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**Federal Railroad
Administration**

X2000 U.S. DEMONSTRATION VEHICLE DYNAMICS TESTS FINAL TEST REPORT

Office of Research and
Development
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Final Report

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In numerous places, this report discusses whether various aspects of the technology that is the subject of this report comply with Federal safety laws and regulations. Those discussions, which reflect the seasoned judgment of commentators qualified in their fields, do not constitute rulings by the Federal Railroad Administration's Office of Safety or its Office of Chief Counsel concerning compliance with the law.

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13. ABSTRACT (Maximum 200 words)

This report documents the procedures, events, and results of vehicle dynamic tests carried out on the ASEA-Brown Boveri (ABB) X2000 tilt body trainset in the U.S. between October 1992 and May 1993. These tests, sponsored by Amtrak and supported by the FRA, were conducted to assess the suitability of the X2000 trainset for operation at elevated cant deficiencies and speeds in Amtrak's Northeast Corridor under existing track conditions in a revenue service demonstration.

The report describes the safety criteria against which the performance of the X2000 test train was examined, the instrumentation used, the test locations, and the track conditions. Results are presented from tests conducted on Amtrak lines between Philadelphia and Harrisburg, PA, and between Washington DC and New York NY, in which cant deficiencies of 12.5 inches and speeds of 154 mph were reached in a safe and controlled manner. The significance of the results is discussed. Conclusions and recommendations are presented.

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PREFACE

Several advanced intercity high-speed train technologies have become an operating reality overseas in recent years. Though of foreign origin, these new trains have potential for immediate application in the United States to lessen trip times and improve ridership. Each high-speed train has been developed to meet the particular operating environment and in accordance with the parent country's transportation policy. Therefore a candidate train must be evaluated with regard to applicability to U.S. practices and expectations to ensure that safety levels are maintained in the U.S. environment. The responsibility for such evaluation rests with the Federal Railroad Administration (FRA), U.S. Department of Transportation (U.S. DOT), which is charged with ensuring the safety of rail systems in the United States under the Federal Railroad Safety Act of 1970, as amended.

The Swedish X2000 tilting train, manufactured by ASEA-Brown Boveri (ABB), offers potential for application over the existing rail infrastructure. For evaluation purposes, a representative X2000 trainset was provided to Amtrak by the Swedish State Railways (SJ) for test and revenue service demonstration in the U.S. Northeast Corridor. A cooperative test effort was conducted under the direction of Amtrak and supported by the FRA Office of Research and Development, with test instrumentation supplied and operated by SJ, data analysis support provided by ABB, and test monitoring maintained by the FRA Office of Safety. Based on the results of the performance testing, the trainset was entered into a revenue service demonstration.

This report describes the procedures and results of the vehicle dynamics tests carried out with the X2000 trainset in the Northeast Corridor and on the Philadelphia - Harrisburg line, during the time period between October, 1992, and March, 1993. Instrumented wheelsets, installed on both the power car and cab car ends of the trainset, provided direct and immediate measurement of the wheel/rail forces experienced during high speed and high cant deficiency operation. In order to attain maximum speeds in tangent and curved track, the tests were conducted incrementally, with analysis of forces and accelerations evaluated against safety criteria during and at the conclusion of each test run before proceeding to the next stage.

The authors wish to thank Arne Bang and Thomas Schultz of the FRA Office of Research and Development, for their direction and support in realizing the test and demonstration. Valuable information during the test program and in the preparation of this document was provided by Amtrak, under the direction of Ed Lombardi, by Al Shaw, Michael Trosino and Conrad Ruppert.

The authors also wish to thank Al MacDowell and William O'Sullivan of the FRA Office of Safety, and Herbert Weinstock of the Volpe National Transportation Systems Center for their careful monitoring and judgement in the progression of all tests.

In the conduct of tests, the personnel of ABB Traction, lead by Jan-Olof Häggblad and Roger Nilsson, and the personnel of SJ, lead by Lennart Kloow and Martin Bäfverfeldt are gratefully acknowledged for their careful preparation, proficient data collection and presentation.

Finally, the authors wish to thank Thomas Edwards of ABB Traction for his thorough, informed analysis and interpretation of the test data and valuable discussions throughout the program.

