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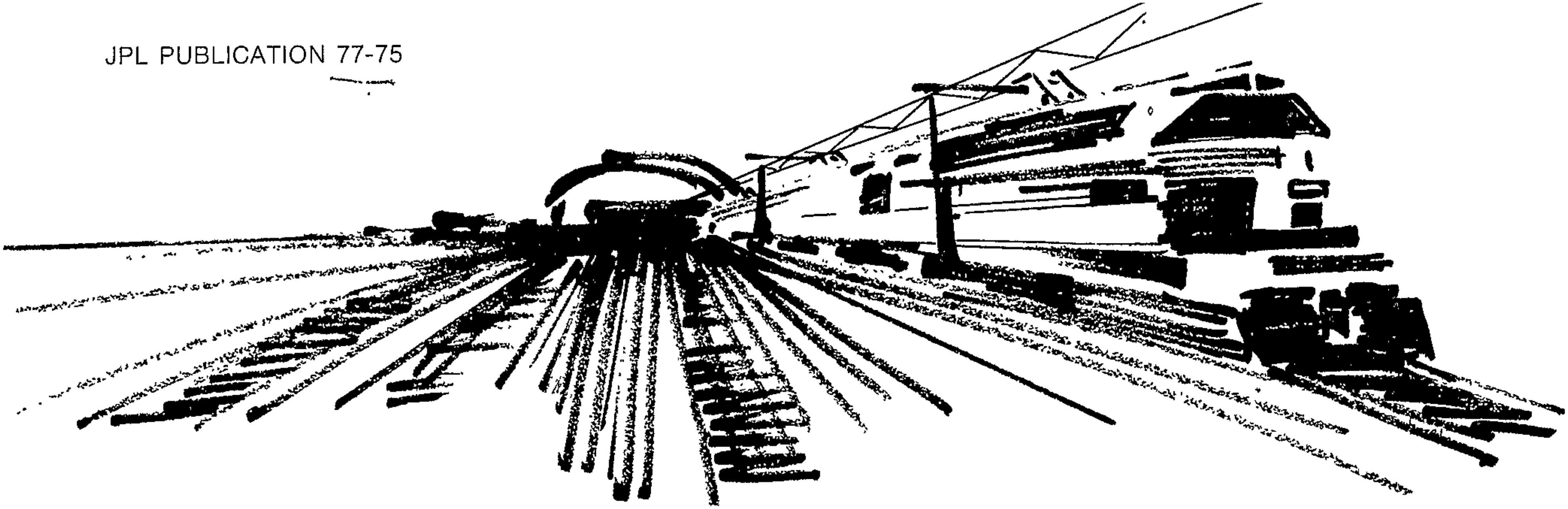

Parametric Studies of North East Corridor Rail Passenger Service

Between New York City and Washington, D.C.

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The Federal Railroad Administration
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Washington, D.C.

by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

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John A. Stallkamp

October 3, 1977

Prepared for

U.S. Department of Transportation
The Federal Railroad Administration
Office of Research and Development
Washington, D.C.

by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

Prepared by the Jet Propulsion Laboratory, California Institute of Technology, for the Department of Transportation, Federal Railroad Administration, Office of Research and Development, Reimbursable Agreement AR-30006, with the National Aeronautics and Space Administration.

PREFACE

The work described in this report was performed by the Power Systems Control and Energy Conversion Division of the Jet Propulsion Laboratory, under the cognizance of the Civil Systems Project.

ABSTRACT

A parametric study of high speed rail passenger service between New York City and Washington, D.C. is carried out. From published data a series of speed profiles is developed that progressively have fewer speed restrictions and increasing maximum speeds. The significant equipment characteristics include the portion of the total weight on driven axles, i.e., Multiple Unit (MU) cars versus locomotive hauled trains, and the short term tractive effort rating of the motors. The ratio of acceleration plus braking time to total time is provided for validation of the use of the short term propulsion equipment ratings. Absolute trip times are shown to be determined primarily by the allowed speed profile. Locomotive hauled train weights and lengths and the locomotive capabilities and characteristics that are required to make the performance of this type of train comparable to that of MU trains are given.

TABLE OF CONTENTS

INTRODUCTION

Rail passenger trains in Europe provide fast service utilizing lightweight electric locomotives with DC or single phase AC commutator motors. A recent European development is the application of three phase asychronous (induction) motors to electric locomotives. A potential improvement of overall performance is offered by several of its characteristics; viz., higher horsepower per unit weight and size, constant horsepower over full speed range and automatic wheel slip control by virtue of its steep speed-torque characteristic. The potential decrease in locomotive weight should significantly increase the maximum speed of locomotive hauled trains without adverse effect on track maintenance. This study addresses the potential impact of these technologies on a North American high speed-high density passenger line, the New York to Washington, D.C. portion of the Northeast Corridor (NEC). The areas of interest are trip time and specific energy consumption. This work is part of a larger task for FRA, Office of Research and Development whose overall purpose is to understand foreign technology and its potential application to the full spectrum of freight and passenger operations in this country.

EUROPEAN PRACTICE

- Lightweight electric locomotives with DC and single phase AC commutator motor drives are in use at present time.

- New generation of rugged, commutatorless, three phase AC asychronous (induction) motor driven locomotives and multiple unit cars are developed and coming into use.

STUDY OBJECTIVES

The present New York to Washington, D.C. premium service (Metroliner) schedule is three hours. The enabling legislation of 1976 for improvement of service in the NEC requires a schedule of 2 hrs. 40 min. by 1981 and also requires the completion by 1978 of feasibility studies for further reduction to 2 hrs. 30 min. No time for implementation of the 2 hrs. 30 min. schedule is given; the nature of future standard service, either schedule or time of implementation, is not defined. In the report the parametric relationships between the two major elements, equipment capability and realizable track speed profiles, are investigated with respect to attainable trip times. Specific energy consumption, kwh per ton at rail, is provided.

This study assumes that the catenary and power supply system can deliver the required power and is focused on equipment performance and track characteristics only.

NORTHEAST CORRIDOR SCHEDULE

NEW YORK CITY TO WASHINGTON, D.C.

Premium Service:

Present	3 hrs.	Metroliner Service
By 1981	2 hrs. 40 min.	
By 198?	2 hrs. 30 min.	

Standard Service:

Present	4 hrs.	Amfleet Coach Service
Future	? hrs.	

SIMULATION RESULTS

Simulation studies clearly indicate:

- Improving the condition of the track to permit higher speeds is the most important factor in reducing the trip time.

- Certain track improvements that remove or decrease the shorter length speed restrictions can concurrently reduce the specific energy requirement and trip time with no increase in maximum speed.

- Locomotive hauled trains can perform comparable to multiple unit cars (MU) provided the locomotive weight, i.e., the weight on the driven axles, is not less than 20% of the total train weight.

GENERAL CONCLUSIONS

The track speed profile is the predominant factor in determining the trip time and energy consumption; see graphs on pages 19 and 21.

The range of performance of locomotive hauled trains is comparable to that of MU cars; see above referenced graphs.

Each track improvement task should be evaluated considering trade-offs among trip time reduction, energy required and maximum speed.

STUDY APPROACH: ROUTE

The route characteristics and permitted speeds are paramount in determining time performance and energy performance.

The NEC passenger operations serve major cities and must necessarily pass through thoroughly built-up areas. Some station situations (Trenton and Wilmington) are almost ideal with few speed restrictions. Others, however, (Baltimore and Philadelphia) are burdened with tunnels, curves and competing traffic which require extended low speed operation. Elimination of all associated speed restrictions or major re-routing is presumed to be too costly or detrimental to the character of the service.

The existing route is not fully dedicated, engineered for continuous very high speed operation, nor is it a start-stop operation like urban rapid transit.

Some amount of fundamental upgrading and track realignment, in contrast with pure rehabilitation and maintenance, is believed to be necessary to attain time performance specified by legislation.

ROUTE CHARACTERISTICS

NEW YORK CITY TO WASHINGTON, D.C.

- 226 miles with five intermediate stops.
- Relatively flat grade.
- Near station speed restrictions caused by tunnels, curves and competing traffic.
- Between station speed restrictions caused by curves, bridges and trestles.

SELECTION OF SPEED PROFILES

The series of speed profiles selected for this study are characterized by a range of maximum speeds and the number and severity of speed restrictions.

Profiles B and G are input data from the listed sources; the other profiles have been derived from them as stated. Profiles C through F consist of incremental steps toward G that have been taken from the Task 11S report.

Complete mile post and speed listings are given in the appendix.

These profiles do not provide for delays associated with practical operational procedures. It is suggested that eight minutes be added to allow for track changes (diverts), slow orders and other speed restricting situations. Station dwell times of 75 sec. each for five stops are included.

SPEED PROFILES

PROFILE	MAX SPEED	
A	105	Profile B limited to 105 mph.
B	120	Best (fastest) profile with existing track configuration.[1]
C	120	Profile B with minor upgrade, superelevate curves, no realignment.
D	120	Profile C with major upgrades, Elizabeth curve realigned and super-elevated, Susquehana bridge upgrade, for example.
E	135	Profile D with additional superelevation and realignment.
F	135	Profile G limited to 135 mph.
G	150	Task 11S profile.[2]

(1) Original 1970 profile, derived from Bechtel report July 1976, "Calculated Performance of the Metroliner and of the Locomotive Hauled Amfleet Consists" - New York to Washington, D.C., with minor adjustments.

(2) Task 11S, Volume II, July 1975, Improvement Plan for Physical Plant with Estimated Costs, prepared for DOT/FRA Office of Northeast Corridor Development.

STUDY APPROACH: EQUIPMENT

Equipment parameters are varied between expanded limits that are beyond practical ones, e.g., ideal cases, and ones that would not be used because of poor performance.

Percent locomotive weight with its adhesion limit implications and traction motor characteristics are the dominant parameters. These are discussed in more detail in the next pages.

Aerodynamic load is increasingly important as the maximum speed is increased. This load is most important in determining the short term versus continuous motor rating that is then applied to the acceleration-deceleration times versus the constant speed time. This is discussed on page 31 in the appendix.

The constant and velocity dependent loads are taken from the classic Davis equation.

A fixed braking schedule was used.

EQUIPMENT PARAMETERS

- Percent locomotive weight

  = 100 X weight on driven axles/total train weight

- Traction motor capabilities
- Aerodynamic loads
- Constant and velocity dependent friction loads
- Braking capabilities

ADHESION

M.U. cars operating at 1 mphps acceleration require an adhesion factor of .045 (at .65 mphps it is about .029).

