Engineering Options for the Northeast Corridor

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ABSTRACT

Two topics are presented in this paper. First, results of train performance integrations that show how train running times on the Northeast Corridor route would be affected by progressive increases in maximum speed up to 210 mph and by progressive increases in curve speed limits up to the corresponding tangent track maximums are presented. The results show that, for the curves that exist on the Northeast Corridor, full benefit can be derived from the high maximum speeds offered by available technology only if curve speed limits are raised along with maximum speed. Second, two approaches for achieving increased speeds on existing curves are considered. One is the well-known approach of operating tilting body vehicles on track with moderately increased superelevation. The other approach is to operate nontilting vehicles on track with dramatically increased rail superelevation. It is noted in this paper that this latter approach not only offers substantial advantages but also presents substantial problems. Methods of overcoming these problems are suggested.

The purpose of this paper is to review some basic physical constraints on and possibilities for a high-speed passenger service between New York City and Washington, D.C. (NY-W).

There are three reasons for rexamining NY-W service:

1. Of all the linearly arranged city groups in the United States, NY-W offers the best market for high-speed rail service.
2. The tide of governmental initiatives that has resulted in an improved level of service in the Northeast Corridor has almost ended; however, these initiatives were based on a sense of what was practical about 15 years ago.
3. Japan and France have demonstrated that levels of service substantially higher than those being achieved in the Northeast Corridor are technically feasible and economically attractive.

Thus, the following question is investigated: What kind of train operation will be most suitable for achieving high average speed on the NY-W corridor?

PREMISES OF THIS PAPER

This paper is based on three premises:

1. That there is a market for service with substantially shorter trip times than those now being offered.
2. That tracks for a new high-speed service would be used for that service only. This assumption is based on considerations of safety and of service optimization, including choice of curve superelevations without regard to the requirements of conventional trains. (Detailed arrangements for providing dedicated high-speed tracks while still supporting existing freight and passenger services are not considered here but will have to be worked out if an economic feasibility study is undertaken.)
3. That it would not be economically feasible to eliminate most of the curves that exist in the NY-W right-of-way. Thus, it is assumed here that initial planning should accept the curves that exist in the present right-of-way.

BASIC VARIABLES AFFECTING TRIP TIME

If high-speed service on dedicated tracks is considered, there is no reason for train speed to be routinely restricted by any factor other than safe braking before curves and station stops. Assuming that this is the case, trip time is determined by only three factors: (a) maximum speed, (b) how speed restrictions on curves are determined, and (c) the accelerating and braking power with which the vehicles are endowed. Each of these factors is examined in more detail in the following paragraphs.

The effect of maximum speed on trip time is fairly obvious. Examples of maximum speeds that have been achieved are given in Table 1. Sample maximum speeds that will be considered in this paper are 120, 150, 180, and 210 mph.

TABLE 1 Examples of Maximum Speeds Achieved on Several Rail Lines

Service	Maximum Speed (mph)	Year
Tokaido	130	1964
Congressional (6 stops)[a]	100	1967
Metroliner (6 stops)[b]	120	1969
Tohoku	150	1982
Paris-Lyon	168	1982
Test runs		
DOT test cars	150	1966
Metroliners	165	1969
Tohoku	198	1979
TGV[c]	237	1981

[a]The NY-W trip took 210 min on this train.
[b]The NY-W trip took 180 min on this train.
[c]TGV is Tres Grand Vitesse (French high-speed train).

The effect of curve speed restrictions on trip time is also fairly obvious. Although there can be some complicating considerations, speed on a given curve is determined by the superelevation of the rails and by the unbalance, which is a measure of the amount by which actual speed on a curve is allowed to exceed the equilibrium speed for the given curvature and superelevation. What determines the speed allowed on a curve is the resultant of the superelevation and unbalance. Superelevation up to 6 in. and unbalance up to 3 in. are conventional. Both figures can be increased for low center-of-gravity rolling stock, especially if passenger car bodies lean enough to reduce the unbalance felt by passengers. However, for simplicity, the resultant will be referred to as though it were due only to superelevation. The NY-W running times that are obtained with maximum permissible resultant elevations of 9, 12, 17, 22, 30, and 60 in. will be examined. (The 60-in. figure corresponds to rotation of the plane of the track by 90 degrees and means that curves impose no speed restrictions.)