X2000 U.S. DEMONSTRATION VEHICLE DYNAMICS TESTS
FINAL TEST REPORT

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EXECUTIVE SUMMARY

The U.S. Federal Railway Administration (FRA), Amtrak, ABB, and the Swedish State Railways (SJ) conducted a test and demonstration program to evaluate the X2000 trainset under North American conditions, with particular emphasis on the applicability to U.S. safety practices. SJ provided a representative X2000 trainset to Amtrak for the evaluation, which took place primarily in the U.S. Northeast Corridor (NEC). This program involved the following key elements:

- Safety Criteria Determination - to establish the required safety criteria and guidelines on which to assess the vehicle performance and determine safe operating limits, during testing and revenue service operations
- Waiver Petition and Requirements - to test and operate the trainset under conditions not fully compliant with current U.S. federal regulations, but always within the established safety limits
- Pre-Test Safety Assurance - to predict the safe performance limits of the test trainset through simulation and analysis prior to testing, such that limits were not exceeded and were approached incrementally during the test
- Commissioning Tests - to confirm operational readiness of the test trainset
- Cant Deficiency Tests - to establish safe curving limits
- High Speed Stability Tests - to establish maximum safe speed
- Pre-Revenue Service Demonstration Runs - to demonstrate the safe operating limits established for the intended revenue service operation
- Revenue Service Demonstration - to assess the trainset operation and performance in revenue service
- National Tour - to assess and expose the vehicle to a wide range of conditions

Safety criteria were established to assess the risk of vehicle derailment through vehicle overturning, wheel climb, track panel shift, rail rollover, and truck instability. The principal focus of the dynamic tests, based on the design features of the X2000 trainset, was on curving performance and safety at higher speeds and cant deficiencies. The FRA Safety Board granted a conditional waiver with strict guidelines to test and demonstrate the equipment at speeds and cant deficiencies greater than currently permitted within the Code of Federal Regulations.

The test trainset, modified for operation in the U.S. infrastructure, was commissioned in Washington, DC, in early November, 1992. Commissioning tests assured adequate braking, safety from electromagnetic interference, and adequate clearances from wayside structures. Brake stop distance tests, from speeds of 30 mph to 135 mph, showed that the X2000 braking performance was well within the acceptable envelope established for Amtrak's NEC signaling system.

High cant deficiency and high speed stability tests were conducted to provide an estimate of the limits of safe performance under conditions that were more extreme than those to be used in the subsequent revenue service demonstration. These tests were conducted under the direction of Amtrak and supported by the FRA Office of Research and Development. Test instrumentation was supplied and operated by SJ, data analysis support was provided by ABB, and test monitoring was maintained by the FRA Office of Safety. Instrumented wheelsets, installed on both the power car and cab car ends of the trainset, provided direct and immediate measurement of the wheel/rail forces. In order to attain maximum speeds in tangent and curved track, the tests were conducted incrementally, with analysis of forces and accelerations evaluated against safety criteria during and at the conclusion of each test run before proceeding to the next stage.

The tests were conducted over specific test zones on Amtrak's Philadelphia - Harrisburg Line between Parkesburg and Lancaster, PA, and on the NEC between Trenton and Newark, NJ, over a time period from 30 November to 12 December. Specific test curves chosen for detailed analysis ranged from 1.5° to 4.2° curvature, which gave a cant deficiency of 12 inches at speeds ranging from 77 mph to 134 mph respectively. Trials were carried out in each of these selected curves at up to 12 inches of cant deficiency or at a maximum of 125 mph, whichever limit was reached first. The test runs were made in conditions varying from dry to wet and with the tilt activated and deactivated on separate runs.

During 42 cant deficiency test runs, from which 156 curve transits were analyzed, no safety criterion was exceeded. The highest average cant deficiency recorded through an entire curve during trials was 12.5". During 6 high speed stability runs on tangent track between Trenton and New Brunswick, NJ, the maximum speed recorded was 154 mph. No truck instability was observed during the tests. Fully instrumented test runs concluded with two pre-revenue-service, round trip demonstration runs between Washington, DC, and New York, NY, 14-15 December, at speeds to 125 mph and cant deficiencies to 9 inches. The X2000 was also demonstrated, in tow, over Amtrak's NEC Mainline between Boston, MA and New Haven, CT, 12-15 January, 1993, at cant deficiencies up to 8 inches.

