Guidelines for Estimating Trip Times, Energy Use and Emissions for HSGT Technologies

Final Report

Prepared For Participants In The Maglev Deployment Program*

by

Donald M. Rote

December 14, 2001

Argonne National Laboratory
Center for Transportation Research
9700 S. Cass Ave.
Argonne, IL 60439

*Under Interagency Agreement DTFR53-96 X00029, MOD 12 between the Department of Transportation, Federal Railroad Administration and the Department of Energy, Argonne National Laboratory

16-Energy

Table of Contents

Guidelines For Estimating Trip Times, Energy Use and Emissions For HSGT Technologies

1. Introduction

Energy utilization and the production of air pollutant emissions are closely-related, critical aspects of the evaluation of alternative transportation technologies. Both of these topics have important domestic and international aspects. Domestically, changes in emissions affect the ability of U. S. areas to be in compliance with present and future air quality and emissions standards. The most recent EPA Trend Reports (see Refs. 1 & 2) show that air quality is generally improving and emissions are continuing to decline, although some projections indicate that future emissions of some pollutants may increase after the year 2005. Despite these improvements, some 130 areas are still designated "nonattainment" for at least one of the criteria pollutants. This statistic may increase when the U.S. EPA releases new area designations consistent with revised ozone (O_3) and particulate matter (PM_{10}) standards.

The main international issue with respect to air pollutants is the emission of radiatively-active gases such as carbon dioxide (CO_2) and methane (CH_4) that contribute to global warming. A recent report from the Carbon Dioxide Information Analysis Center, Ref. 3, states that the 1996 estimate for global CO_2 emissions is the highest ever for fossil-fuel emissions.

Since emissions are closely related to energy use, it is not surprising that changes in energy use are equally important. In addition to the emission implications associated with changes in energy use there are also other important domestic and international issues including the growing dependence on foreign petroleum sources, protection of those sources, balance of payments, and environmental problems associated with shipping accidents.

As Table 1 shows, consumption and importation of crude oil and petroleum products in the U.S. is projected to continue to grow for the foreseeable future. This is driven, in large part, by the continuing growth in the use of petroleum-based transportation technologies. Improvements in vehicle technology efficiencies are being overwhelmed by the growth in transportation demand.

In the present report, the task of estimating, quantitatively, the energy use and emissions associated with the introduction of maglev as a new mode of mass transportation is addressed. For comparison purposes, methods of estimating those quantities for more conventional modes of transportation including high-speed rail and commercial jet aircraft are also presented.

Table 1 Energy Projections (quadrillion Btu/year). Data from Ref. 4

Year		1999	2010	2020	% Growth/Y 1997-2020
Imports					
	Crude Oil	18.45	23.91	26.03	1.7
	Petrol. Products	3.69	7.35	9.92	4.2
Consumption					
	Petrol. Products	37.67	44.22	48.08	1.2
Transportation Energy Use					
	LD* Vehicles	14.53	18.1	19.6	1.5
	Aircraft	3.41	5.17	6.38	2.8
	Rail	0.55	0.61	0.66	1.0
Efficiency					
	LD Fleet(MPG)	20.5	20.3	21.4	0.2
	Aircraft(SMPG)	51.7	55.7	59.6	0.7
	Rail(TM/10^3Btu	2.8	2.9	3.1	0.5

*LD = light-duty highway vehicles including autos, vans, SUVs, and pickups.

Making quantitative estimates of energy and emissions changes associated with the introduction of a new transportation technology, depending on the level of detail desired, can be a rather complicated task. This complexity arises for several reasons. First, the energy use and emissions depend on the technology and how it is used. In addition, in the case of electrically-powered HSGT technologies, the fuel mix used to generate the electric power varies considerably with geographic region and year of projected use. In fact, the projections themselves vary year by year. Third, some of the changes in energy use and emissions will result directly from one-for-one substitutions of trips on the existing modes with trips on the new mode. Additional changes may arise in a variety of ways including from induced trips on the new mode (trips that might not have otherwise taken place), or from changes in life style brought about by the attributes of the new mode. In addition, to the extent that trip substitutions result in improved performance on the existing modes, further changes in energy use and emissions may occur.

It is important to point out at the onset that quantitative estimates alone are not sufficient to fully describe the impacts of alternative transportation technologies on the issues affected by changes in energy and emissions budgets. To be complete, one must take into account the primary energy sources that are affected and where specific pollutants species are emitted. For example, comparison of electric and fossil-fueled high-speed ground transportation (HSGT) technologies should account for the fact that electricity-fueled technologies derive their power from a utility grid that is comprised of a variety of electricity-generating technologies including fossil-fuel-fired plants, nuclear plants, and renewable energy – based technologies. In addition, whereas the ground-based fossil-fueled transportation modes emit their pollutants at ground level, the power plants emit their pollutants from tall stacks. The impacts of ground-level emissions tend to be localized (e.g., health effects of the criteria pollutants) whereas emission from tall stacks tend to be more regional in nature (e.g. acid rain). Ultimately, of course, both contribute to global warming. Emissions from jet aircraft occur both at ground level and at various altitudes in the atmosphere. For convenience, aircraft emissions are separated into at or near ground-level (called LTO-cycle) emissions and cruising emissions. The LTO-cycle emission impacts are also localized in nature, while the emissions at cruising altitude may impact global warming.

In the following, some guidance is given in the computation of trip times, energy use and emissions associated with specific transportation modes. It is important to consider these three quantities together because they are quite closely related. In general, one can expect a tradeoff between trip times and power demand and energy usage and emissions. That is, the higher the vehicle speed and the higher the acceleration, the greater the energy consumption, and the greater the power demand. Emission species depend in a rather complex way on vehicle operating conditions as well as technology, but in general, they tend to increase with energy use. For comparison purposes an effort is made, where possible, to provide information in a consistent manner. However, it must be realized that the information, data, and results of example calculations presented here are generic rather than application specific in nature.

This report presents numerous formulas for various quantities. Some of these formulas have general applicability while others apply to only rather specific sets of conditions (note, in particular, those formulas that apply to the hypothetical route). The report also gives numerous examples of calculations of trip times, energy use, and emissions on a hypothetical route. These calculations are performed for very specific sets of conditions and the reader should not attempt to apply the results of these calculations without proper consideration of these specific conditions to which they apply.

Finally, for comparisons between various HSGT technologies and short-haul jet aircraft, "energy per seat.mile" is an appropriate metric since load factors are roughly equal for such technologies. However, if comparisons between these technologies and light-duty (LD) highway vehicles are desired, then a more appropriate metric would be "energy per passenger.mile" since the load factor for LD highway vehicles is much smaller. (energy per passenger.mile = energy per seat.mile÷load factor).

2. Guided Ground Transportation Modes - Rail & Maglev

For the Commercial Feasibility Study (CFS) sponsored by the Federal Railroad Administration FRA in the mid-nineties, eight different guided ground transportation technologies were defined (Ref. 5). These covered the speed ranges of 90 to 300 mph. Properties of these technologies are summarized in Table 2, together with an existing base-case 79-mph technology. The data presented in this table are from Ref. 6 unless noted otherwise.

The basic equation that relates the applied propulsion force and vehicle mass to the acceleration for each of these technologies is given by Newton's second law:

$$\mathcal{F}(V) = M \times A(V) + R(V), \tag{1}$$

where A(V) is the acceleration as a function of velocity (V), $\mathcal{F}(V)$ is the available traction force as a function of velocity and R(V) is the resistance to forward motion as a function of velocity. Solving for the acceleration,

$$A(V) = \frac{\mathcal{F}(V) - R(V)}{M} \qquad (2)$$

Computation, with this equation, of the acceleration and the other kinetic variables (velocity and distance as a function of time) requires that $\mathcal{F}$ & R be known as functions of velocity. If analytic forms of $\mathcal{F}$ & R are available, then the acceleration can be easily determined by analytic integration of Eqn.(2). Otherwise, Eqn.(2) must be integrated numerically.

The results of the numerical integration of Eqn. (2) for a hypothetical 2-car, 300-mph maglev technology having a maximum output power of 16,200 Hp are shown in Table 3. Note that the initial acceleration is arbitrarily limited to a maximum value of 1.569 m/s^2. As the speed increases, the acceleration becomes limited by the available power.

Tabulated values of $\mathcal{F}$ & R versus velocity are available for all of the technologies listed in Table 2 from Argonne National Laboratory's Center for Transportation Research and from the Volpe National Transportation System Center (VNTSC) in Cambridge, Massachusetts (Ref. 6).

The power required for traction at any time is given by

$$P(V) = \mathcal{F}(V) \times V, \qquad (3)$$

and the power for cruising at any particular velocity say V_1, is given by,

$$P_1 = R(V_1) \times V_1$$

The percent of rated propulsion power is then given by

$$100\% \times P(V)/P_{rated}. \qquad (4)$$

Table 2 Summary of HSGT Technologies

Technology	Consist	Weight (tons)	No. of Seats	Accel.. Time (min)	Accel. Dist. (mi)	Fuel for Hotel Functions (GPM)	Efficiency	Comments
79 Non Electric[1] 3500 hp	1-4	362 (130 ton loco)	264	0-79 2.28	2.0	0.396	0.2784[2]	Based on P-40 with Amfleet type coaches
90 Non Electric 3500 hp	1-4	346 (130 ton loco)	264	0-90 2.64	2.7	0.396	0.3965[2]	Based on P-40 (AMD 103) with X-2000 type Coaches
110 Non Electric 4000 hp (min.)	1-4	346	264	0-110 3.80	5.0	0.396	0.3554[2]	Based on modified Diesel With X-2000 type Coaches
125 Non Electric 4500 hp (min.)	1-4	326 (110 t loco)	264	0-125 3.66	5.4	0.396	0.3371[2]	Based on advanced Diesel (110t) w/X-2000 type coach
125 Electric 7000 hp/loco	1-4	316	264	0-125 2.54	3.7	240kw	0.815[3]	Based on AEM-7 with X-2000 type Coaches
150 Non Electric 7000 hp/loco	1-4	316 (100 ton loco)	264	0-150 3.86	6.9	0.317	0.3217[2]	Based on Adv. Diesel Loco with X-2000 type Coaches
150 Electric 7200 hp/loco	1-4	306 (90 ton loco)	264	0-150 2.80	4.6	240kw	0.815[3]	Based on improved AEM-7 with X-2000 type Coaches
200 Electric 6000 hp/loco	1-8-1	460 (73 ton loco)	388 284	0-200 6.34	14.0	360kw	0.817[3]	Based on TGV-A 1-8-1
Maglev 8100 hp/car	2 car 4 car	45 ton nose (65/85 seats) 45 ton middle (105 seats)	150 360	0-300 1.79	5.2	120kw	0.849[3]	Based on U.S. Maglev with ride comfort limit 0.16g Accel

[1] This technology comprises a mix of the older FP40-PH (3000 HP) and newer AMD103 (3500HP) locomotives. The mix is 100% older in 1985 and progresses linearly to 100% newer by 2015.

[2] Input fuel + output energy required to accel. to max. speed (K.E. + work to overcome resistance to forward motion + hotel energy).

[3] Output energy to Train/Maglev + input electric energy to substation.

Table 3 Numerical Simulation of the Acceleration of a Maglev Vehicle From 0 to 300 mph.

Technology= 300 Maglev--2 Cars # Of Seats = 150
Maximum Velocity= 300 mph (134 m/s)
Max. Accel. = 0.16g = 1.56912 (m/s^2)
Max. Prop. Power = 16200 Hp
Resistance to forward motion R(v)= A+Bv+Cv^2, for v </= 10(m/s), and
= A/v+Bv+Cv^2 for v >10(m/s).

	Speed </=10(m/s)	Speed >10(m/s)
A=	800	630000
B=	0	8.33
C=	2.134	2.134

Total consist mass = 88.184 (tons) = 80000 (kg)

v(I) (mph)	v(I) (m/s)	Power-Limited F (N)	Accel.-Limited F (N)	Thrust Force (N)	R(I)	a(I)	Avg.a
0	0	126330	126330	126330	800	1.57	1.57
5	2.235	5407248	126340	126340	811	1.57	1.57
10	4.47	2703624	126372	126372	843	1.57	1.57
20	8.94	1351812	126500	126500	971	1.57	1.57
30	13.41	901208	173005	173005	47475	1.57	1.57
40	17.88	675906	161596	161596	36066	1.57	1.57
50	22.35	540725	154970	154970	29440	1.57	1.57
60	26.82	450604	150778	150778	25248	1.57	1.57
70	31.29	386232	148014	148014	22484	1.57	1.57
80	35.76	337953	146174	146174	20644	1.57	1.57
90	40.23	300403	144978	144978	19449	1.57	1.57
100	44.7	270362	144260	144260	18730	1.57	1.57
110	49.17	245784	143911	143911	18382	1.57	1.57
120	53.64	225302	143861	143861	18332	1.57	1.57
130	58.11	207971	144061	144061	18532	1.57	1.57
140	62.58	193116	144475	144475	18946	1.57	1.57
150	67.05	180242	145078	145078	19548	1.57	1.57
160	71.52	168977	145850	145850	20320	1.57	1.57
170	75.99	159037	146776	146776	21246	1.57	1.57
180	80.46	150201	147845	147845	22315	1.57	1.57
190	84.93	142296	149048	142296	23518	1.48	1.53
200	89.4	135181	150377	135181	24847	1.38	1.43
210	93.87	128744	151827	128744	26297	1.28	1.33
220	98.34	122892	153393	122892	27863	1.19	1.23
230	102.81	117549	155070	117549	29540	1.10	1.14
240	107.28	112651	156856	112651	31326	1.02	1.06
250	111.75	108145	158748	108145	33218	0.94	0.98
260	116.22	103986	160743	103986	35213	0.86	0.90
270	120.69	100134	162839	100134	37309	0.79	0.82
280	125.16	96558	165035	96558	39505	0.71	0.75
290	129.63	93228	167329	93228	41799	0.64	0.68
299.776	134	90188	169665	90188	44136	0.58	0.61
Subtotal							
Total							
Cruise @ 200 mph			89.4	24847	24847		
Cruise @ 300 mph			134.0	44136	44136		

NOTCH SETTING	% Output Power Range Min. % Peak Pow.	Max. % Peak Pow.
1	0	5
2	5	12
3	12	31
4	31	46
5	46	59
6	59	74
7	74	89
8	89	100
0	0	0

t(I)	x(I) (m)	Power For Thrust (HP)	% Avail. Traction Power	Notch Setting	Work Done against total drag force w(I) (MJ)	Accum Work Done against total drag force w(MJ)
0.00	0.00	0	0	1	0.00	0.00
1.42	1.59	379	2	1	0.00	0.00
2.85	6.37	757	5	1	0.00	0.01
5.70	25.47	1516	9	2	0.02	0.02
8.55	57.30	3110	19	3	0.77	0.79
11.39	101.87	3873	24	3	1.86	2.66
14.24	159.17	4643	29	3	1.88	4.53
17.09	229.21	5421	33	4	1.92	6.45
19.94	311.98	6208	38	4	1.98	8.42
22.79	407.48	7007	43	4	2.06	10.48
25.64	515.72	7818	48	5	2.17	12.65
28.49	636.69	8644	53	5	2.31	14.96
31.34	770.40	9485	59	5	2.48	17.44
34.18	916.84	10344	64	6	2.69	20.13
37.03	1076.01	11222	69	6	2.93	23.06
39.88	1247.91	12120	75	7	3.22	26.29
42.73	1432.56	13040	80	7	3.55	29.84
45.58	1629.93	13983	86	7	3.93	33.77
48.43	1840.04	14951	92	8	4.37	38.14
51.28	2062.88	15946	98	8	4.85	42.99
54.20	2304.97	16200	100	8	5.55	48.54
57.33	2577.06	16200	100	8	6.58	55.12
60.69	2885.07	16200	100	8	7.88	63.00
64.31	3233.13	16200	100	8	9.43	72.42
68.22	3626.12	16200	100	8	11.28	83.70
72.44	4069.79	16200	100	8	13.50	97.21
77.02	4571.06	16200	100	8	16.18	113.38
81.99	5138.37	16200	100	8	19.41	132.79
87.43	5782.15	16200	100	8	23.34	156.14
93.40	6515.53	16200	100	8	28.17	184.30
99.99	7355.42	16200	100	8	34.14	218.45
107.16	8300.85	16200	100	8	40.62	259.07
1.79 minutes						
		2978	18.4	3		
		7928	48.9	6		

2.1 Diesel-Electric Locomotive-Drawn Train Technologies

Fuel flow rates and emission factors for these technologies are given in Table 4 in terms of "notch settings". The data is from Refs. 7 & 8. Values for overnight idling are given in Table 5. Diesel-electric locomotives are assumed to be left idling overnight (10 hours). [No idle time is assumed for gas-turbine- and electric-powered vehicles.]

In order to compute energy use and emissions for each of these technologies, it is necessary to determine, for a given route, how much time is spent in each notch setting. Depending on the level of detail desired, there are several ways to do this. The most effort-intensive method involves using a train simulation computer model that requires detailed input information for a specific alignment and mode of operation. A simpler approach, which is less specific to a particular application, is to use a standard time-in-notch profile. Standard profiles are available for freight and passenger service. Care must be taken to ensure the profile used is applicable to the planned project. Both the U.S. EPA (see Ref. 9) and the State of California (see Ref. 10) have adopted time-in-mode profiles. For example, EPA's passenger train profile from Ref. 9 is given in Table 6.

A third approach, which is midway between these two, is to make comparative estimates of trip times, energy consumption and emissions based on a hypothetical route. A fairly complex hypothetical route was defined for comparative evaluations of maglev system concepts in the System Concept Definition (SCD) program sponsored by the FRA and the Army Corps of Engineers (ACE) in the early 90's.

The hypothetical route used in this report, for illustrative purposes, is simpler and may be adapted to a variety of actual routes if desired. All of the technologies defined in Table 2 may be applied to this route. However, the user is cautioned that while the use of such a hypothetical route provides a good method of comparing different technologies, it will not produce results as accurate as the application of a train simulation model to an actual route including hills, curves, speed restrictions, etc.

Table 4 Non-Electric HSGT Emission Factors and Total Fuel Flow Rates vs. Notch Setting

79 Non-El, F40PH 3000HP 0.24% Sulfur
Engine: EMD 16-645E3 85.8% Carbon
CARB Emission Rates (g poll./h)

Notch Setting	PM	NOX	CO	HC	SO2	CO2 (10^5)	Total FFR (GPM)
Idle	34	1635	564	185	435.1	2.852	0.493
1	24	2810	267	156	486.3	3.187	0.551
2	133	6040	292	201	708.7	4.645	0.803
3	227	10179	329	247	939.1	6.155	1.064
4	258	15416	435	321	1219	7.988	1.381
5	336	20899	760	424	1547	10.14	1.753
6	545	25568	1912	611	1947	12.76	2.206
7	648	31188	5029	878	2478	16.24	2.808
8	837	36933	5908	1169	2878	18.86	3.261
Brake	80	4104	655	293	634.6	4.159	0.719

79 & 90 Non-El, P40 3500HP, Dash 8 0.28% Sulfur
Engine: GE-16-3600 85.8% Carbon
CARB Estimated Emission Rates (g poll./h)

Notch Setting	PM	NOX	CO	HC	SO2	CO2 (10^5)	Total FFR (GPM)
Idle	38	320	534	333	478.3	2.687	0.465
1	70	1159	336	163	590.5	3.317	0.574
2	80	2742	569	182	702.8	3.948	0.683
3	154	5970	1084	246	1038	5.834	1.009
4	231	12982	2738	338	1375	7.725	1.336
5	355	20423	4335	399	1711	9.611	1.662
6	505	27127	8059	489	2048	11.5	1.989
7	519	31670	6069	758	2383	13.39	2.315
8	595	38158	4844	866	2720	15.28	2.642
Brake	451	1461	2914	1384	639.1	3.59	0.621

110 Non-El, 4000HP
Engine: EMD 16-710G3A 0.21% Sulfur
EMD's Projected Emission Rates 85.8% Carbon
for Yr 2000 (g poll./h)

Notch Setting	PM	NOX	CO	HC	SO2	CO2 10^5	Total FFR (GPM)
Idle	7	253	31	30	22.88	0.171	0.465
1	29	1701	150	112	169.7	1.271	0.617
2	64	3546	247	176	320.3	2.400	0.769
3	186	7325	264	319	665.5	4.985	1.224
4	244	8171	356	371	900.0	6.742	1.68
5	336	9530	789	462	1176	8.813	2.136
6	395	11775	899	521	1480	11.08	2.591
7	613	17712	2605	776	2214	16.58	3.047
8	855	24707	4672	1141	2578	19.31	3.503
Brake	96	1224	237	261	164.0	1.228	0.608

Table 4 Continued

125 Non-El, AMD125-5200HP

EMD Year 2000 Scaled Emission Rates (g poll./h); 0.21% Sulfur, 85.8% Carbon

Notch Setting	PM	NOX	CO	HC	SO2	CO2 (10^5)	Total FFR (GPM)
Idle	9.1	328.9	40.3	39	29.75	0.223	0.465
1	37.7	2211	195	145.6	220.6	1.653	0.663
2	83.2	4610	321.1	228.8	416.4	3.119	0.862
3	241.8	9523	343.2	414.7	865.1	6.48	1.457
4	317.2	10622	462.8	482.3	1170	8.764	2.053
5	436.8	12389	1026	600.6	1529	11.46	2.648
6	513.5	15308	1169	677.3	1924	14.41	3.244
7	796.9	23026	3387	1009	2878	21.56	3.839
8	1112	32119	6074	1483	3351	25.1	4.435
Brake	124.8	1591	308.1	339.3	213.2	1.597	0.608

150 Non-El, Hypothetical 7000HP

Emissions scaled by g/bhph from EMD data. Emission rates (g poll./h); 0.21% Sulfur, 85.8% Carbon

Notch Setting	PM	NOX	CO	HC	SO2*	CO2 (10^5)	Total FFR (GPM)
Idle	91.17	2690	400.4	137.4	285.5	2.139	0.37
1	147.2	4342	646.3	221.7	460.8	3.452	0.597
2	216.2	6380	949.6	325.7	677	5.071	0.877
3	423.4	12492	1859	637.8	1326	9.93	1.717
4	630.5	18604	2769	949.9	1974	14.79	2.557
5	837.7	24717	3679	1262	2623	19.65	3.397
6	1045	30829	4589	1574	3272	24.51	4.237
7	1252	36942	5499	1886	3921	29.37	5.077
8	1459	43054	6409	2198	4569	34.23	5.917
Brake	169.7	5009	745.5	255.7	531.5	3.982	0.688

Table 5 Over-Night Idle Fuel Flow Rates and Idle Emission Factors

Technology	Fuel Flow Rate (GPM)	---Emission Rate (g pollutant/hour)--- PM	NOX	CO	HC	SO2*	CO2* (10^5)
79 NE (F40)	0.097	34	1635	564	185	74.91	0.561
79 NE (P40)	0.069	38	320	534	333	53.29	0.399
90 NE (P40)	0.069	38	320	534	333	53.29	0.399
110 Non-Electric	0.069	7	253	84	63	53.29	0.399
125 Non-Electric	0.069	9.1	328.9	40.3	39	53.29	0.399
150 NE, 7000HP	0.069	9.1	328.9	40.3	39	53.29	0.399

*Assume 0.21% S & 85.8% C

Table 6 EPA's Default Duty Cycle For Passenger Trains

Throttle Position	% Time In Mode
Idle	49.8
1	7.2
2	4.7
3	5.0
4	4.3
5	3.9
6	2.7
7	1.4
8	15.0
Dynamic Braking	6.0
Total	100.0

2.1.1 Fuel Use and Emissions Calculation Procedures

The calculation of fuel use and emissions of diesel-electric train technologies proceeds as follows:

The route is divided into operational segments: acceleration to some specified velocity, cruising at that velocity, braking to some other velocity or to a station stop, idling at the stop, etc. The times, distances, power demands, and energy consumed during each such operational segment are then calculated. The total time spent at each value of the percent of rated power is then determined by summing over the entire route. Then each value of the percent of rated power is related to a corresponding notch setting using the information in Table 7 (Ref. 11).