The third factor that affects trip time is the power for accelerating and braking with which the vehicles are endowed. As a part of the preparation for this paper, some running times were computed to examine the effect of increasing propulsion power above levels that might be considered minimum reasonable levels. The amounts by which trip time was reduced as propulsion power was increased were slight. It was therefore decided to examine results for only one level of accelerating power for each maximum speed. The values are given in a later section.

Thus, for the route under examination, trip time is determined by only two factors: maximum speed and speeds on curves.

DETAILED ASSUMPTIONS

The computed trip times that will be presented are based on assumptions about the wayside, the vehicles, and train operation as follows.

Wayside

Three assumptions about the wayside are used for computing trip times.

1. The effect of grades is ignored.
2. Curves are assumed to be as given in the Federal Railroad Administration's report on the Northeast Corridor High Speed Rail Passenger Service Improvement Project (1).
3. Speed limits on curves are based on the stated maximum allowable resultant elevation but truncated to the next lower integral multiple of 10 mph or to the stated maximum speed, whichever is less. (Presumably there will be locations where it is not possible to realize as much superelevation as is allowed in general. For example, some reverse curves may not allow spirals as long as would be desired. Effects of limitations of this kind are not included in this paper. Analysis of spiral geometry for typical highly elevated curves and reverse curves will be reported later.)

Vehicles

The following assumptions about vehicles are used for computing trip times.

1. Train resistance is based on the traditional Davis coefficients: 1.3 lb/ton, 0.03 lb/ton/mph, and 29 lb/axle. The coefficients of the speed square terms are taken to be 0.37 lb/mph/mph for the lead car and 0.05 lb/mph/mph for trailing cars. These values give slightly more drag than values reported by the Japanese and significantly more than the values reported by the French. (For operation at high speed, there is strong incentive to reduce drag as much as possible.)
2. Values for maximum speed, acceleration at maximum speed for a 12-car train, maximum propulsion power per car at the rail (force-speed product) and vehicle weight are given in the following table.

Maximum Speed (mph)	Acceleration at Maximum Speed (mph/sec)	Force-Speed Product (lb·mph)	Car Weight (lb)
120	0.3	334,000	115,000
150	0.2	465,000	130,000
180	0.1	616,000	150,000
210	0.1	1,020,000	205,000

The values given in the table for propulsion power at the rail (force-speed product) and car weight are based on: (a) train resistance (as stated in Assumption 1 in this section) and (b) the assumption that car weight varies linearly with power at the rail (as exemplified by the Jersey Arrow I and Metroliner cars). Those two cars can be placed in the above table as follows:

	Force-Speed Product (lb·mph)	Car Weight (lb)
Jersey Arrow I	405,000	115,000
Metroliner	756,000	173,000

The stated values of power at the rail are assumed to be available from one-third of maximum speed to maximum speed. This then assumes use of alternating current drive with synchronous motors, such as recently developed by the French. Tractive effort is assumed to be constant from zero speed up through one-third of maximum speed. The car weights given are assumed to include an allowance for rotational inertia. Electrical energy consumption while accelerating is based on a propulsion system overall efficiency of 85 percent and on an auxiliary power consumption per car of 40 kW.

3. Braking effort is based on wet rail adhesion assumed to be given by the formula:

$$\text{Adhesion coefficient} = 14/(v + 109)$$

where v is in miles per hour.

4. Regenerative braking effort at any speed equals tractive effort at that speed, and net recovery amounts to 50 percent of the energy removed at the rail by the dynamic brake.

Train Operation

There are three assumptions about train operation used for computing trip times.

1. Trains consist of 12 cars, all of which are powered.
2. There is no coasting. That is, full power or constant speed is maintained until full braking effort is applied to reduce speed for a station stop or before entry into a curve.
3. Trains leave New York City and stop at Newark, Philadelphia, Wilmington, Baltimore, and Washington. The station dwell allowance at each intermediate stop is 3 min. Because actual dwell times are in the

1- to 2-min range, there are a few minutes of schedule slack.

COMPUTED TRIP TIMES

Computed times for the trip from New York City to Washington, D.C., are shown in Figures 1-3.