Following successful completion of all tests and a review of results, the FRA granted approval for revenue service operation of the tested X2000 trainset in the NEC at speeds up to 135 mph in selected locations and cant deficiencies up to 9 inches. The X2000 trainset was entered into revenue service between Washington, DC and New York, NY, 1 February 1993.

Key results from the overall test program which provided the basis for establishing these safety limits are listed below:

- Over the Harrisburg Line and NEC test zones, the peak dynamic responses for the safety relevant parameters never reached more than 92% of the stop test criteria at up to 12" of cant deficiency.

- A linear projection of the exhibited trends, for the conditions tested, suggested that the X2000 would not exceed any safety criterion in the test curves for cant deficiencies up to 15 inches.
- Test results showed the X2000 radial truck to be effective in transferring lateral loads from the high rail to the low rail and between axles at elevated cant deficiency. Vertical load transfer and vehicle overturning were effectively controlled by the truck design that incorporates a roll stabilizer.
- Test runs carried out at 9 inches of cant deficiency with normal tilting and with tilting de-activated showed little or no difference in the measured wheel/rail forces and the derailment related safety parameters.
- The effects of wet rail conditions and lower adhesion levels were not pronounced.

In establishing the limits, the effects of side wind, track condition variance, speed variance, and vehicle condition were other factors, not evaluated during the test, that were considered to affect the margin of safety for high cant deficiency operation. Operation at 9 inches of cant deficiency based on average geometry might, in worst case conditions, produce a total equivalent cant deficiency of just below 15 inches.

Based upon the experimental work and the results, the following conclusions were drawn:

- 9" cant deficiency operation can be safely achieved on NEC track
- 10" cant deficiency operation can be permitted for selected curves with good track structure and geometry
- 135 mph operation can be permitted in locations where track structure, geometry and rail profile are good
- Track structure and geometry should be monitored before revenue service begins, 1 week after service has been in operation, and henceforth on a monthly basis to examine for changes, particularly in the high cant deficiency and high speed zones
- Vehicle wheel profiles and damper elements should be monitored for condition on a monthly basis
- Operation should be limited to 5" cant deficiency when wind conditions exceed 45 mph
- Specifics of engineer training should be considered, and precise control of overspeed may be required

1. INTRODUCTION

1.1 BACKGROUND

The Federal Railroad Administration (FRA) is evaluating technological advances made in railroad passenger transportation in Europe to determine the applicability of this technology in the United States. It is the responsibility of the FRA to assure the safety of rail systems in the U.S. under the Federal Railroad Safety Act of 1970. A number of high speed integral trainsets are in operation in Europe, or in the final stage of development. Examples of such trains are the diesel powered InterCity 125 and the electric InterCity 225 of British Rail, the French TGV, the German ICE, the Italian Pendolino and the Swedish X2000. A series of reports, including "Safety Relevant Observations on the X2000 Tilting Train," were prepared based upon brief visits and literature reviews sponsored by the FRA, which provided a brief description of high speed systems being considered for use on new passenger service lines by regional transportation authorities.

Concurrently Amtrak has been searching for new passenger equipment to replace its aging fleet for its existing passenger routes and to satisfy the increasing demand of the United States public for modern high speed ground transportation. Amtrak is particularly interested in the possibility of operating passenger trains at higher speeds than are presently permitted. The fastest existing Amtrak train, the Metroliner, is limited to a line speed of 125 mph on the Northeast Corridor (NEC). The Metroliner, as presently configured, consists of a train of 85 foot, lightweight stainless steel passenger cars pulled by an AEM-7 electric locomotive.

The Swedish X2000, developed by ASEA-Brown Boveri (ABB), incorporates radially steered trucks to minimize wheel/rail forces and an active tilting mechanism to sustain passenger comfort while travelling in curves at speeds significantly higher than balance. These are valuable features when operating high speed trains on existing track alignments. Amtrak wished to explore the potential of the X2000 concept in the United States. Accordingly, one X2000 trainset was leased from the Swedish State Railways (SJ) for test and demonstration under American conditions. A cooperative effort was initiated with ABB, Amtrak, and SJ to help identify potential concerns of the FRA's Office of Safety in implementing the procedures for the demonstration and to help identify technical data that can be applied to address these concerns.

