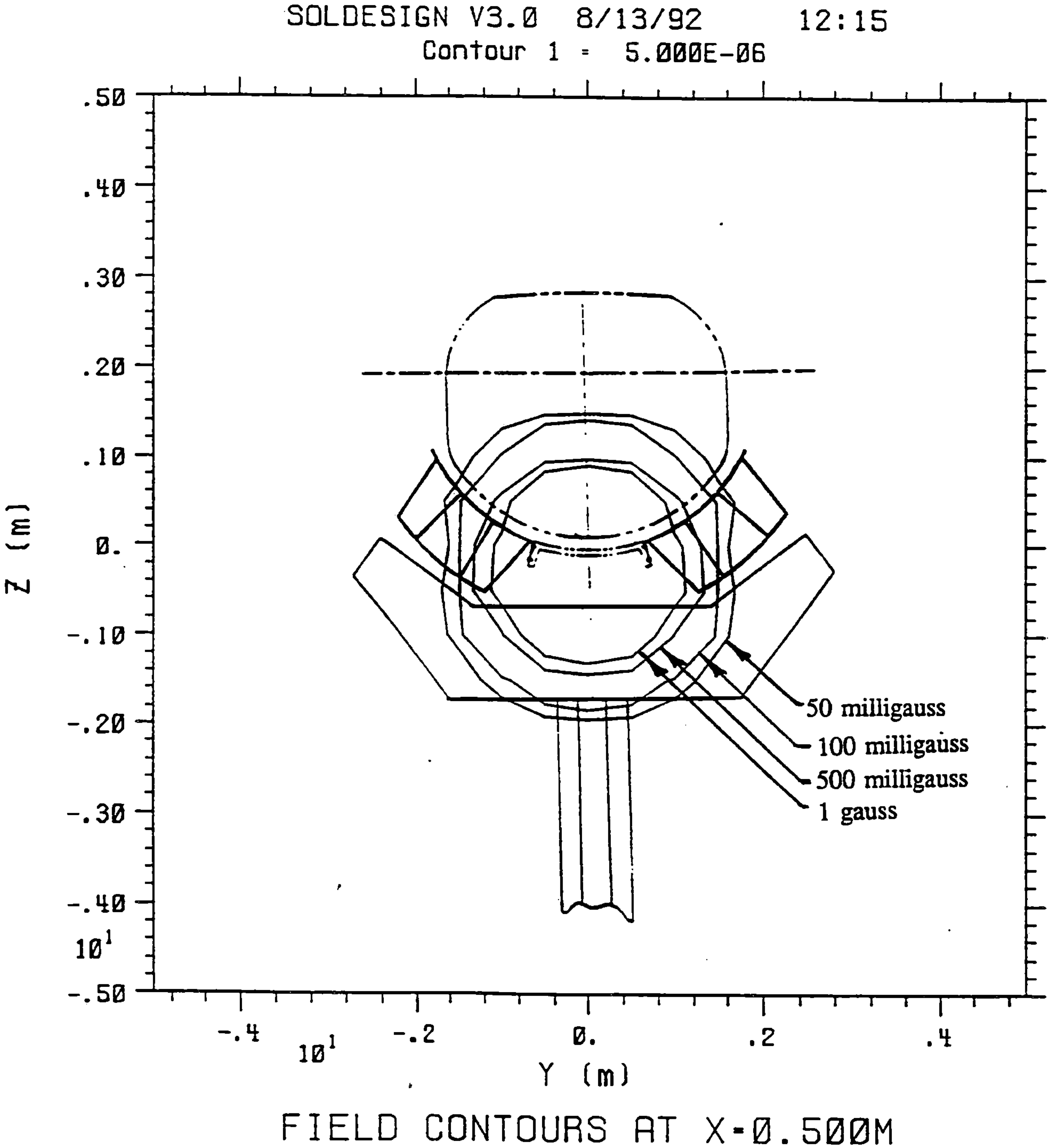


Figure 20 Peak ac magnetic field contours due to LSM propulsion currents

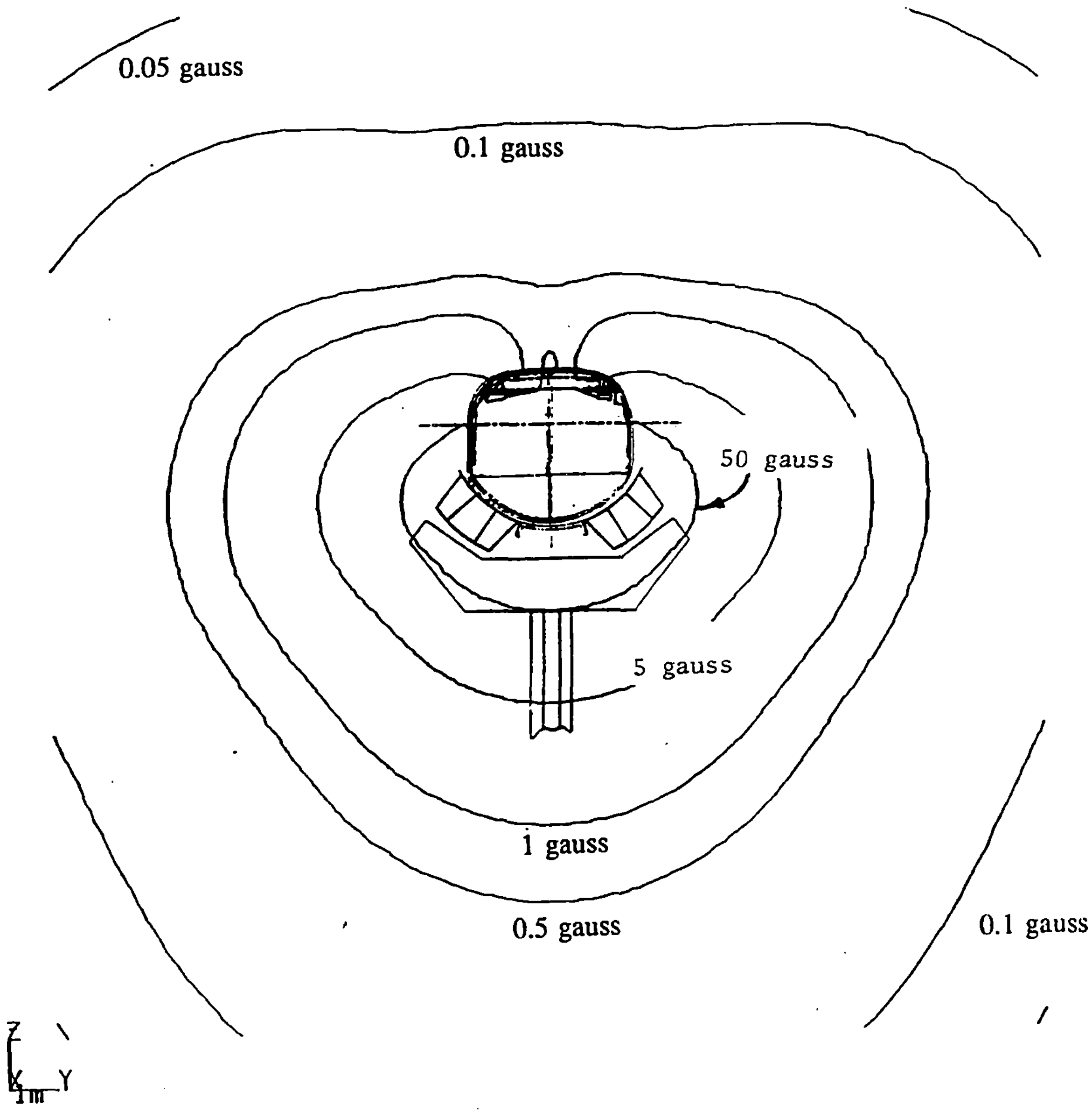


Figure 21 Contours of constant flux density in a transverse plant through the bogies with shield active (M07)

5.3.7. ADVANTAGES AND DISADVANTAGES

Keep in mind as you read this section that transportation is the world's largest industry, a major determinant of where we live and of our lifestyles, and the biggest polluter. Transportation systems are *not* just for getting places - they are an integral part of any country's demographic patterns and economic system. ***New transportation systems must be evaluated on this scale.***

Transportation technology cannot be reduced to a simple question of whether to buy a foreign system that is a few years ahead in research or to develop our own. It should encompass broader economic, environmental, and other questions.