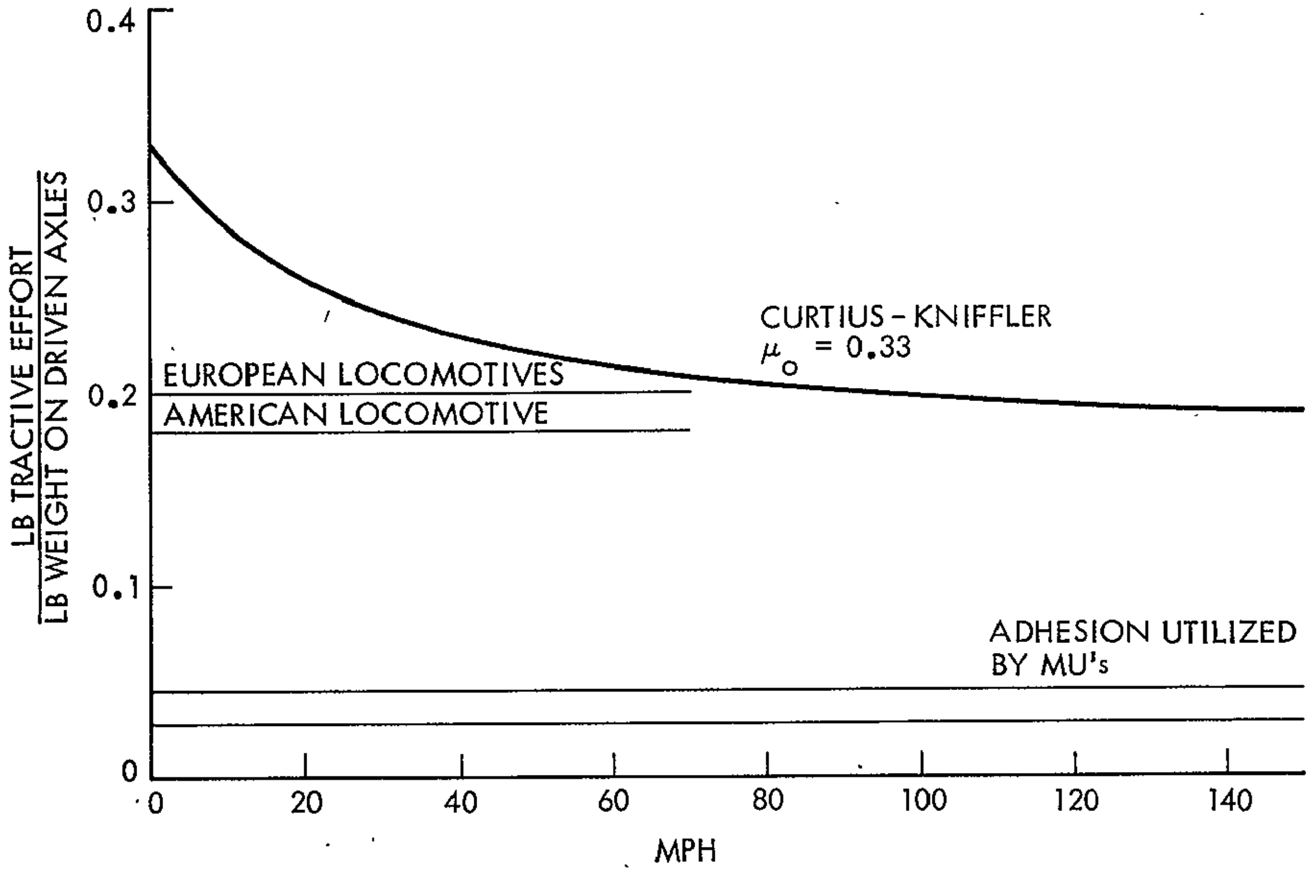
American practice for diesel locomotives and DC motors, utilizes adhesion factors in the range of .18 to .2.

European practice, particularly in electrified service, utilizes adhesion factors above .2 at low speeds.

The Curtius-Kniffler curve is an experimentally determined adhesion limit in wide use in Germany. It is used in this study as an upper bound for adhesion.

From the Curtius-Kniffler curve, a locomotive hauled train with a 20 percent locomotive weight can be accelerated at greater than 1 mphps up to a speed of about 45 mph.

For operation near adhesion limits, wheelslip must be carefully controlled. The three phase asychronous motor is reported to provide automatic wheelslip control by virtue of its steep torque-speed curve.


0.4
0.3
0.2
0.1
0
LB TRACTIVE EFFORT
LB WEIGHT ON DRIVEN AXLES
CURTIUS - KNIFFLER
$\mu_o = 0.33$
EUROPEAN LOCOMOTIVES
AMERICAN LOCOMOTIVE
ADHESION UTILIZED
BY MU's
0
20
40
60
80
100
120
140
MPH

TRACTION MOTOR CHARACTERISTICS

Idealized tractive effort (TE) curves are given on the facing page.

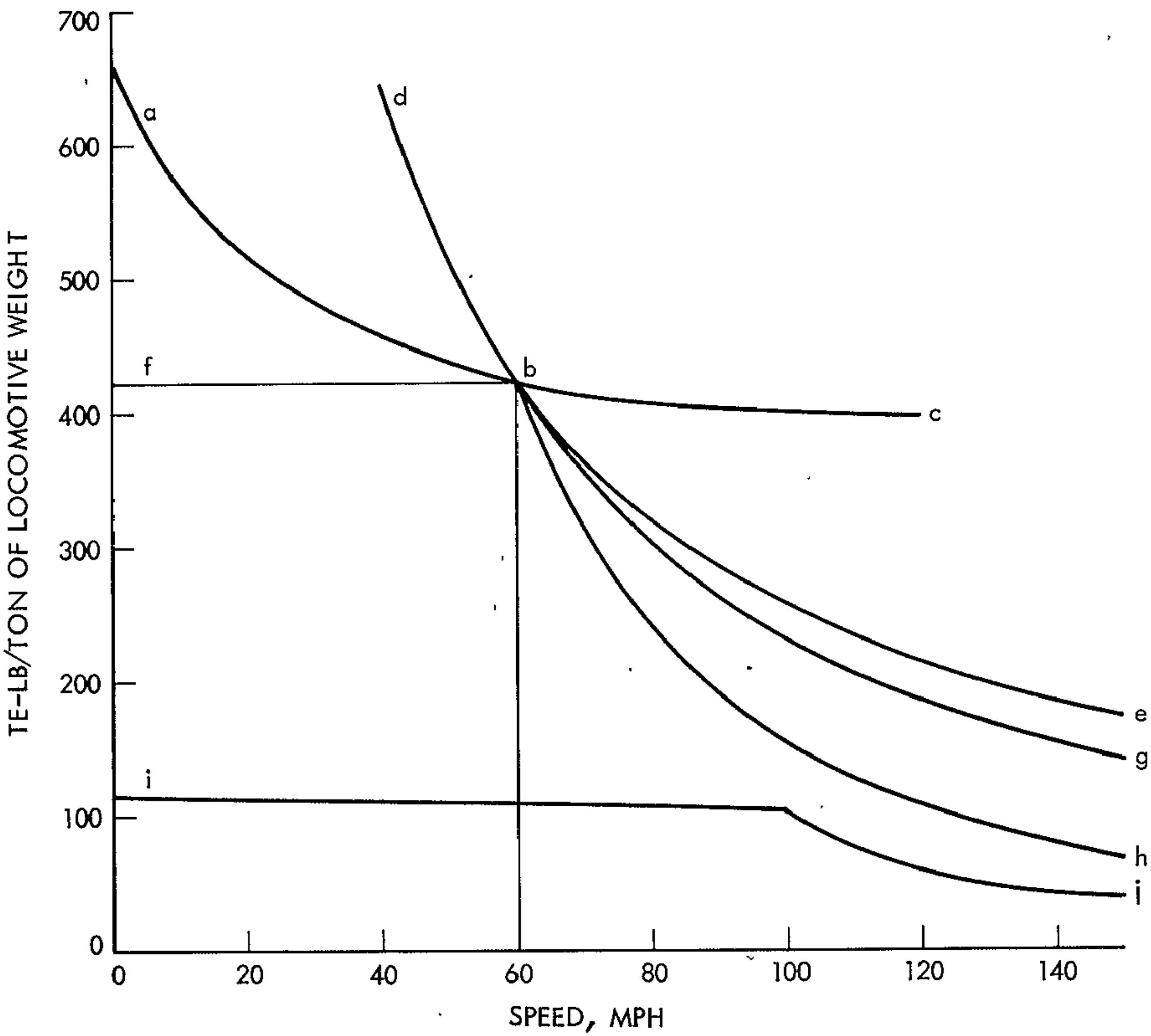
The curve abc is the Curtius-Kniffler adhesion limited TE curve. All conventional wheel driven trains must operate below this line.

A power limited speed of 60 mph has been selected, point b. This will be shown to be an appropriate value for NEC operations. The TE at point b is 428 lb/ton and represents a power level of 68.5 HP/ton. A 100 ton locomotive with four motors would require a 1700 HP/motor; this is comparable to the short time ratings of the ASEA RC-4 motor and the continuous rating of the Brown-Boveri three phase AC motor. The constant horsepower curve is dbe.

The continuous rated three phase AC motor would operate along a path between lines ab and fb at low speed and then along line be at high speed. The DC motor (and single phase AC motor) would operate along line fb at low speed and then along a path between lines bg and bh depending on its overload characteristics. It is assumed that the DC motor at low speed is operated beyond its continuous rating in order to get higher horsepower per pound of motor weight. Consequently, the fall off of torque with speed is not 1/V as would be the case for a continuous rating. Lines bg and bh show the tractive effort falling off proportional to $1/V^{1.2}$ and $1/V^2$, respectively.

Curve ij is the tractive effort for the Improved Metroliner (MU cars) with 1 mphps acceleration at 100 mph. All axles are driven for the Metroliners, i.e., they are 100% locomotive trains. In order to make comparison of specific tractive effort between Metroliners and conventional locomotive hauled trains it is necessary to select a percent locomotive weight for the latter. For example, for a 25% locomotive train, raise the ij curve by a factor of 100%/25% = 4, then divide the vertical scale by the same factor and interpret the resulting value as lb/ton of total train weight.

TRACTIVE EFFORT (TE)



DISCUSSION

Step A: A train weight of 540 tons with a drag coefficient of 1.5 and high performance braking (2 mphps from 70 mph) was used. This approximates a six car train. Longer trains or better streamlining would result in better absolute energy performance but would not significantly change relative performance for the parameters that were varied.

The appropriate power limited speed was determined to be 60 mph when further increases produced little change in trip time (this might be increased to 75 mph for the G profile with its 150 mph maximum speed). Percent locomotive weights below 20% give increasingly significant performance penalties. Above the 30% level, the train is really MU with trailer cars and ultimately completely MU (100% locomotive weight). The range of 20% to 30% seemed appropriate for study.

Step B: Three torque-speed relationships are assumed. All have constant torque up to power limited speed (60 mph). Above 60 mph, the torque falls off according to either $1/V$, $1/V^{1.2}$ and $1/V^2$.

Case I	-	Characteristic of the three phase asychronous motor or an idealized DC motor run at its continuous rated output (constant power case).
Case II $\frac{1}{V^{1.2}}$	-	Characteristic of a moderately overloaded DC motor with a HP ratio (short term peak/continuous) of 1.32. Similar to ASEA RC-4 short term ratings.
Case III $\frac{1}{V^2}$	-	Characteristic of a heavily overloaded motor (HP ratio of 2.0). Similar to GE E60 CP short term ratings.

Case I, of course, yields the best time performance. Case II was acceptable, i.e., trip time was only slightly increased. Case III, however, significantly increased the trip times primarily because it was power limited and could not reach the higher speeds required by the faster profiles. The precise allowable operational envelope for the DC motor is, thus, of prime importance. It can be varied within limits by tradeoff in the motor design and by the auxiliary apparatus provided such as forced air cooling. The continuous rating of the three phase motors at relatively high output per pound and volume would seem to make them particularly attractive.