The testing and demonstration of the X2000 tilting train described in this report is part of the research being conducted by Amtrak to prepare for specification and acquisition of a modernized rail passenger car fleet. In this program, the approach to proving safety was to first conduct a test program which provided an estimate of the limits of safe performance under conditions that were more extreme than those to be used in the demonstration. Based on the test results, limits and procedures for the demonstration program, carrying paying passengers, were established. The test program, using instrumented wheelsets and other instrumentation, was conducted in carefully controlled increments. The test proceeded incrementally from known safe conditions to increasingly severe conditions. At each step, the data was carefully evaluated against established safety conditions and used as the basis for the next test condition.

1.2 TEST AND DEMONSTRATION OBJECTIVES

In order to evaluate the safety of the X2000 trainset in operations on United States track typical of Amtrak operation, special testing was conducted to provide data to establish the range of safe operation, providing a basis for Amtrak to request a waiver from the FRA for conduct of their in-service evaluations.

The objective of the demonstration was to provide an opportunity for Amtrak staff, government personnel and the American public at large to evaluate, inspect and ride on the X2000 trainset in the Northeast Corridor. The primary objective of the test program was to determine that the X2000 trainset was safe while running in the United States. The second objective of the test program was the determination, evaluation and assessment of the performance of the X2000 concept generally with particular reference to the future requirements of Amtrak.

1.3 TEST PROGRAM SUMMARY

The evaluation program for the X2000 trainset involved a series of different technical tests followed by two demonstration revenue service operations. Each test in sequence was dependent upon successful completion and analysis of the performance from previous tests.

The overall test sequence was as follows:

1) Commissioning - to confirm operational readiness.
2) Cant Deficiency - to establish safe curving limits.
3) High Speed Stability - to establish maximum safe speed.
4) Demonstration Revenue Service Runs - to demonstrate the safety of the intended revenue service operation.

Commissioning Tests in Northeast Corridor

The purpose of the commissioning tests was to confirm operational readiness, up to a speed of 125 mph, with particular interest in:

1- Propulsion systems
2- Safety equipment (i.e.- lights, horns, etc.)
3- Brake systems and stop distances
4- Cab signal system

Operational checkout was also performed by Amtrak for:

- Tight switch/curve negotiation
- Clearances
- Ride quality of a coach and locomotive
- Basic vehicle stability
- Electromagnetic Interference (EMI), including that during regenerative braking
- Pantograph uplift forces
- Acceleration/current draw and transformer in-rush current.

(NOTE: Interior and wayside sound level, stop distances, and wheel and disc temperatures were assessed using data provided by ABB).

Cant Deficiency Tests

Test runs from 3" to 12" cant deficiency were conducted over a test zone between Harrisburg and Philadelphia, PA. Curves between MP 44 to MP 68 were identified as suitable test candidates. Test runs from 7" to 12" cant deficiency were made on the Northeast Corridor (NEC) between New Brunswick and Metro Park, NJ.

No safety criteria were exceeded during these tests over representative track; results are described in **Section 5.**

High Speed Stability Tests

Tests of high speed stability were conducted on the NEC mainline east of Trenton, NJ, between MP 34 and MP 54. Tests were scheduled to a maximum speed of 150 mph. Stop distance checks, using air brakes only, were conducted during runs at which speeds of 135 mph and 152 mph were achieved. No truck instability was observed during these tests.

Pre-Revenue Service Demonstration Runs - Round Trip Washington to New York City

Based on the results of the cant deficiency and high speed tests, Amtrak submitted a recommended revenue service speed profile for the X2000 in the NEC between Washington, DC, and New York, NY, for approval by the FRA. This proposed cant deficiency/ speed profile was evaluated in two fully-instrumented round trip test runs between Washington and New York City. The first test was undertaken at cant deficiencies up to a 9 inch maximum and speeds to 125 mph. To assess the effects of overspeed, the second test run was conducted with the speed profile increased by 5 mph; however the 125 mph maximum line speed was not exceeded.

The instrumented wheelsets were replaced with conventional wheelsets following these runs. Results from these tests served as a basis for approving the revenue service demonstration of the X2000 trainset in the NEC between Washington and New York City at cant deficiencies to 9 inches and speeds to 135 mph.