The principal advantage of Magneplane over other maglev systems is that our system will actually work *as is*. Other EDS systems will require major concept redesign to make them work, as far as we know based on public information. Transrapid type systems will also work but they do not make use of the many advantages of maglev as Magneplane does.

We sincerely believe that Magneplane has *by far* the best chance of becoming an operation system in five years. We have already solved the major technical problems with a scale model system.

CONTENTS

5.3.7.a. ADVANTAGES

5.3.7.a.1. MAGNEPLANE COMPETES WITH THE AUTOMOBILE

While population is becoming more decentralized, transportation requires hubs of ever-increasing size. The two newest airports, Dallas Fort Worth and Toronto, each occupy 60 km^2 of intermodal infrastructure in the form of parking lots, rental car lots, bus stations, hotels, and associated services.

One or two such hubs serve the entire population of every major city, and account for much of the traffic gridlock. Satellite reliever airports have been tried, but uniformly rejected as a solution because suburban neighbors won't accept them.

Because of its individually targeted vehicle concept and light weight magways, Magneplane can make intercity transportation accessible at shopping malls, industrial and office parks, and residential condominiums. These are the locations where intercity traffic originates and terminates, and where the intermodal facilities already exist. Malls are becoming the demographic centers of the industrial world. They form a 25 km mesh network.

Off-ramps can carry vehicles to one or several magports, which may be located directly above the magway, or along loops which follow segments of peripheral highways and then return to the main magway.

Magneplane can provide high-speed non-stop service to corridors with 25 km magport spacing, such as the Northeast corridor. Vehicles would leave Boston for Washington at twenty second intervals, and each vehicle would stop only once or twice en route.

This would provide service every six minutes at all of the eighteen major stations now in existence. It could also provide service every 12 minutes at thirty-six magports, or every 24 minutes at seventy-two magports.

The more magports, the less intermodal infrastructure is required at each magport, and the more ridership the system will generate.

Very few people will use their cars if 300 mph transportation is available every ten minutes at the nearest shopping mall.

5.3.7.a.2. MAGNEPLANE HAS NO WHEELS

5.3.7.a.2.1. THE PROBLEM WITH WHEELS

During WW-2, when aircraft of significant performance were first used on an operational basis, tires were found to be a severe maintenance problem. DC-3 (C-49) tires, for instance, survived only about 100 landings on paved runways. Larger tires of higher moment of inertia survived even fewer landings. Two solutions to the problem were tried:

> Landing on grass next to paved runways extended life several-fold, but was not always possible.
>
> Pre-rotating the wheels prior to landing with turbine disks proved disastrous. Tires become severely unbalanced after only a few landings, and pre-rotation caused destructive vibrations.

After WW-2, aircraft tires became smaller to reduce the moment of inertia, but increased tire life was soon consumed by heavier aircraft and higher landing speeds. Severe demands were also placed on tires, bearings and brakes.

A landing gear closely matching the performance requirements and space availability of a Magneplane is that installed on several Beechcraft turboprops, such as the Super King-Air model C-120 corporate aircraft. Each of four main-gear wheels, of which Magneplanes would need sixteen, is equipped with dual disks clamped by six hydraulic calipers and surrounded by a compressed air cooling manifold ring fed by turbine compressor air. These brakes are marginally capable of absorbing energy from a normal 60 m/s (120-knot) stop, assisted by reversible-pitch propellers. Failure is common, and typical repair cost is $15,000 per wheel.

It is obvious to an expert that brakes and tires capable of absorbing four times as much energy from a 134 m/s emergency stop are beyond the existing art for commercial vehicle service, would require major development, and would be substantially larger and heavier than currently available aircraft components. For these reasons we consider wheels to be a major disadvantage to maglev.

5.3.7.a.2.2. THE ADVANTAGE OF SKIDS

The use of skids instead of wheels is considered an integral part of the concept being defined. It is logical to use a combination of air-lubricated anti-friction skids for normal operations below levitation speed, and high-friction pads for emergency deceleration. The specific advantages of skids are:

1. Braking energy would be dissipated in a volume of aluminum very much larger than brake disks. (this method used for *emergency* braking only)

2. There is no possibility of a hydraulic failure or brake fluid leak, as these systems would not exist in a skid brake.

3. Skids require less space and weight than wheeled landing gear.

4. Skids require less maintenance than wheels because they are more reliable.

5. Skids will cost less to develop and build.

6. Skids apply less pressure to the magway than wheels (larger area).

Low friction materials have coefficients of 0.05, and high-friction materials have coefficients of 0.65. The low-friction materials could thus operate safely even in the event air lubrication fails, and the high friction materials provide adequate deceleration for emergency requirements. The skids consume very much less space than wheels, and mechanism for extension and retraction does not present any unusual engineering problem. It has to be capable of operating rapidly, and of lifting the vehicle to several cm above levitation height in the event emergency deceleration is required.

Also please see the tradeoff analysis on the choice of landing gear, section 5.3.2.6.

5.3.7.a.2.3. OPTIMIZING SKIDS

The advantage of skids is optimized by:

1. the fact that the same equipment can be used for two separate purposes - landing gear and emergency braking.

2. the fact that the pressurized air supply is used both to inflate the landing gear pads and to provide air-lubrication.

3. building magports that take full advantage of the unlimited low-speed handling ability that skids provide; for example, turning spaces can be the size of one vehicle without the need for a turntable, and vehicles can slide sideways just as easily as forwards.

4. the ability for single vehicles to turn around in a magport and reverse their direction on the main corridor.

5.3.7.a.3. MAGNEPLANE VEHICLES FLY 15 cm OFF THE MAGWAY

Magneplane concept rationale considers large-gap resilient suspension a crucial advantage because, coupled with active phase control, this permits:

- large span deflections
- larger magway discontinuities (up to 5 cm) without any danger
- maximum passenger comfort without the need for a secondary suspension or a tilt mechanism
- roll freedom (roll angle is not rigidly confined by magway)

Thousands of flight tests with scale model systems provided intuitive three-dimensional insight into vehicle dynamics, and proved that resiliency with a large gap is a crucial advantage.

The gap of 15 cm is possible because of superconducting magnet technology, in which the Magneplane team has outstanding expertise.

Please refer to the tradeoff analysis on levitation height, section 5.3.2.1., for further details and justification for the specific gap chosen.

5.3.7.a.4. MAGNEPLANE IS FAST (CRUISING SPEED)

Magneplane can operate along highways at velocities several times higher than what the highway layouts were designed for. This is possible because of the capability to roll like airplanes in order to minimize lateral acceleration. In our concept, rolling to 45° is possible. At 45°, a vehicle can negotiate a 1.8 km radius curve without slowing down and without any lateral acceleration felt by passengers. Flight tests conducted by Volpe National Transportation Systems Center indicate that 90% of passengers rate 40° bank as comfortable.

Rolling like airplanes requires partial roll freedom, rather than a system where the vehicle is secured to the magway. The advantage of partial roll freedom is explained in 5.3.7.a.9.

5.3.7.a.4.1. CRUISING SPEED OPTIMIZATION

The average cruising speed (about 115 to 130 m/s depending on the route) is optimized by

1. the installation of high power in places immediately after tight curves or other slow-downs, in order to allow high acceleration back to cruising speed.

2. the adoption of ride quality standards in some critical areas that permit higher accelerations and require passengers to be seated and belted.

3. the quick public acceptance of a high roll angle. June/July 1992 flight tests by Volpe Naitonal Tranportation Systems Center show that public acceptance will not be a barrier. 90 % of random subjects rated as "comfortable" bank angles of 40°, roll rates of 10°/s, and vertical accelerations of ± 0.25 g.

5.3.7.a.5. MAGNEPLANE IS FAST (TOTAL TRIP TIME)

5.3.7.a.5.1. COMPONENTS OF TRIP TIME

Magneplane is not only fast when at cruising speed: the overall trip is fast. The overall trip is composed of:

t_a = *system access time (proximity of magports)*
t_b = *waiting time (frequency of service)*
t_c = *cruising time (magport to magport)*
t_d = *combined dwell time (spent at magports)*

$t_a + t_b + t_c + t_d$ = ***total trip time***

While airplanes and some trains are "fast" (cruising speed), they are generally much slower than the automobile for distances of 100-200 km or less. Why? Because all the other components of trip time are poorly optimized for these modes. That's why most people drive most places.