Table 7. Relationship Between Notch Settings, % Rated Traction Power, And Fuel Flow Rates

Notch Setting	Nominal % Rated Traction	Range of % Rated Traction	Fuel Flow Rates (gal/min)				
Setting	HP	HP	79NE	90NE	110NE	125NE	150NE
Brake	---	---	0.719	0.621	0.608	0.608	0.688
Idle	0	0	0.493	0.465	0.465	0.465	0.370
1	5	0-5	0.551	0.574	0.617	0.663	0.597
2	10	5-12	0.803	0.683	0.769	0.862	0.877
3	25	12-31	1.064	1.009	1.224	1.457	1.717
4	40	31-46	1.381	1.336	1.680	2.053	2.557
5	55	46-59	1.753	1.662	2.136	2.648	3.397
6	70	59-74	2.206	1.989	2.591	3.244	4.237
7	85	74-89	2.808	2.315	3.047	3.839	5.077
8	100	89-100	3.261	2.642	3.503	4.435	5.917

Once the total time in each notch setting is known, the corresponding fuel and emissions in each notch setting are computed. The total emission of pollutant i for a complete trip is given by

$$\varepsilon_i = \sum_j e_{ij} \text{ (lb poll/gal fuel) x } F_j \text{ (gal fuel/min) x } \Delta t_j \text{ (min)}, \qquad (5a)$$

the total trip fuel use is given by

$$F(\text{gal}) = \sum_j F_j \text{ (gal/min) x } \Delta t_j \text{ (min)}, \qquad (5b)$$

and the energy input is given by

$$E(\text{MBtu}) = 0.1287 \text{ (Mbtu/gal.diesel) x } F(\text{gal}), \qquad (5c)$$

where Δt_j is the total time spent in notch setting j, F_j is the fuel flow rate in notch setting j, and e_{ij} is the emission factor for pollutant i in notch setting j. The emission factors and fuel flow rates are given in Table 7 for each fossil-fueled technology.

One additional refinement to the input energy calculation is to take into account the energy penalty associated with the production of the fuel (in this case diesel fuel). If the production efficiency of diesel fuel is given by η_{DPE}, then the net energy consumption is given by

$$E_{net} \text{ (MBtu)} = E(\text{MBtu}) / \eta_{DPE} \qquad (6)$$

The evaluation of the fuel production efficiency for diesel and other fuels is discussed in the following section.

2.1.2 Taking Account of the Energy Penalty of Producing the Fuel

Providing fuel to consumers involves the consumption of energy and the generation of emissions. The energy consuming steps include extraction or recovery, international shipping, processing or refining, and domestic distribution. The total energy penalties associated with the production of several fuels are listed in Table 8. With the exception of the values for kerosene, the energy penalties in this table come from Ref. 12.

Table 8 Energy Penalties Associated With The Production of Fuels

	Energy Penalties (Btu/10^6 Btu of fuel produced)	Fuel Production Efficiency (η_{FPE})
Kerosene	153,000	0.867
Reformulated Gasoline	259,000	0.794
Diesel	195,000	0.837
Reformulated Diesel	225,000	0.816
Natural Gas	96,000	0.912
Coal	19,000	0.981

2.2 Electrically-Powered HSGT Modes

These modes are described in Table 2. Because they derive their power from the utility network and their associated emissions come from the combustion of fuels used to generate a portion of the electric power, their treatment is necessarily different from that for the fossil-fueled HSGT modes. Furthermore, it is important to note that whereas the emissions from fossil-fuel burning vehicles occur where the vehicles are located, the emissions associated with electrically-powered vehicles occur at the power plants. Consequently, the impact of the emissions from these disparate source classes may be much different. To put it another way, the impact of emissions from various technologies is not necessarily well represented by the magnitudes of the emissions alone. The derivation of the energy formulas for each of the electrically-powered technologies is given in this section. The derivation of the electric generating efficiencies and the corresponding power plant emissions is described later.

2.2.1 Output Energy Required for a Trip

In contrast to the fossil-fueled vehicle technologies, it is not necessary to refer to "notch settings" to compute energy use or emissions. Hence the total output energy, E_T^o, required for a trip of length D, is given by

$$E_T^o = E_{hotel} + E_{idle} + E_{brake} + E_{cruise} + E_{accel} + E_{decel}, \qquad (7)$$

where

E_{hotel} = total energy required for all hotel functions on board the train,
E_{idle} = total energy required for all idling,
E_{brake} = total energy required for all braking episodes or decelerations,
E_{cruise} = total energy required for all cruising at constant speeds (both urban and maximum),
E_{accel} = total energy required for all accelerations, and
E_{decel} = total energy required for all decelerations.

With the exception of E_{hotel} ,which depends on the technology and consist size, each of the energy terms listed above is evaluated in accordance with the specific route being considered. The hotel energy is given by

$$E_{hotel} = P_{hotel} \times (T - t_d), \qquad (8)$$

where P_{hotel} is the hotel power (an input parameter, given in Table 2), T is the total trip time, and t_d is the total decelerating time (during which electric power is assumed to be regenerated for braking and hotel functions). It is also assumed that

$$E_{idle} = E_{decel} = E_{brake} = 0. \qquad (9)$$

The total acceleration energy, E_{accel}, equals the sum of all kinetic energy terms plus the work done against resistance to forward motion during all acceleration episodes. The contribution to E_{accel} from each acceleration episode, say from velocity V_1 to V_2 is obtained by integrating the work done against all resistance to forward motion between these two velocities and then adding the difference in kinetic energies, i.e.

$$E_{accel} = 1/2\, M\,(V_2^2 - V_1^2) + \Sigma F_i \Delta x_i \tag{10}$$

where F_i is the force required to counteract the resistance at a particular velocity, that is,

$$F_i(V) = R_i(V),$$

and Δx_i is a short interval over which the velocity and force changes relatively little, and the sum extends over the distance from where $V = V_1$ to where $V = V_2$.

The total energy for all cruising episodes is given by

$$E_{cruise} = \sum_i P_i T_i, \tag{11}$$

where the sum goes over all cruising episodes, P_i is the power required for cruising at speed V_i and T_i is the time spent cruising at V_i.

2.2.2 System Efficiencies

Once the total output energy, E_T^o, is obtained, the primary energy input to the power generating system is given by

$$E^{in} = E_T^o / \eta_{net} \tag{12}$$

where

$$\eta_{net} = \eta_G^{net} \times \eta_T \times \eta_I \tag{13a}$$

η_G^{net} = the net generating system efficiency, η_T = transmission efficiency, and η_I is the technology efficiency for a particular technology and accounts for all system component losses from, and including, the substation down to the propulsion motors (see Table 2). The value of η_G^{net} depends on the mix of generating technologies and fuels used, which, in turn, depend on the region and year. It is given by

$$1/\eta_G^{net} = \sum_i f_i \Big/ \eta_{C,i}\,\eta_{FPE,i}\,\eta_{IP,i} \tag{13b}$$

where f_i is the fraction of the output energy supplied by the i^{th} generating/fuel technology, $\eta_{C,i}$ is its thermal energy conversion efficiency, $\eta_{FPE,i}$ is the fuel production efficiency, and $\eta_{IP,i}$ is the in-plant efficiency (i.e., the ratio of the electric energy generated to the electric energy output from the plant). An estimate of the national average is presented here for the year 1997. The estimate is based on data given in Table 9. The fuel mix is from Ref. 13, the fuel production efficiencies are from Table 8, and estimates of thermal efficiencies are from Ref. 14.

Table 9 National Average Electricity Generating Efficiency For 1997

Fuel Type	Fraction of Electricity Generated by Fuel	Thermal Conversion Efficiency (η_C)	Fuel Production Efficiency (η_{FPE})	$f/(\eta_C \cdot \eta_{FPE})$
Coal	0.5653	0.345	0.981	1.670
Natural Gas	0.0929	0.360	0.912	0.283
Petroleum	0.0258	0.355	0.852	0.085
Nuclear	0.2051	0.332	1	0.618
Renewable	0.1110	0.346	1	0.321
Total =	1.0000			
Conversion Eff.	0.3443	0.3441		0.336
In- Plant Eff.	0.95			0.950
Net Gen. Eff.	0.3268			0.319
T&D Eff	0.9100			
Est. Trans. Eff.	0.9500			

Data in column two (except for "Est. Trans. Eff.") from EIA, 1998.
Conversion efficiency = electrical energy generated/fuel energy input
In- Plant Eff. = Electrical energy output from plant/electrical energy generated
Net Gen. Eff. = Electrical energy output from plant/fuel energy input to plant
T&D Eff. = transmission and distribution efficiency. (includes substation losses)
Est. Trans. Eff. = Estimated efficiency from plant output to substation input.

The net national average generating efficiency for 1997 is estimated to be

$$\eta_G^{net} = 0.319 \tag{14a}$$

Based on calculations given in Ref. 14, this value is estimated to increase by about 0.0016 units per year. For example, by the year 2010, η_G^{net} is projected to be about $0.319 + 13 \times 0.0016 = 0.34$.

The transmission efficiency is estimated to be

$$\eta_T = 0.95. \tag{14b}$$

2.2.3 Electric Power Generating Efficiencies and Emission Factors

The process of estimating total input energy and emissions associated with the operation of electrically-driven HSGT technologies is somewhat complex and involves three key assumptions and a number of steps that are outlined below:

2.2.3.1 Key Assumptions

Roughly one-third to one-half of the primary thermal energy is converted into electricity in a power plant, yielding thermal conversion efficiencies of about 33 to 50%. The rest is considered waste heat. Using at least some of this waste heat for other useful purposes such as industrial processes or district space heating would improve this efficiency. Cogeneration (the production of electricity and steam) is used by many industries in the U.S., but most of the energy generated is used by the industries themselves. Net sales to utilities comprise about one-third of the net cogenerated energy. This, in turn, constitutes about 0.4% of the total electricity generated in the U.S. (Ref.13). Given the small quantities involved, it is assumed here that all waste heat is lost to the environment.

The thermal energy conversion efficiency of power plants fueled by renewable energy sources (hydroelectric, wind, solar, biomass, etc.) is a difficult number to estimate, and depends upon whether such energy sources are considered to be "free" in some sense. Obviously, the facilities are not free even if the energy supplies are inexhaustible. It is common practice in the U.S. to assume that an efficiency be assigned such that the overall efficiency of the electric generating system (see further discussion below) is not changed. This practice will be followed here.

These assumptions should be regarded as conservative since, if the waste heat can be utilized and/or if the renewable energy sources can be regarded in some sense as "free;" i.e., not diminishable, then the net efficiency of the generating system would be higher.

Finally, it is assumed that the nuclear and renewable generating technologies do not produce any emissions and that the fuel production efficiencies for these technologies is 100%. Neither of these assumptions is strictly true. In particular, the processing of nuclear fuel does require some energy expenditure and combustion of biomass (e.g. wood), could be a significant source of emissions in some locations. Nationally, biomass is only about one quarter of the renewable energy part of the fuel mix used to generate electricity (Ref. 15).

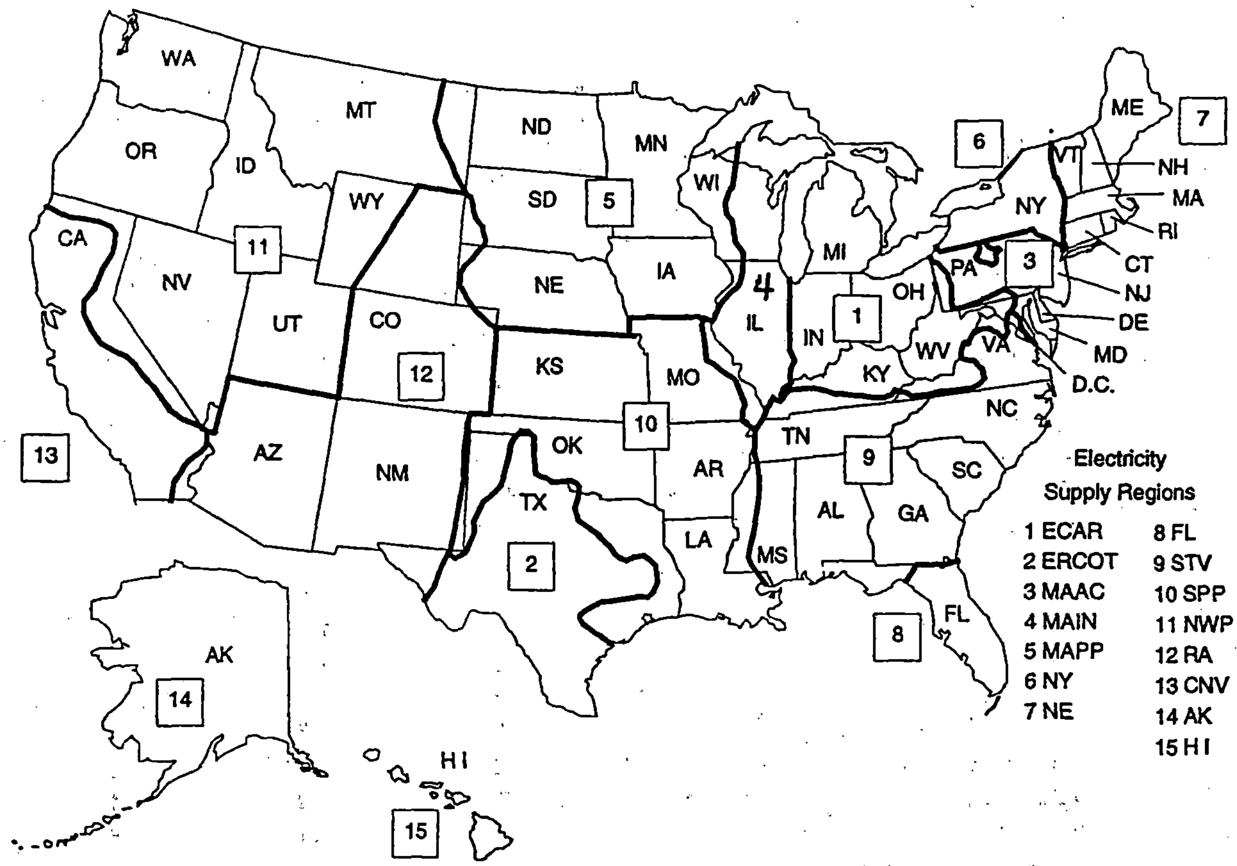
2.2.3.2 Calculation Steps

1. Determine the total output electrical energy required for a trip E_T^o (kWh) (see Eqn. 7).
2. Determine the corresponding input energy to the HSGT substation from the utility grid

$$E_{SS}^{in} = \frac{1}{\eta_I} E_T^o \tag{15}$$

3. Determine the required output energy from the generating system $= E_G^o = \frac{1}{\eta_T} E_{SS}^{in}$

Figure 1. Electricity Market Module (EMM) Regions



1. ECAR = East Central Area Reliability Coordination Agreement
2. ERCOT = Electric Reliability Council of Texas
3. MACC = Mid-Atlantic Area Council
4. MAIN = Mid-America Interconnected Network
5. MAPP = Mid-Continent Area Power Pool
6. NY = Northeast Power Coordinating Council/ New York
7. NE = Northeast Power Coordinating Council/ New England
8. FL = Southeastern Electric Reliability Council/ Florida
9. STV = Southeastern Electric Reliability Council/ excluding Florida
10. SPP = Southwest Power Pool
11. NWP = Western Systems Coordinating Council/ Northwest Power Pool Area
12. RA = Western Systems Coordinating Council/ Rocky Mountain Power Area and Arizona
13. CNV = Western Systems Coordinating Council/ California-Southern Nevada Power
14. AK = Alaska
15. HI = Hawaii

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

Table 10 Projected Electricity Generation by EMM Region, Fuel Type, and Year (from Energy Administration/Supplement to the Annual Energy Outlook 1994, DOE/EIA-0554(94))

EMM Region	Fuel Type	Generation[1] by Fuel Type (10^9 kWh) 2000	Generation[1] by Fuel Type (10^9 kWh) 2010	% Generation by Fuel Type 2000	% Generation by Fuel Type 2010
1. ECAR	Coal	470.73	487.16	88.44	82.97
	Petroleum/Other[2]	0.17	0.02	0.03	0.00
	Natural Gas	2	38.84	0.38	6.61
	Nuclear	49.94	44.54	9.38	7.59
	Pumped storage/Other[3]	-1.47	-1.47	-0.28	-0.25
	Renewable	10.91	18.08	2.05	3.08
	Total Utility	532.28	587.17	100.00	100.00
2. ERCOT	Coal	69.49	88.23	34.57	38.64
	Petroleum/Other[2]	0.28	0.23	0.14	0.10
	Natural Gas	98.46	106.84	48.98	46.79
	Nuclear	31.2	30.78	15.52	13.48
	Pumped storage/Other[3]	0	0	0.00	0.00
	Renewable	1.59	2.27	0.79	0.99
	Total Utility	201.02	228.35	100.00	100.00
3. MAAC	Coal	109.52	130.6	48.82	53.26
	Petroleum/Other[2]	5.74	3.31	2.56	1.35
	Natural Gas	18.59	25.52	8.29	10.41
	Nuclear	83.38	65.18	37.17	26.58
	Pumped storage/Other[3]	-0.64	-0.64	-0.29	-0.26
	Renewable	7.76	21.24	3.46	8.66
	Total Utility	224.35	245.21	100.00	100.00
4. MAIN	Coal	136.96	157.53	57.36	60.71
	Petroleum/Other[2]	0.03	0.02	0.01	0.01
	Natural Gas	1.23	5.32	0.52	2.05
	Nuclear	96.91	91.6	40.58	35.30
	Pumped storage/Other[3]	-0.15	-0.15	-0.06	-0.06
	Renewable	3.81	5.15	1.60	1.98
	Total Utility	238.79	259.47	100.00	100.00
5. MAPP	Coal	97.22	107.48	71.75	73.28
	Petroleum/Other[2]	0.03	0.03	0.02	0.02
	Natural Gas	2.92	7.34	2.16	5.00
	Nuclear	24.42	20.46	18.02	13.95
	Pumped storage/Other[3]	0	0	0.00	0.00
	Renewable	10.9	11.37	8.04	7.75
	Total Utility	135.49	146.68	100.00	100.00
6. NPCC/NY	Coal	19.5	20.69	15.64	16.49
	Petroleum/Other[2]	24.69	24.41	19.80	19.46
	Natural Gas	19.88	20.54	15.94	16.37
	Nuclear	31.63	24.46	25.37	19.50
	Pumped storage/Other[3]	-1.86	-1.87	-1.49	-1.49
	Renewable	30.84	37.23	24.74	29.67
	Total Utility	124.68	125.46	100.00	100.00

7. NPCC/NE	Coal	16.65	16.44	15.78	16.09
	Petroleum/Other[2]	19.06	15.31	18.06	14.98
	Natural Gas	15.09	15.86	14.30	15.52
	Nuclear	41.82	32.27	39.63	31.58
	Pumped storage/Other[3]	-0.79	-0.79	-0.75	-0.77
	Renewable	13.7	23.11	12.98	22.61
	Total Utility	105.53	102.2	100.00	100.00
8. SERC/STV (Florida)	Coal	54.92	70.05	35.27	42.97
	Petroleum/Other[2]	29.68	27.23	19.06	16.70
	Natural Gas	43.17	45.33	27.72	27.81
	Nuclear	25.07	16.33	16.10	10.02
	Pumped storage/Other[3]	0	0	0.00	0.00
	Renewable	2.88	4.08	1.85	2.50
	Total Utility	155.72	163.02	100.00	100.00
9. SERC/STV (exc. Florida)	Coal	332.02	393.08	56.60	56.16
	Petroleum/Other[2]	1.83	2.17	0.31	0.31
	Natural Gas	17.27	52.51	2.94	7.50
	Nuclear	197.68	203.87	33.70	29.13
	Pumped storage/Other[3]	-3.36	-3.37	-0.57	-0.48
	Renewable	41.18	51.64	7.02	7.38
	Total Utility	586.62	699.9	100.00	100.00
10. SPP	Coal	189.36	209.99	65.47	66.99
	Petroleum/Other[2]	0.63	0.8	0.22	0.26
	Natural Gas	64.37	63.25	22.26	20.18
	Nuclear	27.2	27.23	9.40	8.69
	Pumped storage/Other[3]	-0.44	-0.44	-0.15	-0.14
	Renewable	8.11	12.64	2.80	4.03
	Total Utility	289.23	313.47	100.00	100.00
11. WSCC/NWP	Coal	79.28	81.69	27.25	24.11
	Petroleum/Other[2]	0.15	0.06	0.05	0.02
	Natural Gas	43.79	81.27	15.05	23.98
	Nuclear	7.19	7.17	2.47	2.12
	Pumped storage/Other[3]	-0.59	-0.59	-0.20	-0.17
	Renewable	161.07	169.27	55.37	49.95
	Total Utility	290.89	338.87	100.00	100.00
12. WSCC/RA	Coal	108.21	119.66	62.58	63.20
	Petroleum/Other[2]	0.22	0.01	0.13	0.01
	Natural Gas	30.17	27.17	17.45	14.35
	Nuclear	20.58	20.53	11.90	10.84
	Pumped storage/Other[3]	-0.37	-0.37	-0.21	-0.20
	Renewable	14.11	22.34	8.16	11.80
	Total Utility	172.92	189.34	100.00	100.00

13. WSCC/CNV	Coal	13.62	57.77	8.17	29.05
	Petroleum/Other[2]	2.72	0.71	1.63	0.36
	Natural Gas	50.12	27.99	30.05	14.08
	Nuclear	34.24	27.65	20.53	13.91
	Pumped storage/Other[3]	-1.36	-1.37	-0.82	-0.69
	Renewable	67.43	86.08	40.43	43.29
	Total Utility	166.77	198.83	100.00	100.00
Total U.S.	Coal	1696.48	1940.38	52.63	53.93
	Petroleum/Other[2]	85.21	74.32	2.64	2.07
	Natural Gas	407.07	517.8	12.63	14.39
	Nuclear	671.26	612.06	20.83	17.01
	Pumped storage/Other[3]	-11.05	-11.05	-0.34	-0.31
	Renewable	374.27	464.51	11.61	12.91
	Total Utility	3223.24	3598.02	100.00	100.00

[1]Utilities and non-utilities, excluding cogeneration.

[2]Other includes hydrogen, sulfur, batteries, chemicals, fish oil, & spent sulfite liquor.

[3]Other includes methane, propane, & blast furnace gas.