New York to Boston Demonstration

Before introduction into revenue service, the X2000 was operated on the heavily curved region of the NEC between New York City and Boston, MA. Demonstration runs were conducted at a maximum of three inches cant deficiency on Metro North track and eight inches of cant deficiency elsewhere. The trainset was powered by two Amtrak Rohr Turboliner (RTL) power cars on the non-electrified territory between New Haven, CT, and Boston.

Revenue Service Operation

Following successful completion of the tests described above and a review of results, approval was given by the FRA for revenue service operation of the X2000 at speeds up to 135 mph in selected locations and cant deficiencies up to 9 inches. Pre-revenue round-trip check runs were made at Amtrak's intended speed profile, and the X2000 was placed in service in the Northeast Corridor between New York City and Washington from 1 February, 1993 until 10 April, 1993. Service was then extended to New Haven on Metro North track until mid May, 1993.

National Tour

The X2000 trainset was taken on a nationwide demonstration tour, from 26 May until 21 July, 1993. The trainset was towed by RTL power cars in the Empire corridor in New York State, and by conventional F40PH diesel-electric locomotives over the remainder of the country.

1.4 TEST REPORT OBJECTIVES AND ORGANIZATION

This test report documents the process, procedures, events, and results from the test program required to support Amtrak's request for FRA approval to demonstrate and operate an X2000 trainset in revenue service.

Preparations for the test, including the waiver process, train modifications and configuration for the U.S. demonstration, shipping and unloading of the trainset, and the commissioning tests are given in **Section 2.**

The safety and stop test criteria established for the X2000 trainset test, together with pre-test dynamic analysis and predictions of safety assurance, are given in **Section 3.**

Vehicle performance tests, procedures and test locations, are described in **Section 4,** and results of test runs on the Philadelphia - Harrisburg line and in the Northeast Corridor between Washington and New York are given in **Section 5.**

The significance of the results is discussed in **Section 6,** and recommendations and conclusions are presented in **Section 7.**

2. TEST PREPARATION

A test program was planned to meet the stated objectives and provide estimates of the limits of safe performance of the X2000 trainset in the U.S. Test preparations included: provision of sufficient information to enable Amtrak to petition the FRA for a waiver to test and demonstrate the X2000 under conditions exceeding criteria currently permitted; essential modifications to the trainset for compatibility with Amtrak's operating environment in the U.S.; safe shipment of the trainset from Sweden to the U.S.; and commissioning tests to initiate operation in the U.S.

2.1 WAIVER PROCESS

The X2000 trainset employs different equipment and operating procedures than those customarily seen in the U.S. It was not practical, and in some cases, not possible to bring the trainset into full compliance with all the requirements of Section 49 of the Code of Federal Regulations. In addition, test and demonstration of the equipment was requested at speeds and cant deficiencies greater than are presently permitted within the Code. As a result, a waiver of some requirements by the FRA was necessary before the train could be operated for test purposes in the United States.

The subject areas included in the waiver for the X2000 trainset, the applicable regulation numbers, and details of the procedure for requesting, processing, and obtaining the waiver are given in **Appendix A.**

In summary, the test sponsor, Amtrak, petitioned the FRA for the necessary waiver. Based on the text of the petition, the FRA published a notice in the Federal Register which provided information regarding the receipt of the petition, its content, and an explanation of how the FRA proposed to ensure safety during the tests.

Taking into account any comments received, the FRA prepared a brief for consideration by the FRA Safety Board. The brief provided complete details of the tests proposed, described measures to be taken to minimize the risk of an accident, and gave the justification for such measures. The brief also described measures taken by Amtrak to ensure that performance limits of the test trainset had been estimated through analysis prior to testing, and that, as these limits were approached incrementally during the test operations, test direction personnel were provided the opportunity to terminate testing if one or more limits were likely to be exceeded.

Subsequently, the Board approved the petition and Amtrak was then able to proceed with the tests as proposed, while adhering precisely to the conditions stated in the notice of approval and under the critical observation of an FRA test monitor.

The test sponsor prepared a detailed test plan which included the following items:

a. Test objectives; one objective was confirmation of the test trainset performance as predicted analytically.

b. Test procedures, including data to be collected, instrumentation to be employed, data analysis techniques to be used and the general test methodology.

c. Test safety constraints, including consideration of the safety requirements of previous cant deficiency testing and the applicable conditions contained in the FRA test approval document.

d. Recognition of the need to prepare clear and precise train operating instructions for locomotive engineers that give the speed restriction for each particular curve, based on the analysis of data from a track geometry measurement car, including curvature and superelevation data.

e. Designation of responsibilities.

f. Test schedule.