Magneplane optimizes *every* component of trip time. As a result, the passenger's perception of speed and convenience is maximized, and Magneplane can therefore compete successfully with the automobile.

System access time is minimized by Magneplane's ability to locate multiple magports in every metropolitan area, and at frequent intervals along interstate highways. Individual magplanes can exit and enter the main corridor without slowing the main traffic flow so as to service a large number of off-line magports located along loops and spurs.

Magports can be located where travel and priority freight originates and terminates: at shopping malls, office parks, residential developments, downtown centers, and existing transit stations and airports. *Well-chosen locations* as well as sufficiently *high density* of magports is important to insure low system access time.

Waiting time is minimized by dynamic scheduling. Traffic management is based on immediate demand, as continuously calculated by ticket purchases. Purchases by telephone several minutes in advance can reduce waiting time to nearly zero. A vehicle will be dispatched to provide non-stop or one-stop service between any magport pair whenever a certain number of riders have purchased tickets between these magports, or whenever any smaller number of riders have waited at the origin magport for some time limit (probably 5-10 minutes). This is made possible by the use of small, individually controlled vehicles operating at minimum headways as short as 20 seconds.

Cruising time is minimized by high speeds, as discussed immediately above in section 5.3.7.a.4.

Combined dwell time is minimized by non-stop or one-stop service and low dwell time at each stop, Most of the time spent in a magplane is spent cruising. It is not like an airplane, which sits on the ground for a half hour or more every time it stops. Our magplanes stop infrequently (because passengers going to the same destination are grouped together on one vehicle), and they do not require service when they stop (no refueling or *anything*). Multiple doors permit faster loading and unloading than airplanes. No handling procedure is needed between loading and the initiation of maximum acceleration departing from the magport platform.

5.3.7.a.5.2. TRIP TIME OPTIMIZATION

Section 5.3.2.4., a tradeoff analysis on service method, explains the details on what kind of service Magneplane can offer to maximize these advantages numerically. The topic discussed in section 5.3.2.4. is determining the relationships and appropriate balance among these factors:

- *number of stops per trip*
- *density of magports*
- *service time*
- *number, size, and load of magplanes*

Please refer to that tradeoff analysis for the details on this topic. Also see section 3.2.3.i. for an explanation of the scheduling approach.

Other ways to optimize total trip time are

1. cooperation and leadership by government to secure real estate for the construction of magports in the most convenient areas. (Note: government initiative is also required to *disallow* development in some areas in order to prevent further uncontrolled expansion of urban sprawl, such as the "greenbelt" zoning laws in England.)

2. the development of convenient intermodal connections for local use, such as self-rental cars and personal transit vehicles like Taxi 2000. (and again, the cooperation of government in the development of these technologies)

3. the careful design of magports for low dwell time - eg. attention to the ticketing system, waiting areas, time to open doors and align vehicle with magport passenger transfer points, loading and unloading procedure, and adequate power systems to handle several vehicles simultaneously.

5.3.7.a.5.3. THE COST OF HIGH SPEED

Although it may appear that an increase in speed (reduced total trip time) would incur an added cost, the opposite is true. The faster magplanes go and the quicker they can get into and out of magports, the less the system will cost. The main reason for this is that average trip time is proportional to the number of vehicles needed in the system. For numerical details on this topic see the Parametric Performance Report, section 5.3.3.2.a.

5.3.7.a.6. MAGNEPLANE IS THE ONLY DAMPED EDS

5.3.7.a.6.1. EXPENSIVE MISCONCEPTIONS ABOUT EDS

Attraction (EMS) suspensions are known to require servo-stabilization, while repulsion (EDS) suspensions are thought to require none. This is an expensive misconception. It is true that EDS suspensions are inherently stable, but they are also inherently undamped, and are susceptible to catastrophic oscillations, particularly in rectangular trough configurations.

Magneplane is the only team which has studied and solved this problem. No other team has yet discovered it. This has led to some expensive mistakes, and may lead to more in the future.

o The Japanese have spent over one billion dollars building three full-scale prototype magways, without recognizing that rectangular trough magways have an inherent yaw instability. This mistake has caused frequent magnet quenching and wall-scraping accidents. The most recent one destroyed their test vehicle in August 1991, when a tire was ignited by friction.

o A US maglev evaluator asked in June 92 why the Magneplane team doesn't "...learn from the proven EDS maglev system operated by the Japanese..." He is evidently unaware of the fundamental instability problem of the Japanese system and of its admitted inability to negotiate curves. This might result in the US repeating the mistake.

o The NMI funded a study entitled: "Maglev Vehicle-Suspension Guideway Interaction Study" by Wormley, et. al. (BAA No. 204, Contract DTFR 53-91-C-00062) which is based on very simple one-dimensional analysis not applicable to actual EDS maglev vehicles (i.e., vertical lift and acceleration only). Two erroneous conclusions have been drawn from the Wormley analysis. One: suspensions that function satisfactorily in a one-dimensional model will perform satisfactorily in 3 dimensions, and two: satisfactory performance of a vehicle with secondary suspension solves the interaction problem between the unsprung mass (bogie) and the magway. A secondary suspension will not, of itself, stabilize the unsprung structure, and Wormley never intended to imply that it would! His conclusions are generally mis-interpreted.

The Magneplane team discovered and solved a critical problem in the seventies which nobody else has yet discovered: that EDS suspensions can be unstable, what makes them unstable, and how to stabilize them. The following information is intended to clarify the issue and prevent future mistakes we cannot afford to make.

5.3.7.a.6.2. THE MAGNEPLANE APPROACH, 1970

The original Magneplane team performed thousands of flight tests with 1/25 scale model vehicles to supplement analog inductance simulations and computer model simulations, and to acquire an intuitive three-dimensional understanding of maglev dynamics. The initial vehicles used permanent magnet arrays (alnico five and samarium-cobalt) and were towed by cables over magways of variable configuration. Later vehicles used superconducting coils in the persistent current mode, and were propelled by smart LSMs in the magway. Some vehicles had tuned secondary suspensions, and the final one had an active second-order damping system. It was by such techniques that the Magneplane team was able to learn more in four years from a one million dollar program than the Japanese team has learned in twenty years from a one billion dollar program. Had the Magneplane program not been terminated abruptly, the world might now have a textbook on maglev engineering.

5.3.7.a.6.2. DISCOVERING THAT MAGNETS DON'T ROLL, THEY FLY!

The first series of tests were conducted at the Francis Bitter National Magnet Laboratory, before an active magway was constructed at the Raytheon Wayland facility. 1/25 scale model vehicles (about 9 inches wide by 40 inches long) were towed over various magways, starting with a rectangular one, by a thin stainless steel cable pulled by various weights. Vehicle motion was recorded on 16mm film (videotapes hadn't been invented).

Although vehicles would occasionally accelerate smoothly along the 20 m rectangular magway, they often reached a limiting velocity, and then fishtailed along the remaining magway. Occasionally the oscillations increased to catastrophic amplitude, causing wall-scraping and even derailment. Changing clearances, mass distribution, and center of thrust had very little effect. It became clear within several days that repulsive levitation, although theoretically stable under ideal assumptions, is subject to severe instabilities when a finite dimension vehicle is involved. Like any elastically suspended mass, a maglev vehicle can oscillate. And there is very little inherent damping. Worst of all: there is a mechanism for propulsion energy to be fed into the oscillation, resulting in potentially catastrophic amplitudes.

A stiffer suspension does not solve the oscillation problem, contrary to general opinion. It only increases the frequency of oscillation. The problem cannot be swept under the rug; it needs to be tackled and solved.

5.3.7.a.6.3. UNDERSTANDING MAGNETIC FLIGHT

To understand the dynamics involved, we used inductance simulation to measure lift, guidance and drag forces as a function of vehicle position and attitude in the magway: a vehicle with magnet coils was clamped above a magway containing sheets or coils, and the force profiles were plotted by measuring complex inductance as a function of vehicle position and attitude. Effects of speed (field penetration depth) were analyzed by varying the frequency at which induction was measured. We invented the maglev-equivalent of the wind tunnel.[1] Had the Japanese team done similar experiments, they would never have selected one of the most unstable configurations possible: a square box magway with null-flux guidance.