Figure 1 shows trip time (min) as a function of resultant elevation for each of the four sample maximum speeds. Each of the circled points gives a trip time that is 8 percent longer than the time the train would achieve if there were no speed restrictions because of curves. (The circled point on the 150-mph curve is interpolated rather than computed.) The elevations corresponding to the circled points appear to be almost optimal for the respective maximum speeds in the sense that higher elevations achieve little further reduction in trip time. Elevation of 60 in. eliminates all speed restrictions and corresponds to tangent track. It is proposed in this paper that the elevations indicated by the circled points can and should be achieved in practice.

Figure 2 shows the same set of computed trip times but uses them to show trip time as a function of maximum speed for fixed resultant elevation. If it were believed that a particular resultant elevation were practical, there might be a temptation to determine from Figure 2 the maximum speed that would be suitable for that elevation. However, various costs increase rather rapidly with maximum speed. Therefore, because Figure 2 includes no information about costs, the only conclusion that can be drawn from the figure with any confidence is that speeds faster than 150 mph will not be of value with the curves assumed if resultant elevations do not exceed 12 in.

Figure 3 shows the same data by means of curves that give superelevation as a function of maximum speed for several fixed values of trip time. (Points at which given curves intersect grid lines have been found by interpolation where the intercepts are not primary data points.) The optimal points are close to the points where the curves have a slope equal to -1. However, these points have been selected for illustration on the basis of plausible judgment rather than on the basis of a quantitative optimization.

Net energy consumption was computed along with trip time for each of the 24 cases. For maximum speeds of 120 and 150 mph, energy consumption decreased slightly with increasing resultant elevation. For maximum speeds of 180 and 210 mph, energy consumption first increased slightly and then decreased slightly as resultant elevation was increased. The effect of resultant elevation was slight for all four maximum speeds. Energy consumption values for the circled cases were computed as follows (the value for energy consumption corresponding to 150 mph was interpolated):

Maximum Speed (mph)	Energy Consumption (kWh)
120	12,170
150	16,300
180	21,122
210	29,736

It is interesting to note how incremental reductions in trip time and corresponding incremental

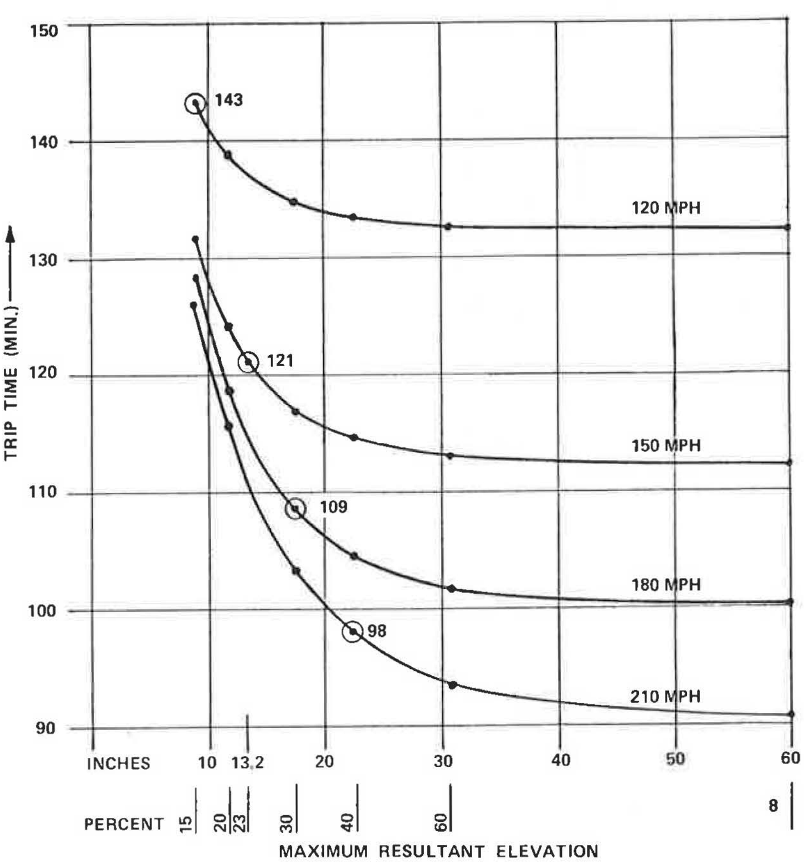

FIGURE 1 Trip time as a function of resultant elevation.