4. Determine which Electricity Market Module (EMM) Regions the trip route passes through (See map in Fig. 1).

5. Determine the amounts of various fuels used to generate electric power in those regions, i.e., the amount of coal, petroleum, natural gas, nuclear, and renewable energy used by utilities and non utility generators that sell electric power to the grid. For example, calculations presented in this section, unless noted otherwise, use projected fuel mixes for each EMM Region based on the projections given for the "reference case" in Ref. 16. The projections for the years 2000 and 2010 are reproduced in Table 10. More recent projections are available from the Energy Information Administration (EIA) web site (www.eia.doe.gov/oiaf/aeo99/homepage.html). The reader should be aware that EIA's projections for a given future year change significantly from one edition of its annual report to the next.

6. Using various data sources (see Refs. 17-23), estimate the thermal energy conversion efficiencies ($\eta_{C,i}$) for all generating technologies and all years of interest. (See Table 11)

7. Compute the net energy generating efficiency for each EMM Region and year of interest using

$$1/\eta_G = \sum_i^n f_i / \eta_{C,i}\eta_{FPE,i}\eta_{IP,i} = 1/\eta_{IP} \sum_i^n f_i / \eta_{C,i}\eta_{FPE,i} \qquad (16)$$

where f_i is the fraction of the output energy supplied by the i^{th} generating technology, $\eta_{IP,I}$ is the in-plant efficiency (see Table 9), and $\eta_{FPE,I}$ is the fuel production efficiency from Table 8. It is assumed in Eqn. (16) that the in-plant efficiency is independent of technology. Note that the fractions f_i vary with time. Power plants are assumed to have the average life times shown in Table 11 and their populations are assumed to vary linearly with time.

The question arises, "What generating efficiency should be assigned to the renewable energy generating technology? Since the renewable energy generating contribution comes from a variety of different technologies including hydroelectric, wind, solar, geothermal, etc. this is not any easy question to answer. In this report, it is assumed that the renewable generating efficiency takes on a value such that the net generating efficiency of the system is unchanged. If the net generating efficiency without the renewable energy contribution is given by

$$1 / \eta'_G = \sum_j' f'_j / \eta_{G,j} \quad ,$$

and, with the renewable term included, is given by

$$1 / \eta_G = \sum_i f_i / \eta_{G,i} \quad ,$$

and it is required that

$$\eta'_G = \eta_G \ ,$$

then it follows by substitution that the renewable energy generating efficiency must be defined as

$$1 / \eta_{ren} = \sum_i \left(\frac{f_i}{(1 - f_{ren})} \right) \times 1 / \eta_{G,i} \qquad (17)$$

Note that the prime on the summation sign in the above equations means that the renewable energy contribution is excluded. The prime on the f_j means that the fractional contributions of the energy generating technologies have been redefined to exclude the fractional renewable energy contribution f_{ren}. That is,

$$f'_j = E_j/(E-E_{ren}) = f_j/(1-f_{ren}) \qquad (18)$$

Note that with η_G so defined, the input energy to the power generating system can be related to the output energy from the generating system as follows:

$$E_G^{in} = E_G^o/\eta_G \qquad (19)$$

The results of an example calculation of the energy generating efficiencies for each EMM region are given in Table 12. Unfortunately, these results do not include the fuel production efficiencies or the in-plant efficiencies given in Tables 8 and 9, respectively. These exclusions result in over estimates of the net generating efficiencies of the order of 7%. That is, to approximately convert from the generating efficiencies listed in Table 12 to the net generating efficiencies that include the fuel production efficiency and the in-plant efficiency, multiply the former by 0.93.

8. Next, determine the emission factors (grams of pollutant per MBtu of fuel used to generate the electric power) for each electric generating technology used in a particular EMM Region. This task is

complicated by the fact that there are two sources of emissions for each generating technology; first, the fuel production processes, and second, the combustion of the fuel to produce electric power. Hence, the total emissions of pollutant "i" from generating technology "j" are given by

$$\varepsilon_{i,j} = \varepsilon_{i,j} \text{ (fuel production)} + \varepsilon_{i,j} \text{ (fuel combustion).} \tag{20a}$$

For fossil fuels, the second term is generally dominant. In the example cases shown in this report, the first term is ignored. This is consistent with the treatment of emissions from the non-electric HSGT and aircraft technologies. Fuel production emission data can be obtained from Ref. 12. The second term may be written as

$$\varepsilon_{i,j} \text{ (fuel combustion)} = e_{i,j} \times E_j^{in}, \tag{20b}$$

where $e_{i,j}$ is the emission factor for pollutant species "i" and generating technology "j" (g poll/unit of input energy), and E_j^{in} is the energy input to the power plant. Information about the emission factors can be obtained from a number of sources (see, for example, Refs. 19, 23-25). Some emission factors for various generating technologies are given in Table 11.

9. Determine a set of net or effective combustion emission factors for each EMM Region of interest: The total emissions of pollutant species "i "from generating technology "j" are given by Eqn. (20b) above. An effective or net emission factor for species "i" for an entire EMM Region is given by

$$e_i = \eta_C \sum_j e_{i,j} f_j / \eta_{C,j}. \tag{20c}$$

Note that the thermal energy conversion efficiencies are used in this expression instead of the generating efficiencies. The results of an example calculation of the effective emission factors in (g poll/MBtu energy input) for the EMM regions are given in Table 12. That table also gives the projected fraction of petroleum used in generating electricity in each EMM region based on the projections given in Ref. 16. This quantity may be useful for estimating the amount of petroleum saved when fossil-fueled transportation modes are replaced by electrically-powered modes. The amount of petroleum used tends to be quite small especially after the year 2000 for all regions with the exception of the East Coast.

10. Finally, compute the total combustion emissions using

$$\varepsilon_i(\text{g poll}) = e_i \text{ (g poll/}10^6 \text{ energy input)} \bullet E_G^{in}, \tag{21}$$

where the effective emission factors e_i are defined in Eqn. (20c).

Table 11 Energy Generating Technology Emission Factors and Thermal Efficiencies
(NOTE: Thermal efficiency does not include "in-plant" or "fuel production" efficiency.)

	Emission Factors (g/10^6 BTU of fuel input)							Life	Thermal
Fuel/Technology	PM	HC	CO	NOx	SOx	CO2 (10^3)	Start Year	Time (Y)	Efficiency %/100
Utility Coal									
a.Conv. Coal St.	45.4	1.50	13.0	228	419	95.5	<1985	40	0.340
b.PFB	45.4	1.50	2.00	120	94	95.5	1997	40	0.373
c.Coal Gas. Com. Cycle	45.4	1.50	2.00	43	34	95.5	1997	30	0.413
d.MCFC/CG	0	1.00	1.00	10	1	95.5	2000	30	0.514
Utility Pet.									
a.Pet. Steam	45.4	2.3	15.2	124	197	75.1	<1985	30	0.352
a.Pet. Comb. Turb.	27.7	7.7	21.8	155	197	75.1	<1985	30	0.250
a.Pet. CCC	45.4	2.3	15.2	124	197	75.1	<1985	30	0.402
b.Pet. Adv. Com. Cycle	45.4	2.3	15.2	124	197	75.1	1990	30	0.414
c.Pet. CT St. Injec.	45.4	2.8	51	45	197	75.1	1993	30	0.345
Utility NG									
a.Gas/Liq.St.	1.10	0.6	17.6	121	0.3	53.6	<1985	30	0.352
a.Gas/Liq Comb. Turb.	6.16	2.8	50.6	90.8	0.3	53.6	<1985	30	0.250
a.Gas/Liq.CCC	6.16	2.8	50.6	90.8	0.3	53.6	<1985	30	0.402
b.G/L CC Adv.	6.16	2.8	50.6	90.8	0.3	53.6	1990	30	0.414
c.G/L CT St. Inj.	6.16	2.8	50.6	45.0	0.3	53.6	1993	30	0.345
d.Un.Te.FT8-CC	6.16	2.8	50.6	90.8	0.3	53.6	1989	30	0.504
e.Gas CC Adv.	6.16	2.8	50.6	90.8	0.3	53.6	1993	30	0.503
e.NG CC	6.16	2.8	50.6	90.8	0.3	53.6	1993	30	0.454
e.GEC VEGA CC	6.16	2.8	50.6	90.8	0.3	53.6	1993	30	0.550
Utility Nuclear									
a.Nuclear LWR	0	0	0	0	0	0	<1985	30	0.324
b.Nucl. LMFBR	0	0	0	0	0	0	2006	40	0.340
NonUtil.Coal									
a.Conv. Coal St.	45.4	1.5	13	228	419	95.5	<1985	40	0.340
b.PFB	45.4	1.5	2	120	94	95.5	1997	40	0.373
c.Coal Gas. Com. Cycle	45.4	1.5	2	43	34	95.5	1997	30	0.413
d.MCFC/CG	0	1	1	10	1	95.5	2005	30	0.514
NonUtil. Pet.									
a.Pet. Steam	45.4	2.3	15.2	124	197	75.1	<1985	30	0.352
a.Pet. Comb. Turb.	27.7	7.7	21.8	155	197	75.1	<1985	30	0.250
a.Pet. CCC	45.4	2.3	15.2	124	197	75.1	<1985	30	0.402
b.Pet. Adv. Com. Cycle	45.4	2.3	15.2	124	197	75.1	1990	30	0.414
c.Pet. CT St. Injec.	45.4	2.8	51	45	197	75.1	1993	30	0.345
NonUtil. NG									
a.Gas/Liq.St.	1.10	0.6	17.6	121	0.3	53.6	<1985	30	0.352
a.Gas/Liq CT	6.16	2.8	50.6	90.8	0.3	53.6	<1985	30	0.250
a.Gas/Liq.CCC	6.16	2.8	50.6	90.8	0.3	53.6	<1985	30	0.402
b.G/L CC Adv.	6.16	2.8	50.6	90.8	0.3	53.6	1989	30	0.504
c.G/L CT St. Inj.	6.16	2.8	50.6	45.0	0.3	53.6	1990	30	0.414
d.Un.Te.FT8-CC	6.16	2.8	50.6	90.8	0.3	53.6	1993	30	0.345
e.Gas CC Adv.	6.16	2.8	50.6	90.8	0.3	53.6	1993	30	0.503
e.NG CC	6.16	2.8	50.6	90.8	0.3	53.6	1993	30	0.454
e.GEC VEGA CC	6.16	2.8	50.6	90.8	0.3	53.6	1993	30	0.550
Fuel Cells									
Phos. Acid FC							1997	30	0.399
MCFC/CG	0	1	1	10	1	53.6	2005	30	0.514
MCFC/NG	0	1	1	3	0.3	53.6	2005		0.514
MCFC/BIG	0	1	1	10	0	53.6	2005		0.514
Renewable									
Utility	0	0	0	0	0	0			
Non Utility	0	0	0	0	0	0			

Table 12 EMM Region Electric Generating Net Thermal Efficiencies and Emission Factors
Emission factors are given in (g/MBtu of input energy to the power plants).
The thermal efficiency does not include the "in-plant" or "fuel production" efficiencies.

CNV

Year	Net Thermal Efficiency	HC	CO	NOx	SOx	PM	CO_2 (10^3)	Pet. used in elect. gen.
1990	0.325	1.04	16.3	59.4	41.1	6.69	29.7	3.10%
2000	0.336	0.85	13.6	47.6	34.1	5.65	24.5	1.69%
2005	0.351	0.83	12.4	44.0	30.7	6.73	26.0	1.22%
2010	0.373	0.68	6.94	37.1	30.3	9.93	31.3	0.41%
2020	0.406	0.79	5.00	37.6	30.3	14.6	43.4	0.00%
2030	0.419	0.89	5.19	38.9	26.5	16.5	50.0	0.00%
2040	0.425	0.95	5.34	40.3	25.1	17.8	54.2	0.00%

ECAR

Year	Net Thermal Efficiency	HC	CO	NOx	SOx	PM	CO_2 (10^3)	Pet. used in elect. gen.
1990	0.338	1.37	11.8	204	375	40.7	85.7	0.45%
2000	0.342	1.33	10.8	190	342	39.8	84.0	0.03%
2005	0.352	1.34	10.5	171	297	38.2	82.8	0.00%
2010	0.364	1.33	10.2	148	244	34.9	79.5	0.00%
2020	0.387	1.43	10.5	118	169	32.4	81.2	0.00%
2030	0.408	1.47	10.3	84.7	89.6	28.7	79.8	0.00%
2040	0.423	1.51	10.7	62.7	36.1	26.0	78.6	0.00%

ERCOT

Year	Net Thermal Efficiency	HC	CO	NOx	SOx	PM	CO_2 (10^3)	Pet. used in elect. gen.
1990	0.329	1.67	25.9	136	155	19.2	63.1	0.26%
2000	0.345	1.63	24.8	120	133	18.0	58.7	0.15%
2005	0.360	1.66	24.1	110	116	18.7	60.3	0.12%
2010	0.375	1.62	22.8	97.8	96.4	18.0	58.8	0.12%
2020	0.402	1.74	22.8	84.7	70.0	19.0	63.3	0.09%
2030	0.418	1.76	21.7	70.8	41.6	18.8	65.1	0.06%
2040	0.424	1.76	20.9	63.0	23.7	18.6	66.4	0.03%

MAAC

Year	Net Thermal Efficiency	HC	CO	NOx	SOx	PM	CO_2 (10^3)	Pet. used in elect. gen.
1990	0.332	1.09	8.98	127	224	25.4	54.6	5.63%
2000	0.338	1.02	9.60	114	193	23.1	51.6	2.47%
2005	0.348	1.07	10.5	103	164	21.9	51.1	2.17%
2010	0.360	1.02	8.72	92.2	140	22.0	53.5	1.41%
2020	0.383	1.11	8.58	78.1	101	22.4	59.6	0.41%
2030	0.406	1.18	8.20	61.7	58.1	22.0	63.6	0.00%
2040	0.423	1.25	8.20	52.0	30.9	22.1	67.4	0.00%

MAIN

Year	Net Thermal Efficiency	HC	CO	NOx	SOx	PM	CO_2 (10^3)	Pet. used in elect. gen.
1990	0.332	0.81	7.03	120	220	23.9	50.4	0.26%
2000	0.337	0.85	6.75	118	211	25.4	53.5	0.01%
2005	0.344	0.86	6.16	107	184	25.0	54.1	0.01%
2010	0.355	0.88	5.62	94.8	155	24.1	54.9	0.01%
2020	0.372	0.95	4.89	77.8	110	24.0	59.5	0.00%
2030	0.389	0.99	4.04	58.8	63.5	23.1	62.1	0.00%
2040	0.400	1.03	3.60	46.6	32.5	22.7	64.5	0.00%

Table 12 Continued

NE

Year	Net Thermal Efficiency	HC	CO	NOx	SOx	PM	CO2 (10^3)	Pet. used in elect. gen.
1990	0.326	1.66	9.81	80.7	121	18.0	39.5	27.6%
2000	0.335	1.39	10.9	70.5	97.2	14.7	35.3	18.5%
2005	0.339	1.43	10.7	67.0	90.7	14.5	34.8	19.7%
2010	0.346	1.27	10.3	60.2	78.4	13.1	32.9	15.8%
2020	0.363	1.24	10.6	53.1	62.6	12.4	33.0	13.3%
2030	0.385	1.13	10.5	42.8	39.9	10.8	31.7	9.82%
2040	0.412	1.02	10.7	34.2	20.0	9.25	30.6	5.57%

NY

Year	Net Thermal Efficiency	HC	CO	NOx	SOx	PM	CO2 (10^3)	Pet. used in elect. gen.
1990	0.326	1.81	13.6	92.7	126	18.7	45.3	25.8%
2000	0.330	1.49	11.9	76.1	102	15.1	37.5	20.0%
2005	0.336	1.53	11.9	72.8	96.3	15.0	37.0	21.2%
2010	0.346	1.49	11.5	67.6	87.3	14.7	36.9	20.6%
2020	0.365	1.61	11.9	63.5	78.0	15.4	39.1	21.6%
2030	0.378	1.65	11.9	57.5	62.7	15.1	40.2	22.0%
2040	0.388	1.68	11.9	53.7	52.2	15.1	41.2	22.2%

NWP

Year	Net Thermal Efficiency	HC	CO	NOx	SOx	PM	CO2 (10^3)	Pet. used in elect. gen.
1990	0.337	0.505	4.59	73.6	133	14.5	31.0	0.13%
2000	0.361	0.774	9.79	74.0	113	13.7	34.5	0.06%
2005	0.380	0.926	12.4	70.5	94.9	13.3	36.5	0.06%
2010	0.391	0.942	12.8	63.1	77.6	12.2	35.4	0.02%
2020	0.413	1.13	16.0	56.4	50.9	11.2	37.9	0.00%
2030	0.428	1.26	18.2	48.5	25.4	9.90	38.6	0.00%
2040	0.437	1.36	20.2	44.6	9.67	9.01	39.3	0.00%

STV & FL*

Year	Net Thermal Efficiency	HC	CO	NOx	SOx	PM	CO2 (10^3)	Pet. used in elect. gen.
1990	0.330	1.96	15.6	143	224	28.5	65.5	21.6%
2000	0.344	2.09	19.3	128	179	25.1	62.6	20.4%
2005	0.352	2.17	20.0	120	161	24.5	62.5	21.6%
2010	0.364	2.06	18.1	112	143	25.1	65.7	18.9%
2020	0.385	2.17	18.1	103	116	26.6	73.3	17.4%
2030	0.406	2.20	17.3	89.0	81.9	27.0	78.2	15.8%
2040	0.416	2.10	15.9	75.9	54.8	26.2	78.9	13.2%

*There was insufficient energy data to consider the FL region separately.

3. Hypothetical Trip Scenario and Illustrative Calculations of Travel Times, Fuel & Energy Use and Emissions

A hypothetical route is defined here so that the HSGT technologies can be compared on a common basis. The hypothetical route must, of course, be useable by all technologies being compared. This may result in a bias in favor of the lowest performance technology. In practice, planners may elect to take advantage of the special performance capabilities of maglev technology. This could lead to a different alignment from that used for wheel-on-rail technologies. This, in turn, may result in different energy use and emissions as well as different trip times and perhaps even different markets being served.

3.1 The Hypothetical Route

The hypothetical route consists of the following operations:

accelerate from rest at the origin city CBD to the urban speed limit;
cruise at the urban speed limit;
make as many urban/suburban stops as desired for a specified dwell time;
accelerate to the urban/suburban speed limit after each stop;
cruise at the urban/suburban speed limit to the urban/suburban speed limit boundary;
accelerate to the technology's maximum design speed;
make one or more in-route stops for the specified dwell time ;
return to the maximum design speed after each in-route stop;
when the destination city boundary is reached decelerate to urban/suburban speed limit;
cruise at the urban/suburban speed limit;
make the same number of urban/suburban stops as before;
decelerate to a stop at the destination city CBD.

The user may select the total trip distance and the number of urban/suburban stops and in-route stops. However, some restrictions apply and are discussed below. Several possible trip profiles are illustrated in Fig. 2 together with the definitions of the trip constants, parameters and variables. The hypothetical route assumptions and values of the trip constants remain the same for all technologies except where noted and are specified in Table 13.

The urban/suburban speed limits given in Table 13 are based on somewhat arbitrary considerations of safety, noise restrictions, and the levels of infrastructure investments consistent with the technologies. See Ref. 26 for guidance on estimating noise emissions from various train technologies and whether guideways are at ground level or elevated and whether the guideways are open (Transrapid maglev technology) or partially enclosed (Japanese maglev technology).

Assumed parameters used for the example calculations that follow are given in Table 14. The times and distances to reach the urban speed limits and the maximum cruising speeds are determined by numerical integration of Eqn. (2) using tabulated values of traction force and resistance to forward motion from Ref.11.

Table 13. Assumptions Used in Example Calculations & Values of Trip Constants

The trip profile must be symmetrical about the trip center	
The total number of urban or suburban stops must be an even number (0, 2, 4, etc.)	
The total number of in-route stops can be any number (0, 1, 2, 3, etc.)	
Station Dwell Time (s)	90
Urban Speed Limits (mph)	
Technologies with at-grade crossings (79NE, 90NE, 110NE)	50
Grade-separated or otherwise protected crossings and rights of way	
125NE, 150NE, 125E	75
150E	100
TGV (200mph)	125
Maglev	200
The average total distance (origin plus destination cities) over which the urban speed limit (miles)	30.77
Acceleration rate = deceleration rate	
Acceleration profiles are technology and speed dependent and are derived from data from the VNTSC.	
The maximum allowed acceleration	+0.16g (1.569m/s^2)
The maximum allowed deceleration	-0.16g
No hills or curves are considered. (Hills, curves, or additional stops would increase the total trip time of all HSGT modes relative to that of maglev.)	