5.3.7.a.6.4. WHY DO MAGNETS OSCILLATE?

A vehicle with wheels on its bottom and sides can travel inside a square box magway. It can even give a comfortable ride if the wheels have soft tires, and if the magway is banked at exactly the correct angle for the radius and speed at every point. It is tempting to think about magnets as if they were soft wheels.

Unfortunately magnets don't behave like wheels. Each magnet is repelled by a mirror image which it induces in the magway as it travels. Inducing this mirror image causes drag because the image is really a circulating current in the magway, and currents use power. In other words, lift is produced at the expense of drag, just as in the case of an airplane. As each magnet is pushed closer to the magway wall, its lift and drag both increase drastically as it approaches the wall. To complicate matters, the drag depends on the speed. To further complicate matters, so does the effective spring constant, because the restoring force profile is very non-linear. You might think of a magnet as a sticky wheel which gets stickier the harder you push on it and the slower you go.

As soon as the magnet vehicle is disturbed, it will approach one sidewall or the other. As it does, it will yaw strongly toward the nearest sidewall, because the drag on that side increases very strongly. The closer it gets, the more it will yaw, and the stronger will be the repulsive force. When the repulsive force finally overcomes the drag-induced yaw, the vehicle will bounce off the nearest wall and repeat the process in the opposite direction. The result is a fishtailing motion, with an oscillation frequency which depends in a complex way on its mass, moment of inertia, speed, and magnet strength.

What drives this oscillation is a periodic variation in drag at exactly the oscillation frequency. The process is analogous to the violin bow effect: continuous motion which generates and sustains an oscillation at whatever the resonant system frequency. In the maglev case, the energy comes from the propulsion system, and the oscillations can grow to catastrophic amplitudes, since there is very little natural damping. For this reason, the vehicle with magnets will not travel smoothly inside a square trough.

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[1] Y.Iwasa: Electromagnetic Flight Stability by Model Impedance Simulation. Jour Appl Phys Vol 44, No 2 Feb 1973, p 858.

Although the EDS suspension is inherently stable, its response to perturbations is unstable. A rectangular trough is particularly susceptible to this instability for reasons which our experiments have explained.

Recognizing the problem, we dismantled our nine inch wide rectangular magway. At about the same time, the Japanese team started building a full-size one, four miles long.

5.3.7.a.6.5. HEART OF THE MAGNEPLANE INVENTION: CONTROLLED RESILIENCY

By playing with actual maglev vehicles we gained a three-dimensional understanding of EDS maglev vehicle dynamics. We recognized that higher stiffness doesn't solve the problem: it only raises the oscillation frequency and causes destructive effects. After all, isn't stiffness the main problem with wheels? Magneplane's dominant advantage is its ability to control resiliency.

Resiliency was recognized as a six-dimensional concept which needs to be stabilized in six modes of motion: heave, sway, pitch, yaw, roll and thrust. Stabilizing means in essence active damping of oscillations in every mode.

A secondary suspension is not a substitute for active damping. It will not prevent the unsprung mass from fishtailing, galloping or corkscrewing down the magway with ever-increasing violence. A secondary suspension, in fact, is superfluous once the primary suspension has been properly damped.

5.3.7.a.6.6. THE CIRCULAR TROUGH MAGWAY

Magneplane's circular trough magway is the logical choice because it is the only magway configuration which provides resiliency in all degrees of freedom, including the roll mode. Roll-freedom is of course necessary to achieve coordinated self-banking. But there is an additional and unexpected advantage in the circular trough: it couples oscillation modes in such a way that they can be controlled.

Having selected the semi-circular trough configuration (because it meets the self-banking requirement), we performed a second series of tests in a straight magway section, ultimately 500 ft long and powered by a smart linear synchronous motor. The yaw instability was gone: no more fishtailing. Two new and considerably slower oscillations appeared instead: a slow galloping motion, and an even slower roll oscillation.

5.3.7.a.6.7. THE MAGNETIC KEEL

The roll was easily controlled by re-configuring the magnets so as to increase the field intensity along the keel. This "magnetic keel effect" generates a "righting moment" just like the keel of a ship, except that the magnetic keel pulls toward the center of the magway, not the center of the earth. In addition to this magnetic keel, magplanes also have an inertial keel, because the center of lift is above the center of mass. In straight and level magway sections, both keel moments tend to keep the vehicle upright.

As a magplane negotiates a curve, the magnetic and inertial keel moments will produce the same bank only if the magway bank is coordinated for the magplane's speed. If the speed is too high or too low, the inertial keel will roll toward a coordinated bank, while the magnetic keel will attempt to roll toward the magway bank. The result of these two keel moments is elasticity in roll. In other words, the vehicle bank is free to deviate from the magway bank against an elastic restoring moment caused by the magnetic keel. Both the magnetic and inertial keel moments are important design variables, subject to precise control.

5.3.7.a.6.8. THE GALLOPING SYNDROME

The galloping oscillation proved more difficult to control, but provided considerable learning experience. It also demonstrates dramatically the actual mechanism of instability.

> A bump in the magway induces heave oscillation. As the vehicle heaves, a pitch oscillation is induced by the variation in drag. This is analogous to "brake dip" in an automobile, except that it is vastly more complex, and oscillatory.
>
> Oscillations are generated and sustained by variations in thrust and lift as the vehicle's phase position oscillates about the stable point in the travelling wave which propels it. The effect is similar to towing a car with an elastic cable along a bumpy road. Propulsion energy drives oscillations, as in the case of the violin bow.

The bottom line: the linear synchronous motor is able to feed energy into coupled heave-pitch oscillations and cause them to reach catastrophic amplitudes. The closest known analogy is "fuguoid instability" in airplanes, which arises from a three-way coupling between pitch, velocity and thrust. To the best of our knowledge, instability phenomena in EDS maglev vehicles have never been discovered, much less studied or named.

Analogous oscillations occur in other modes, although they are less pronounced. For example sway is coupled to yaw by a similar mechanism, and in the circular magway, both are coupled to heave.

5.3.7.a.6.9. TACKLING THE GALLOP

The solution to the galloping syndrome eluded our team for the better part of a summer. We improved the magway alignment, refined the synchronization, and played with tuned secondary suspensions. We changed all relevant parameters: magnet configuration, mass distribution, phase position and control characteristics. The galloping never stopped. Sometimes it was accompanied by yaw oscillations at incommensurate frequency, resulting in a peculiar corkscrew motion reminiscent of a certain V-tail aircraft, famous for this instability.

The solution, as often happens, came after a period of frustration. It was obvious, elegantly simple, and very effective. It consisted in teaching the smart linear synchronous motor we had invented to be just one notch smarter. Instead of slavishly keeping the phase position of the vehicle in the travelling wave as constant as possible, we made it adjust the phase position in response to the input from a vertical axis accelerometer aboard the vehicle. Whenever the vehicle accelerated upward or downward, its position was shifted to cancel the acceleration.

Since this feedback control servo system operates on a second derivative input (acceleration rather than displacement), it provides more than just active oscillation damping. It actually prevents oscillations, rather than merely killing them after they start. It is a shock preventor, not just an active shock absorber.[2]

Ride quality improvement was dramatic: in the first trial flight, heave oscillation amplitude decreased by a factor of twenty. The gallop was gone and, surprisingly, so was the sway oscillation.[3]

5.3.7.a.6.10. UNEXPECTED BENEFIT OF THE CIRCULAR TROUGH MAGWAY

In addition to allowing self-banking, the circular trough magway also ameliorates the severe yaw instability inherent in the rectangular trough configuration, and makes it controllable by active intervention. There is something inherently natural about the configuration, although it is not intuitively obvious or easy to explain. A circular trough couples different modes so that they are no longer independent and tend to stabilize each other.

> A sway disturbance in a circular trough, for instance, does not produce adverse yaw, as it would in a rectangular trough. Instead, it produces both heave and roll, as the vehicle is forced to climb up the wall and to bank inward, toward the center of the trough.