Tabular data for cases of Step B are given on page 47 in the appendix.

METHODOLOGY LEADING TO GENERAL CONCLUSION

A. Examine performance of a representative consist which is adhesion limited at low speed and power limited at high speed.

Fixed parameters: total train weight, friction loads, braking

Variable parameters: percent locomotive weight and speed at which power limitation is reached

Output: specific power and time and energy performance

B. From Step A, select appropriate power limited speed(s) and range of percent locomotive weights. Examine time and energy performance for several torque versus speed characteristics.

Fixed parameters: total train weight, friction loads, brakings

Limited variation parameters: power limited speed, percent locomotive weight

Variable parameters: torque-speed characteristics and reduced power levels

Output: time and energy performance, speed restrictions from torque-speed characteristics

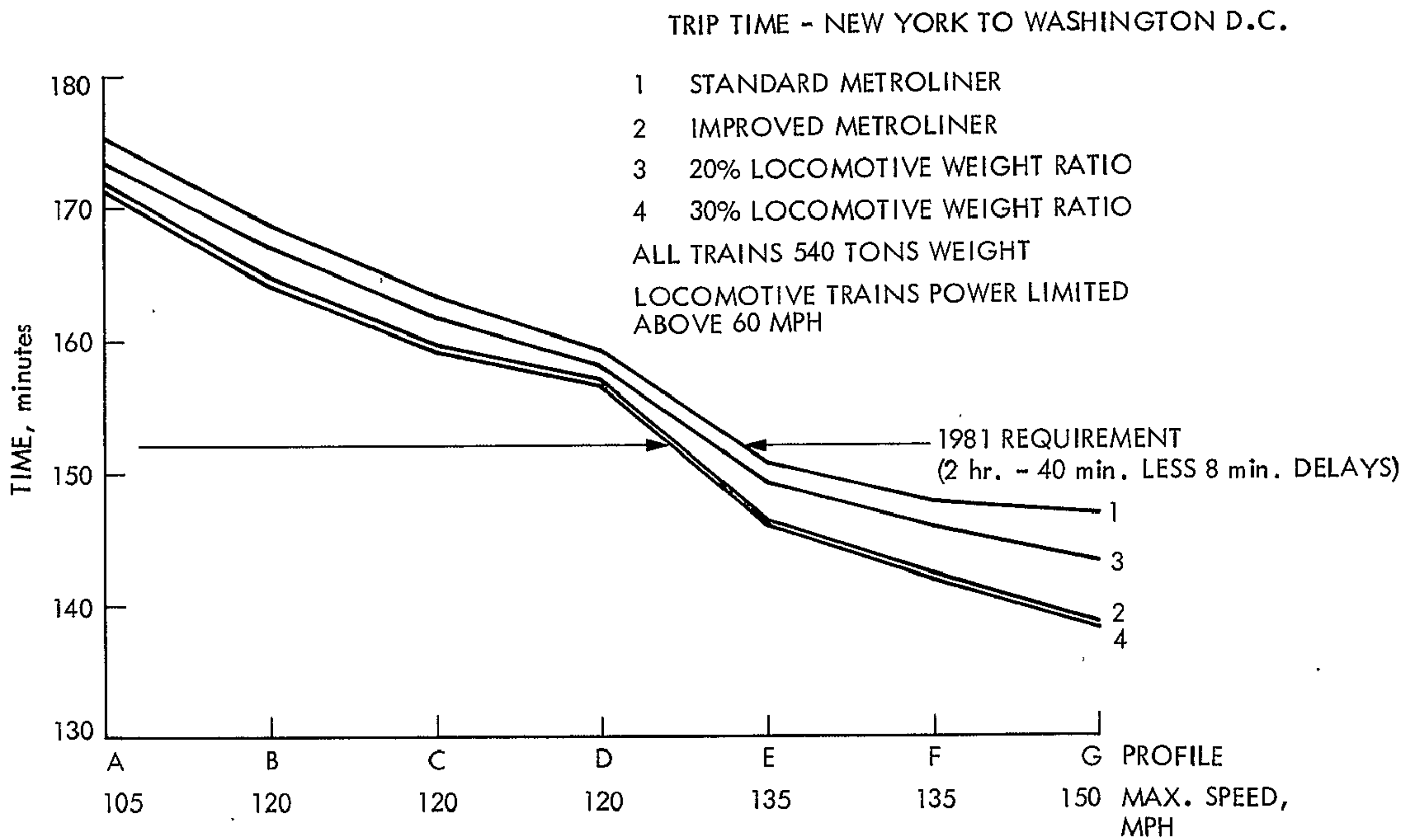
TRIP TIME

The facing graph gives the trip times for four train consists, two MU trains and two locomotive hauled trains. Total weights and aerodynamic constants are the same; they correspond to a typical six car train for the MU's. For actual locomotive hauled trains the consist would be somewhat different; some examples are given on page 25.

The MU trains are representative of the standard and improved Metroliners.

The locomotive hauled trains are synthesized for comparison purposes, they are adhesion limited below 60 mph and have constant power above 60 mph.

The profiles with their maximum speeds are those selected for this study. It is to be noted that as the track conditions are improved, A to G, the time performance for all consists improved in very nearly the same way. The failure of consists 1 and 3 to improve going from F to G is because they are power limited; the aerodynamic loads do not permit 150 mph speeds under continuous motor rating assumptions. See data on page 20. Also see appendix, page 48, for tractive effort tabulations and additional comments on 150 mph maximum speeds.


TRIP TIME - NEW YORK TO WASHINGTON D.C.
1 STANDARD METROLINER
2 IMPROVED METROLINER
3 20% LOCOMOTIVE WEIGHT RATIO
4 30% LOCOMOTIVE WEIGHT RATIO
ALL TRAINS 540 TONS WEIGHT
LOCOMOTIVE TRAINS POWER LIMITED ABOVE 60 MPH
1981 REQUIREMENT
(2 hr. - 40 min. LESS 8 min. DELAYS)
TIME, minutes
180
170
160
150
140
130
1
3
2
4
A B C D E F G PROFILE
105 120 120 120 135 135 150 MAX. SPEED, MPH

SPECIFIC ENERGY

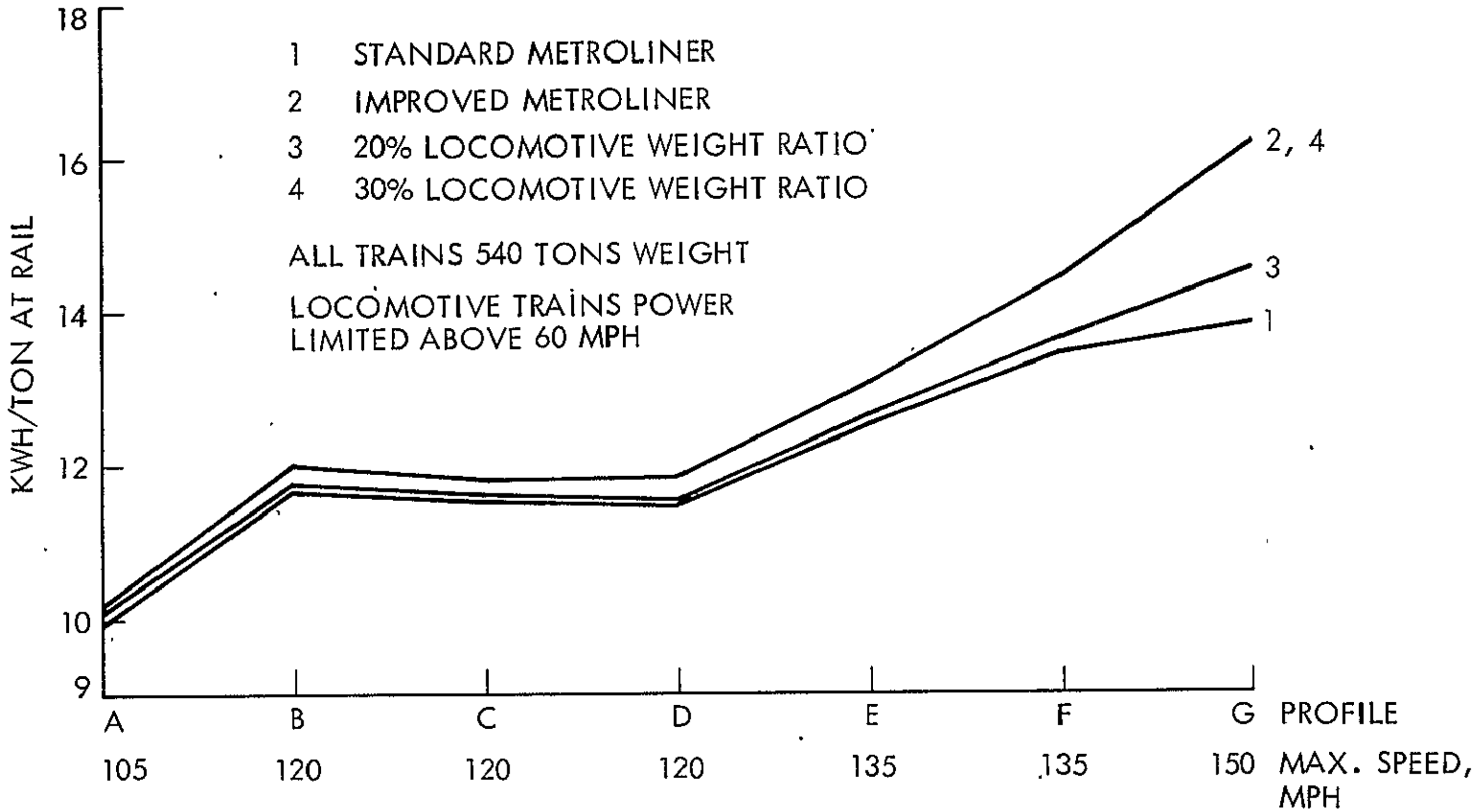
The facing graph gives the energy consumed for the trips of the preceeding trip time graph. This is energy transferred at the rail interface. It does not include any auxiliary energy such as traction motor blowers or the energy losses associated with the power conditioning equipment or motor efficiency.

Curves 2 and 4 are indistinguishable on the scale plotted. The corresponding trip times from the preceeding graph are also extremely close. The departure of curves 1 and 3 are again caused by the speed limitation of these consists.

Data on acceleration, constant speed running, and braking times and tractive effort available and total friction losses versus speed are given below for selected profiles. In carrying out the computer simulation runs these latter data were produced first so that equipment speed limits could be imposed when the tractive effort required for friction losses began to approach about 80% of the available force. Even this percentage may be on the high side if the distinction between short term ratings and continuous rating is to be valid.