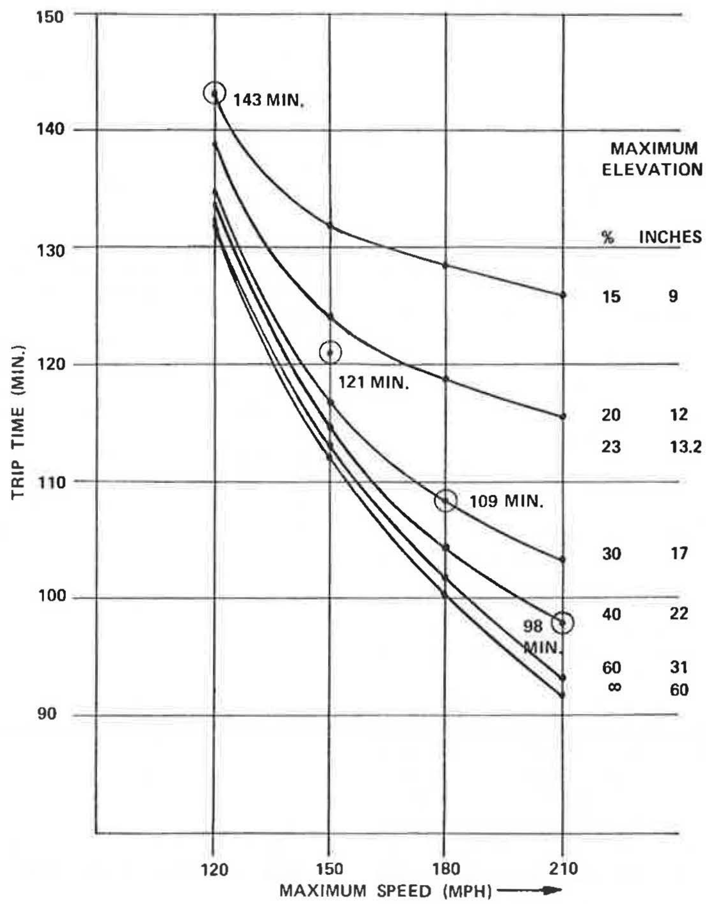

FIGURE 2 Trip time as a function of maximum speed for six values of resultant elevation.

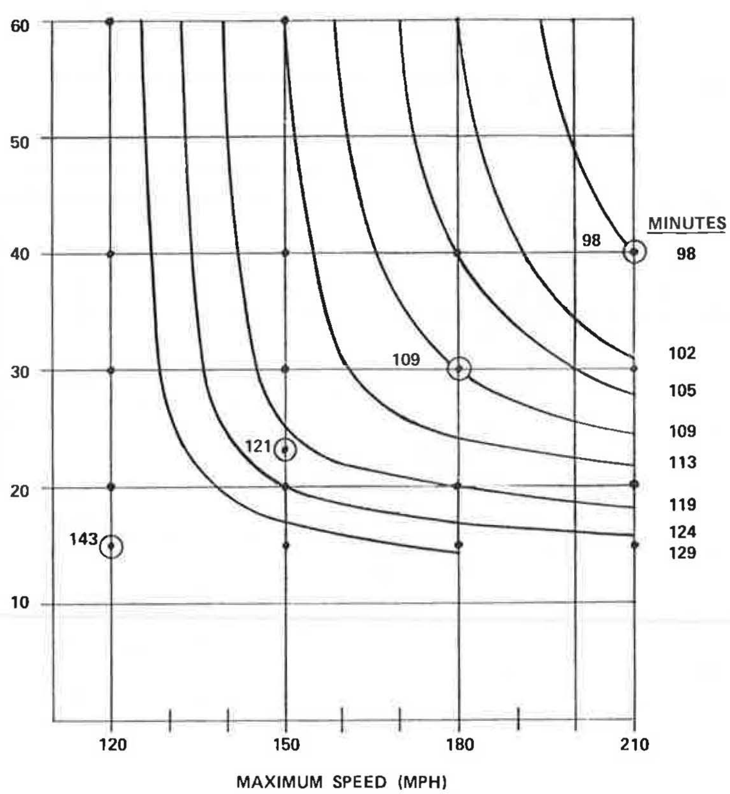

FIGURE 3 Superelevation as a function of maximum speed for fixed trip time.