In other words, the vehicle cannot fishtail without also bouncing and galloping, because these three oscillations are coupled to each other by the circular trough. It is therefore possible to suppress all three oscillations by suppressing heave.

In the present Magneplane concept, the primary damping mechanism is phase position control by the wayside power conditioning unit in response to on-board accelerometers. This primary active heave damping is supplemented and fine-tuned by aerodynamic surfaces at the bow and stern, which can apply heave and sway forces, as well as yaw, pitch and roll moments. These surfaces are particularly effective at high speed, where control authority is most important.

5.3.7.a.6.11. THE NEED FOR ACTIVE DAMPING

On a philosophical note, consider the human body. We each have our very own control center, which is connected to our muscles through a *two way* communications path. One set of nerves controls muscle tension: it carries commands from the control center to each of the separate moving parts. The other set of nerves reads the actual tension of the muscles and the position of each of the moving parts and reports back to control center. The control center makes *constant and minute* modifications to the muscle tension to achieve smooth movements. We could not walk or even stand still without this two-way self-correcting system! This is active damping *par excellence!*

We designed Magneplane the way nature designed us: two-way communication between the moving parts and the control system allows movement that is actively damped, smooth, and responsive to the condition of the system's organs and the environment.

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[2] U S Patents No 3,871,301, and 4,969,401.

[3] W.S.Brown: Ph.D. dissertation, MIT Dept of Electr Engr; 196 pages; unpublished.

Wheeled vehicles have operated successfully with primitive passive shock-absorbers. But aircraft have used active damping since the early sixties, when the tragic Trident accident underscored its necessity. Today, if we are to fly safely and comfortably along imperfect magways through a turbulent atmosphere at 134 m/s, we will need to use active damping, just as we did when we started walking upright. Let us be thankful that the necessary technology was developed just in time!

5.3.7.a.7. MAGNEPLANE IS A NEW CONCEPT

Magneplane is a new concept in transportation, not just a revision. We do not treat maglev like a wheelless train or a low-flying airplane. We are aware of and fundamentally take account of the possibilities for maglev.

In our concept development, we considered:

- the long-term trends in transportation and the needs of the 21st century, eg. reduced dependence on the automobile
- the ways of producing energy, the costs of foreign and domestic energy, and the US foreign trade deficit
- the environmental damage that transportation and other industries cause, and the particular solutions that the transportation industry can offer
- the ways to optimize a completely automatic control system

As the reader can surely see, Magneplane International is not just developing a new piece of equipment; we are proposing a mega-scale concept that will benefit the US and the world economically and environmentally.

5.3.7.a.8. MAGNEPLANE IS AN EXPERT TEAM

The advantages of the Magneplane team are numerous:

1. The Magneplane team is expert in all areas of design: superconducting magnets, cryogenics, civil structure, foundations, motors, and controls.
2. The Magneplane team has already solved the major technical challenges of maglev when we developed a scale model in 1973.
3. The Magneplane team is small and innovative, and unconstrained by conventional thinking.
4. The Magneplane team has approached the technology with the aim of creating one whole working system, not to solve a collection of problems. In the current contract, we have worked with the

customer in understanding the important issues and defining the needs of a maglev system, and have worked beyond the individual requirements of the Statement of Work, rather than simply working through the given list of problems.

5. The Magneplane team is interdisciplinary, and we successfully coordinate the different fields of engineering involved. Each group in our team is at the cutting edge of its technical expertise. This is crucial, because there are connections between system elements that might be overlooked by a team relying on the traditional divisions between engineering fields.

6. The Magneplane team is prepared to develop a maglev system on a five-year time scale.

7. The members of the Magneplane team are personally committed to our work. We are not looking for post-cold-war income.

5.3.7.a.8.1. OPTIMIZING THE TEAM

The advantages of the collection of expertise in the Magneplane team can be "optimized" by government cooperation in keeping our work going now (before major decisions are made), rather than letting it fall apart and get involved in other work.

5.3.7.a.9. MAGNEPLANE HAS PARTIAL ROLL FREEDOM

Roll freedom is the measure of coupling between the magway bank angle and the vehicle attitude in operation. There are three general categories of options:

- zero roll freedom (vehicle affixed to magway)
- partial roll freedom (vehicle held in magway with some deviation allowed)
- total roll freedom (vehicle allowed to roll independently of magway)

The problem with zero roll freedom is that the magway can never be banked higher than it is acceptable to be stopped in the curve at that angle. For example, if it was not acceptable for a vehicle to be stopped in a curve banked at 12° or higher, then no curve could be banked higher than 12°.

Magneplane has partial roll freedom, which is an advantage over the other two options. Partial roll freedom is achieved by using a trough-shaped magway with a magnetic keel. A magnetic keel generates a "righting moment" just like the keel of a ship, except that the magnetic keel pulls toward the center of the magway, not the center of the earth. In addition to this magnetic keel, magplanes also have an inertial keel, because the center of lift is above the center of mass. In straight and level magway sections, both keel moments tend to keep the vehicle upright.

As a magplane negotiates a curve, the magnetic and inertial keel moments will produce the same bank only if the magway bank is coordinated for the magplane's speed. If the speed is too high or too low, the inertial keel will roll toward a coordinated bank, while the magnetic keel will attempt to roll toward the magway bank. The result of these two keel moments is elasticity in roll. In other words, the vehicle bank is free to deviate from the magway bank against an elastic restoring moment caused by the magnetic keel. Both the magnetic and inertial keel moments are important design variables, subject to precise control.

In summary:

- An advantage of partial roll freedom is that the magway can be banked steeply, yet in an emergency if the vehicle must stop in a curve, it can drop to an upright position without losing thrust capability.

- The velocity at which vehicles operate in a curve can differ from the design velocity by a certain margin. Two opposing roll moments determine the precise amount of roll.

- Oscillations in all six degrees of freedom are damped actively by the LSM, supplemented by aerodynamic surfaces.

5.3.7.a.10. MAGNEPLANE HAS A CURVED MAGWAY TROUGH

The curved magway trough is a central feature of Magneplane which is an ingredient in many other advantages. These advantages are:

1. The curved through permits switching without moving the magway. Wraparound maglev technology requires magway movement for switching. This is too slow for short headways.

2. The curved trough magway is the only magway configuration which provides resiliency in all degrees of freedom, including the roll mode.

3. The curved trough ameliorates the severe yaw instability inherent in the rectangular trough configuration, and makes it controllable by active intervention. There is something inherently natural about the configuration, although it is not intuitively obvious or easy to explain. A circular trough couples different modes so that they are no longer independent and tend to stabilize each other.

   A sway disturbance in a circular trough, for instance, does not produce adverse yaw, as it would in a rectangular trough. Instead, it produces both heave and roll, as the vehicle is forced to climb up the wall and to bank inward, toward the center of the trough.

   In other words, the vehicle cannot fishtail without also bouncing and galloping, because these three oscillations are coupled to each other by the circular trough. It is therefore possible to suppress all three oscillations by suppressing heave.

5.3.7.a.11. MAGNEPLANE FEATURES DISTRIBUTED ACCESS

The Magneplane system is designed to be accessible conveniently, where people live, work, and shop. This implies a distribution of magports over a metropolitan area including suburbs.

Since people often travel to and from suburbs, magports ought to be located there.

The reason Magneplane is specifically suited for distributed access is that our magports can be small and off-line, and can also be built "way off line" - on loops and spurs off the main corridor.

5.3.7.a.11.1. OPTIMIZING DISTRIBUTED ACCESS

The proper distribution of system access can be optimized by cooperation and leadership by government to secure real estate for the construction of magports in the most convenient areas. (Note: government initiative is also required to *disallow* development in some areas in order to prevent further uncontrolled expansion of urban sprawl, such as the "greenbelt" zoning laws in England.)

5.3.7.a.12. MAGNEPLANE HAS MULTIPLE USES

The off-line magport capability described above also makes Magneplane highly applicable to other uses, because most freight, particularly high-priority freight, originates where passengers live, shop or work.

Since short-haul mail and priority freight bring more revenue per pound than do passengers, this will provide Magneplane with substantial off-peak revenue. Produce and even toxic and medical waste may become a market.