Consist	Standard Metro			Improved Metro			30% Locomotive			20% Locomotive		
Profile	B	E	G	B	E	G	B	E	G	B	E	G
Acceleration Time Minutes	44	48	60	25	26	47	26	27	45	43	44	68
Braking Time Minutes	12	11	13	13	12	18	13	12	18	12	11	15
Constant Speed Time Minutes	106	85	68	121	102	67	119	101	69	106	87	54
Total Time Minutes Incl. Station Stops	169	151	147	165	146	139	164	146	138	167	149	143
Maximum Speed mph	120	135	140	120	135	150	120	135	150	120	135	150
Tractive Effort at Maximum Speed lb	22k	17k	16k	37k	29k	22k	35k	31k	28k	23k	20k	18k
Drag at Max. Speed lb	10k	12k	13k	11k	13k	15k	11k	13k	15k	11k	13k	15k

SPECIFIC ENERGY - NEW YORK TO WASHINGTON



HARDWARE IMPLEMENTATION OF THE PARAMETRIC STUDY

To this point, investigations and conclusions for locomotive hauled trains have been relative to generalized consists defined parametrically by specific quantities. Here, several consists based on existing and alternative NEC equipment are evaluated.

The Metroliner and Amfleet Coach are nearly identical as far as passenger service capabilities are concerned (seats, etc.).

Existing American Practice:

Metroliners - high powered - self contained, multiple unit cars:
90 tons; 85 ft; B-B trucks.
Premium passenger service between NYC and Washington, D.C.

Amfleet Coaches - light weight - require auxiliary power:
60 tons; 85 ft; B-B trucks.
General use all over US and in locomotive hauled trains in NEC.

American electric locomotives - E60CP (example) heavy weight:
180 tons; 63 ft; C-C trucks.
Weight causes additional speed restrictions in NEC.

Alternative:

Amfleet coaches hauled by light weight electric locomotive typical of European practice but with auxiliary (hotel) power capability and meeting American structural requirements.

Lightweight locomotive
Weight 100 tons, B-B trucks, 25 tons/axle
Same speed restrictions as Metroliners

Tabular data for several locomotive hauled consists and MU car performance are given on pages 24 and 25. No cases were run using heavy weight locomotives because severe speed restrictions apply and performance is not acceptable.

U.S. EQUIPMENT CHARACTERISTICS

(Present Practice and Alternative Approach)

Existing American Practice:

Metroliners - high powered, multiple unit cars

Amfleet Coaches hauled by American electric locomotives

Alternative:

Amfleet Coaches hauled by European type electric locomotives

NOTES FOR FACING PAGE

Trip times, specific energy and other data are given for a series of trains that would be applicable to NEC operations.

The first six columns are AC motor locomotives that are adhesion limited below 60 mph and constant power above that speed. Locomotive weight is 100 tons, coach weight is 60 tons. The train consists are one or two locomotives and five to twelve coaches.

The seventh column, 2D+9, is a DC motor locomotive with constant tractive effort to 60 mph and tractive effort proportional to V to the -1.2 power above that speed. The consist is two locomotives at 100 tons each and nine coaches at 60 tons each.

The last column, M6A, is a six car Improved Metroliner train that is included for comparison purposes.

Note that trip time does include station dwell time but no time for operational delays. An indicated time of 152 min should provide a total operational trip time of 160 min or 2 hr 40 min; 142 min indicated would be 2 hr 30 min total.

LOCOMOTIVE HAULED TRAINS

Locomotives + coaches	1+5	1+6	1+9	1+12	2+9	2+12	2D+9	(M6A)
Total weight tons	400	460	640	820	740	920	740	540
Percent loco. weight	25	22	16	11	27	22	27	100
Maximum speed, mph	150	145	135	125	150	150	150	150
Tractive effort at maximum speed, lb/ton	43k	39k	30k	25k	46k	37k	38k	41k
Drag force at maximum speed, lb/ton	36k	32k	26k	21k	28k	27k	28k	28k
Trip times, min								
Profile A 105 mph max	172	173	176	178	172	173	172	172
B 120 mph max	166	167	170	173	165	166	166	165
C 120 mph max	160	161	164	168	160	161	161	160
D 120 mph max	158	159	161	165	157	158	158	157
E 135 mph max	147	149	153	159	147	148	148	146
F 135 mph max	144	145	150	156	143	145	144	142
G 150 mph max	141	143	150	156	139	142	141	139
Specific energy, kWh/ton								
Profile A 105 mph max	11.4	11.0	10.3	9.8	10.2	9.9	10.1	10.1
B 120 mph max	13.3	12.8	11.8	10.9	11.9	11.5	11.9	12.0
C 120 mph max	13.2	12.7	11.7	10.9	11.7	11.4	11.7	11.8
D 120 mph max	13.2	12.7	11.6	10.7	11.7	11.3	11.7	11.8
E 135 mph max	14.6	14.1	12.4	11.0	12.9	12.5	12.8	13.1
F 135 mph max	15.8	15.1	12.9	11.3	14.2	13.5	14.0	14.5
G 150 mph max	17.1	16.0	13.9	11.3	15.8	14.7	15.2	16.2

DISCUSSION

Matching the motors, particularly DC motors, to the actual service conditions is a real requirement for achieving highest possible performance. DC motors certainly must operate for part time at increased, short time, ratings to provide the required acceleration (and part of) the braking loads. Three phase AC motors inherently have high continuous ratings but probably require heavier and more complex control equipment. In any case the high axle power density, HP per ton on the driving axles, is required for locomotives.

Each of the route defects or deficiencies contributes a share to overall poor performance. A careful complete analysis of benefits obtained versus cost for improvement at each location may be very profitable and produce significant decreases in trip time within reasonable and available resources.

Aerodynamic loads, separately and in conjunction with train parameters, require special evaluation. At 120 mph, aero loads appear to be separable from train parameters; existing NEC equipment has sufficient power for the weight and drag losses. In the 150 mph range, however, weight, external size and shape (streamlining) all interact and define the power and adhesion requirements. Underpowered trains become speed limited and are unable to provide required power on a continuous basis.

SUMMARY AND OBSERVATIONS

Comparable performance of MU and locomotive hauled trains can be obtained if:

Locomotive weight is not less than 20% of train weight.
High adhesion at low speeds is obtained.
Motors can operate at required power ratings.

Route speed profile is the major determinant of trip time. The present route has many serious, and certainly some unalterable, defects.

Aerodynamic loads become increasingly important at the higher speeds (approaching 150 mph).

INDEX TO APPENDIX

CONSTANTS AND DYNAMIC EQUATION

Davis Coefficients:

C_0 = 1.3 lb/ton static drag

C_1 = 29 lb/axle axle bearing drag

C_2 = .045 lb/ton/mph velocity drag

Aerodynamic drag:

C_D = .7 lead car

C_D = .4 trail car

C_D = .1 intermediate car

Dynamic pressure: $\rho/2$ = .00256 $lb/ft^2/(mph)^2$

Gravity: $1/g$ = 91.1 (lb/ton)/(mphps) which is increased to 100.0 (lb/ton)/(mphps) to account for inertia of rotating parts

Dynamic Equation:

$$100\ (lb/ton)/(mphps)\,(dV/dt)\,(mphps) = (TE/W)\,(lb/ton) - Drag\ (lb/ton)$$

$$Drag = C_0 + C_1 N/W + C_2 V + (\rho/2) C_D A V^2/W$$

where

v = velocity, mph
t = time, sec.
W = weight, tons

N = number of axles
A = frontal area, ft^2

Braking: 2 mphps from 70 mph to stop; above 70 mph straight line passing through 1.1 mphps at 130 mph.

DISCUSSION

A typical speed profile involves 40 to 50 segments of acceleration or braking operation and 70 to 80 segments of constant speed. The time duration condition as stated is usually met; in many cases the a+b time is less than 1/3 of the total time. However, at 150 mph the a+b time can exceed 1/2 of total.

At the low maximum speeds (120 mph), the tractive effort to sustain maximum speed is consistent with a continuous motor rating. Aerodynamic loads are not too large and the continuous rating is 75% to 50% of the short time rating used during acceleration and deceleration.

At the high maximum speeds (150 mph), aerodynamic loads can increase sufficiently to violate continuous rating for sustained constant speed. Special attention must be given in an actual design of equipment. More extensive streamlining and fairing between cars similar to permanently connected train sets may be desirable and even necessary.

In the typical computer simulation runs, a maximum speed was assigned when the total drag load approached about 80% of the available tractive effort. Performance degradation is readily noticeable in the low powered trains, particularly for profile G which was the only one with 150 mph permissible speed. See page 47.

PROPULSION EQUIPMENT RATINGS

Speed Mode	Equipment Operation Mode	Duration
Accelerating	Short Time	a min.
Constant Speed	Continuous	c min.
Decelerating	Short Time	b min.

Desired Situation: The sum of the short term ratings should be less than half of the total time. $(a+b) \leq (a+b+c)/2$

Aerodynamic load is the significant parameter in determining the constant speed load at higher speeds.

$$\frac{\text{Aero Power at 150 mph}}{\text{Aero Power at 120 mph}} = \left(\frac{150}{120}\right)^3 = 1.95 \approx 200\%$$

The aerodynamic load thus determines the actual value of the ratio of the short time to continuous motor rating.

ACCELERATION

This is the kinematic case, the ideal train-ideal track with constant acceleration to maximum speed and constant deceleration from maximum speed.

Equation: $T = D/V + nV/a$

T	=	Trip time	D	=	Total distance = 226 miles
V	=	Max speed	a	=	Accel/decel rate
n	=	Number of start/stop pairs	n	=	1 is no intermediate stops