increases in energy consumption compare. The relationship can be understood on an order of magnitude basis as follows. Assume that passengers who would use a premium train service are willing to spend an average of $20.00 to save 1 hour of travel time. (Passengers who now choose a Metroliner instead of a conventional train from New York to Washington spend an additional $9.00 and save about 36 min. To the extent that those passengers are paying for speed, they are valuing their travel time at $15.00 per hour. Those who prefer to pay for the Metroliner instead of an excursion fare by conventional train are valuing their travel time at $30.00 per hour. Patrons of a service providing trip times significantly shorter than those of the current Metroliner service presumably would place higher values on their time.)

Assume that a 12-car train carries an average of 600 passengers. Then trip time reduction has a value of $100.00 per minute per one-way trip. Assume that the cost per kWh of electrical energy delivered to the pantograph of a train is $0.08; then a table can be set up to compare incremental time and energy values per one-way train trip as follows:

Speed Change (mph)		Time Saved	Value of Minutes	Added	Cost of kWh
From	To	(min)	($)	kWh	($)
120	150	22	4,400	4,130	330
150	180	13	2,600	4,822	390
180	210	10	2,000	8,614	690

Energy is only one of many costs that vary with maximum speed. Some costs such as crew labor and vehicle cleaning decrease slightly with increasing speed. However, track structure, wayside power fixtures, and vehicle costs increase with maximum speed. If the cost factors assumed previously are reasonable, the increase in value of service if maximum speed is raised from 180 mph to 210 mph may or may not exceed the cost of the increase in energy usage by enough to also cover the additional capital and maintenance costs. The results would be more favorable to higher speeds if the low wind resistance values reported by the French were adopted.

A PROPOSED GOAL

On the basis of the information presented in this paper, it is argued that the U.S. passenger rail community should begin to develop a proposal for a new service between New York and Washington with parameters in the following ranges: maximum speed--180 to 210 mph; resultant elevation--17 to 22 in.; and trip time with four intermediate stops--110 to 100 min.

Design of the equipment should benefit significantly from Japanese and French experience. However, this service would introduce something new in that it would deal with curvature through engineering rather than through land acquisition that would be environmentally disruptive and economically burdensome.

Although the use of conventional steel wheels on steel-rails for support and traction is generally presupposed in this paper, the basic questions being considered here would apply equally to use of a magnetic-levitation system. That is, a magnetic-levitation system design must also deal with existing curves and with the cost of energy to overcome increasing wind resistance as speed is increased. If use of steel wheels on steel rails could not demonstrate adequate dynamic stability, durability, or adhesion, then use of magnetic levitation would have something definite to offer. However, for speeds up to 210 mph, use of steel wheels on steel rails has been found to be adequate in all three respects.

The question that remains is whether a resultant elevation in the 17 to 22 in. range is practical.

ACHIEVING RESULTANT ELEVATIONS OF 17 TO 22 INCHES

The superelevation of the track itself traditionally has been limited by the requirements that (a) a train be able to stop anywhere and (b) there should be no inconvenience when a train stops on a curve. Track superelevations have been a maximum of 6 to 7 in. partly because passengers are uncomfortable if a train stops on a curve with higher superelevation and partly to minimize the possibility of high center-of-gravity cars being overturned by strong side winds. Speeds for conventional passenger trains are usually set to limit running unbalance to 3 in. to achieve ride comfort. The discomfort that is encountered with running unbalance above 3 in. is due to the lateral suspension being held against the end of its travel and thus being unable to isolate irregularities in the alignment of the rails.

A desired resultant elevation can be achieved by using any one of a range of combinations of track superelevation and running unbalance. The unbalance is given in terms of other quantities by Equation 1:

$$U = G[\tan(R)\cos(S) - \sin(S)] \quad (1)$$

where

- R = angle of resultant elevation (i.e., superelevation angle that would give zero unbalance);
- S = angle of actual superelevation of the track;
- G = track gauge between wheel-to-rail contact points (conventionally 60 in. for standard gauge); and
- U = running unbalance (inches of track elevation on which a stationary car would experience the same lateral force as it experiences while traversing the actual curve at the design speed).