Magneplane can also handle exceptional freight which now requires dedicated charter flights, such as "just-in-time" production deliveries, emergency maintenance crews, organ transplants and cancelled checks, for example.

Off-line magports can also serve the function of freight sidings, where freighters can stand in reserve to be loaded as required. Individual freighters can be dispatched without the need to "make up" a freight train, or wait for return cargo.

5.3.7.a.13. MAGNEPLANE CAN USE EXISTING CORRIDORS

It is no longer possible to build new railroad rights-of-way, particularly in the congested areas where they are needed. The only available space to punch through populated areas is the existing network of roads and interstate highways.

New transportation must therefore be installable along existing highways, with minimum deviation from the existing right-of-way, and with minimum disruption of existing traffic.

The implications of this requirement are severe. They include:

1. Ability to negotiate horizontal curves of 2.5 km, as compared to the 25 km radius curves typical of conventional railroads.

   Ability to negotiate vertical curves required to follow highway grades and clear overpasses in available space.

2. Ability to eliminate all grade crossings by elevated structure along entire routes, or on-grade installation in medians or shoulders; cross section must be small enough to fit below existing overpasses, and to use economically sized tube-tunnels.

3. Advanced footing technology to eliminate conflict with wetlands regulations or disruption of traffic.

4. Aesthetically acceptable pylons and spans, installable without disruption of traffic.

Magneplane can meet these requirements because of several unique features:

1. Magway and associated power system carries only one twentieth the live load of conventional railroad.

2. Resilient levitation at six inch gap and active oscillation damping eliminates the need for high precision alignment or very stiff spans.

3. Self-banking assures coordinated turns at any cruising speed around curves down to 2.5 km radius, with passenger comfort comparable to airliners.

4. Self-banking permits tight vertical curves by cancelling negative vertical acceleration with horizontal curvature, a maneuver known in aviation as the "chandelle". This is important because it eliminates the most stringent ride quality problem, that of negative vertical gee-force on overpass ramps.

5.3.7.a.14. MAGNEPLANE IS ENERGY EFFICIENT

Magneplane requires less wayside power demand capability than any other system proposed. It requires about *one tenth* the power capacity of conventional railroads. Energy saving features are:

- Vehicles are constructed like an aircraft fuselage and contain no propulsion unit. They weigh about 0.3 tons/seat, about one third the weight of railroad trains.

- Vehicles travel non-stop or one-stop origin to destination and don't need to be accelerated at frequent magport-stops.

- Wayside power supply needs to accelerate only one vehicle at a time, not twenty. The same advantage reduces grade climbing power requirements.

- Deceleration is regenerative: braking power is returned to the power system.

- Magneplanes have small cross section and fit into a 5 to 6 meter (16 TO 20 foot) diameter tube. This will minimize the cost of evacuated tube magways when the system is ultimately upgraded to supersonic speed. For atmospheric tunnels, a somewhat larger diameter will have to be provided to minimize drag.

5.3.7.a.15. MAGNEPLANE IS ENVIRONMENTALLY AND AESTHETICALLY ATTRACTIVE

Magways consist of slim box girders forming long spans which rest on slim pylons. Advanced non-invasive footing technology will be developed to permit pylons to be installed across wetlands without violating EPA and CoE wetlands regulations, and without the need to construct access roads.

Elevated structures are inexpensive enough to eliminate the need for on-grade construction, with its associated environmental impact on drainage, wildlife migration, and wetlands filling requirements.

External electromagnetic AC fields around magways will be comparable to those of powerlines.

Passengers will be subjected only to DC fields comparable to the earth's magnetic field (one half gauss).

Noise will be limited to the rush of air.

Decentralized, small magports will eliminate the need for major transportation hubs with their associated parking and service areas, and the resulting traffic congestion.
Magneplane will eliminate the need for new highways, and reduce automobile and airline traffic.

5.3.7.a.16. MAGNEPLANE IS ECONOMICALLY ATTRACTIVE

The economically advantageous features of the Magneplane system include:

- Modular prefabrication reduces manufacturing and installation cost, and minimizes interference with existing highway traffic.

- The size and number of initial vehicles and wayside power systems can be down-sized for the reduced initial traffic. The system can later be upgraded in both speed and capacity at low cost, and without penalty, by use of modular concepts.

- Magway design permits maximum flexibility in future vehicle design without requiring magway modification.

- Life cycle cost is low due to small live load, low accuracy requirement, structural flexibility, no mechanical contact, and low vibration.
- High passenger capacity and off-peak freight market contribute to high revenue.
- Fully automated system reduces labor cost, increases safety and reliability.
- Small cross section minimizes size of tunnels, overpasses. It also facilitates installation in evacuated tubes when even higher speeds become economically desirable.
- Construction of a magway network and reduction of oil imports would save the US billions of dollars annually.
- A simple electrical system that uses existing components, and uses few switches or other moving parts.

5.3.7.a.17. MAGNEPLANE IS ROBUST

Magways are flexible and do not require high-precision alignment, due to resiliency of suspension and six inch levitation height. They are therefore inherently resistant to earthquake and other transient damage. Bridge and overpass spans can be light, flexible, and aesthetically attractive.

Due to modular prefabrication, installation and replacement of pylons and spans is simple and inexpensive.

The magway trough has openings at the center, where the propulsion windings are located, and therefore sheds water, snow and ice.

Normal operating currents should keep magway temperature above ambient, which prevents catastrophic icing.

5.3.7.a.18. MAGNEPLANE IS UPGRADABLE

Magneplane magway can be built at minimum cost to handle low traffic volumes initially, and upgraded later without penalty or waste of labor or components. This results from the very simple and straightforward configuration of the magway and vehicle. The following upgrades in capacity and/or speed can easily be made. (Also see 5.3.2.1.c.)

1. Vehicle size can be increased from 45 seat capacity (or equivalent freight), and a length of 20 m, to 140 seat capacity and a length of 60 m. Power conditioning units will have to be enlarged. No change in magway configuration is required.

2. Maximum cruising speed can be increased by increasing the capacity of each power conditioning unit (adding solid state switching elements). The vehicle is free to self-bank by plus or minus ten degrees from the magway bank angle.

3. Operation in evacuated tunnels at supersonic speed will be relatively inexpensive, because the vehicle and magway will fit into a tube of about 5 to 6 m diameter (16 to 20 feet). This option may become important if we ever make the decision of not developing supersonic transport aircraft for operation over land.

5.3.7.a.19. MAGNEPLANE IS FEASIBLE TO DEVELOP

The current lack of support for a U.S. Maglev program is due primarily to the widely held opinion that maglev offers nothing more than faster railroads, and railroads fail to meet modern transportation requirements. Two events confirm this assertion:

- When results of Senator Moynihan's Maglev Task Force Study were announced at a press conference in the Russel Building, there was only one question from the floor: "Why should the United States invest in a new railroad system, when railroads have been unpopular and unprofitable for at least forty years?"

- When Secretary of Transportation Skinner was interviewed by "Inside DOT", he was quoted as saying "...and then there are maglev trains. But they are very expensive, and what good is a 300 mph train? It can't stop often enough to be useful."

There are two other widely held opinions, one is:

- "The Germans and the Japanese have spent a billion dollars each on maglev, while ours has been dead in the water for fifteen years. What chance to we have?" do

The third opinion widely held is a management reaction to efforts to raise support from U.S. Industry:

- "The Germans and Japanese have already spent a billion dollars each, and have gotten nowhere. Maglev is too big for private industry. Let the Government do it!"

Any maglev initiative must be sufficiently robust to overcome these attitudes.

5.3.7.a.20. MAGNEPLANE WILL INSPIRE PUBLIC ACCEPTANCE OF MAGLEV

Magneplane can provide a partial answer to the three major objections facing a U.S. Maglev initiative. The technically educated media have already shown strong support, as indicated by four NOVA features, a cover article in Popular Mechanics, June 1988, and an article in Scientific American, August 1992.

1. Magneplane is not just a faster railroad. It is an entirely new concept. It can meet modern transportation requirements, alleviate congestion and pollution, and restore U.S. leadership in transportation technology.

2. The Germans and Japanese have invested a billion dollars each, but they have not taken advantage of the unique features of maglev. They are no nearer to a practical, affordable system then they where when they started. The Magneplane concept remains the most promising concept, despite having spent only one million dollars and having been dormant for fifteen years.