Limitation: $D/nV >$ or speed V is not reached in distance D/n

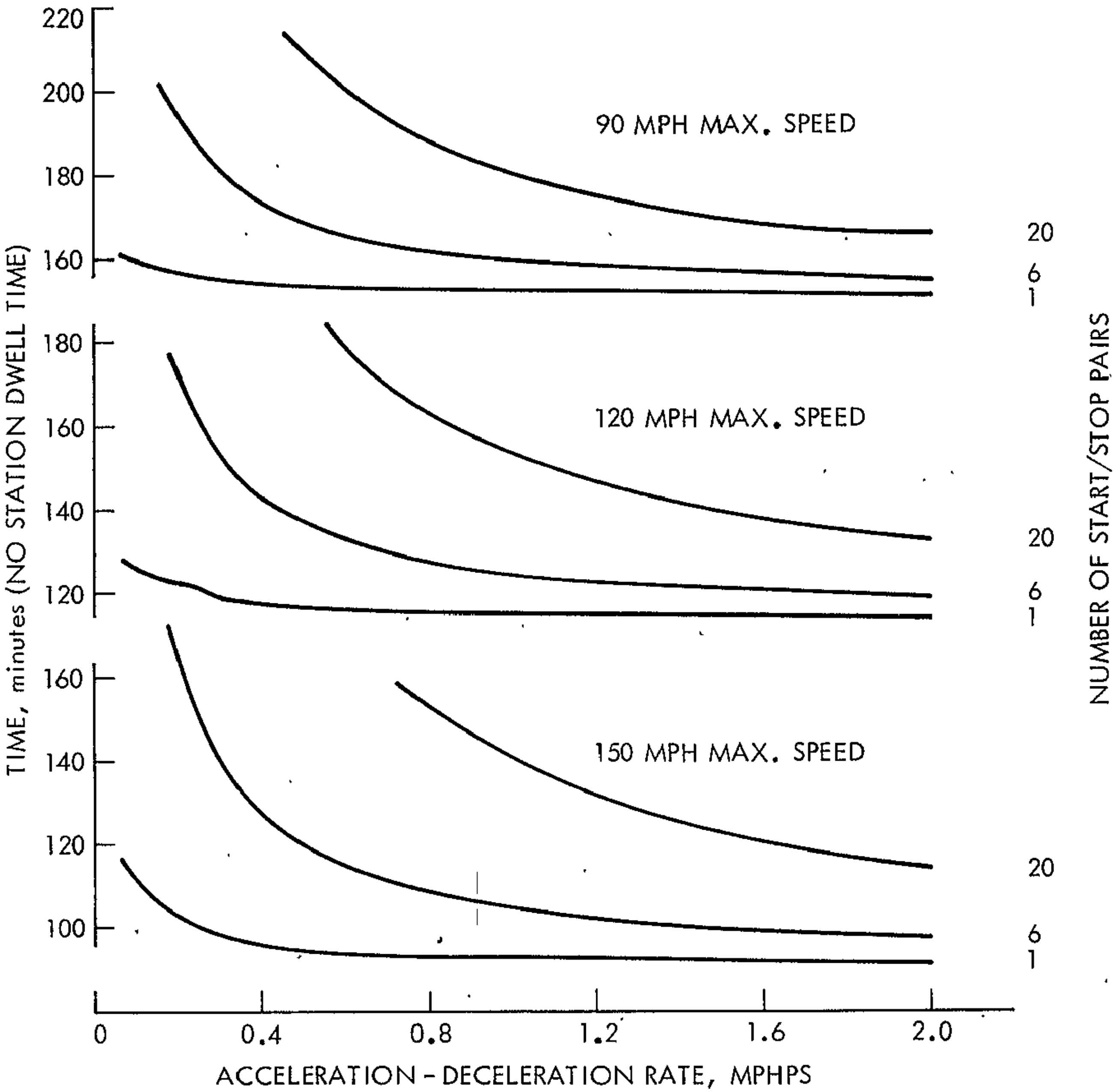
From graph:

For non-stop run, very low accel/decel rate, i.e., .3 to .4 mphps, is adequate to reach and utilize effectively maximum speeds in the region of 90 to 150 mph.

For the case with five intermediate station stops, accel/decel rate should not be much lower than 1 mphps.

For a large number of intermediate stops, the example of 20 is given, accel/decel rates above 1 mphps would produce significant decreases in trip time.

Message: 1 mphps is proper range for NYC-Washington, D.C. service.


90 MPH MAX. SPEED
120 MPH MAX. SPEED
150 MPH MAX. SPEED
TIME, minutes (NO STATION DWELL TIME)
NUMBER OF START/STOP PAIRS
220
200
180
160
140
120
100
20
6
1
0
0.4
0.8
1.2
1.6
2.0
ACCELERATION - DECELERATION RATE, MPHPS

SPEED PROFILE NOTES

Milepost listings for speed profiles A through G are given on pages 35 to 41. The few .1 mi discrepancies are due to the different sources for profiles B and G from which the others are derived; these differences are not relevant in the use of the profiles.

Plots for profiles B through G are given on pages 42 to 45. Profile A is not plotted; it consists of profile B with maximum speed limited to 105 mph. The horizontal distance scale is ten miles per inch with 10 mile tic marks from the left station stop (not cumulative from New York). The vertical speed scale is 160 mph per inch with tic marks at 40, 80, 120 and 160 mph.

Representative acceleration-deceleration curves are given on page 45. The data are given below; note differences in maximum speeds.

M6A	150 mph max.	Improved Metroliner	6 cars
M6B	140 mph max.	Standard Metroliner	6 cars
1A6	150 mph max.	AC motor locomotive, 100 tons with 6-60 ton coaches, constant power above 60 mph.	
1D6	135 mph max.	DC motor locomotive, 100 tons with 6-60 ton coaches, torque proportional to one over velocity to the 1.2 power above 60 mph.	

SPEED PROFILE A 105 MPH MAX. PROFILE B LIMITED TO 105 MPH

M.P.=MILE POST START, MI=ZONE LENGTH, MPH= MAXIMUM SPEED

M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH
NEW YORK			27.1	.6	100	85.2	1.0	70	50.0	.6	90	99.7	3.6	105
0.0	.9	15	27.7	26.4	105	86.2	.3	60	50.6	1.1	100	103.3	.7	100
.9	2.1	60	54.1	2.0	80	86.5	1.0	70	51.7	5.0	105	104.0	2.5	105
3.0	.4	75	56.1	.5	45	87.5	.7	30	56.7	.3	95	106.5	.4	90
3.4	2.8	90	TRENTON			88.2	.8	60	57.0	2.4	105	106.9	6.1	105
6.2	.1	60	56.6	.5	45	89.0	.2	30	59.4	1.1	70	113.0	.3	100
6.3	1.7	90	57.1	1.0	80	PHILADELPHIA			60.5	17.4	105	113.3	3.5	105
8.0	1.3	60	58.1	1.1	105	89.2	.6	30	77.9	.4	100	116.8	.4	90
7.9	.7	45	59.2	.6	100	89.8	.2	40	78.3	11.9	105	117.2	.3	105
8.6	.2	35	59.8	10.4	105	90.0	1.6	50	90.2	1.6	100	117.5	.3	100
8.8	1.8	70	70.2	.6	100	3.2	2.1	100	91.8	2.1	60	117.8	.4	105
10.6	3.5	100	70.8	3.3	105	5.3	1.9	70	93.9	.2	45	118.2	.2	100
14.1	.7	55	74.1	1.0	90	7.2	9.3	100	94.1	.4	60	118.4	10.2	105
14.8	4.8	105	75.1	.9	105	16.5	6.5	105	94.5	.7	45	128.6	.3	100
19.6	.2	45	76.0	4.9	100	23.0	.5	90	95.2	.3	15	128.9	4.1	105
19.8	3.5	80	80.9	.2	60	23.5	1.7	105	BALTIMORE			133.0	1.9	100
METRO PARK			81.1	.6	50	25.2	1.1	80	95.5	.4	15	134.9	.2	30
23.3	2.5	80	81.7	.3	100	26.3	.3	40	95.9	1.5	30	135.1	.9	15
25.8	.2	45	82.0	1.1	70	WILMINGTON			97.4	.7	40	WASHINGTON		
26.0	.3	105	83.1	.7	65	26.6	.9	40	98.1	.5	50	136.0		
26.3	.5	80	83.8	.4	70	27.5	.5	80	98.6	.7	75			
26.8	.3	90	84.2	1.0	50	28.0	22.0	105	99.3	.4	70			

SPEED PROFILE B 120 MPH MAX. BEST WITH EXISTING CONFIGURATION

M.P.=MILE POST START, MI=ZONE LENGTH, MPH= MAXIMUM SPEED

M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH
NEW YORK			32.9	21.2	120	87.5	.7	30	51.7	1.6	115	99.7	1.7	115
0.0	.9	15	54.1	2.0	80	88.2	.8	60	53.3	.5	105	101.4	.7	110
.9	2.1	60	56.1	.5	45	89.0	.2	30	53.8	2.9	115	102.1	1.2	115
3.0	.4	75	TRENTON			PHILADELPHIA			56.7	.3	95	103.3	.7	100
3.4	2.8	90	56.6	.5	45	89.2	.6	30	57.0	2.4	115	104.0	2.5	115
6.2	.1	60	57.1	1.0	80	89.8	.2	40	59.4	1.1	70	106.5	.4	90
6.3	1.7	90	58.1	1.1	115	90.0	1.6	50	60.5	4.8	115	106.9	6.1	115
8.0	1.3	60	59.2	.6	100	3.2	2.1	100	65.3	12.6	120	113.0	.3	100
7.9	.7	45	59.8	10.4	115	5.3	1.9	70	77.9	.4	100	113.3	3.5	115
8.6	.2	35	70.2	.6	100	7.2	9.3	100	78.3	6.7	120	116.8	.4	90
8.8	1.8	70	70.8	3.3	115	16.5	6.5	115	85.0	5.2	115	117.2	.3	115
10.6	3.5	100	74.1	1.0	90	23.0	.5	90	90.2	1.6	100	117.5	.3	100
14.1	.7	55	75.1	.9	115	23.5	1.7	115	91.8	2.1	60	117.8	.4	115
14.8	4.8	115	76.0	4.9	100	25.2	1.1	80	93.9	.2	45	118.2	.2	100
19.6	.2	45	80.9	.2	60	26.3	.3	40	94.1	.4	60	118.4	2.1	115
19.8	3.5	80	81.1	.6	50	WILMINGTON			94.5	.7	45	120.5	4.6	120
METRO PARK			81.7	.3	100	26.6	.9	40	95.2	.3	15	125.1	3.5	115
23.3	2.5	80	82.0	1.1	70	27.5	.5	80	BALTIMORE			128.6	.3	100
25.8	.2	45	83.1	.7	65	28.0	4.8	115	95.5	.4	15	128.9	4.1	115
26.0	.3	110	83.8	.4	70	32.8	.3	110	95.9	1.5	30	133.0	1.9	100
26.3	.5	80	84.2	1.0	50	33.1	8.8	120	97.4	.7	40	134.9	.2	30
26.8	.3	90	85.2	1.0	70	41.9	8.1	115	98.1	.5	50	135.1	.9	15
27.1	.6	100	86.2	.3	60	50.0	.6	90	98.6	.7	75	WASHINGTON		
27.7	5.2	110	86.5	1.0	70	50.6	1.1	100	99.3	.4	70	136.0		

SPEED PROFILE C 120 MPH MAX. PROFILE B WITH MINOR UPGRAGE

M.P.=MILE POST START, MI=ZONE LENGTH, MPH= MAXIMUM SPEED

M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH
NEW YORK			32.9	21.2	120	88.2	.8	60	50.6	1.1	100	103.4	.8	110
0.0	.9	15	54.1	2.0	80	89.0	.2	30	51.7	1.6	115	104.2	2.3	115
.9	2.1	60	56.1	.5	45	PHILADELPHIA			53.3	.5	105	106.5	.4	90
3.0	.4	75	TRENTON			89.2	.6	30	53.8	2.9	115	106.9	6.1	115
3.4	2.8	90	56.6	.5	45	89.8	.2	40	56.7	.3	95	113.0	.3	100
6.2	.1	60	57.1	1.0	80	90.0	1.3	70	57.0	2.4	115	113.3	3.5	115
6.3	1.7	90	58.1	1.1	115	2.9	.3	85	59.4	1.1	70	116.8	.4	90
8.0	1.3	60	59.2	.6	100	3.2	2.1	100	60.5	4.8	115	117.2	.3	115
7.9	.7	45	59.8	10.4	115	5.3	1.9	70	65.3	12.6	120	117.5	.3	100
8.6	.2	35	70.2	.6	100	7.2	9.3	100	77.9	.4	100	117.8	.4	115
8.8	1.8	70	70.8	3.3	115	16.5	6.5	115	78.3	7.4	120	118.2	.2	100
10.6	3.5	100	74.1	1.0	90	23.0	.5	90	85.7	6.3	115	118.4	2.1	115
14.1	.7	55	75.1	.9	115	23.5	1.7	115	92.0	1.8	80	120.5	4.6	120
14.8	8.0	115	76.0	4.9	100	25.2	1.1	80	93.8	1.3	55	125.1	3.5	115
22.8	.5	45	80.9	.2	60	26.3	.3	40	95.1	.4	15	128.6	.3	100
METRO PARK			81.1	.6	50	WILMINGTON			BALTIMORE			128.9	4.1	115
23.3	.5	45	81.7	.3	100	26.6	.9	40	95.5	1.7	40	133.0	1.9	100
23.8	.8	90	82.0	1.1	70	27.5	.5	80	97.2	1.4	60	134.9	.2	30
24.6	1.7	100	83.1	.7	65	28.0	4.8	115	98.6	1.2	75	135.1	.9	15
26.3	.5	80	83.8	2.4	70	32.8	.3	110	99.8	.3	90	WASHINGTON		
26.8	.3	90	86.2	.3	60	33.1	8.8	120	100.1	1.3	115	136.0		
27.1	.6	100	86.5	1.0	70	41.9	8.1	115	101.4	.7	110			
27.7	5.2	110	87.5	.7	30	50.0	.6	90	102.1	1.3	115			