Table 14 Values of Parameters Used In Hypothetical Route Calculations

Technology	79 NE	90 NE	110 NE	125 NE	150 NE	125 E	150 E	200E	300E
No. Of Seats	264	264	264	264	264	264	264	388	150
Urban/sub cruising speed V_1	50	50	50	75	75	75	100	125	200
Rural cruising speed V_2	79	90	110	125	150	125	150	200	300
Total urban/sub distance L	30.77	30.77	30.77	30.77	30.77	30.77	30.77	30.77	30.77
t1	43.4	43.4	38.1	61.3	47	46.6	71.2	144.8	57.3
t2	43.4	43.4	38.1	61.3	47	46.6	71.2	144.8	57.3
t4	90	90	90	90	90	90	90	90	90
t8	111.7	157.1	228.2	219.8	231.3	152.5	168	380.3	107.2
t9	111.7	157.1	228.2	219.8	231.3	152.5	168	380.3	107.2
d1	0.36	0.36	0.31	0.790	0.579	0.512	1.134	2.81	1.60
d2	0.36	0.36	0.31	0.790	0.579	0.512	1.134	2.81	1.60
d8	1.62	2.69	4.95	5.45	6.82	3.66	4.59	14.00	5.16
d9	1.62	2.69	4.95	5.45	6.82	3.66	4.59	14.00	5.16

Figure 2a Trip Profile With L = 0, And No Suburban Or In-Route Stops

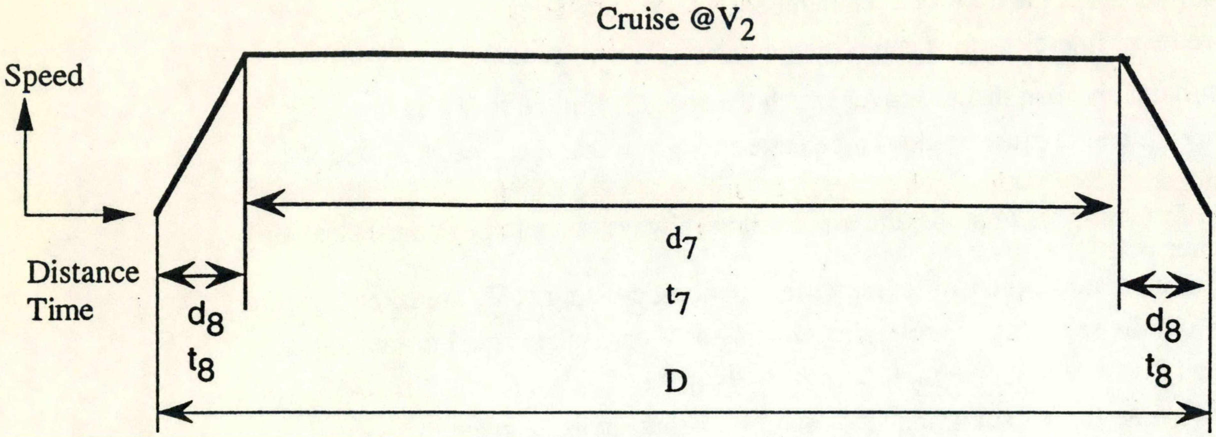


Figure 2b Trip Profile With finite L And No Suburban Or In-Route Stops

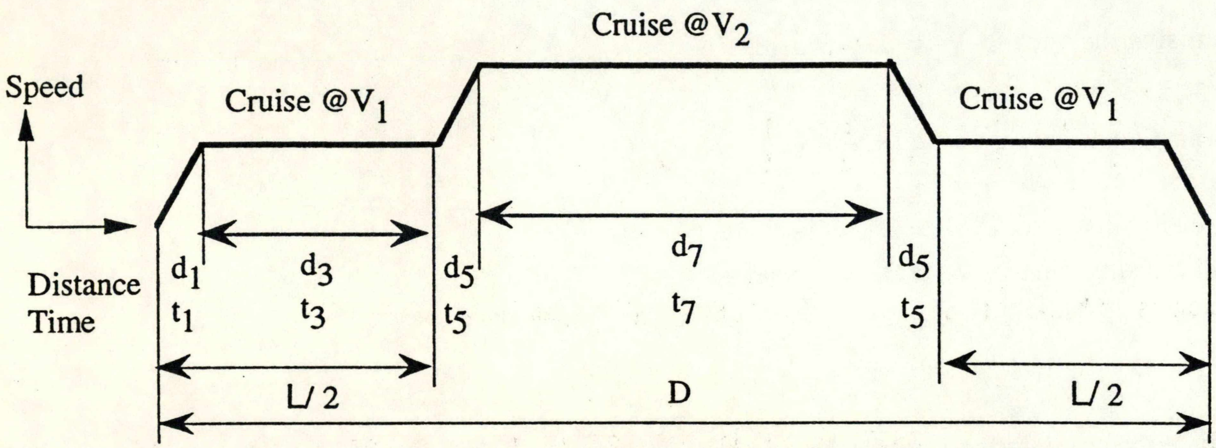
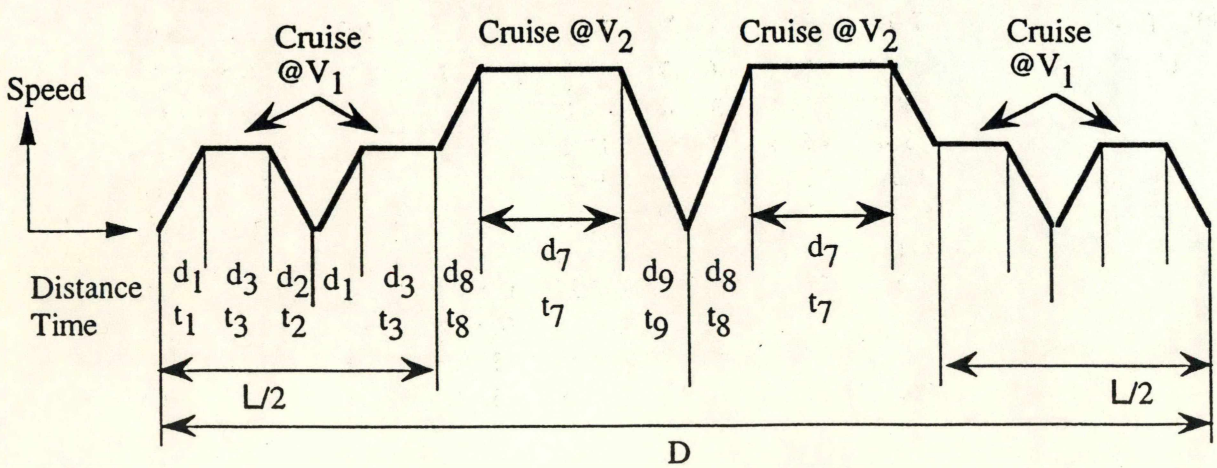


Figure 2c Trip Profile With Finite L , Two Suburban And One In-Route Stop



Notes For Figure 2

No. of suburban stops must be an even number ($N_1 = 0, 2, 4$, etc.),

No. of in-route or intercity stops can be any number ($N_2 = 0, 1$, etc.),

The total urban/suburban distance over which the speed is limited to V_1 is L.

The distances L and D must be chosen be large enough so that the speeds V_1 and V_2 are always reached.

Regardles of the number of stops, the trip profile is always taken to be symmetrical about the trip center point.

For a given no. of stops, the trip segments representing cruising at V_1 are taken equal to each other and the segments representing cruising at V_2 are taken equal to each other.

It is assumed that $d_1 = d_2$, $t_1 = t_2$, $t_8 = t_9$ & $d_8 = d_9$,

The total trip time for N_1 suburban stops and N_2 in-route stops is given by:

If $L = 0$, $T = (1+N_2)(t_7+2t_8)+N_2t_4$, and

If $L > 0$, $T = (1+N_2)(t_7+2t_8)+ (N_1 + N_2)t_4 + 2N_1t_1 + (2+N_1)t_3$, where t_4 is the station dwell time.

The total cruising distance @ $V_1 = D_3$, where,

if $L = 0$, $D_3 = 0$, and ,

if $L > 0$, $D_3 = (2 + N_1)d_3 = L - 2(1+N_1)d_1$.

The total cruising time @ $V_1 = T_3 = D_3/V_1$

The total cruising distance @ $V_2 = D_7 = (1+N_2)d_7$

and the total cruising time @ $V_2 = D_7/V_2$, where,

if $L = 0$, $D_7 = D - 2(N_2 + 1)d_8$, and

if $L > 0$, $D_7 = D - L - 2(N_2 + 1)d_8 + 2d_1$.

Note that since the acceleration is generally not constant, the quantities t_1, d_1, t_8, & d_8 must be determined by numerical integration of the equation of motion.

3.2 HSGT Trip Times On The Hypothetical Route

The following formulae apply to the hypothetical routes illustrated in Fig. 2 for N1 urban/suburban stops and N2 in-route stops (All times in seconds and all distances in miles, unless otherwise noted). The urban distance "L" and total trip distance "D" must be selected to be large enough to permit the urban speed limit and the maximum design speed to be reached between stops:

$L = 0$ implies that $N1 = 0$. (22)

If $L \neq 0$, then L must be selected $\geq Lmin = 2(1+N1)d1$. (23)
This condition is needed to ensure that there is sufficient distance to reach the urban speed limit (V_1) between stops.

D must be selected such that

$D \geq Dmin = 2(1+N2).d8$ if $L = 0$; otherwise, $= L-2.d1+2(1+N2).d8$. (24)
This condition is needed to ensure that there is sufficient distance to reach the maximum design speed (V_2) between stops.

$d3 = 0$ if $L = 0$; otherwise, $= (L - 2(1+N1)d1)/(2+N1)$. (25)

$t3 = d3/V_1$ (26)

$d7 = D/(N2+1) - 2d8$, if $L = 0$; otherwise, $= (D-L+2d1)/(N2+1)-2.d8$ (27)

$t7 = d7/V_2$ (28)

Total time cruising at $V_1 = 0$ if $L = 0$; otherwise, $= 2(N1+1).t3$. (29)

Total time cruising at $V_2 = (N2 + 1).t7$. (30)

Total Trip Time $= (N2 + 1).(t7+ 2.t8)+ N2.t4$ if $L = 0$;
otherwise $= 2.t3+(1 + N2).(t7+ 2.t8) + (N1+ N2).t4 + 2.N1.t1 + N1.t3$ (31)

In the above formulae, the total trip distance "D" and the number of stops N1 and N2 can be given any value consistent with the rules stated above.

Results of some example trip-time calculations for the hypothetical route are given in Table 15. The value of "Dmin" (see Eqn. 24) is also given in Table 15 for each technology. Whenever D < Dmin, i.e. when the distance is too short to allow the maximum design speed to be reached during the trip (because the acceleration is too low), the word "ERROR" is printed. Note that in order for the 200 mph electric train technology to reach its maximum design speed, the total trip distance must be at least 53.4 miles. The maglev technology, using the same trip profile, can reach its design maximum speed during a trip of length => 37.88 miles. Of course, these values of Dmin depend on the values chosen for the hypothetical route parameters given in Table 14. In particular, if the value used for "L" (30.77 miles) were reduced, the values of "Dmin" for all of the technologies would also be reduced

Table 15 also includes some calculations for a 12,000 Hp maglev system. Such a system could use the same vehicle as the 16,200 Hp system but with guideway-mounted and wayside components having a lower rated power. The results show that the reduction in rated power makes very little difference on the hypothetical route. The difference would be more pronounced if the hypothetical route were more demanding (included more accelerations, hills, and curves). This can be explained as follows: To keep costs down, maglev technologies are generally designed to be "power limited", meaning that, for a given design, beyond a critical speed, further increases in speed must be achieved at lower values of acceleration, thus taking more time. The critical speed is the speed at which the power demand of the system reaches the system's rated power (12,000 Hp, 16,200 Hp, or whatever). For the high-speed maglev technology, the power limitation generally comes from the installed rated power of the wayside power conditioning equipment and the propulsion motor windings mounted on the guideway. The 16,200 Hp Maglev system reaches its power limit at 180 mph (that is, the acceleration remains constant at the passenger comfort limit of 1.569 m/s^2 up to a speed of 180 mph (80.5 m/s) (see Table 3). At higher speeds the acceleration diminishes to a value of 0.576 m/s^2 at 300 mph. The 12,000 Hp system maintains the same acceleration up to 140 mph (62.6 m/s). At higher speeds its acceleration diminishes to a value of 0.283 m/s^2 at 300 mph. By contrast, the 200-mph electric technology is traction-force limited through most of its speed range and becomes power limited only near 170 mph. However, its initial acceleration is only 0.5 m/s^2, which is maintained up to about 38 mph (16 m/s). At higher speeds its acceleration diminishes to a value of 0.063 m/s^2 at 200 mph. This slow acceleration accounts for the relatively large distance required to reach its maximum design speed.

For conventional rail systems the power capacity is generally limited by the locomotive's power train or by the pantograph/catenary system. If it is the former, higher output power can be achieved by adding more locomotives.

Table 15 Total Line-Haul Trip Times (h) on Hypothetical Route. (Total low-speed region length = 30.77 miles)

N1	N2	Trip Distance D (mi)	Technologies 79 NE	90 NE	110 NE	125 NE	150 NE	125 E	150 E	200 E	16200hp 300 E	12000hp 300 E
0	0	Dmin	33.28	35.42	40.04	40.09	43.25	37.06	37.69	53.14	37.88	
		40	0.75	0.74	ERROR	ERROR	ERROR	0.50	0.39	ERROR	0.20	
		50	0.87	0.85	0.82	0.59	0.57	0.58	0.46	ERROR	0.24	0.24
		60	1.00	0.96	0.91	0.67	0.63	0.66	0.53	0.45	0.27	0.27
		100	1.51	1.41	1.27	0.99	0.90	0.98	0.79	0.65	0.40	0.41
		300	4.04	3.63	3.09	2.59	2.23	2.58	2.13	1.65	1.07	1.07
		600	7.84	6.96	5.82	4.99	4.23	4.98	4.13	3.15	2.07	2.07
		900	11.63	10.29	8.55	7.39	6.23	7.38	6.13	4.65	3.07	3.07
0	1	Dmin	36.52	40.8	49.94	50.99	56.89	44.38	46.87	81.14	48.2	
		50	0.92	0.90	0.88	ERROR	ERROR	0.64	0.52	ERROR	0.29	
		60	1.05	1.01	0.97	0.73	0.70	0.72	0.58	ERROR	0.32	
		90	1.43	1.35	1.25	0.97	0.90	0.96	0.78	0.69	0.42	
		100	1.55	1.46	1.34	1.05	0.96	1.04	0.85	0.74	0.45	
		300	4.09	3.68	3.15	2.65	2.30	2.64	2.18	1.74	1.12	
		600	7.88	7.01	5.88	5.05	4.30	5.04	4.18	3.24	2.12	
		900	11.68	10.35	8.61	7.45	6.30	7.44	6.18	4.74	3.12	
2	0	Dmin	33.28	35.42	40.04	40.09	43.25	37.06	37.69	53.14	37.884	
		40	0.817	0.808	ERROR	ERROR	ERROR	0.579	0.478	ERROR	0.2861	
		50	0.94	0.92	0.89	0.67	0.64	0.66	0.54	ERROR	0.32	
		60	1.07	1.03	0.98	0.75	0.71	0.74	0.61	0.57	0.35	
		100	1.58	1.47	1.34	1.07	0.97	1.06	0.87	0.77	0.49	
		300	4.11	3.70	3.16	2.67	2.31	2.66	2.21	1.77	1.15	
		600	7.91	7.03	5.89	5.07	4.31	5.06	4.21	3.27	2.15	
		900	11.70	10.36	8.61	7.47	6.31	7.46	6.21	4.77	3.15	
2	1	Dmin	36.52	40.8	49.94	50.99	56.89	44.38	46.87	81.14	48.2	
		50	0.99	0.97	0.95	ERROR	ERROR	0.71	0.60	ERROR	0.37	0.38
		60	1.12	1.08	1.04	0.81	0.77	0.79	0.67	ERROR	0.40	0.41
		70	1.24	1.19	1.13	0.89	0.84	0.87	0.73	ERROR	0.44	0.44
		90	1.50	1.42	1.31	1.05	0.97	1.03	0.86	0.81	0.50	0.51
		100	1.62	1.53	1.40	1.13	1.04	1.11	0.93	0.86	0.54	0.54
		300	4.15	3.75	3.22	2.73	2.37	2.71	2.26	1.86	1.20	1.21
		600	7.95	7.08	5.95	5.13	4.37	5.11	4.26	3.36	2.20	2.21
		900	11.75	10.42	8.68	7.53	6.37	7.51	6.26	4.86	3.20	3.21
2	2	Dmin	39.76	46.18	59.84	61.89	70.53	51.70	56.05	109.1	58.52	
		60	1.16	1.14	1.10	ERROR	ERROR	0.84	0.73	ERROR	0.45	
		70	1.29	1.25	1.19	0.95	ERROR	0.92	0.79	ERROR	0.49	
		90	1.54	1.47	1.37	1.11	1.03	1.08	0.93	ERROR	0.55	
		100	1.67	1.58	1.47	1.19	1.10	1.16	0.99	ERROR	0.59	
		110	1.80	1.69	1.56	1.27	1.16	1.24	1.06	1.01	0.62	
		300	4.20	3.80	3.28	2.79	2.43	2.76	2.32	1.96	1.25	
		600	8.00	7.14	6.01	5.19	4.43	5.16	4.32	3.46	2.25	
		900	11.80	10.47	8.74	7.59	6.43	7.56	6.32	4.96	3.25	

"ERROR" means the distance was too short to allow the maximum design speed to be reached.

The results for trip times given in Table 14 illustrate the following points:

- The differences for the various technologies is quite significant
- The difference between the 12,000 Hp and the 16,200 Hp maglev systems is negligible.
- The impact of stops is relatively small for all technologies.
- Because of the relatively low acceleration of the 200 E technology, the total trip distance must be 60 miles or more (depending on the no. of stops) before there is any time savings relative to the 150 E technology. By contrast, even for distances of 40 miles the time savings of the maglev technology is significant relative to all other technologies.

3.3 Comparison of HSGT Trip Times With Short-Haul Jet Aircraft Flights

For comparison purposes, gate to gate times (also called block times) for commercial short-haul jet aircraft flights have been computed as a function of stage length. Estimates of the aircraft block times at ANL in 1991 were based on an analysis of aircraft operations at large airports during peak periods. The effects of queuing at runways was taken into account. A regression analysis of the trip times yielded the equation:

$$\text{Time (min)} = 0.1139*\text{Stage Length (miles)} + 42.86 \quad (32)$$

A recent regression analysis of scheduled trip times published in the OAG Desk Top Guide, North American Edition, May 15, 1999, yielded the equation:

$$\text{Time (min)} = 0.1393*\text{Stage Length (miles)} + 32.572. \quad (33)$$

The Eqn. (33), which is based on 27 city pairs ranging in air distance from 71 to 702 miles, has a somewhat steeper slope and smaller intercept than the earlier ANL-based data analysis. Hence the second equation predicts smaller times for short trips and larger times for longer trips. The difference between these two equations results, in a large part, from the greater taxiing and queuing times (associated with peak periods at large airports) used in deriving Eqn. (32).

Line-haul trip times for the high-speed electric ground technologies (hypothetical trip profile shown in Fig, 2a) and jet aircraft (Eqn. 33) are plotted in Fig. 3 for the case of no stops and in Fig. 4 for the case of one in-route stop for both the HSGT and jet aircraft technologies. For the latter, it was assumed, based on limited data from the OAG, that a stop would add about one hour to the jet trip time. With no stops the maglev line-haul times are shorter than those of the jet aircraft flights for distances up to about 500 miles. With one in-route stop, the maglev line-haul time is shorter for distances greater than 900 miles.

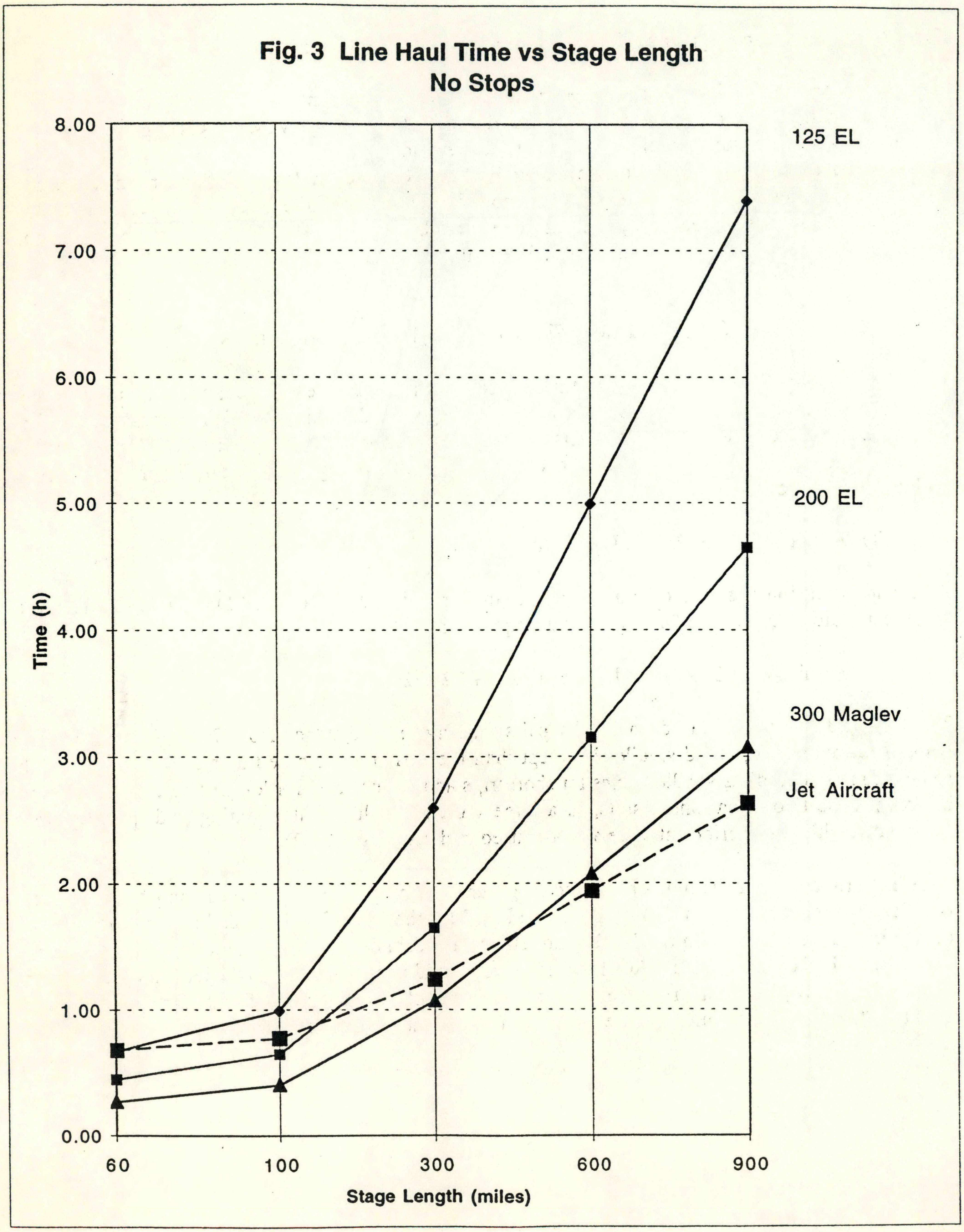


Fig. 3 Line Haul Time vs Stage Length
No Stops
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Time (h)
60
100
300
600
900
Stage Length (miles)
125 EL
200 EL
300 Maglev
Jet Aircraft