3. Private industry will build Magneplane for the same reason that private industry built all previous transportation systems: It can do something people are willing to pay for. What industry needs from government is leadership, enabling legislation, and a positive atmosphere which will be conducive to raising private capital.

4. What is needed from Government is a 1991 version of the 1837 Land Grant Act which gave us the world's best railroad system. It also repaid the government generously, and created the largest fortunes in modern history. Our national cultural institutions are still supported by endowments from the railroad barons: Carnegie, Mellon, Rockefeller, and Vanderbilt.

5.3.7.a.21. SUMMARY OF ADVANTAGES

The most promising alternative is advanced rail, as exemplified by TGV, ABB, ICE, ANE, and several more recent tilt-vehicle projects.

Advanced rail offers a viable interim system for Europe, which already owns a highly developed rail systems, and where most travel still originates in large cities. It is also applicable in Japan.

In the U.S. however, railroads have been unpopular and unprofitable for forty years because they cannot serve our decentralized population, and because it is no longer possible to build new railroad type rights of way to punch through our urban sprawl.

Transrapid is unacceptable for the same reasons. In fact, it is even less applicable than advanced railroads. It is much heavier, has far less acceleration, requires magways which are even straighter and leveller, and substantially more expensive. A cost of $26M per two-way km is indicated by the Transrapid proposal for the Orlando demonstration project. Soil mechanics experts in Florida have questioned whether the required alignment accuracy can be maintained at all.

The Japanese Technova (originally JNR) repulsive maglev system is far from ready, despite claims to the contrary. They have changed the total configuration of their premature full-scale demonstration system three times, and it still has a basic yaw-instability which prevents it from negotiating even curves of 12 km radius. They have not addressed, much less solved, the oscillation damping problem, and their refrigeration system cannot prevent accidental quenching of the superconducting magnets caused by sloshing of the liquid helium.

Both Technova (JNR) and Transrapid need to use multiple coupled vehicles to achieve reasonable passenger capacity.

We believe that Magneplane is the only concept proposed thus far which is capable of relieving our gridlock by the year 2,000, at an affordable cost in terms of investment, operating cost, energy and environmental cost.

5.3.7.b. DISADVANTAGES

5.3.7.b.1. MAGNEPLANE DEPARTS FROM CONVENTIONAL THINKING

The single crucial disadvantage of Magneplane is its radical departure from conventional thinking. This requires innovative engineering in a large number of fields.

One means we have chosen to minimize this disadvantage is to assemble a multi-disciplinary consortium composed of leading-edge teams in every required field of specialization, and leadership at all levels which is unconstrained by conventional thinking, educated in the relevant disciplines, and capable of leading, not merely managing the overall effort.

5.3.7.b.2. MAGNEPLANE HAS CLOSE VEHICLE SPACING

Magneplane, because of the requirement for low-capacity vehicles (as compared with conventional trains) must have far less time between vehicles. Using all large (140-passenger) vehicles, the spacing is 42 s at 12,000 passengers/hour. The spacing drops to 20 s at 25,000 passengers/hour.

Conventional trains have headways of many times what we propose. Our headways are a disadvantage because they leave less room for error than longer headways. The kinds of error that might occur are operator error in judgement, and unreliable detection of emergencies. Short headways also require a reliable emergency brake.

These disadvantages are far outweighed by the advantages of individually targeted vehicles and frequent service that our system provides. In addition, we have minimized the potential disadvantage by:

1. using an emergency skid brake, which is safer and more reliable than wheel-brakes.

2. not requiring a human operator in the control loop - although human intervention is possible in the Global Control Center.

3. using a multi-layered control and communications system that maintains safe headways, detects and averts emergencies, and can safely maneuver an emergency shutdown even in the event of total communications failure between all of its parts.

Because of these elements of concept design, which are required elements as a result of the 20 or 40 s vehicle spacing, there is no safety hazard associated with the short spacing.

5.3.7.b.3. MAGNEPLANE HAS MORE DRAG THAN OTHER SYSTEMS

This is a widespread mis-perception based on superficial understanding and misleading advertising. Here are the relevant facts.

1. All EDS systems have more drag than EMS systems, whether they use sheets, coils or ladders, but the Transrapid pays a price in terms of vehicle weight, guideway cost, and inflexibility of performance which we consider unacceptable. Energy cost, it turns out, is completely dominated by capital and demand cost.

2. Sheet magways have more drag than coil or ladder magways, but only if they are compared (normalized) on the bais of same aluminum mass per unit length. This is because coils and ladders can make better electric use of the aluminum. Coils and ladders can concentrate the aluminum where most of the current flows (along edges), while sheets use uniformly distributed aluminum over the whole magway width.

3. Detailed quantitiatve computer comparisons based on the Magneplane configuration are shown in section 5.3.2.13. These results indicate that sheets actually have 30% less drag than coils or ladders, providing they use 2.5 times more aluminum than ladders, and about 1.5 times more than coils of comparable dimensions in order to achieve these better lift/drag ratios.

4. The increased amount of aluminum used by sheets does not imply that sheets cost more than coils or ladders, because sheets serve both electrical and structural functions and cost less to manufacture. Coils and ladders need to be supported against vertical, lateral and longitudinal forces. Sheets are substantially self-supporting. The JNR reports very high guideway costs, and is inherently unstable.

5. The higher drag of Magneplane is more mis-perception than fact. The use of sheet magways is one of many trade-off decisions and is a basic feature of the concept under study.

5.3.7.b.4. A DISABLED VEHICLE CAN DISRUPT A WHOLE CORRIDOR

In our system, if a magplane experiences a total failure and becomes stuck in the magway, every vehicle must stop or change course. Airplanes and cars can immediately switch to alternate routes if there is any kind of barrier; trains run far enough apart that the effect is not so immediate, The frequency of occurrence of this situation and the length of time that a disruption can occur are minimized by:

1. building redundancy into key places in the propulsion system to achieve reliability high enough to make a total breakdown very rare. See section 3.2.3.h.

2. the use of an intelligent control system, which will, immediately upon detecting a vehicle that is in danger of malfunctioning, and even before that vehicle has stopped:
   (a) slow down or stop the vehicles directly behind the malfunctioning vehicle as required to maintain a safe separation.
   (b) slow down vehicles farther down the corridor less abruptly, so they don't experience sudden steep braking.
   (c) prevent new vehicles from entering the corridor in the area of the potential breakdown.
   (d) re-route all vehicles as appropriate, either onto an alternate branch of the magway network, if available, or through a cross-over to the opposite side of the dual magway. A section of magway can handle bi-directional traffic while the emergency is being taken care of.
   (e) send a tow/repair vehicle to the site if necessary.

3. the ability to restart all vehicles that are stopped no matter how closely spaced they are and regardless of the design speed of the curve that they may be in. Moreover, the restart operation will not subject passengers to any accelerations outside the ride quality standard. If a vehicle becomes disabled due to a temporary failure which can be corrected externally, it can restart without any service to the vehicle, and the total effect to the system could be only a few minutes.

Because of these elements of design, we believe that a disabled vehicle will almost never be a problem that delays service in an operation system.

5.3.7.b.5. CURVES MUST BE TRAVERSED NEAR DESIGN SPEED

In our concept, there is partial roll freedom, meaning that a vehicle can roll one way or the other (up to a point) away from the design roll angle in a curve. If the vehicle enters the curve lower than design speed, there is some lateral acceleration due to the keel effect. If it enters a steeply banked curve at a very low speed, the lateral acceleration will exceed the ride quality standard, and passengers (if they are standing) could be injured.

The effect of the magnetic keel drops off below about 20 m/s, however, and so if a vehicle must go that speed, the ride quality will meet the standard. When a vehicle slows to a stop in a curve (which would only happen in an emergency situation) there is a short period in which lateral acceleration is high.

The velocity limitations on curves are minimized by:

1. the use of a coordinated global routing system, which plans ahead and ensures that vehicles operate at design speeds - unless there is a vehicle or LSM failure.

2. the acceptable velocity envelope for any curve is less restrictive than the requirements for global velocity control in general.

3. the relatively minimal impact of negotiating a curve off design speed: there is only a decrease in energy efficiency and an increase in lateral acceleration; there are no high-impact considerations.