SPEED PROFILE D 120 MPH MAX. PROFILE C WITH MAJOR UPGRADE

M.P.=MILE POST START, MI=ZONE LENGTH, MPH= MAXIMUM SPEED

M.P.	MI	MPH
NEW YORK		
0.0	.9	15
.9	2.1	60
3.0	.4	75
3.4	2.8	90
6.2	.1	60
6.3	1.7	90
8.0	1.3	60
7.9	.7	45
8.6	.2	35
8.8	1.8	70
10.6	3.4	115
14.0	.8	90
14.8	8.0	115
22.8	.5	45
METRO PARK		
23.3	.5	45
23.8	.8	90
24.6	1.7	100
26.3	.5	80
26.8	.5	90
27.3	.5	115
27.8	26.3	120

M.P.	MI	MPH
54.1	2.0	80
56.1	.5	45
TRENTON		
56.6	.5	45
57.1	1.0	80
58.1	1.1	115
59.2	.6	100
59.8	10.4	115
70.2	.6	100
70.8	3.3	115
74.1	1.0	90
75.1	.9	115
76.0	4.8	100
80.8	.4	80
81.2	.7	55
81.9	1.1	120
83.0	.9	70
83.9	.9	120
84.8	.5	85
85.3	.9	80
86.2	.7	75
86.9	1.2	30
88.1	.9	65

M.P.	MI	MPH
89.0	.2	30
PHILADELPHIA		
89.2	.6	30
89.8	.2	40
90.0	1.3	70
2.9	.3	85
3.2	6.2	110
9.4	7.1	100
16.5	6.5	115
23.0	.5	90
23.5	1.7	115
25.2	1.1	80
26.3	.3	40
WILMINGTON		
26.6	.9	40
27.5	.5	80
28.0	4.8	115
32.8	.3	110
33.1	8.8	120
41.9	8.1	115
50.0	.6	90
50.6	1.1	100
51.7	1.6	115

M.P.	MI	MPH
53.3	.5	105
53.8	2.9	115
56.7	.3	95
57.0	2.4	115
59.4	1.2	105
60.6	4.7	115
65.3	12.6	120
77.9	.4	100
78.3	7.4	120
85.7	6.3	115
92.0	1.8	80
93.8	1.3	55
95.1	.4	15
BALTIMORE		
95.5	1.7	40
97.2	1.4	60
98.6	1.2	75
99.8	.3	90
100.1	1.3	115
101.4	.7	110
102.1	1.3	115
103.4	.8	110
104.2	2.3	115

M.P.	MI	MPH
106.5	.4	90
106.9	6.1	115
113.0	.3	100
113.3	3.5	115
116.8	.4	90
117.2	.3	115
117.5	.3	100
117.8	.4	115
118.2	.2	100
118.4	2.1	115
120.5	4.6	120
125.1	3.3	115
128.4	.4	110
128.8	4.2	120
133.0	1.9	115
134.9	.2	30
135.1	.9	15
WASHINGTON		
136.0		

SPEED PROFILE E 135 MPH MAX. PROFILE D WITH ADDITIONAL UPGRADES

M.P.=MILE POST START, MI=ZONE LENGTH, MPH= MAXIMUM SPEED

M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH
NEW YORK			23.8	.8	90	83.9	.9	120	19.9	1.9	130	95.5	1.7	40
0.0	.9	15	24.6	1.7	100	84.8	.5	85	21.8	1.1	115	97.2	1.4	60
.9	2.1	60	26.3	.5	80	85.3	.9	80	22.9	.8	90	98.6	1.2	75
3.0	.4	75	26.8	.5	90	86.2	.7	75	23.7	2.4	115	99.8	.3	90
3.4	2.8	90	27.3	.5	115	86.9	1.2	30	26.1	.5	85	100.1	1.3	115
6.2	.1	60	27.8	27.2	135	88.1	.9	65	WILMINGTON			101.4	.7	110
6.3	1.7	90	55.0	1.1	80	89.0	.2	30	26.6	.9	40	102.1	1.3	115
8.0	1.3	60	56.1	.5	45	PHILADELPHIA			27.5	.5	80	103.4	.8	110
7.9	.7	45	TRENTON			89.2	.6	30	28.0	2.6	115	104.2	20.9	135
8.6	.2	35	56.6	.5	45	89.8	.2	40	30.6	28.8	135	125.1	3.3	115
8.8	.2	80	57.1	2.1	120	90.0	1.3	70	59.4	1.2	105	128.4	.4	110
9.0	.4	90	59.2	14.8	135	2.9	.3	85	60.6	4.7	115	128.8	4.2	120
9.4	1.2	115	74.0	.5	125	3.2	2.1	135	65.3	12.6	120	133.0	1.9	115
10.6	3.4	135	74.5	.8	115	5.3	2.1	115	77.9	.4	100	134.9	.2	30
14.0	.8	90	75.3	3.8	135	7.4	2.0	135	78.3	7.4	120	135.1	.9	15
14.8	6.8	135	79.1	1.7	130	9.4	1.7	115	85.7	6.3	115	WASHINGTON		
21.6	1.2	125	80.8	.4	80	11.1	1.7	125	92.0	1.8	80	136.0		
22.8	.5	45	81.2	.7	55	12.8	1.3	130	93.8	1.3	55			
METRO PARK			81.9	1.1	120	14.1	3.8	135	95.1	.4	15			
23.3	.5	45	83.0	.9	70	17.9	2.0	115	BALTIMORE					