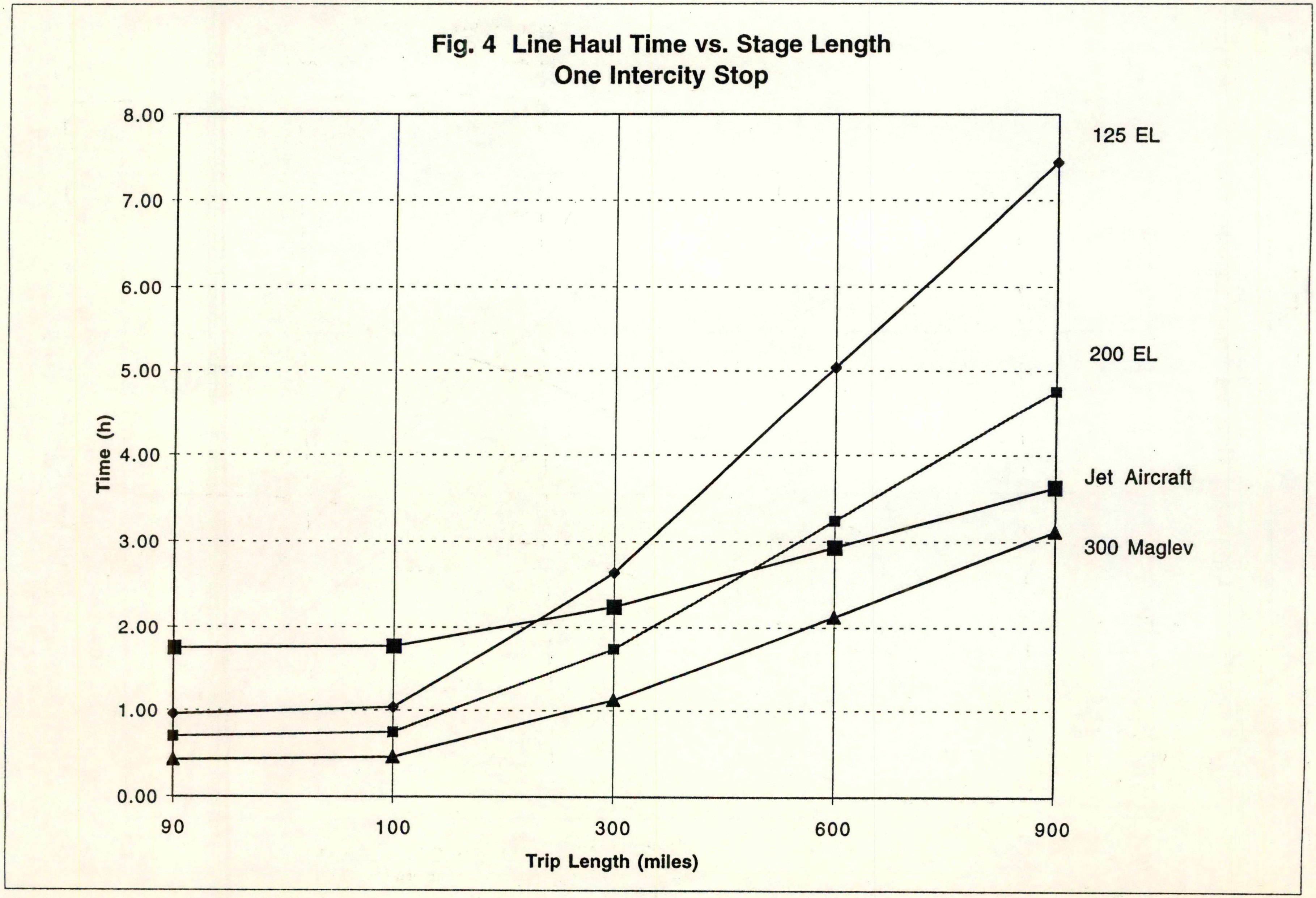
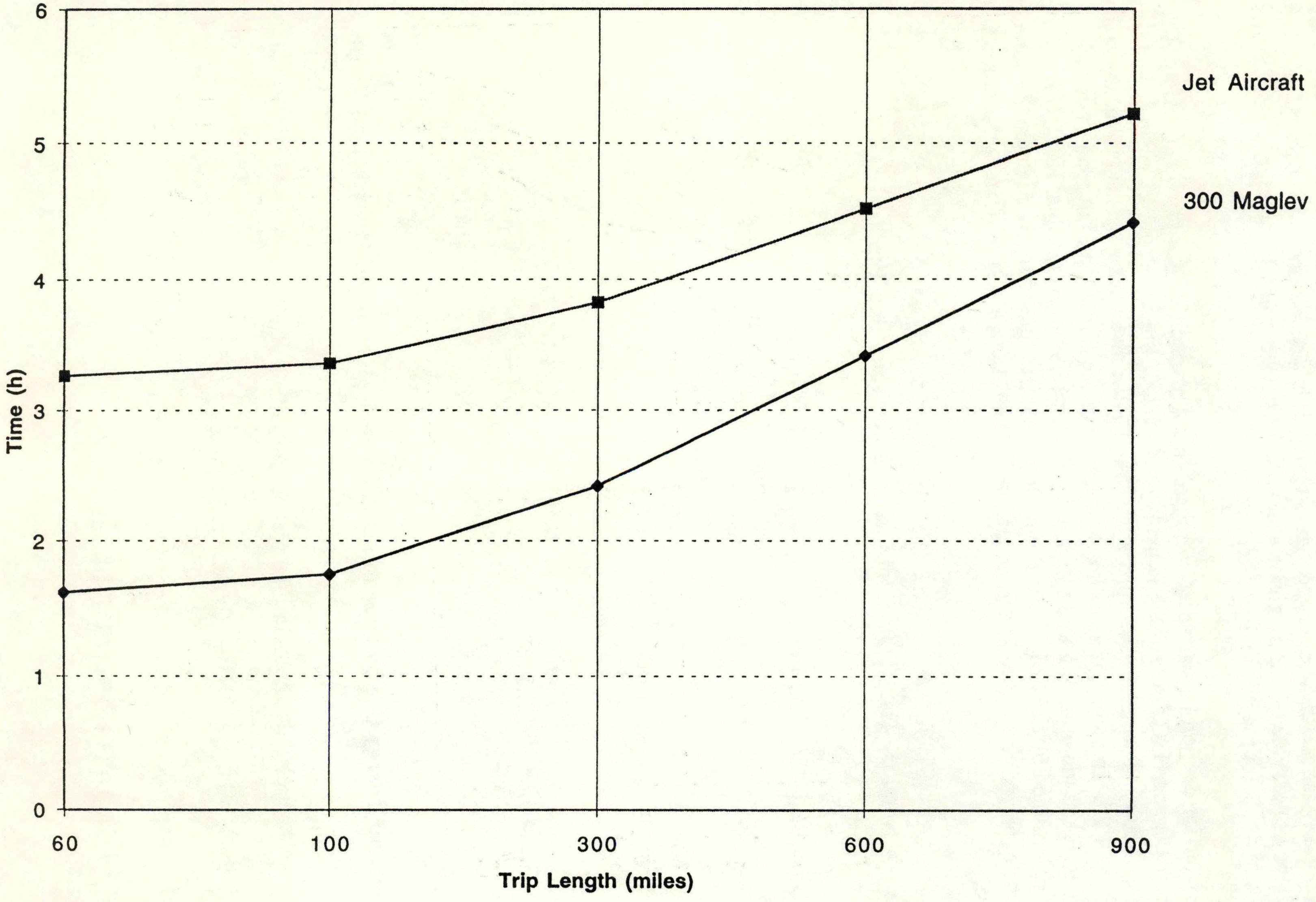


Fig. 4 Line Haul Time vs. Stage Length
One Intercity Stop
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Time (h)
90
100
300
600
900
Trip Length (miles)
125 EL
200 EL
Jet Aircraft
300 Maglev

Fig. 5 Total Trip Times vs. Trip Distance
Two Urban Stops for Maglev, No stops for Jet Aircraft



Total trip times may also be compared for maglev and jet aircraft flights. This requires estimates of access and egress times in addition to line-haul times. Table 16 contains estimates for all components of the total trip time (excluding line-haul time) assuming the maglev makes two suburban stops, which substantially reduce the access and egress times. It is also assumed that, because of the relatively high frequency of service of the maglev system, the in-station times are shorter. Fig. 5 shows a plot of the total trip times for maglev and jet aircraft trips.

One word of caution is warranted in regard to comparison of trip times for different modes. Airline flight paths and HSGT routes are generally not straight lines. In Ref. 27 airline routes are assumed to have a circuity factor of 1.15 compared to straight-line distances whereas rail distances have a circuity factor of 1.25. In theory, maglev routes could be more direct than rail routes because of their greater capacity for grade climbing and tilting around curves. However, actual HSGT routes are more likely to be determined by right-of-way and ridership considerations than route length. Differences in circuity are not expected to be more than about 10% unless there are significant geographic obstacles to be overcome

Table 16 Non Line-Haul Time Contributions to the Total Trip Times

Non Line-Haul Time Contributions	Airline Trip Times (h)	Maglev Reduction Factors	Maglev Trip Times
Station Access	0.667	0.667	0.445
Origin Station	1.000	0.25	0.250
Destination Station	0.250	0.5	0.125
Station Egress	0.667	0.667	0.445
Total time	2.583		1.264

3.4 Fuel and Energy Use by Diesel-Fueled Technologies On The Hypothetical Route

For the diesel-fueled technologies, the fuel use formula is expressed as

$$F(gal) = F0 + F1*N1 + F2*N2 + F3*D(miles). \quad (34)$$

The relationship between fuel and energy is given by the conversion

$$E(MBtu) = F(gal)*0.1287 \text{ (MBtu/gal diesel)} \quad (35)$$

Incorporating the diesel production efficiency from Table 8 (for the year 2010),

$$Ein(MBtu) = E(MBtu)/\_DPE = E(MBtu)/0.837 \quad (36)$$

For convenience, this equation is expressed in terms of the number of stops and the total distance as

$$Ein(MBtu) = E0 + E1*N1 + E2*N2 + E3*D(miles) \quad (37)$$

The corresponding energy per seat.mile is given by

$$E(Btu/seat.mile) = Ein(MBtu) * 10^6 /(\text{no. of seats x trip length in miles}) \quad (38)$$

3.5 Energy Use by Electricity-Powered Technologies On The Hypothetical Route

For the electricity-fueled technologies, the input energy to the electricity generating system is given by Eqns. (12) & (13), namely,

$$E^{in}(kWh) = E_T^{o}\ (kWh)/\ \eta_{net} \qquad (39)$$

In order to be consistent, this expression can be converted to thermal energy units as follows:

$$E^{in}(MBtu) = 0.003412\ (MBtu/kWh).\ E^{in}(kWh)$$

For convenience, this can be expressed in terms of the number of stops and the total distance as

$$E^{in}(MBtu) = E0 + E1*N1 + E2*N2 + E3*D(miles). \qquad (40)$$

The energy per seat.mile is given by the same expression as Eqn. (38). Note that Eqn. (40) includes the net generating efficiency, which from Eqns. (13) and (16) already includes the in-plant and fuel production efficiencies for each of the fuels in the mix of electricity generating technologies.

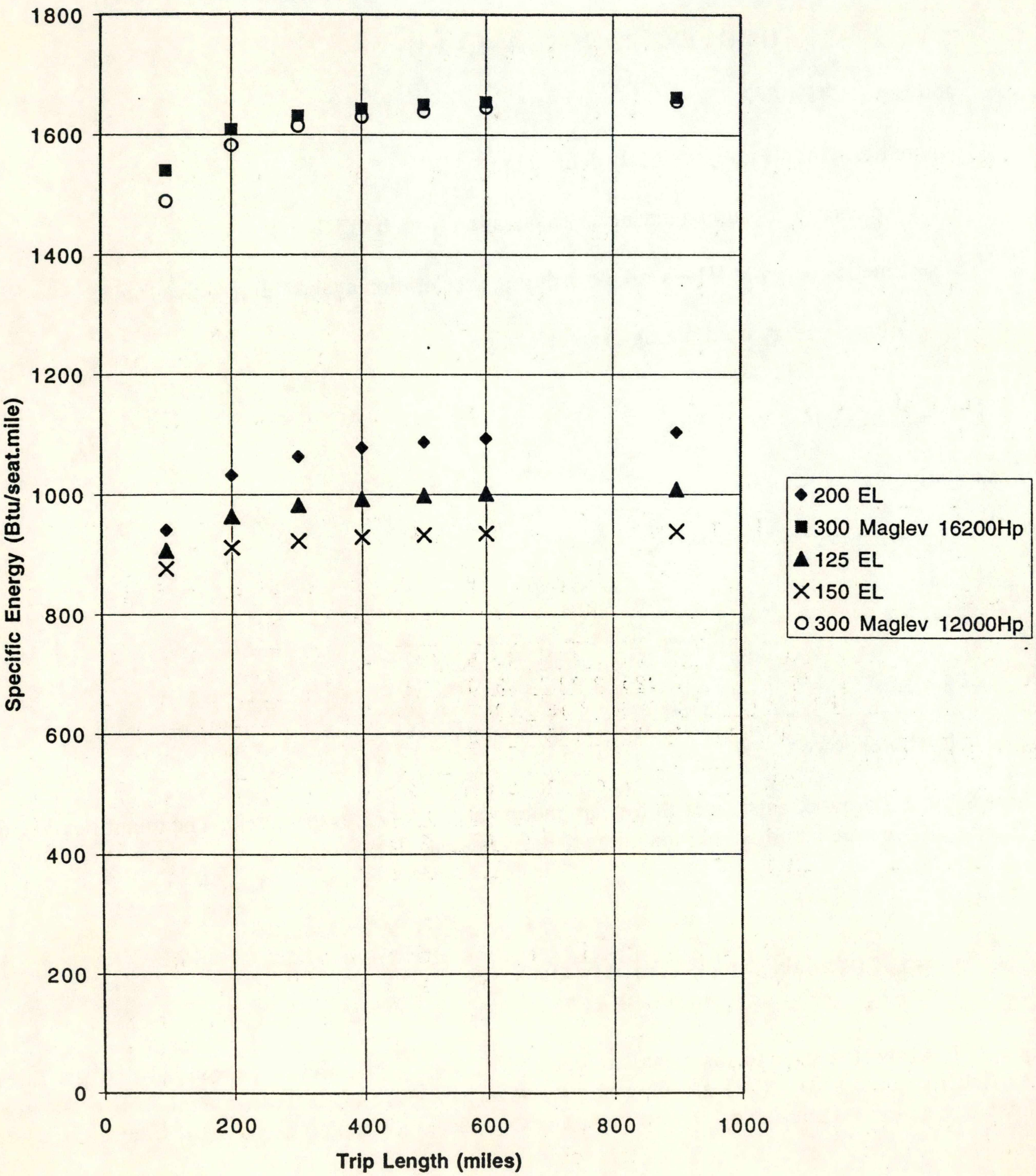
The estimated values, for the year 2010, of the coefficients appearing in Eqns. (34), (37), and (40) are listed in Table 17.

Table 17 Fuel Use & Input Energy Coefficients for the Year 2010.

Technology		79 NE	90 NE	110 NE	125 NE	150 NE	125 E	150 E	200E	300E
No. Of Seats		264	264	264	264	264	264	264	388	150
Fuel Use Coeff.										
	F0 (gal)	8.524	5.474	-13.5	-14.7	-27.7				
	F1(gal)	2.025	2.025	2.363	2.86	4.273				
	F2 (gal)	3.336	3.13	1.967	1.838	2.249				
	F3 (gal/mi)	1.014	1.108	1.413	1.557	1.695				
Input Energy Coeff.										
	E0 (Mbtu)	1.311	0.842	-2.08	-2.26	-4.26	-3.01	-1.86	-7.09	-2.05
	E1 (Mbtu)	0.311	0.311	0.363	0.44	0.657	0.742	1.236	2.99	1.36
	E2 (Mbtu)	0.513	0.481	0.302	0.283	0.346	0.517	0.922	-1.61	0.882
	E3 (Mbtu/mi	0.156	0.17	0.217	0.239	0.261	0.269	0.25	0.436	0.252

The energies per seat.mile for the year 2010 for the electricity-powered technologies are shown in Fig.6 for the case of no stops. The two maglev technologies show very little difference, but there is a significant difference between the 300 mph maglev technologies and the slower technologies due to the increase in energy consumed at greater speed. Both the 200 and 300 mph technologies have relatively high overall efficiencies so that the increased speed results in a corresponding increase in energy per seat.mile. The higher efficiency of the 200 mph technology relative to the lower-speed technologies largely compensates for the increased speed so that the energy per seat.mile is only slightly higher than for the lower speed technologies.

Fig. 6 Energy Per Seat.Mile of Electric HSGT Technologies



A somewhat more general expression for the electrical energy E^{out} is given by

$$E^{out}(kWh) = A + B.D(miles), \quad (41a)$$

where $A = (N2+1).E2 + N2.t4.Ph/3600 - (P2+Ph)/V2 . [2(N2+1).d8]$, if $L = 0$,

and, if $L > 0$, $= N1.E1 + (N2+1).E2 + (N1+N2).t4.Ph/3600 + (L-2.d1)/V1 . (P1+Ph)$

$$- (P2+Ph)/V2 . [2(N2+1).d8 + L - 2.d1], \quad (41b)$$

and $B = (P2+Ph)/V2$, (41c)

where the symbols not previously defined are

E1 = the energy consumed during an acceleration from 0 to V1

= kinetic energy at V1 + work done during acceleration against all resistive forces

+ hotel energy used during the acceleration

$$= 1/2.m.V1^2 + W1 + Ph.t1 \quad (42)$$

and similarly,

$$E2 = 1/2.m.V2^2 + W2 + Ph.t8, \quad (43)$$

and

$P1 = R1.V1$

$P2 = R2.V2$

Ph = hotel power,

where R1 & R2 are the resistances to forward motion at V1 & V2, respectively. The quantities W1 & W2 generally require a numerical integration to be evaluated. They are given by

$$W1 = \int_0^{V1} R\,(v(x)).dx \text{ and } W2 = \int_0^{V2} R\,(v(x)).dx . \quad (44)$$

Eqns. (41) allow the user to insert any values of V1, V2, L, N1, and N2, provided that the rules specified in Eqns. (22) - (24) are obeyed. However, they are not as convenient to use because knowledge of the resistance to forward motion is required as a function of velocity. Use of the other energy equations, i.e. Eqns (34)- (40), is relatively simple but is restricted to L = 30.77 miles and the values of V1 and V2 and the other kinematic variables specified for each technology in Table 14.

Table 3 gives the results of a numerical simulation of a hypothetical 2-car maglev train accelerating from 0 to 300 mph. The values of propulsion force, resistance to forward motion and power are tabulated as a function of velocity along with other data. The hypothetical maglev technology corresponds to an amalgamation of the performance characteristics of the three U.S. repulsive-force maglev design concepts developed during the National Maglev Initiative SCD Program (see Ref. 28-30).

3.6 Comparison of HSGT and Short-Haul Jet Aircraft Energy Use

All short-haul flights are assumed to use large commercial narrow-body jet aircraft. Prior to the year 2000, the commercial jet aircraft fleet consists of stage 2 & 3 aircraft types. By the year 2000 legislation requires that all stage 2 aircraft are supposed to be eliminated . The FAA expects that there will be some extensions granted so that all stage 2 aircraft will be out of the fleet by 2003 (Ref.31).

Present and projected future short-haul jet aircraft inventories were analyzed in detail in Ref.14 and representative (weighted-average) values for fuel and energy use and emission factors were developed for each projection year. The results are given in Table 18 for the LTO-cycle and cruise modes.

The fuel use and energy formulae for the year 2010 for the representative 175-seat jet aircraft are given below:
For no stops,

Fuel use (lb. of kerosene) = 1984 + 10.51*D (miles) (45a)

And for one in-route stop, which requires an additional LTO cycle,

Fuel use (lb. of kerosene) = 3968 + 10.51*D (miles) (45b)

The fuel use can be converted to energy use as follows:

Energy use (Btu) = Fuel use (lb. of kerosene) * 18,838 (Btu/lb) (45c)

Using the kerosene production efficiency factor from Table 8,

Energy Input (Btu) = 18,838 / 0.867 * Fuel use (lb. of kerosene) (45d)

Comparisons of energy per seat mile for HSGT technologies and jet aircraft are shown in Figs. 7 and 8 for no stops, and for one in-route stop for HSGT and aircraft technologies and two urban/suburban stops for the HSGT technologies, respectively. For the no-stop comparison, the maglev consumed less energy per seat mile than the representative jet aircraft for trips up to about 600 miles in length. For the case illustrated in Fig. 8, maglev consumed less energy per seat mile for all distances shown.

Table 18 Jet Aircraft Fuel Use, Emission Factors, and Energy Use by Projection Year

Year	LTO-Cycle Fuel Use (lb)	LTO-Cycle Energy (MBtu)	LTO-Cycle Emissions: VOC (lb)	CO (lb)	NOX (lb)	SO2 (lb)	CO2 (lb)
1990	2453	49.1	10.4	41.0	22.3	1.324	7714
1995	2322	46.4	7.34	35.5	23.4	1.254	7304
2000	2180	43.6	3.99	29.6	24.6	1.177	6856
2005	2075	41.5	2.06	25.9	25.0	1.121	6528
2010	1984	39.7	1.97	24.7	23.9	1.071	6240
2020	1831	36.6	1.82	22.7	22.3	0.989	5760
2030	1653	33.1	1.64	20.5	20.1	0.893	5200
2040	1532	30.6	1.52	19.0	18.6	0.827	4819

Year	Cruise FFR (lb/mi)	Cruise (MBtu /mi)	Cruise emissions: VOC (lb/mi)	CO (lb/mi)	NOX (lb/mi)	SO2 (lb/mi)	CO2 (lb/mi)	No. of Seats
1990	11.91	0.238	0.01362	0.0865	0.0800	0.00624	37.47	145
1995	11.67	0.233	0.00918	0.0659	0.0856	0.00599	36.70	155
2000	11.40	0.228	0.00438	0.0437	0.0916	0.00572	35.85	166
2005	11.10	0.222	0.00162	0.0306	0.0940	0.00550	34.90	173
2010	10.51	0.210	0.00156	0.0292	0.0899	0.00526	33.05	175
2020	9.52	0.190	0.00145	0.0267	0.0830	0.00484	29.94	179
2030	8.37	0.167	0.00131	0.0241	0.0750	0.00437	26.33	182
2040	7.50	0.150	0.00121	0.0223	0.0694	0.00405	23.60	183

NOTE: The FAA recommends that the total hydrocarbon (HC) emission rates be converted to volatile organic compounds (VOC) using the following factor: VOC = HC * 1.0947.
This factor has been incorporated into the above table.
NOTE: For purposes of evaluating the impact of aircraft emissions, a complete set of LTO- cycle emissions are attributed to the origin & destination city for each aircraft round trip.
The cruising emissions are distributed over the counties covered by the route.