5.3.7.b.6. OBJECTS CAN ACCUMULATE IN THE MAGWAY

As a result of the trough shape of the magway, it is possible that objects could accumulate there and interfere with system operation. These objects are examples of what could be problematic:

precipitation: *water, snow, ice*
falling natural debris: *leaves, branches*
wind-blown debris: *trash, leaves*
animals
vandalism: *bricks*

The possibility of these objects existing in the magway is real, and was taken into consideration. Briefly, the methods used to minimize accumulation are:

1. fencing in urban (or possibly all) areas.

2. the use of drainage holes for water.

3. the fact that the magway surface is hot enough to prevent formation of ice and melt snow. All of the energy used to overcome electromagnetic drag becomes heat which is dissipated in the magway aluminum levitation sheets (see section 3.2.3.g.5.).

4. the wind produced by a passing vehicle is sufficient to blow away light objects and snow.

5. the insensitivity of the system to small objects due to the clearance between the vehicle and magway. Anything less than 0.15 m in diameter will go unnoticed.

6. a magway monitoring system, which uses cameras to survey the condition of the magway and to detect large heavy objects.

7. an on-board monitoring system (on each vehicle), which detects potentially dangerous debris and alerts the global control center. In this event, no other vehicle need be affected. Of course it is impossible to prevent a vehicle from hitting an object that lands in the magway just ahead of it, but the system ensures that no subsequent vehicle will be affected.

5.3.7.b.7. MAGWAY AND VEHICLE ARE NOT LOCKED TOGETHER

In our concept, the vehicle is enclosed on three sides by the magway but not secured by a wrap-around configuration like Transrapid.

Theoretically, in the absence of any other information, one could believe that this configuration runs the risk of a vehicle flying out of the trough.

The curved trough is an essential advantage (see 5.3.7.a.10.) and no evidence has yet been discovered that would indicate an associated risk. The un-locked configuration is not a risk because:

1. in curves, the trough is not *rotated* into the bank; it is *extended.* The vehicle can be fully supported in a stopped upright position at all points.

2. the active damping system, in coordination with passive levitation and guidance forces, prevents catastrophic oscillations from occurring (see section 5.3.7.a.6.).

5.3.7.b.8. SUPERCONDUCTING MAGNETS HAVE HIGH STRAY MAGNETIC FIELDS

Because Magneplane uses superconducting magnets, the magnetic fields produced are in excess of those encountered typically by people in their homes and places of work. The exposure to magnetic fields is minimized by:

1. a powered shielding system (see section 3.2.1.i.) which reduces the field in the vehicle to about 5 G or less.

2. the fact that living organisms are apparently not affected by continuous DC magnetic fields of intensities up to 60,000 G for periods of several hours, according to tests with Rhesus monkeys.

5.3.7.b.9. HIGH SPEEDS MEAN HIGH WIND NOISE

As magplanes travel up to 134 m/s, the noise from wind is a potential problem. However, this is minimized by:

1. the fact that Magneplane will operate in high-noise environments anyway, ie. highways. Since Magneplane is capable of high performance along highways, and since no other system is quieter, this is actually an advantage for Magneplane.

2. the fact that there is no other source of noise besides wind - the motor is silent.

3. the elevated magway trough, which provides noise shielding for ground-level pedestrians.

4. the distance from people to the source of noise: the magplanes themselves are farther away than loud trucks and busses typically are from urban pedestrian areas.

5. the acoustic insulation used in the vehicle body, which limits interior noise to a comfortable level.

5.3.7.b.10. MAGNEPLANE HAS A HIGH INITIAL COST

At first glance, it may appear that Magneplane costs too much! It is true that initial investment is a higher portion of 50-year costs than is the case for some other transportation options. This could be a disadvantage if the government was unwilling to make the investment all at once.

All transportation is publicly subsidized. This is because transportation infrastructures are an investment that benefits us all. In the case of Magneplane, an multi-billion dollar transnational magway network that replaces some automobile use would save billions annually in oil imports. Although the initial cost is high, the payoff period is short.

We recognize that high cost can be a perceived disadvantage, but we believe that a high cost is not really a disadvantage at all. Take a look at what the country would *get* from the investment:

- hundreds of thousands of jobs for several decades
- independence from foreign oil, before it's too late
- a transportation system that has a capacity high enough to fill the need
- a cleaner environment, the benefit of which cannot be measured in dollars
- a major shift of the balance of trade, which would restore our country's position as a world economic leader

It is more than a little bit ludicrous for the US government to pay Japan or Germany for our transportation systems when we suffer from a trade deficit and unemployment, on the grounds that it costs "less money". We got into a high-debt high-unemployment situation by failing to *invest* in our own work-force in the first place.

The expenditure of a large capital outlay (that will pay off) is a benefit to this country, and as such, is a central advantage to the Magneplane concept.

Particular ways that the perceived disadvantage of high capital cost are minimized include:

1. efforts to educate people on the actual costs of transportation, the role of the transportation industry in the national economy, and the value of high investment.

2. efforts to educate people on the need to reduce automobile dependence. If the top capacity of Magneplane was used in 15 years (25,000 passengers per hour) (that capacity could easily be used even as soon as the system is installed in places like Long Island), then the cost per passenger is *low*. See section 5.3.3.2.f.

3. the long life-span of the capital equipment

4. a reduction in other transportation costs, *which make Magneplane look like the bargain of the century, which it is!* These other costs are

   (a) costs of automobile and airplane accidents
   (b) costs of pollution, including the indirect cost of environmental damage
   (c) cost of lost time due and human energy to slow ineffective (and *frustrating*) transportation
   (d) costs of *foreign* cars, airplanes, trains, and energy

5. the fact that Magneplane can carry five times the number of passengers of a train, or the Transrapid 007 system (Magneplane carries 25,000 passenger seats per hour each way as compared with 5,000.

5.3.7.b.11. ALUMINUM LEVITATION PLATES REQUIRE EXPANSION JOINTS

Magneplane's aluminum levitation plates require thermal expansion joints, which cause a discontinuity in the image coil induced by the vehicle levitation coils as the bogie passes over the joint.

Any possible effect of this joint is minimized by Magneplane's resilient suspension, sufficiently large coils, and active damping system. As a result, the expansion joints have no noticeable effect on ride quality, even when on the landing gear.

5.3.7.b.12. MAGNEPLANE PROPOSES UNPROVEN TECHNOLOGY

Some of the technology proposed in this concept definition is unproven, and requires effort to develop. For example, the landing gear, emergency brakes, cryogenic systems in a moving environment, and automatic control systems for high speed land vehicles.

Proven alternatives do not require development of these technologies. The potential disadvantage of having to develop new technology for a new application are minimized by:

1. the fact that development of new technology for a new application is more appropriate than using old, inapplicable technology for a new application. For example, wheeled landing gear and brakes are proven in some environments but they are not applicable to maglev, although they may appear to be.

2. the external benefits of developing the technology for this application (see section 5.3.13.).

Please note that the Magneplane team chose options with the feasibility of development in mind.

5.3.7.b.13. SUMMARY OF DISADVANTAGES

Magneplane is proposing a radical new technology, which the public is in general not even aware of, and the government is apparently not prepared to invest in. Even the information presented in this report may appear too good to be true, and it could go unnoticed because it doesn't fit into conventional thinking about railroads or other transportation modes.

The United States is married to the automobile in blissful ignorance of the economic and environmental damage it is causing. Even many elected leaders do not want to think about this transportation crisis, and they certainly don't see the need for any solutions.

It is not difficult to understand how the Magneplane system works, and in fact, there are no major *technical* disadvantages in the Magneplane concept. At the same time, it is easier to think about things in relation to what we already know than to what is new to us. Thus the general disadvantage of Magneplane is its difficulty to understand.

For those content to drive, it is difficult to understand the real requirements for a US transportation system; for those not sensitive to national economics, it is difficult to understand the scale and benefits of our proposal and the necessity for domestic development; and for those who take trains to be the basis of maglev, it is difficult to understand why certain central features of Magneplane are beneficial at all.

A public education campaign is required to disseminate information and spark debate leading to positive legislative action. Without this, Magneplane has a severe disadvantage, and any other more conventional options, including train-like maglev systems, have the advantage.

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