SPEED PROFILE F 135 MPH MAX. PROFILE G LIMITED TO 135 MPH

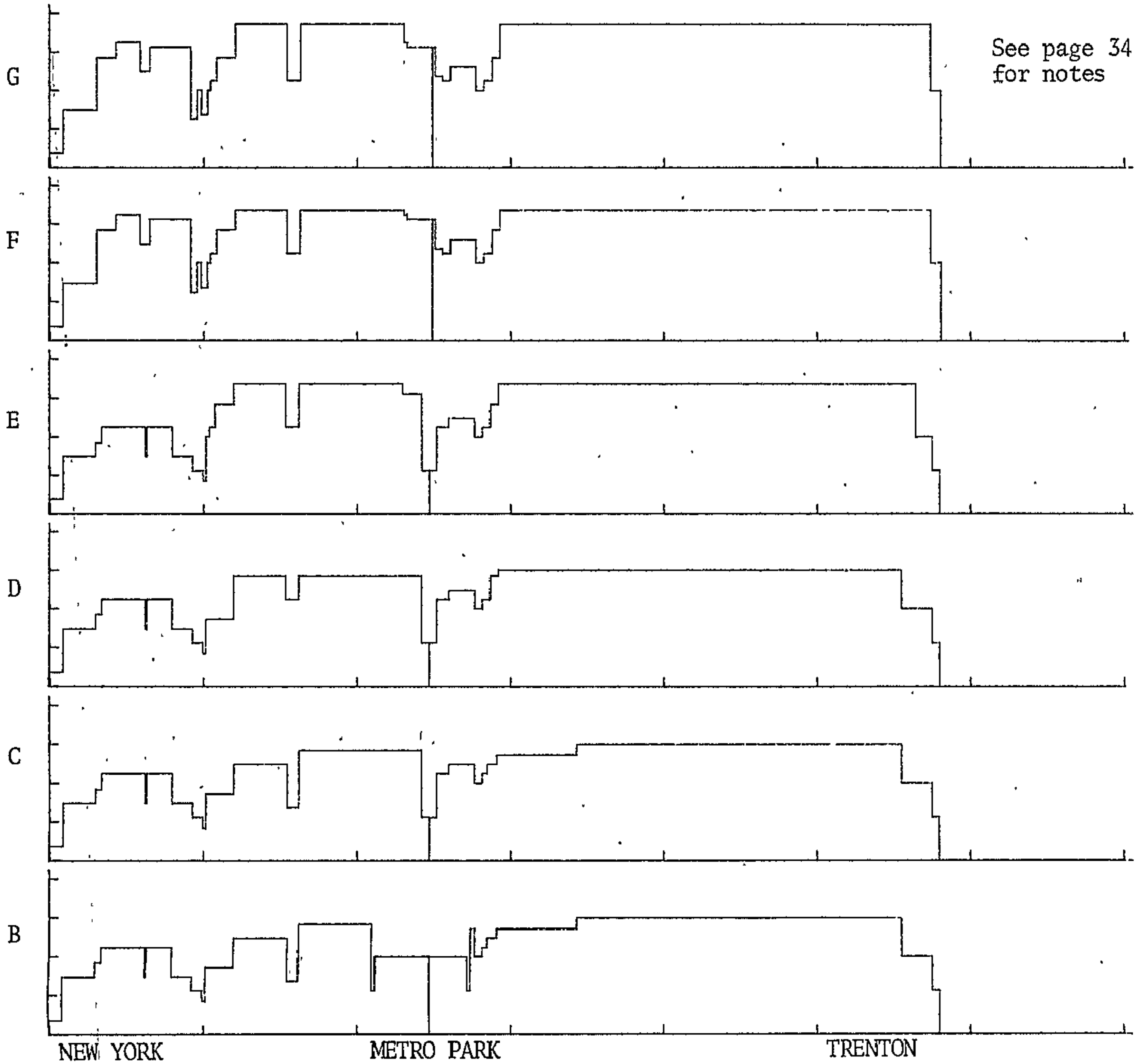
M.P.=MILE POST START, MI=ZONE LENGTH, MPH= MAXIMUM SPEED

M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH
NEW YORK			26.3	.5	80	86.2	.7	75	WILMINGTON			93.8	1.3	55
0.0	.9	15	26.8	.5	90	86.9	1.2	30	26.8	.1	80	95.1	.5	15
.9	2.2	60	27.3	.5	115	88.1	1.0	65	26.9	.7	60	BALTIMORE		
3.1	1.2	115	27.8	28.1	135	89.1	.1	30	27.6	1.0	135	95.6	1.6	40
4.3	1.6	130	55.9	.7	80	PHILADELPHIA			28.6	1.4	120	97.2	1.4	60
5.9	.6	100	TRENTON			89.2	.8	30	30.0	.6	110	98.6	1.2	75
6.5	2.7	125	56.6	.5	80	90.0	1.3	70	30.6	28.8	135	99.8	.3	90
7.7	.4	50	57.1	1.1	135	2.9	.3	85	59.4	1.2	105	100.1	1.3	135
8.1	.3	80	58.2	1.0	120	3.2	2.1	135	60.6	.9	130	101.4	.8	115
8.4	.4	55	59.2	14.8	135	5.3	2.0	115	61.5	3.0	135	102.2	1.2	135
8.8	.2	80	74.0	.5	125	7.3	2.1	135	64.5	.9	115	103.4	.4	110
9.0	.4	90	74.5	.7	115	9.4	1.7	115	65.4	6.4	135	103.8	.4	115
9.4	1.2	115	75.2	3.9	135	11.1	1.7	125	71.8	.7	105	104.2	20.9	135
10.6	3.4	135	79.1	.7	130	12.8	1.3	130	72.5	5.3	135	125.1	2.1	115
14.0	.8	90	79.8	1.0	135	14.1	3.8	135	77.8	.8	100	127.2	1.2	135
14.8	6.8	135	80.8	.4	85	17.9	2.0	115	78.6	.9	105	128.4	.4	115
21.6	.2	130	81.2	.7	55	19.9	1.2	130	79.5	6.2	135	128.8	4.2	135
21.8	1.6	125	81.9	1.1	135	21.1	.7	135	85.7	1.4	120	133.0	1.7	115
METRO PARK			83.0	.9	75	21.8	1.1	115	87.1	1.2	115	134.7	.2	45
23.4	.2	125	83.9	.9	135	22.9	.8	90	88.3	.7	120	134.9	1.0	15
23.6	.5	95	84.8	.2	120	23.7	.2	115	89.0	2.8	135	WASHINGTON		
24.1	.5	90	85.0	.3	85	23.9	2.2	135	91.8	.2	115	135.9		
24.6	1.7	105	85.3	.9	80	26.1	.7	85	92.0	1.8	80			

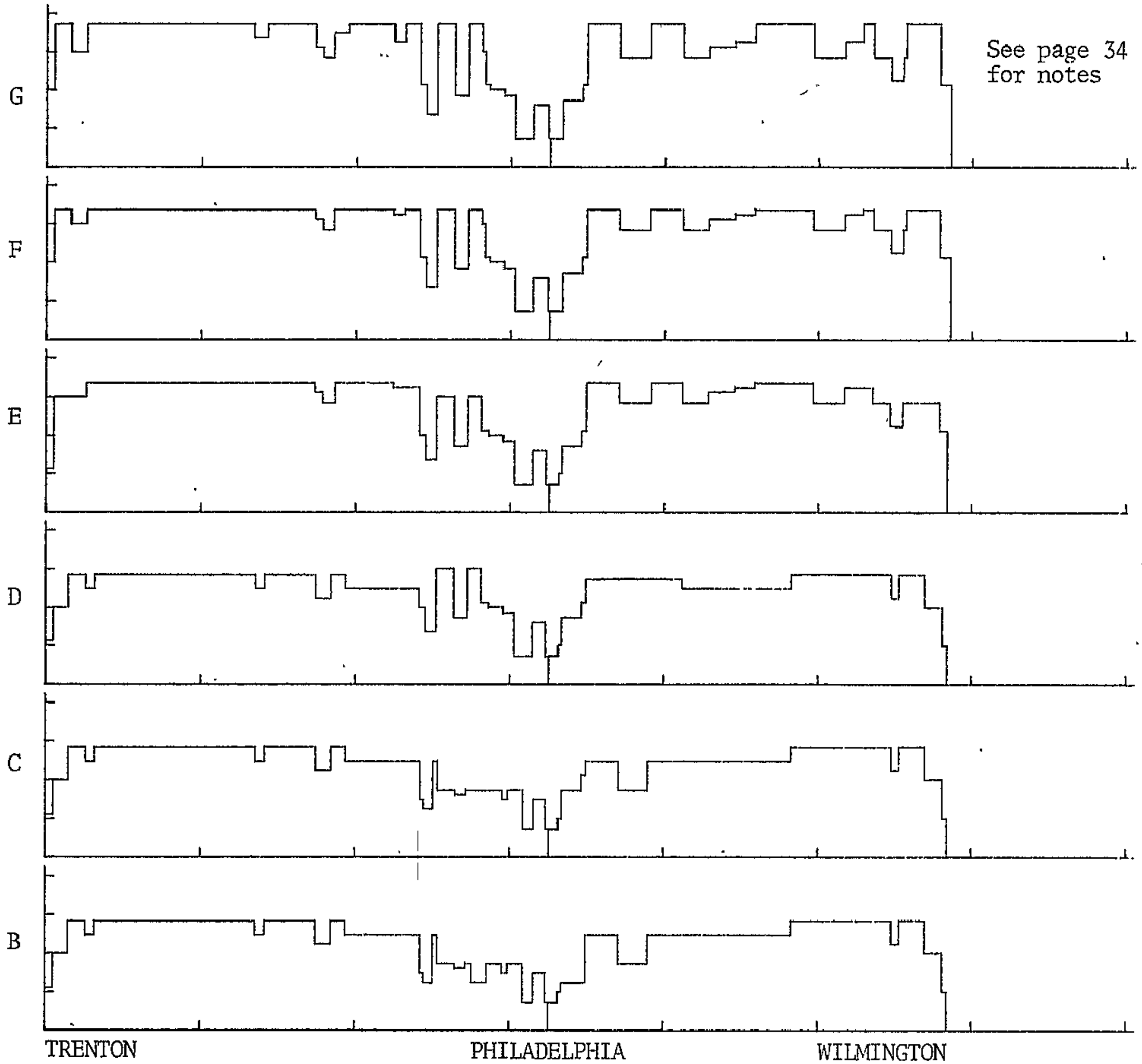
SPEED PROFILE G 150 MPH MAX. TASK 11S PROFILE

M.P.=MILE POST START, MI=ZONE LENGTH, MPH= MAXIMUM SPEED

M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH	M.P.	MI	MPH
NEW YORK			26.8	.5	90	85.3	.9	80	WILMINGTON			93.8	1.3	55
0.0	.9	15	27.3	.5	115	86.2	.7	75	26.8	.1	80	95.1	.5	15
.9	2.2	60	27.8	28.1	150	86.9	1.2	30	26.9	.7	60	BALTIMORE		
3.1	1.2	115	55.9	.7	80	88.1	1.0	65	27.6	1.0	150	95.6	1.6	40
4.3	1.6	130	TRENTON			89.1	.1	30	28.6	1.4	120	97.2	1.4	60
5.9	.6	100	56.6	.5	80	PHILADELPHIA			30.0	.6	110	98.6	1.2	75
6.5	2.7	125	57.1	1.1	150	89.2	.8	30	30.6	28.8	150	99.8	.3	90
7.7	.4	50	58.2	1.0	120	90.0	1.3	70	59.4	1.2	105	100.1	1.3	150
8.1	.3	80	59.2	10.8	150	2.9	.3	85	60.6	.9	130	101.4	.8	115
8.4	.4	55	70.0	.9	135	3.2	2.1	150	61.5	1.4	135	102.2	1.2	150
8.8	.2	80	70.9	3.1	150	5.3	2.0	115	62.9	1.6	150	103.4	.4	110
9.0	.4	90	74.0	.5	125	7.3	2.1	150	64.5	.9	115	103.8	.4	115
9.4	1.2	115	74.5	.7	115	9.4	1.7	115	65.4	6.4	150	104.2	20.9	150
10.6	3.4	150	75.2	.9	140	11.1	1.7	125	71.8	.7	105	125.1	2.1	115
14.0	.8	90	76.1	3.0	150	12.8	1.3	130	72.5	5.3	150	127.2	1.2	150
14.8	6.8	150	79.1	.7	130	14.1	3.8	150	77.8	.8	100	128.4	.4	115
21.6	.2	130	79.8	1.0	150	17.9	2.0	115	78.6	.9	105	128.8	2.1	135
21.8	1.6	125	80.8	.4	85	19.9	1.2	130	79.5	6.2	150	130.9	2.1	150
METRO PARK			81.2	.7	55	21.1	.7	150	85.7	1.4	120	133.0	1.7	115
23.4	.2	125	81.9	1.1	150	21.8	1.1	115	87.1	1.2	115	134.7	.2	45
23.6	.5	95	83.0	.9	75	22.9	.8	90	88.3	.7	120	134.9	1.0	15
24.1	.5	90	83.9	.9	150	23.7	.2	115	89.0	2.8	150	WASHINGTON		
24.6	1.7	105	84.8	.2	120	23.9	2.2	150	91.8	.2	115	135.9		
26.3	.5	80	85.0	.3	85	26.1	.7	85	92.0	1.8	80			