Fig. 7 Energy Per Seat.Mile of HSGT vs. Short-Haul Jet Aircraft (no stops)

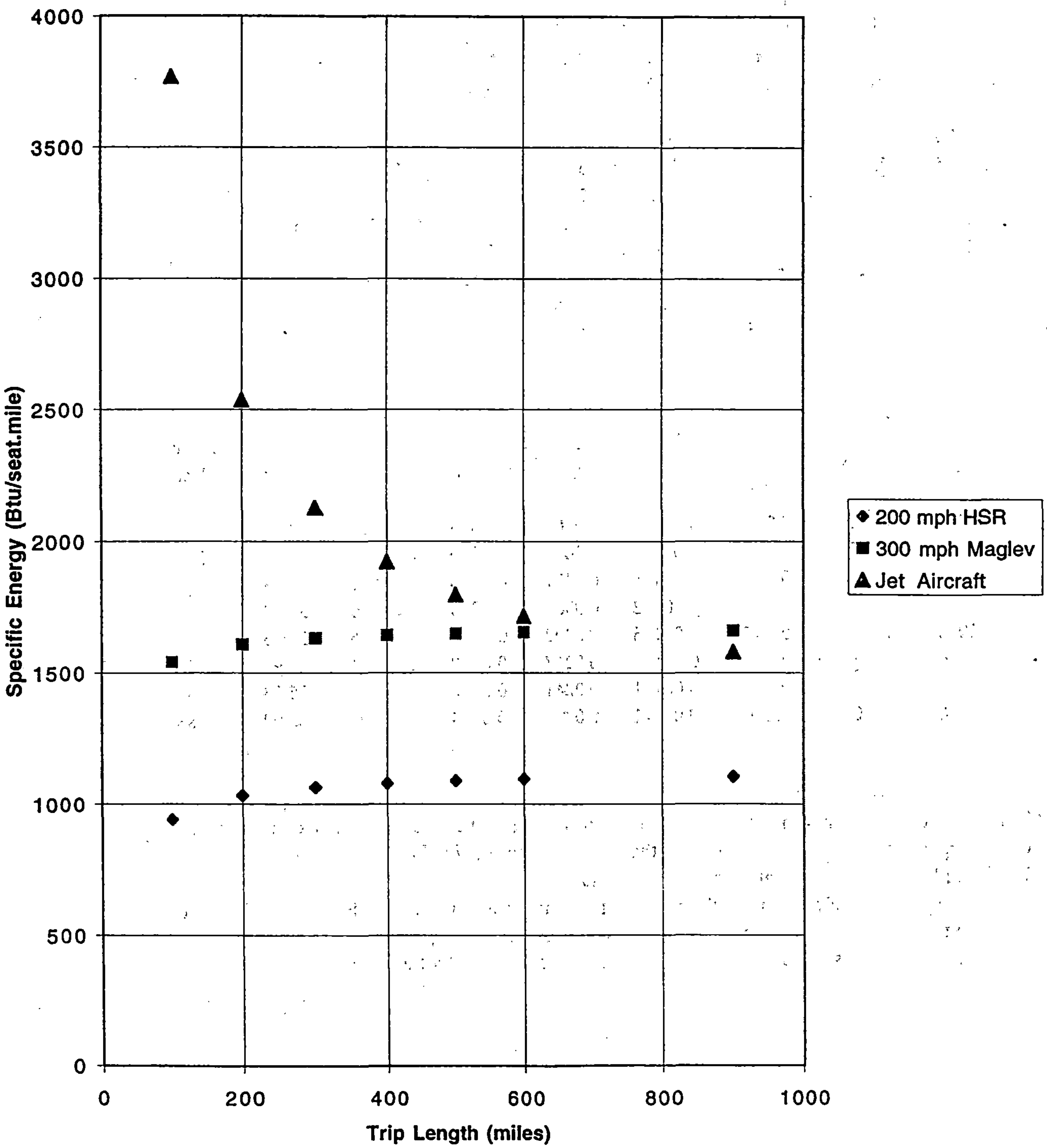
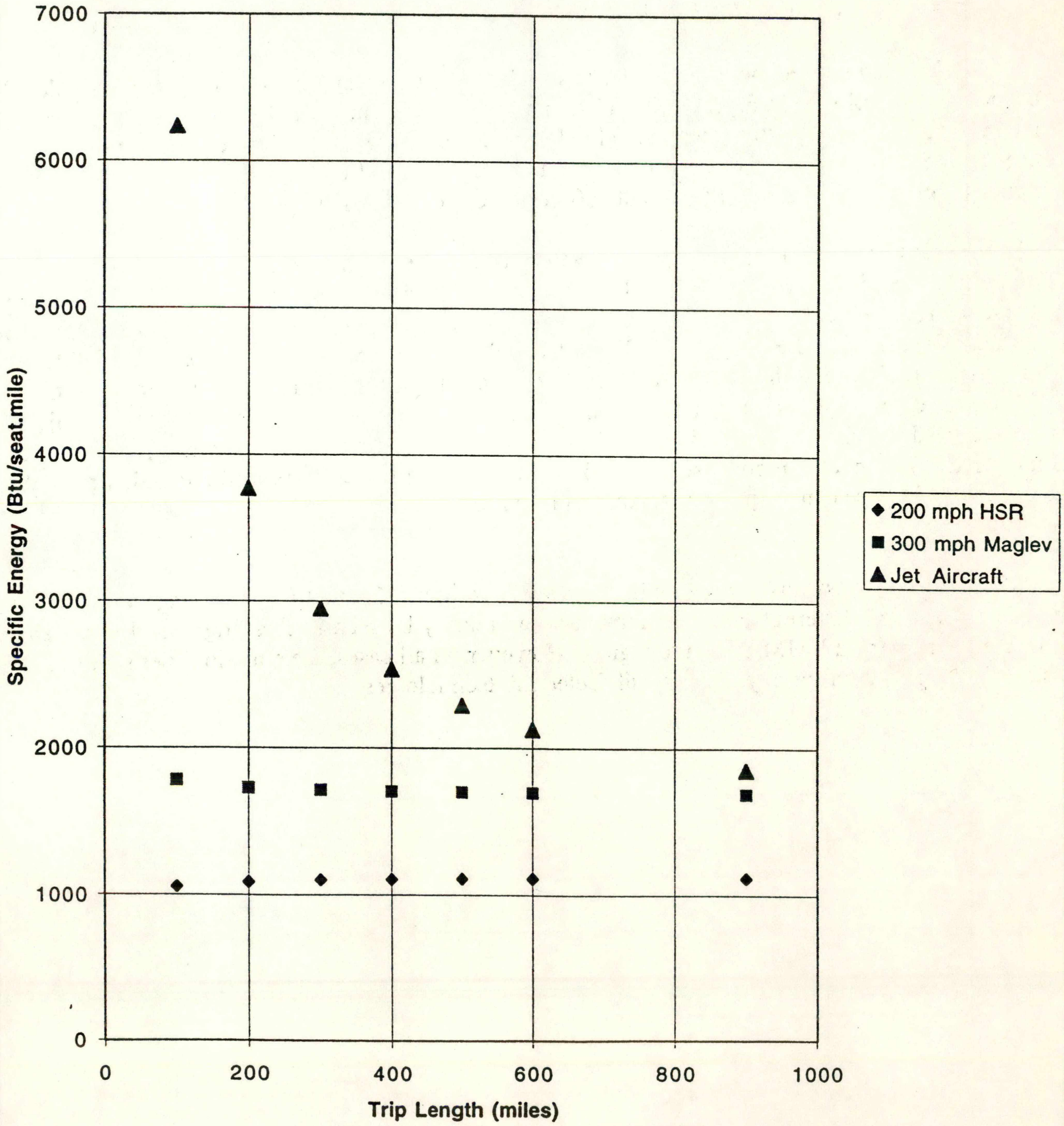


Fig. 8 Energy Per Seat.Mile of HSGT vs. Short-Haul Jet Aircraft (2 urban & 1 in-route stop for HSGT & 1 in-route stop for aircraft)



3.7 Emissions from HSGT on the Hypothetical Route

For all HSGT technologies, and all pollutants, the emissions formulae can be expressed simply as

$$\varepsilon(g) = \varepsilon_0 + \varepsilon_1 {*}N1 + \varepsilon_2 {*}N2 + \varepsilon_3 {*}D \text{ (miles)} \qquad (46)$$

For the fossil-fueled rail technologies, the values of the coefficients in Eqn. (46) are listed in Table 19. NOx emissions are plotted in Figs. 9,10, & 11 for no stops, for two urban and one in-route stop, and for two urban and two in-route stops, respectively. For each technology, the curves converge to the same values at large distances in the three figures. The number of stops affect emissions per seat mile significantly only for distances under about 200 miles. CO emissions are plotted in Fig. 12.

For the electricity-powered technologies, the values of the coefficients in Eqn. (46) are calculated by multiplying the emission factors for the EMM region and year of interest (Table 12) by the energy coefficients for the technology of interest (Table 17). As an example, the resulting emission coefficients for the 16,200 Hp maglev 300 mph technology are given in Table 20 for the year 2010 for several EMM regions for the hypothetical route parameters and technology parameters specified in Table 14. [The emission factors for each EMM region are from Ref. 14. They are based on projected fuel mixes used to generate electricity in each region. These projections come from calculations done with the NEMS computer model (see Ref. 16). It is important to be aware of the fact that published projections of fuel use can vary significantly from year to year.

The NOx and CO emissions per seat mile are plotted in Figs. 13 and 14 for the maglev technology operating in several different EMM regions. As can readily be seen in these figures, the emissions vary significantly from EMM region to region. However, in all cases, the emissions per seat mile are less for the maglev than for any of the fossil-fueled rail technologies.

Table 19 Emission Coefficients for Fossil-Fueled Rail Technologies								
Emission Formula:		Emissions (g) = EM0+EM1*N1 +EM2*N2 + EM3*D(miles)						
Technology	No. of Seats	Coefficient	PM	NOX	CO	HC	SO2	CO2 (10^5)
79 NE	264	EM0	27.04	-700.4	-262.7	74.24	146.3	0.822
		EM1	10.68	350.8	89.80	30.87	34.75	0.195
		EM2	23.30	657.3	140.5	63.29	57.24	0.322
		EM3	2.92	164.3	34.66	4.28	17.41	0.098
90 NE	264	EM0	-2.17	-2770	-717.5	87.97	94.62	0.532
		EM1	10.68	350.8	89.80	30.87	34.75	0.195
		EM2	24.74	468.4	91.50	81.67	53.72	0.302
		EM3	3.94	226.9	48.17	4.43	19.01	0.107
110 NE	264	EM0	-47.51	-1598	-959.5	22.91	-173.9	-1.303
		EM1	6.88	314.5	95.61	9.17	30.42	0.228
		EM2	22.33	347.4	287.2	37.97	25.32	0.190
		EM3	3.59	226.6	43.39	2.73	18.19	0.136
125 NE	264	EM0	-45.61	-256.2	182.0	23.73	-169.7	-1.271
		EM1	8.29	227.3	37.44	13.25	24.80	0.186
		EM2	28.67	669.0	271.7	50.23	44.94	0.337
		EM3	4.11	122.5	9.35	5.42	15.39	0.115
150 NE	264	EM0	-73.35	-2164	-322.2	-110.5	-229.7	-1.721
		EM1	9.24	272.8	40.60	13.93	28.95	0.217
		EM2	9.25	272.9	40.62	13.93	28.96	0.217
		EM3	6.97	205.5	30.59	10.49	21.81	0.163

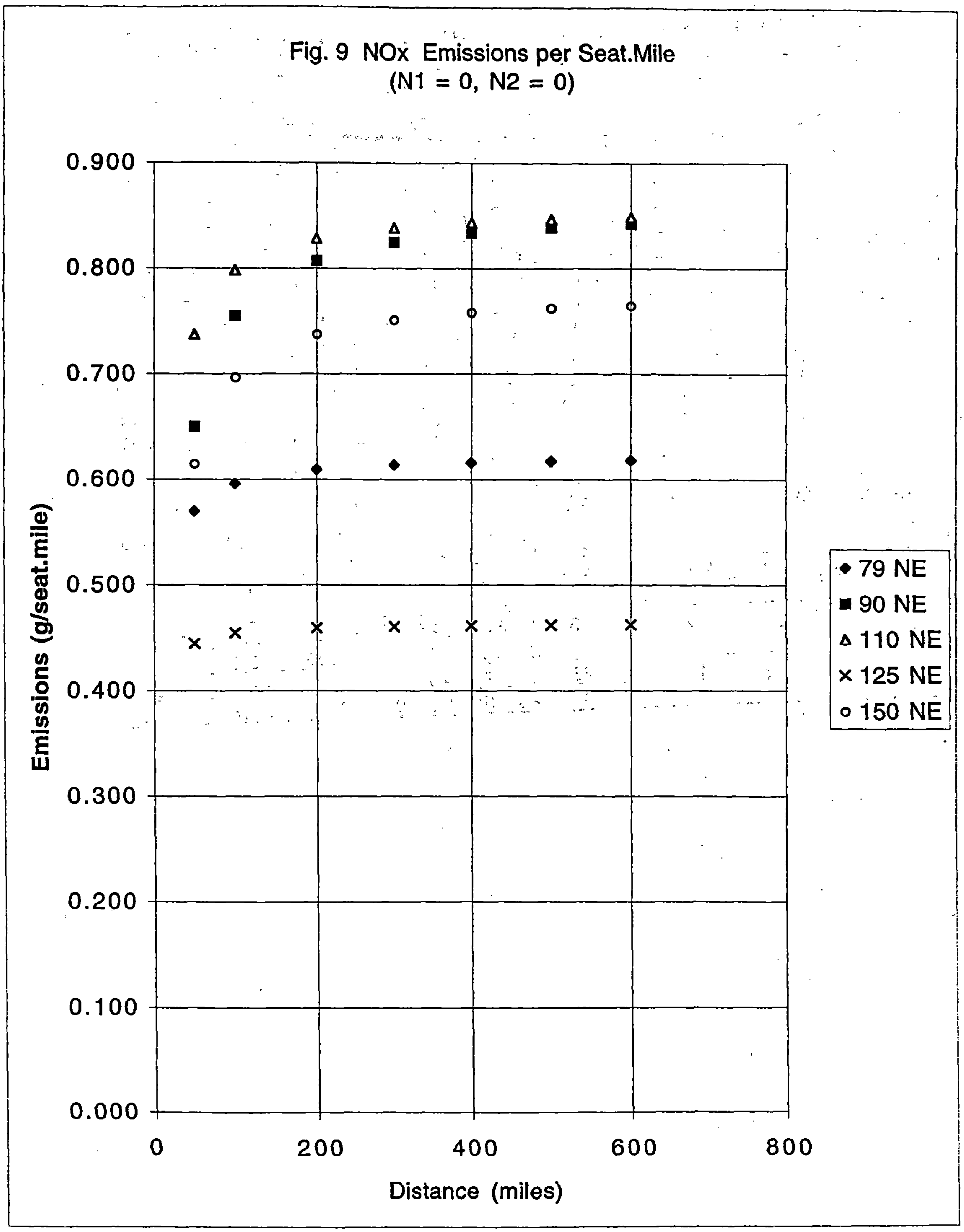


Fig. 9 NOx Emissions per Seat.Mile
(N1 = 0, N2 = 0)
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
Emissions (g/seat.mile)
0
200
400
600
800
Distance (miles)
79 NE
90 NE
110 NE
125 NE
150 NE

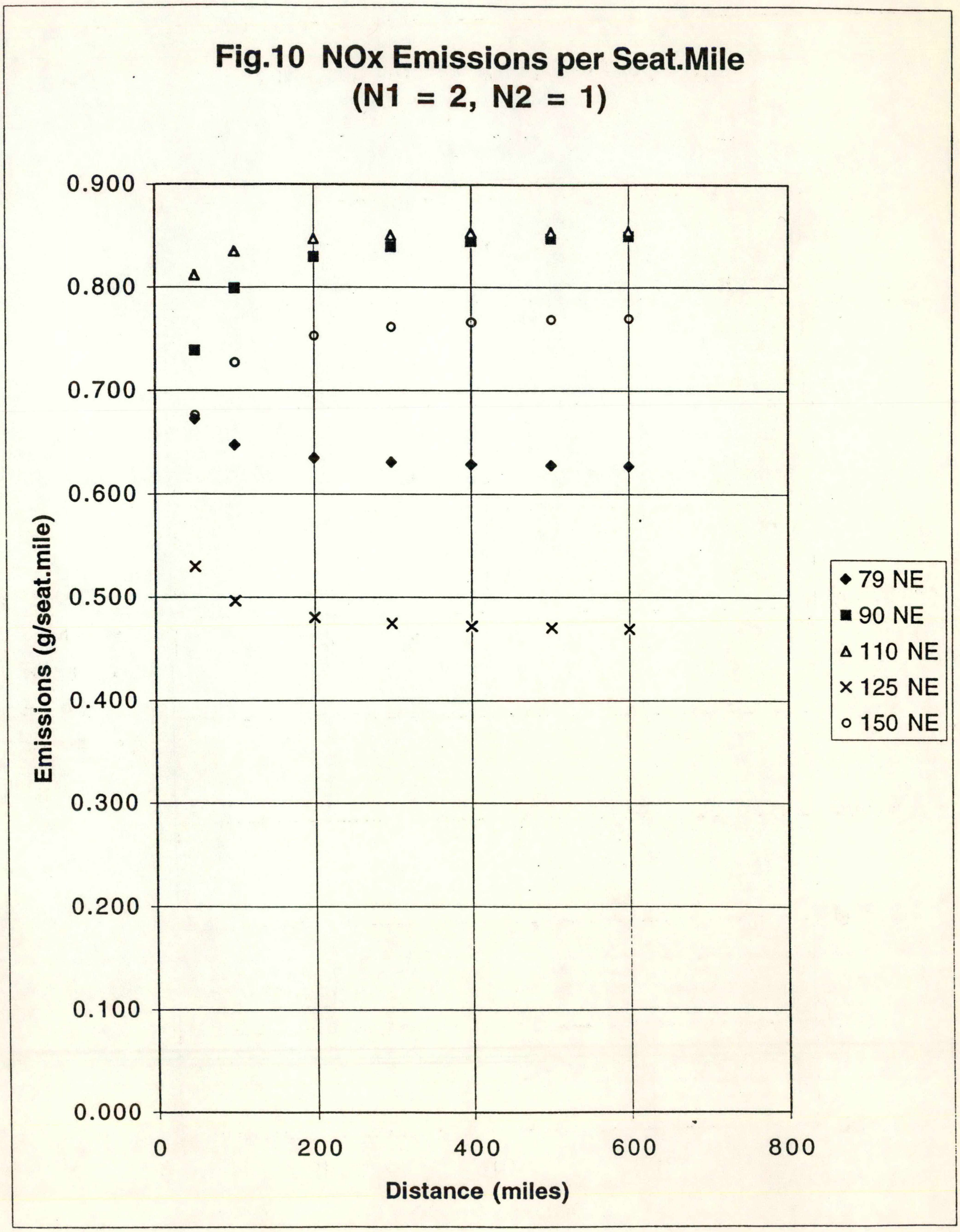


Fig.10 NOx Emissions per Seat.Mile
(N1 = 2, N2 = 1)
Emissions (g/seat.mile)
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0
200
400
600
800
Distance (miles)
79 NE
90 NE
110 NE
125 NE
150 NE

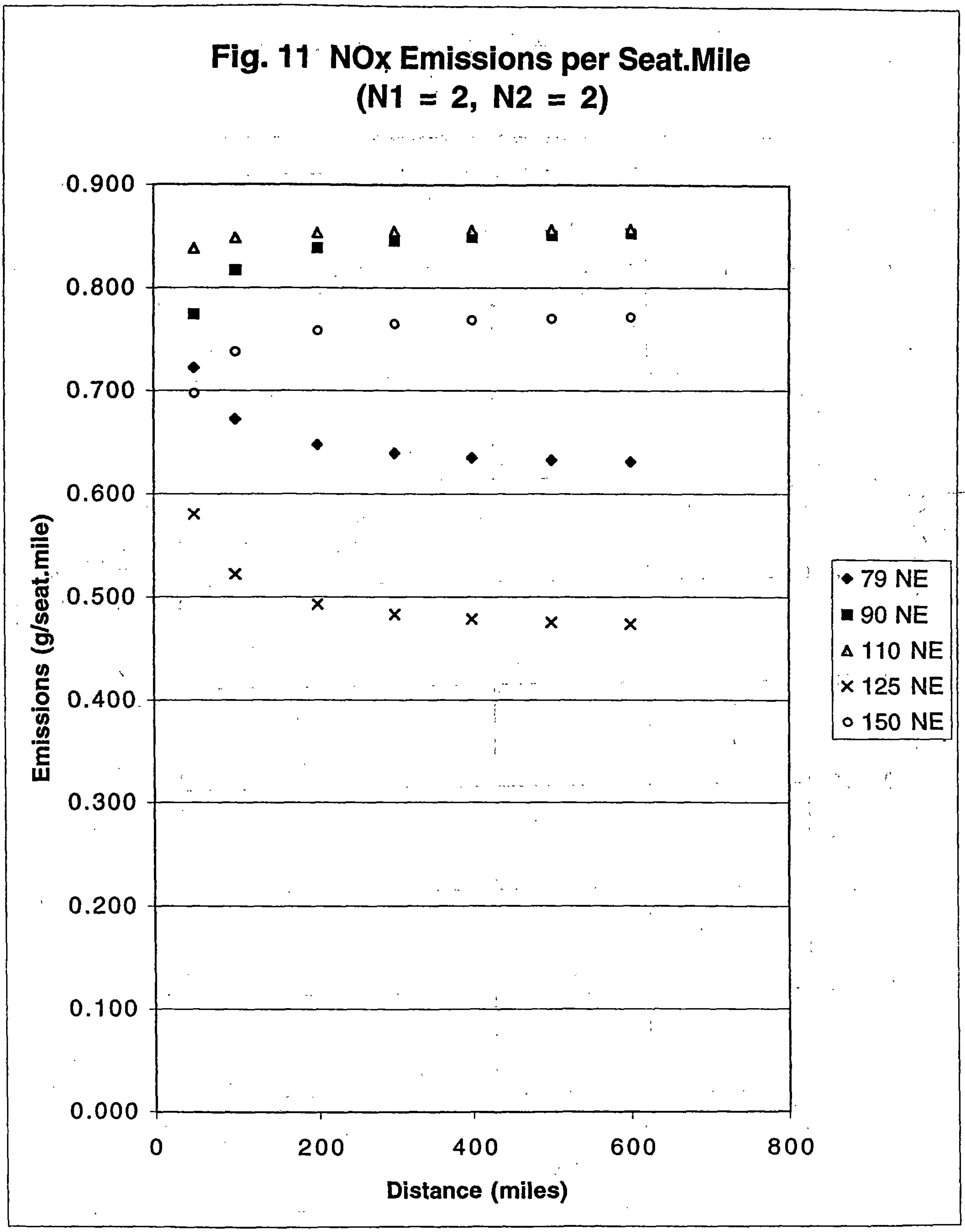


Fig. 11 NOx Emissions per Seat.Mile
(N1 = 2, N2 = 2)
Emissions (g/seat.mile)
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0
200
400
600
800
Distance (miles)
79 NE
90 NE
110 NE
125 NE
150 NE

Fig. 12 CO Emissions per Seat.Mile (N1 = 2, N2 = 1)

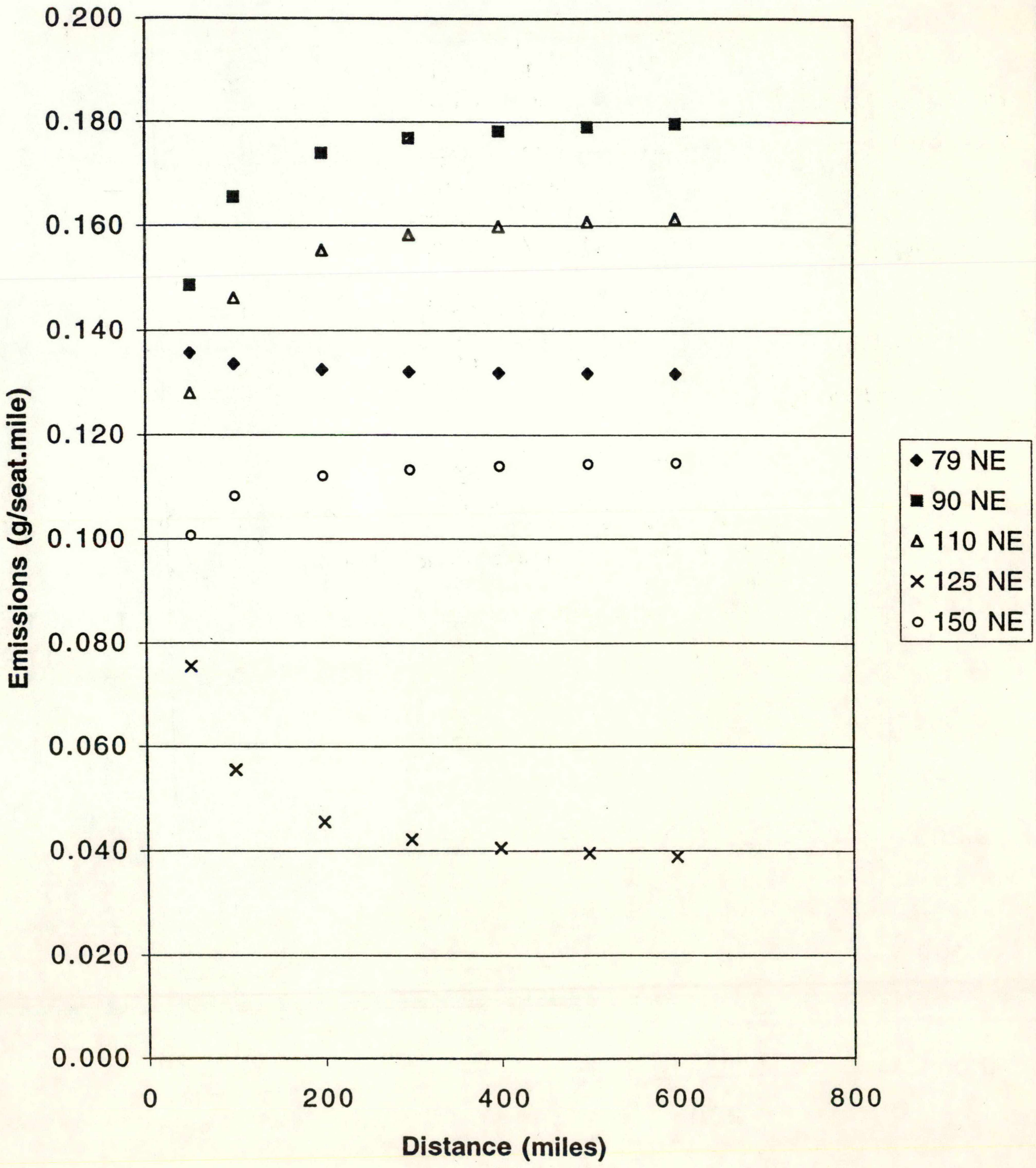


Table 20. Emission Coefficients For The Maglev 300 mph 16200 Hp Technology In Several EMM Regions For The Year 2010