The following table gives examples of combinations of track superelevation and running unbalance all of which yield a resultant elevation of 22.3 in. [tan(R) = 0.4].

Superelevation (in.)	Unbalance (in.)
11.8	11.8
14.0	9.3
16.2	6.9
18.3	4.6
20.3	2.3
22.3	0.0

So far, most efforts to achieve higher resultant elevations have been based on increasing the permissible unbalance. Danger of a vehicle overturning is controlled by reducing the height of the center of gravity of the vehicle. Discomfort that passengers would otherwise feel is reduced by making the vehicles lean into the curves and by preventing the main lateral suspension from going to the end of its travel. This general approach is usually referred to as body tilting. It is exemplified by the Spanish Talgo train, the United Aircraft Turbo Train, the British Advanced Passenger Train, and the Canadian LRC (Light Rapid Comfortable) train.

Referring to the previous table, a tilt body solution could use 14 in. of track superelevation and 9.3 in. of running unbalance. Body tilting could neutralize up to 8 in. of unbalance so that passengers would routinely experience 1.5 in. of unbalance; passengers could, however, experience up to 6 in. if a train were to stop on a fully elevated curve for some reason. The center-of-gravity height would need to be kept down to about 47 in. with (a) standard gauge, (b) the traditional "middle-third" rule for overturning safety relative to the high sides of curves, and (c) center-of-gravity lateral movement limited to 2 in. This 47-in.-height is only a few inches lower than that of the original Metroliners. For this solution, the resulting gravitational force vector for a car stopped on a curve with 14-in. elevation would be about 16.5 in. to the inside of the low rail rather than the traditional minimum value of 20 in. However, dynamic forces at very low speed would be negligible, and danger from crosswinds could easily be countered by means of wind screens along the outsides of fully elevated curves.

Although the tilt body approach is well-known and generally accepted, there is a second approach that deserves consideration. This approach provides about 19 in. of actual superelevation, operates trains at about 3 in. of unbalance, and arranges signaling and dispatching so that a train would never enter a highly elevated curve unless it were cleared to go through the curve at design speed. There might still be rare cases in which a train was forced to slow down or stop unexpectedly. Protection against vehicle overturning in such cases would be provided by a combination of low center of gravity, wider track gauge, and wind screens on the outsides of curves.

Stewardesses would direct any standing passengers to be seated during the period of slowdown. Passengers would be disconcerted but would not be harmed. The possibility of rare occurrences of this kind is accepted by airline passengers, who learn at the beginning of every flight about the location of life jackets, emergency exits, emergency slides, and emergency oxygen, and who are accustomed to pressure changes that cause ear pain for some people. In the rare cases in which planes encounter strong clear air turbulence, passengers are shaken and occasionally injured. However, the basic intent for the proposed high-speed rail service is to conduct maintenance and operation so that slowdowns in highly elevated curves are rare.

The benefits of this second approach to achieving resultant elevation in the 22-in. range are that the vehicles would be simpler and lighter and that wheel and rail wear would be reduced.

The author's preference is the second approach. However, the main purpose of this paper is to encourage the beginning of a program to define, develop, and test a new dedicated track system that can follow the existing alignment between New York and Washington and provide for operation at a maximum speed between 180 and 210 mph.

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High-Speed Passenger Train Safety

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ABSTRACT

The current resurgence of high-speed rail passenger studies in the United States centers around foreign equipment with operating speeds significantly higher than those permitted by the Code of Federal Regulations. It is necessary to develop criteria and standards for a new generation of rail-passenger and magnetically levitated equipment and systems. Their quality must be consistent with the quality of the existing U.S. safety record. A series of technical workshops should be held to establish such new criteria and standards. The issues to be addressed would include structures and standards for tracks and guideways, grade-crossing protection, crashworthiness of vehicles, electrification, rolling stock, and improved emergency procedures. Because a wide variation in both design philosophy and construction criteria exists between U.S. and foreign equipment, it is essential to arrive at a technical consensus before establishing requirements and regulations.