G
F
E
D
C
B
See page 34 for notes
NEW YORK
METRO PARK
TRENTON



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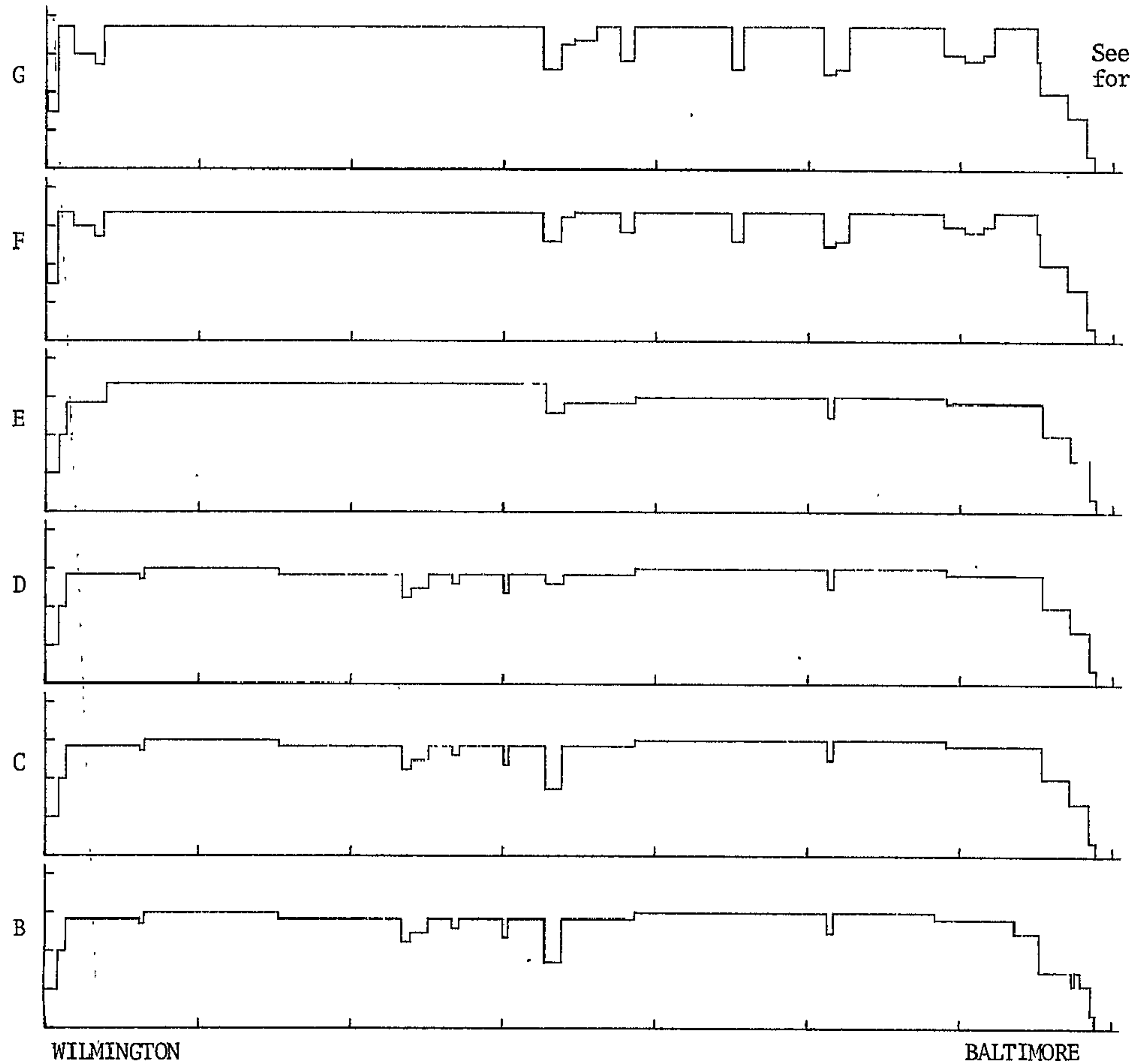
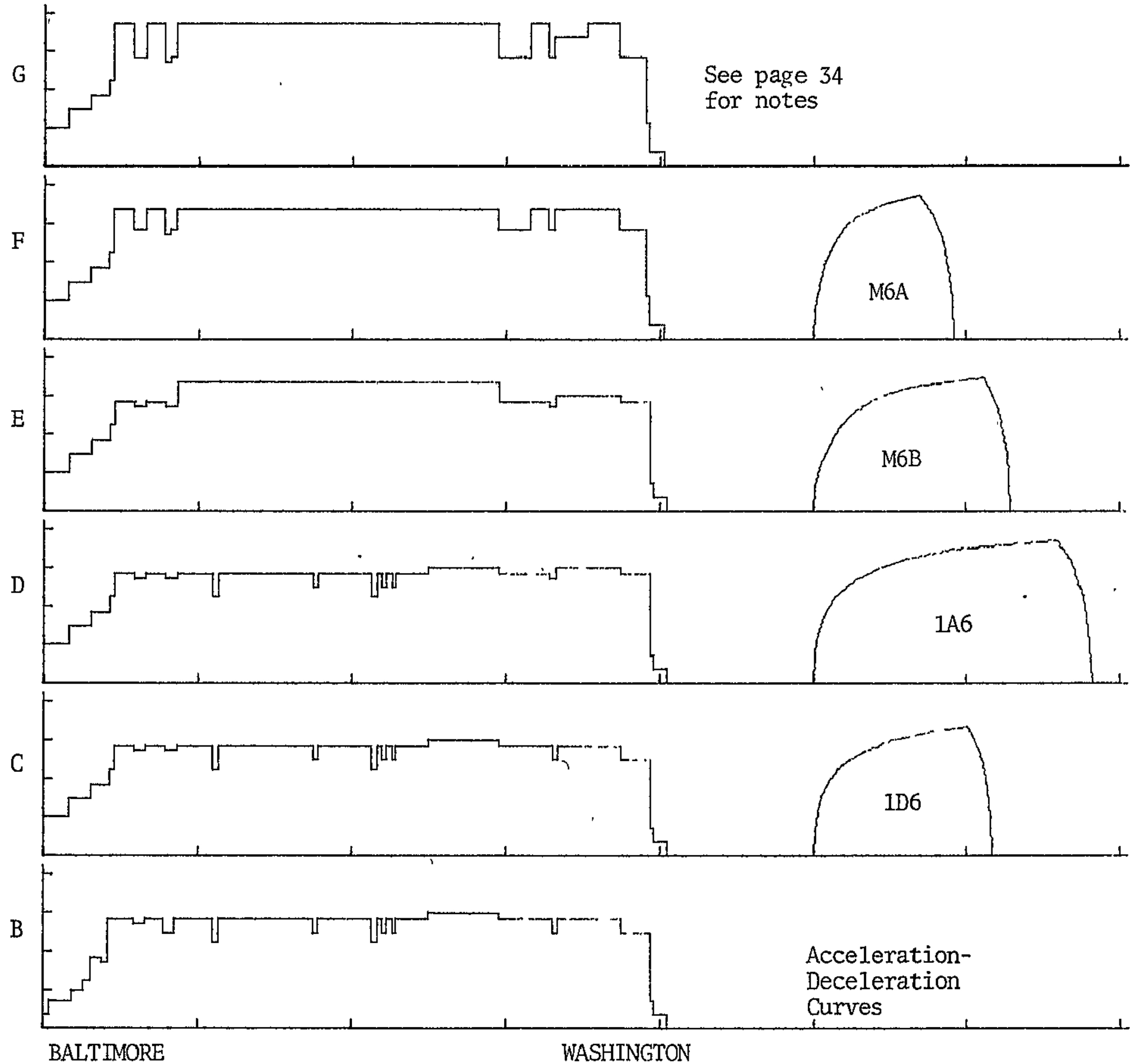


See page 34 for notes


G
F
E
D
C
B
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for notes
M6A
M6B
1A6
1D6
Acceleration-
Deceleration
Curves
BALTIMORE
WASHINGTON

NOTES FOR FACING PAGE DATA

A is six car Improved Metroliner.

B is six car Standard Metroliner; maximum speed is 140 mph.

C.D.E,F. are adhesion limited up to speed listed and power limited above that speed. Decimal value of locomotive to total train weight is given.

G through L are locomotive trains with constant tractive effort at 60 mph at the adhesion limited value for that speed. Above 60 mph the tractive effort varies with velocity as given, e.g., V**2.0 is V squared. Decimal value to total train weight is given. Last item is maximum speed as determined by friction losses approaching 80 percent of available tractive effort.

M through R are similar to G through L with the tractive effort levels reduced to 80 percent of the levels of those cases.

SUPPORTING DATA

REFERENCED IN METHODOLOGY, PAGES 16-17

TRIP TIMES, MIN.

	PROFILE	A	B	C	D	E	F	G
A	MU 1.0 MPHPS AT 100 MPH	172.3	165.2	160.0	157.2	146.7	142.6	139.0
B	MU .65 MPHPS AT 100 MPH	175.1	168.4	163.0	160.1	150.4	147.1	145.4
C	.3 LOCO, 75 MPH	171.2	164.0	158.9	156.2	145.5	141.2	137.1
D	.3 LOCO, 60 MPH	171.4	164.4	159.3	156.6	146.0	142.0	138.2
E	.2 LOCO, 75 MPH	173.1	166.4	161.1	158.3	148.2	144.5	141.4
F	.2 LOCO, 60 MPH	173.6	167.1	168.1	158.9	149.2	145.9	143.4
	100 PERCENT TE MPH							
G	.3 LOCO, TE=1/V**1.0, 150	171.8	164.8	159.7	157.0	146.4	142.4	138.6
H	.3 LOCO, TE=1/V**1.2, 150	171.9	165.0	159.9	157.2	146.8	143.0	139.6
I	.3 LOCO, TE=1/V**2.0, 130	172.5	166.3	161.1	158.4	140.4	147.5	147.5
J	.2 LOCO, TE=1/V**1.0, 150	174.2	167.7	162.4	159.6	149.9	146.6	144.1
K	.2 LOCO, TE=1/V**1.2, 140	174.4	168.1	160.0	150.7	147.6	146.8	146.2
L	.2 LOCO, TE=1/V**2.0, 115	175.4	171.6	166.4	163.6	159.7	157.4	157.4
	80 PERCENT TE MPH							
M	.3 LOCO, TE=1/V**1.0, 150	173.0	166.2	161.0	158.2	148.1	144.4	141.3
N	.3 LOCO, TE=1/V**1.2, 150	173.1	166.5	161.3	158.5	148.6	145.2	142.7
O	.3 LOCO, TE=1/V**2.0, 125	173.9	168.5	163.3	160.5	154.3	151.8	151.8
P	.2 LOCO, TE=1/V**1.0, 140	176.1	170.2	164.8	161.8	153.0	150.2	149.6
Q	.2 LOCO, TE=1/V**1.2, 130	176.4	170.9	165.4	162.4	155.1	152.6	152.6
R	.2 LOCO, TE=1/V**2.0, 110	178.1	176.5	171.4	168.6	165.4	163.4	163.4

Tractive effort versus velocity tables are given for several of the cases used in this study.

The TE curve for the AC type motor is mathematically defined. Below 60 mph the Curtius-Kniffler adhesion limit is used; at 60 mph maximum power is reached at that value of adhesion and the power is constant at that value above 60 mph. Locomotive weight is 100 tons.

The TE curve for the DC type motor is also mathematically defined. A maximum power point is at 60 mph at the adhesion limited value of TE as in the AC motor case. Below 60 mph the TE is constant at this value; above 60 mph the TE is inversely proportional to the speed to the 1.2 power. This value of 1.2 was taken from a plot of the short time rating of the ASEA RC-4 motor. Again locomotive weight is 100 tons.

The Metroliner TE data is essentially from the Bechtel report previously cited. However, it was normalized to a single set of data for computer input so that TE per ton data for the various cases used in the study could be obtained by application of an appropriate multiplying factor, e.g., for Standard Metro, Improved Metro, one inoperative car, mixture of MU and Amfleet coaches, etc. The tabulated data is for a single MU car. The values for the Standard Metro agree quite well with the Bechtel data. The values for the Improved Metro are several percent larger than the Bechtel data; from a few check runs the time differences are less than a minute.

NOTE: This report does not address the question of whether all, any or none of these motors can actually be operated over the speed ranges used in the study and produce the TE indicated. The data for the Metroliners is extrapolated from 120 to 150 mph; the operation of the locomotive motors to a speed of 2.5 times the speed of their initial maximum power point is not examined. However, it is felt that the values at 120 mph are thoroughly realistic and most probably still very applicable at 135 mph. It is the final extension to 150 mph that should be used with some caution. The major theme of the study was to examine the time performance-traction equipment capability relationship in a parametric way with the recognition that operating limits of actual equipment might be reached or exceeded.

MOTOR TRACTIVE EFFORT DATA

Pounds per Locomotive or MU Car

Speed mph	Improved Metroliner	Standard Metroliner	Locomotive AC Motors	Locomotive DC Motors
0	10300	6200	66400	42800
10	10200	6140	57200	42800
20	10150	6080	51200	42800
30	10060	6025	48400	42800
40	9960	5970	46000	42800
50	9870	5915	44200	42800
60	9770	5860	42800	42800
70	9680	5800	36500	35600
80	9590	5745	32200	30400
90	9490	5690	28600	26200
100	9400	5630	25600	23200
110	7425	4450	23400	20600
120	6160	3690	21400	18600
130	5120	3070	19800	17000
140	4390	2630	18400	15400
150	3670	2200	17200	14200

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