EMM Region		Input Energy Coefficient		Emission Coefficient	PM (g)	NOX (g)	CO (g)	HC (g)	SO2 (g)	CO2 (10^5 g)
3	Emission Factor (g/MBtu)				22.0	92.2	8.72	1.02	140	0.535
		E_0 (Mbtu) =	-2.18	ε_0 (g) =	-48.0	-201	-19.0	-2.22	-305	-1.17
		E_1 (Mbtu) =	1.441	ε_1 (g) =	31.7	133	12.6	1.47	202	0.771
		E_2 (Mbtu) =	0.936	ε_2 (g) =	20.6	86.3	8.16	0.955	131	0.501
		E_3 (Mbtu/mi) =	0.267	ε_3 (g/mile) =	5.87	24.6	2.33	0.272	37.4	0.143
9	Emission Factor (g/MBtu)				25.1	112	18.1	2.06	143	0.657
		E_0 (Mbtu) =	-2.18	ε_0 (g) =	-54.7	-244	-39.5	-4.49	-312	-1.43
		E_1 (Mbtu) =	1.441	ε_1 (g) =	36.2	161	26.1	2.97	206	0.947
		E_2 (Mbtu) =	0.936	ε_2 (g) =	23.5	105	16.9	1.93	134	0.615
		E_3 (Mbtu/mi) =	0.267	ε_3 (g/mile) =	6.70	29.9	4.83	0.550	38.2	0.175
11	Emission Factor (g/MBtu)				12.2	63.1	12.8	0.942	77.6	0.354
		E_0 (Mbtu) =	-2.18	ε_0 (g) =	-26.6	-138	-27.9	-2.05	-169	-0.772
		E_1 (Mbtu) =	1.441	ε_1 (g) =	17.6	90.9	18.4	1.36	112	0.510
		E_2 (Mbtu) =	0.936	ε_2 (g) =	11.4	59.1	12.0	0.882	72.6	0.331
		E_3 (Mbtu/mi) =	0.267	ε_3 (g/mile) =	3.26	16.8	3.42	0.252	20.7	0.0945
13	Emission Factor (g/MBtu)				9.93	37.1	6.94	0.680	30.3	0.313
		E_0 (Mbtu) =	-2.18	ε_0 (g) =	-21.6	-80.9	-15.1	-1.48	-66.1	-0.682
		E_1 (Mbtu) =	1.441	ε_1 (g) =	14.3	53.5	10.0	0.980	43.7	0.451
		E_2 (Mbtu) =	0.936	ε_2 (g) =	9.29	34.7	6.50	0.636	28.4	0.293
		E_3 (Mbtu/mi) =	0.267	ε_3 (g/mile) =	2.65	9.91	1.85	0.182	8.09	0.0836

Note: The coefficients above are only for the hypothetical route parameters listed in Table 14

Fig. 13 NOx Emissions per Seat Mile for Maglev 300 (N1 = 2, N2 = 1)

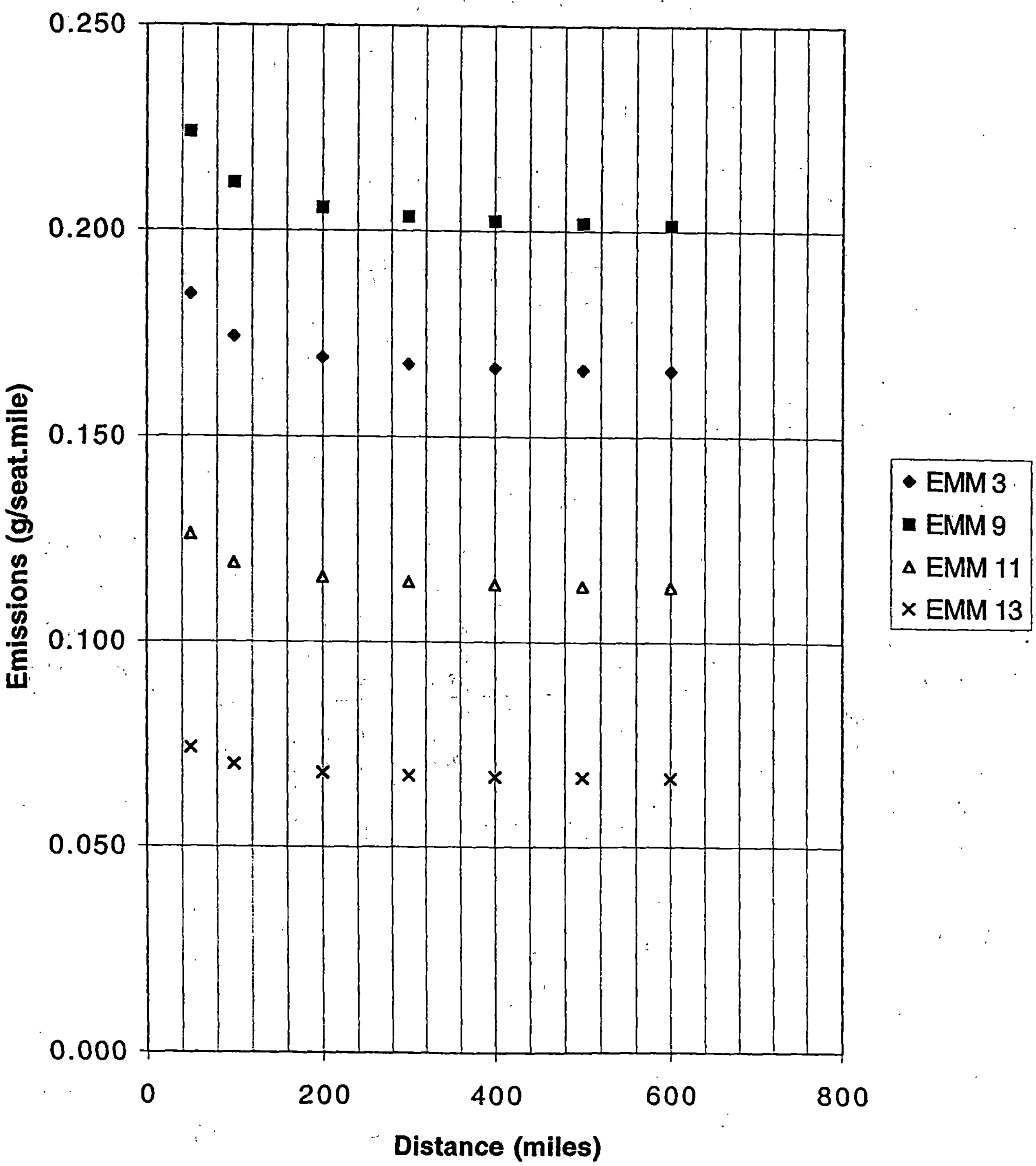
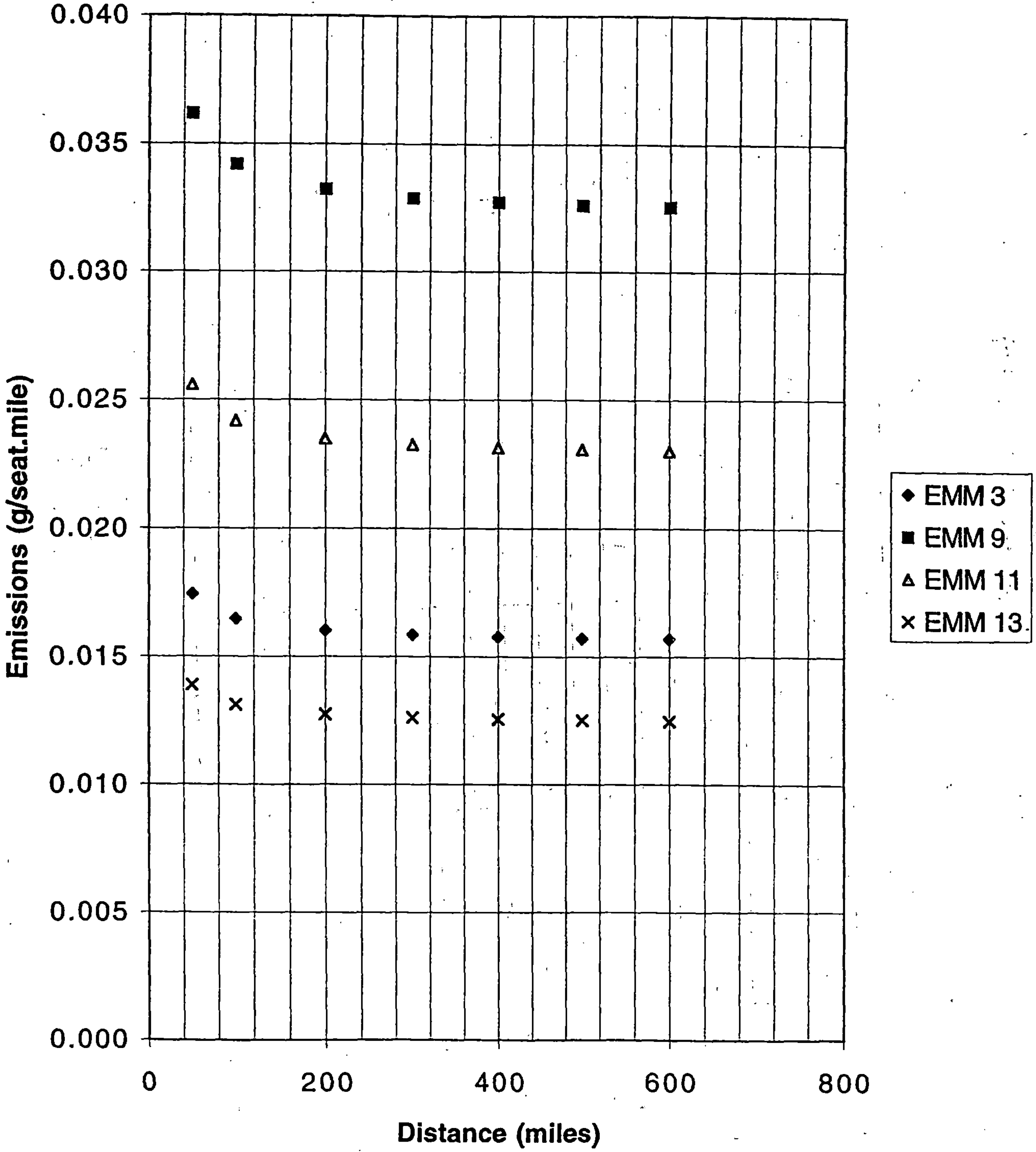


Fig. 14 CO Emissions per Seat.Mile for Maglev 300 (N1 = 2, N2 = 1)



3.8 Comparison of HSGT and Short-Haul Jet Aircraft Emissions

LTO-cycle and cruise emissions from aircraft operations are listed in Table 18. For comparison purposes, it is convenient to express these emissions in the form

$$\mathcal{E}(g) = \mathcal{E}_{LTO}\,(g) + \mathcal{E}_{cruise}\,(g/mile) * D\ (miles) \tag{47}$$

NOx and CO emissions per seat mile from the Maglev 300 technology operating in EMM Region 3 and short-haul jet aircraft are compared in Figs.15 and 16. The aircraft emissions are independent of region. CO2 (the major green-house gas) emissions are compared in Fig. 17 for the year 2010.

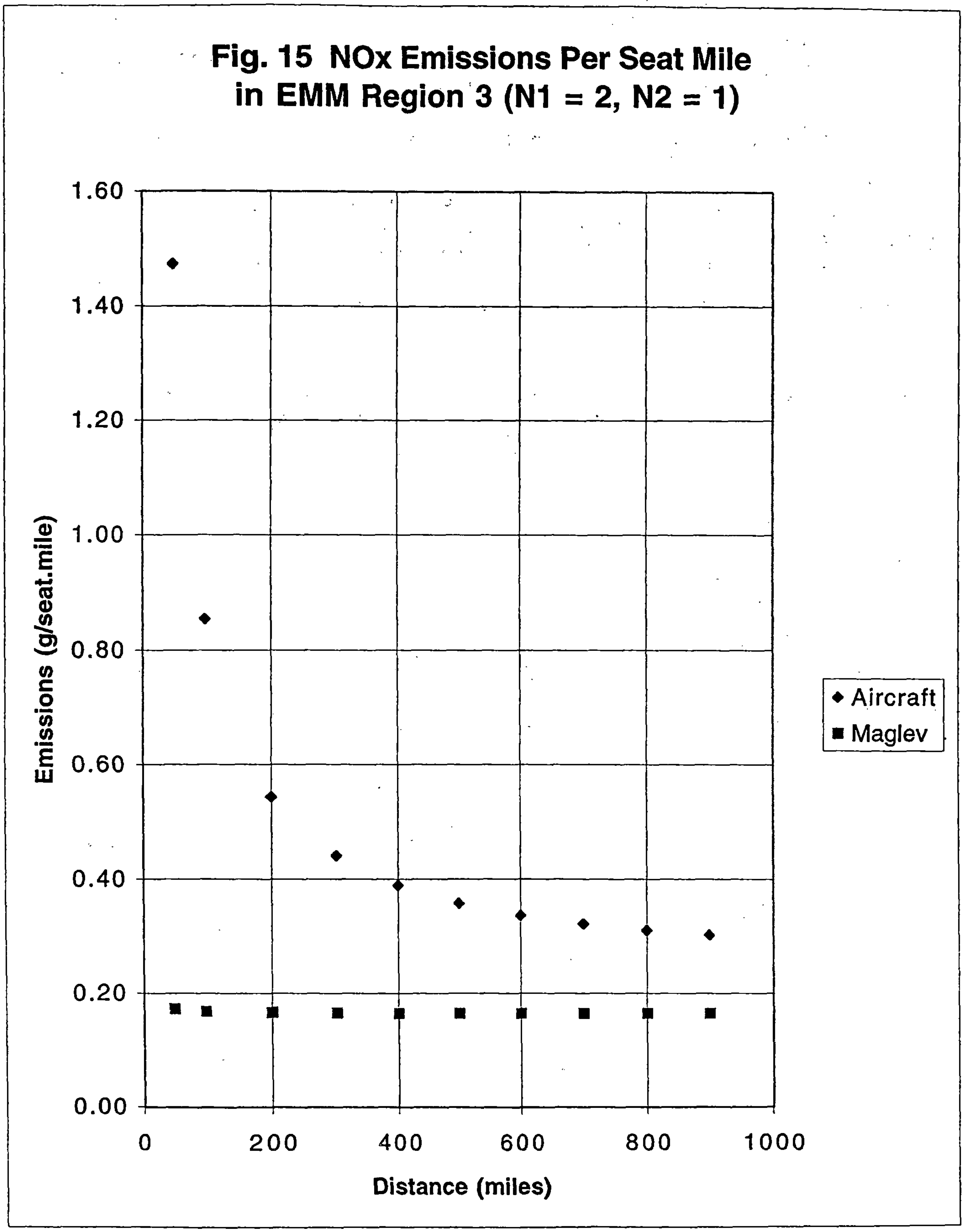


Fig. 15 NOx Emissions Per Seat Mile
in EMM Region 3 (N1 = 2, N2 = 1)
Emissions (g/seat.mile)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
200
400
600
800
1000
Distance (miles)
Aircraft
Maglev

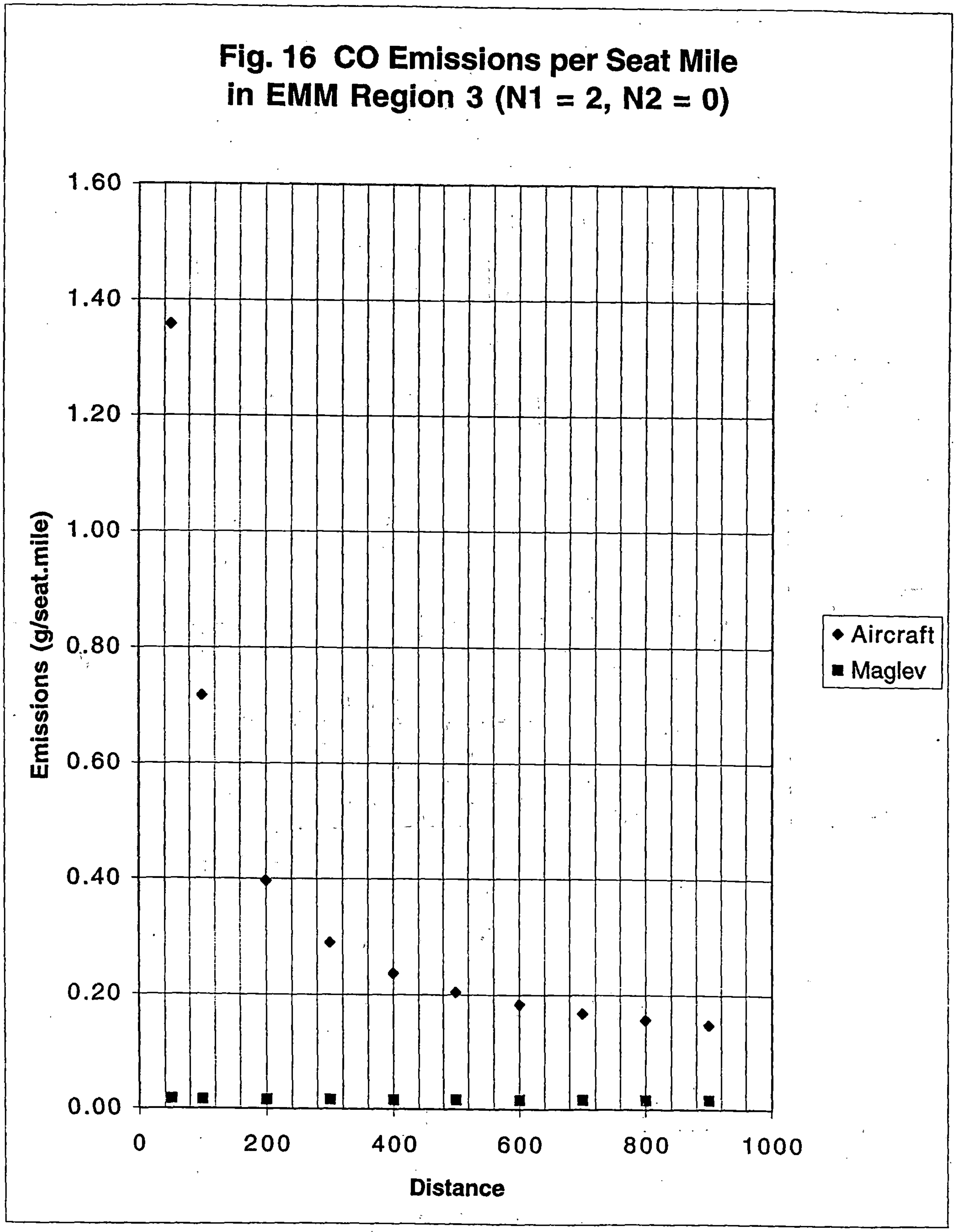
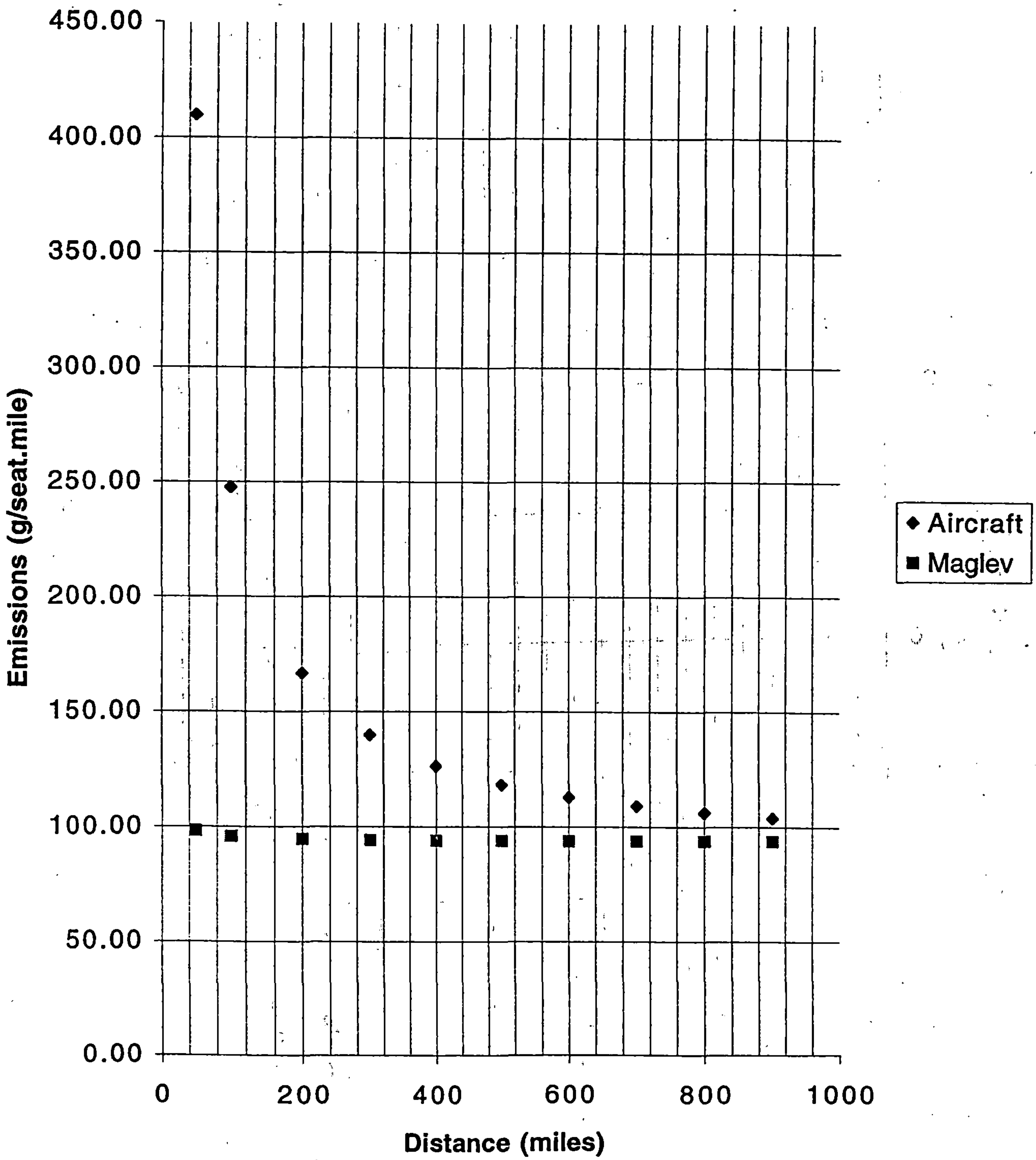


Fig. 16 CO Emissions per Seat Mile
in EMM Region 3 (N1 = 2, N2 = 0)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Emissions (g/seat.mile)
0
200
400
600
800
1000
Distance
Aircraft
Maglev

Fig. 17 CO2 Emissions per Seat Mile in EMM Region 3 (N1 = 2, N2 = 0)



REFERENCES

1. National Air Pollutant Emission Trends, 1900-1996, U.S. EPA report EPA-454/R-97-011, Dec. 1997.

2. National Air Quality and Emissions Trends Report, 1997, U.S. EPA report EPA 454/R-98-016, Dec. 1998.

3. CDIAC Communications, Carbon Dioxide Information Center, Oak Ridge National Laboratory, Issue No. 26, Summer 1999. Available on http://cdiac.esd.ornl.gov/

4. Personal Communication from Anant Vyas, to Donald M. Rote, both from Argonne National Laboratory, Sept. 1999.

5. High-Speed Ground Transportation For America, U.S. Department of Transportation, Federal Railroad Administration, Sept. 1997.