Testing was undertaken in two stages, the first of which was to confirm the general dynamic behavior of the train as predicted by the simulations. This data was reviewed by FRA staff before further testing was undertaken. The second stage consisted of full-scale testing of train performance, within the limitations specified.

Before the test trainset was operated in revenue service, a second petition was filed by Amtrak for a waiver of the applicable FRA regulations. The receipt and contents of this petition were again published in the Federal Register. Subsequently, the FRA Safety Board issued a favorable ruling on the petition.

2.2 TRAINSET MODIFICATIONS

Several changes and modifications were made to the leased X2000 trainset in order to operate the equipment in the U.S. infrastructure. The majority of these changes were made at ABB's facility in Västerås, Sweden, before shipment to the U.S.

2.2.1 Electrical and Control System

Electrical modifications included changes to the power collection and propulsion systems to accommodate the 11 kV, 25 cycle catenary on Amtrak's NEC and Philadelphia - Harrisburg, PA lines, and the 12.5 kV, 60 cycle power on Metro North track to New Haven, CT. Amtrak's cab signalling equipment was also installed. Control and communication capabilities were implemented such that the RTL locomotives, when coupled and used for propulsion, could be commanded from the X2000 trainset.

2.2.2 Adapter Coupler

An adapter coupler was installed on the X2000 trainset for coupling to a conventional locomotive when required for yard movements or propulsion in non-electrified regions. The adapter coupler connected to either a type "E" or a type "H" tightlock coupler.

The nominal yield strength of the adapter coupler was on the order of 224,000 lbs. The speed of the locomotive at coupling should not be greater than 1.86 mph in order that the strength of the adapter coupler not be exceeded.

The adapter coupler was used to couple a pair of Amtrak's Rohr Turboliner (RTL) power cars to the X2000 trainset for propulsion during the test runs between Boston and New Haven and during the National Tour.

2.2.3 Wheel Profile

The wheelsets of the X2000 test trainset were provided throughout with ABB's "S1002" wheel profile incorporating a thin 30mm flange. This profile was chosen by ABB to approximate the AAR 1B profile and to provide:

- o Adequate conicity and thus steering of the wheelsets in curves
- o Stable running at speed even on sections of tight gauge (not less than 1428mm)
- o A stable wheel profile which should not change significantly with wear

The X2000 wheel profile was checked by superimposing it on the standard wheel profile used by Amtrak's passenger equipment. The Amtrak wheel profile is identical to the AAR wheel profile, with the exception of the tread taper being modified from 1:20 to 1:40. The comparison showed the X2000 and Amtrak profiles to be very similar, and the X2000 wheel profile was approved for use on the Amtrak system.

ABB evaluated the suitability of this wheel profile to conditions on the North East Corridor (NEC) for the 140 RE rail profile. Analyses were done using a "new" rail profile and using actual worn rail profiles measured on Track #4 of the Harrisburg Line in curves 662 (Gap) and 663 (Eby's), and on NEC tangent track where speeds up to 150 mph were expected. The combination of wheel profile on new rail was predicted to provide adequate self-steering capability of the wheelsets for all track gauges before the onset of flange contact. For the worn rail profiles measured in curves, the analysis predicted low equivalent conicities that would partly remove some self-steering capability of the wheelsets but not affect the margin of safety significantly. The measured profiles on tangent track indicated that rail heads were worn slightly flatter than new 140RE rail. This could lead to equivalent conicities up to about 0.4 on tighter gauge track, but the critical speed for truck hunting would still be well above 150 mph for this condition. The analysis did conclude that a wheel profile more suited to the prevailing U.S. rail conditions should be considered in future.

A more detailed description and analyses of the probable wheel-rail combinations met during tests on the Harrisburg Line and for nominal conditions in the U. S. was given in ABB's Report TRP 9224, Section 3.3.

2.2.4 Instrumented Wheelsets

Four instrumented wheelsets, with wheels profiled as discussed above, were installed on the X2000 trainset before shipment to the U.S., two on the locomotive and two on the driving trailer or cab car. The instrumented wheelsets were without brakes, and are further described in **Section 4.1**.