6. Personal Communication, memo from Michael Coltman to Ron Mauri, both from the Volpe National Transportation System Center, Feb. 17, 1995.

7. Personal Communication from Marijke Bekken, California Air Resources Board (CARB), to Donald M. Rote, Argonne National Laboratory, Exhibit 4-27, EMD and GE Locomotives for Which Emission Factors Are Available, and Locomotive Emission Factors, Sept. 16, 1994.

8. Personal Communication from David E. Brann, Electro-Motive Division of General Motors, to Donald M. Rote, Argonne National Laboratory, Sept. 25, 1994.

9. Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources, U.S. EPA Report No. EPA-450/4-81-026d(Revised), 1992. Chapters 5 and 6 address aircraft and locomotives, respectively.

10. Controlling Locomotive Emissions In California, submitted to the State of California Air Resources Board by Engine, Fuel, and Emissions Engineering, Inc., Sacramento, CA, Oct. 13. 1993.

11. Data from simulations performed by Frank Raposa at the Volpe Center and sent to Donald M. Rote at Argonne in Jan. 1995.

12. GREET 1.5 – Transportation Fuel-Cycle Model Vol. 1: Methodology, Development, Use, and Results; and Vol. 2: Appendices of Data and Results, ANL/ESD-39, Vol 1 & 2, M. Q. Wang, August, 1999.

13. Annual Energy Review 1997, U.S. Dept. of Energy, Energy Information Administration, Report No. DOE/EIA -0384(97), July 1998.

14. Methodology for Comparing Public Benefits of Diverting Passenger Trips from Conventional Modes to HSGT Modes of Travel, D. M. Rote, Z. Wang, and A.Vyas, Argonne National Laboratory Report, prepared for use with the FRA/DOT Commercial Feasibility Study, May 1, 1996, revised Dec. 10, 2001.

15. Annual Energy Outlook 1999, Energy Information Administration web site www.eia.doe.gov/oiaf/aeo99/homepage.html.

16. Supplement to the Annual Energy Outlook 1994, Energy Information Administration Report DOE/EIA-0554(94), March 1994.

17. TAG-Technical Assessment Guide, Vol. 1: Electricity Supply - 1986, Electric Power Research Institute, EPRI-P-4463-SR, Dec. 1986.

18. TAG-Technical Assessment Guide, Electricity Supply-1993, Electric Power Research Institute, EPRI TR-102276-V1R7, Vol. 1, Revision 7, June 1993.

19. Emission of Greenhouse Gases from the Use of Transportation Fuels and Electricity, (Vol 1 & Vol. 2: Appendexes A-S, prepared for Argonne National Laboratory by M.A. DeLucchi, ANL Report No. ANL/ESD/TM-22, Vol. 1 & Vol. 2, Nov. 1993.

20. Staying Close to the Market, GEC Alsthom News, No. 8, Nov. 1994.

21. United Technologies Turbo Power, advertisement, 1989 Edition, Vol. 54, Diesel and Gas Turbine Catalogue, pg. 546, 1989.

22. The World's Most Efficient Steam Turbine Cycle, GEC Alsthom News, No. 4, Summer, 1993.

23. Assumptions for the Annual Energy Outlook, 1993, Energy Information Administration, 1993.

24. Introduction to the Argonne Utility Simulation (ARGUS) Model, by T.D. Veselka, et al., ANL Report No. ANL/EAIS/TM-10, March 1990.

25. Procedures for Emission Inventory Preparation, Section 3.1 Stationary Gas Turbine for Electricity Generation; Section 3.2 Heavy Duty Natural Gas-Fired Pipeline Compressor Stations; Section 3.3

Gasoline and Diesel Industrial Engines; Section 3.4 Large Stationary Diesel and All Stationary Dual Fuel Engines, U.S. EPA, Oct., 1992.

26. High Speed Ground Transportation Noise and Vibration Impact Assessment, Final Draft, U.S. Department of Transportation, Federal Railroad Administration, Office of Railroad Development report prepared by Harris, Miller, Miller, and Hanson, Inc. Dec. 1998. Report can be downloaded from www.fra.dot.gov/s/regs/env/N&Vman.pdf

27. 1977 Census of Transportation: National Travel Survey - Travel During 1977, U.S. Department of Commerce, Bureau of the Census, Report TC77-N-2, Washington, D.C. Oct. 1979.

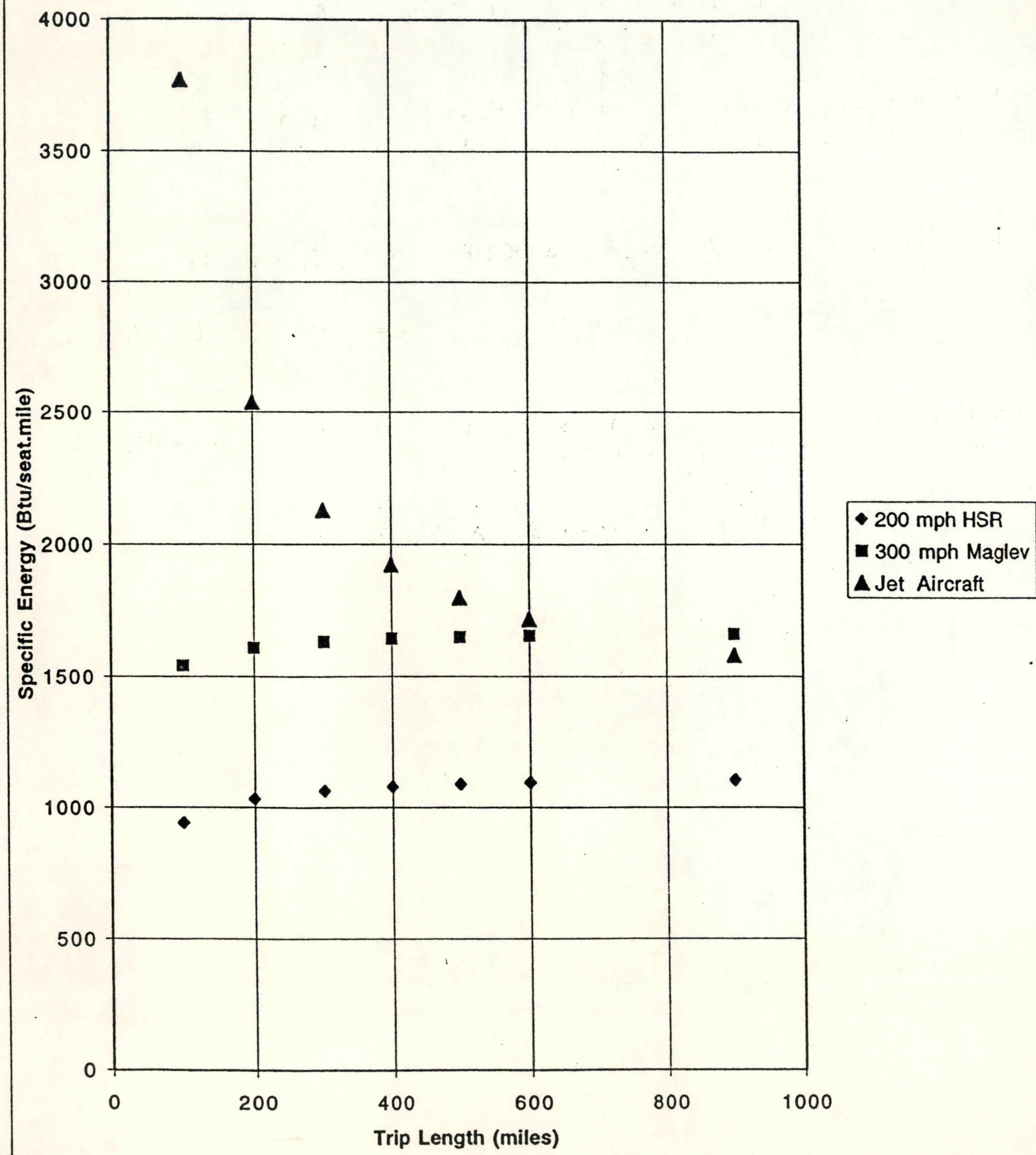
28. Final Report on The National Maglev Initiative, DOT/FRA/NMI-93/03, Sept. 1993.

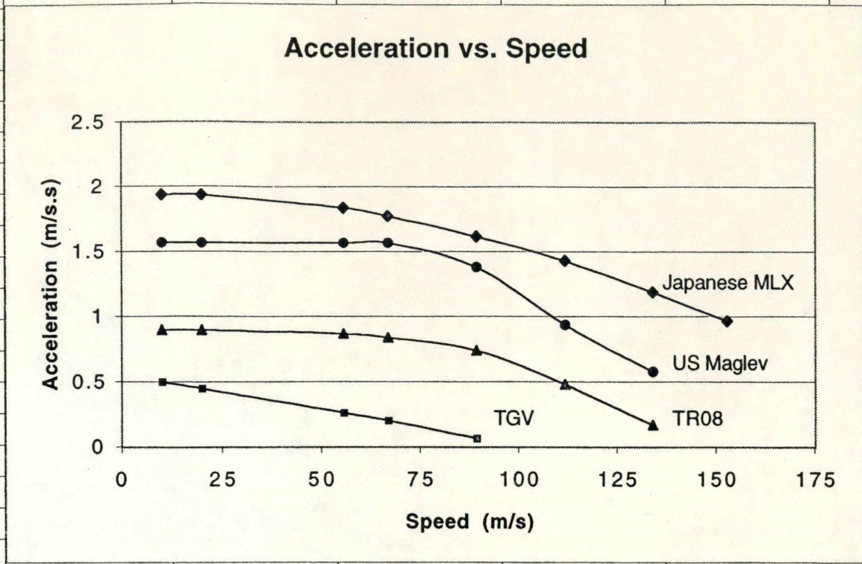
29. Maglev for the United States, prepared by the U.S. Army Engineer Division, Huntsville, Alabama, 1993.

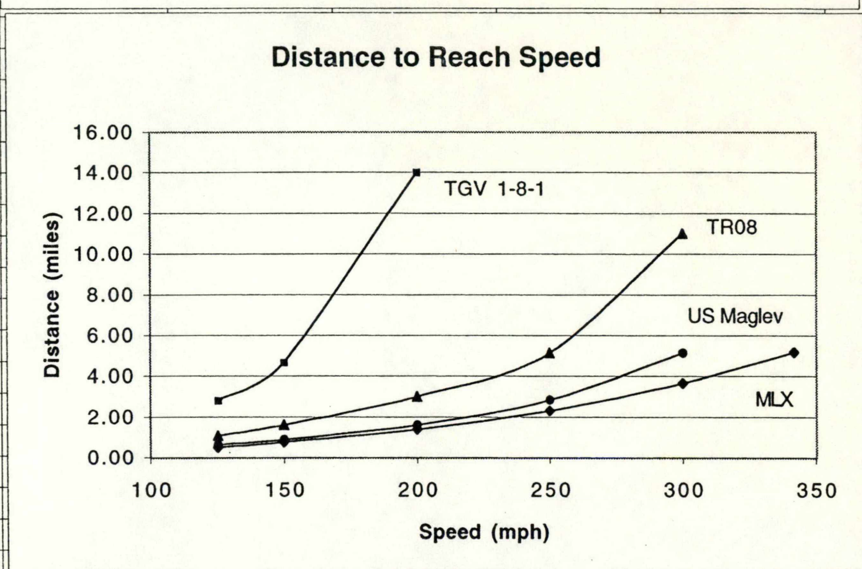
30. Technical Assessment of Maglev System Concepts, Final Report by the Government Maglev System Assessment Team, J. H. Lever, editor, Oct. 1998.

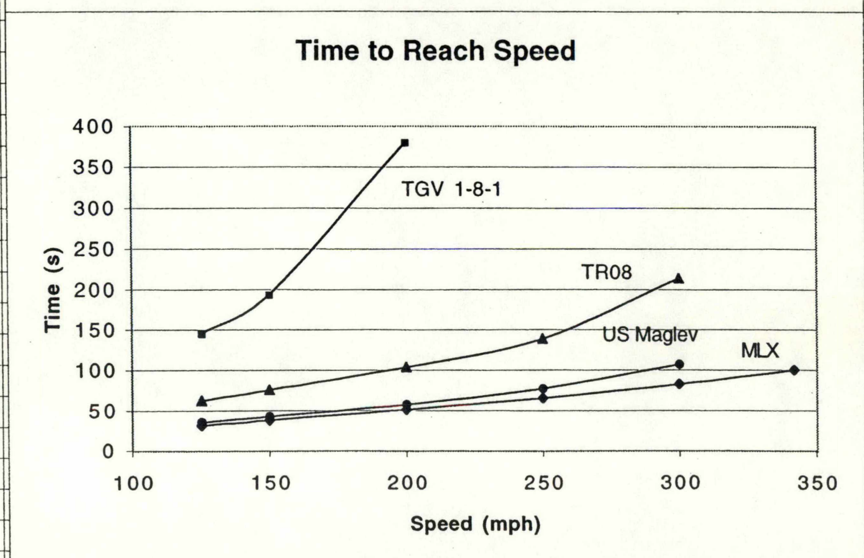
31. FAA Aviation Forecasts, Fiscal Years 1995-2006, FAA-APO-95-1, March 1995.

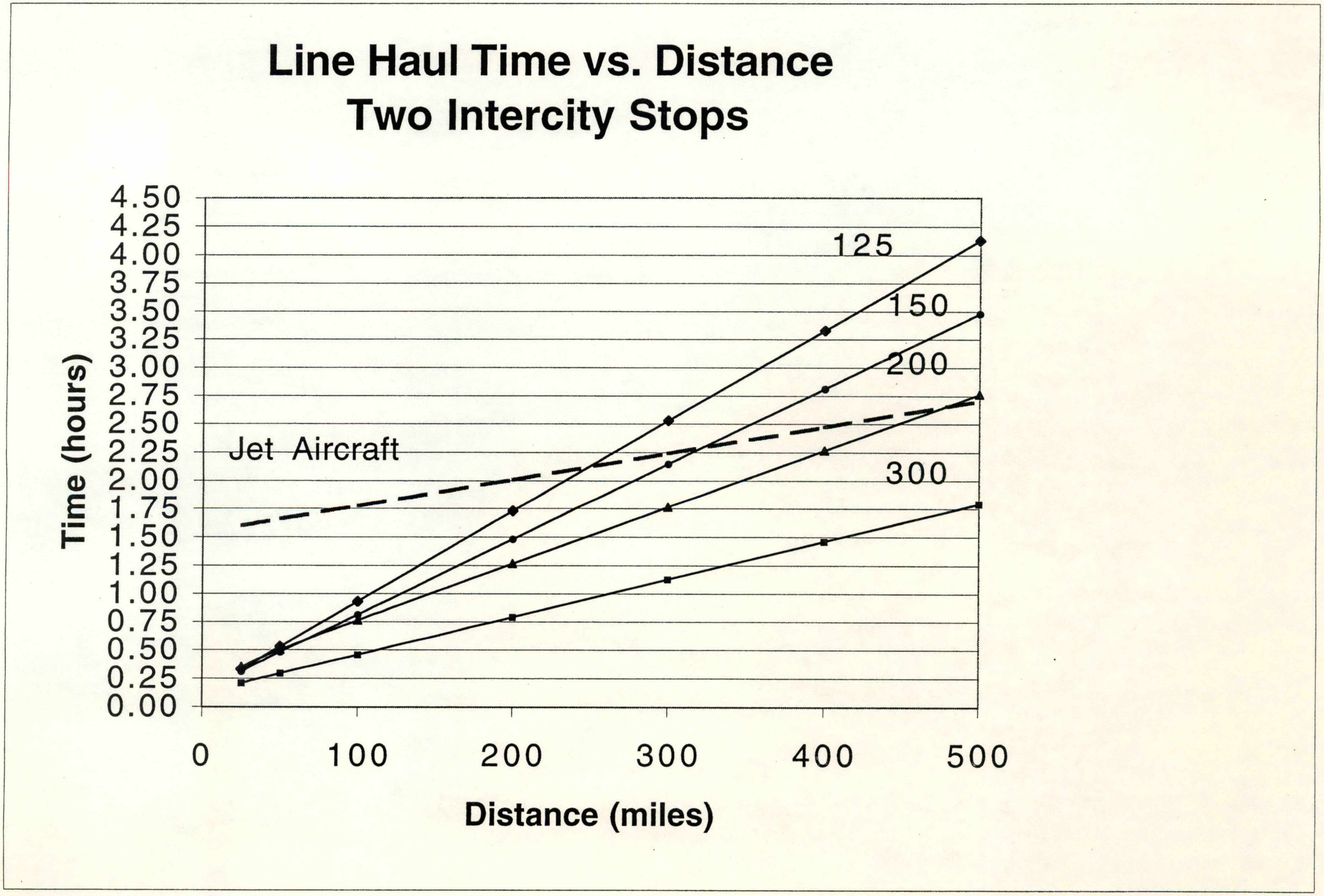
Fig. 7 Energy Per Seat.Mile of HSGT vs. Short-Haul Jet Aircraft (no stops)



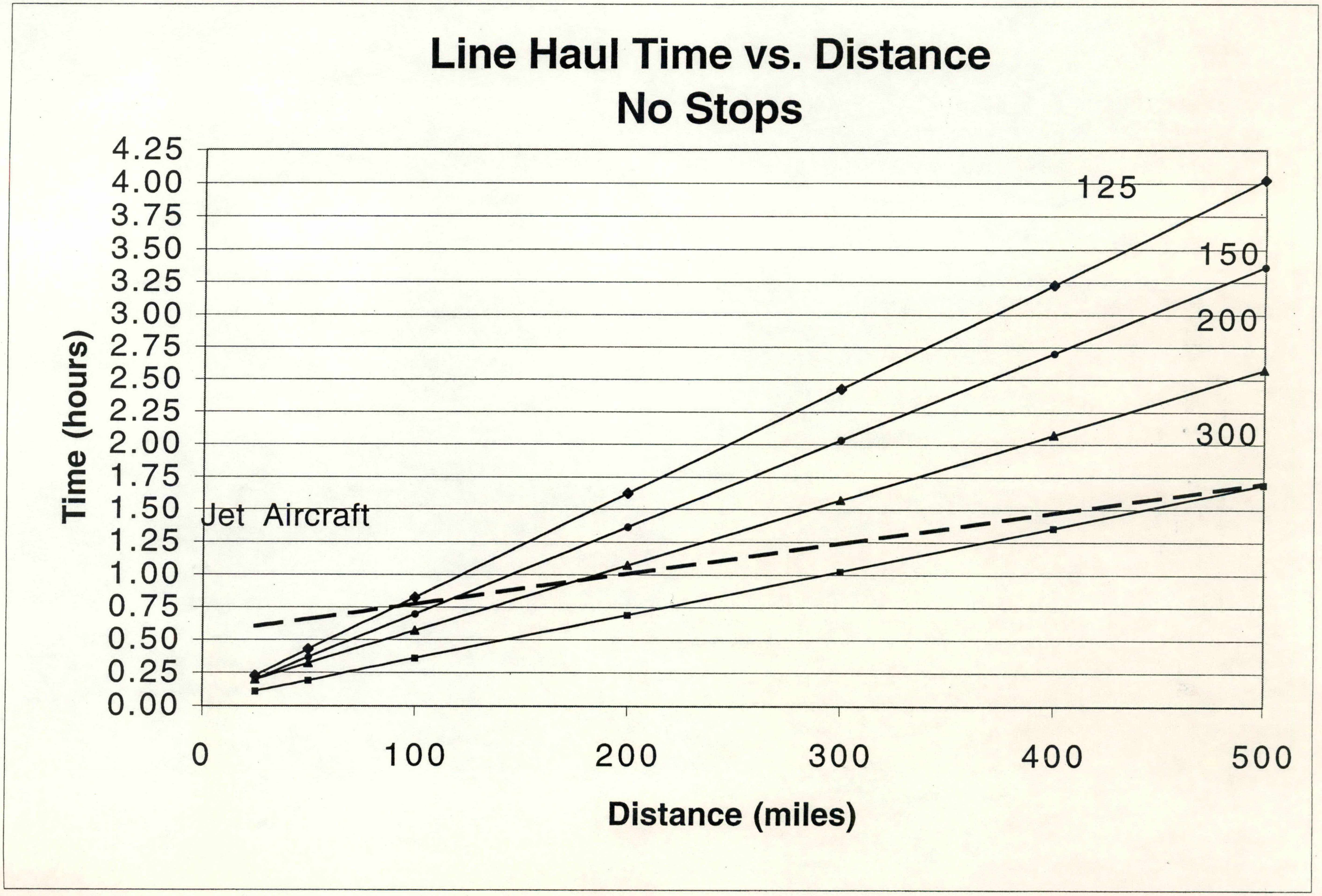

Acceleration vs. Speed
Acceleration (m/s.s)
2.5
2
1.5
1
0.5
0
0
25
50
75
100
125
150
175
Speed (m/s)
Japanese MLX
US Maglev
TGV
TR08


Distance to Reach Speed
Distance (miles)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
100
150
200
250
300
350
Speed (mph)
TGV 1-8-1
TR08
US Maglev
MLX


Time to Reach Speed
Time (s)
400
350
300
250
200
150
100
50
0
100
150
200
250
300
350
Speed (mph)
TGV 1-8-1
TR08
US Maglev
MLX



Line Haul Time vs. Distance
Two Intercity Stops
Time (hours)
4.50
4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
125
150
200
300
Jet Aircraft
0
100
200
300
400
500
Distance (miles)



Line Haul Time vs. Distance
No Stops
Time (hours)
4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
125
150
200
300
Jet Aircraft
0
100
200
300
400
500
Distance (miles)

PROPERTY OF FRA
RESEARCH & DEVELOPMENT
LIBRARY