2.3 SHIPPING AND UNLOADING

The X2000 trainset was conveyed by boat from the Swedish port city of Gothenburg, 4 October, 1992, and arrived at Dundalk Marine Terminal at the port of Baltimore, MD, 20 October, 1992. Over a two day period, the vehicles of the X2000 trainset were unloaded individually and assembled into a trainset at the dock-side track served by Conrail. After a brake test was performed, the trainset, pulled by an Amtrak diesel locomotive, was moved, 22 October, 1992, onto Amtrak trackage in Baltimore where the pantograph was raised and checked. The trainset was then pulled to Union Station in Washington, DC, for final preparations and commissioning.

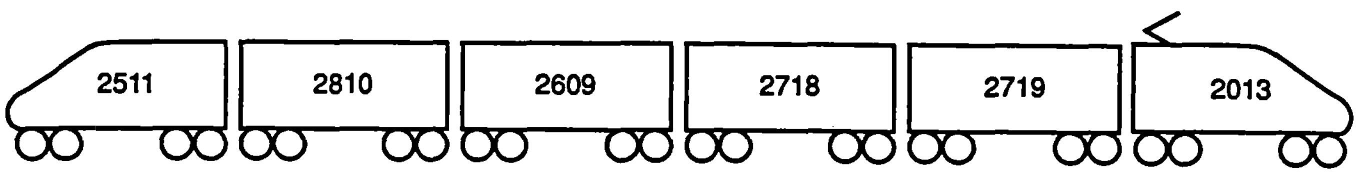
2.4 TRAIN CONFIGURATION

The X2000 trainset used during the tests was a 6-vehicle consist as indicated below. Each car was equipped with radially steered trucks and, with the exception of the locomotive, an active tilting mechanism. Car heights and widths were approximately 3.8 m (12.5 ft) and 3.1 m (10.1 ft) respectively.

CAR TYPE	CAR MODEL NO.	CAR NO.	CAR LENGTH
Locomotive	X2	2013	17 m (56 ft)
Coaches	UA2	2719	24.4 m (80 ft)
	UA2	2718	"
	UA2	2810	"
First-Class Buffet	UAR2	2609	"
Driving Trailer (Cab Car)	UA2X	2511	22 m (72 ft)

UA2X + UA2 + URA2 + UA2 + UA2 + X2

Driving trailer + 1st Class Car + Bistro Car + 1st Class Car + 1st Class Car + Locomotive



Two Amtrak Rohr Turboliner (RTL) power cars were coupled to the X2000 trainset for motive power during test runs in the non-electrified territory between New Haven, CT, and Boston, MA.

2.5 COMMISSIONING TESTS

The commissioning tests described below consist of braking tests, clearance test and other tests, which cover twelve specific categories.

2.5.1 BRAKING

The braking system for the X2000 trainset consists of air, dynamic regenerative, and electromagnetic track brakes. Trucks on the coach cars and cab car contain two brake discs per axle for service braking, and two electromagnetic track brake elements per truck for emergency braking. The locomotive has disc brakes (pads contacting the rim on the inside of the wheels), regenerative dynamic braking, and tread brakes rather than magnetic track brakes. Service brake applications allow a choice between dynamic or blended air and dynamic braking.

During the technical tests, the four instrumented wheelsets were without braking. It should be noted as such that any stop distance measurements taken prior to 17 December 1992 were made without braking on 4 of the 24 axles.

As part of the commissioning of the X2000 trainset, proper braking performance was verified prior to cant deficiency and high speed testing. Brake stop distance tests were carried out between MP 81 and 84 in the vicinity of Gunpow interlocking north of Baltimore. The brake tests were made on Track #3 travelling south on a descending grade of 0.11% with the locomotive leading. The effect of the grade would be to increase stop times and distances by not more than 1% for passenger trains during full service or emergency braking. Stop distances were determined using a pulse counter in conjunction with a gear mounted adjoining a wheel under the cab car to measure the number of wheel revolutions.

Brake disc temperatures were measured at random to check that there was no overheating of the discs. All brake tests were carried out after sufficient time for the brakes and discs to cool. Service brake applications were made at speeds of 30 to 113 mph, both with and without regenerative braking. Emergency brake tests were undertaken for speeds from 32 to 114 mph. Three penalty brake tests, activated by the cab signalling system, were also performed as part of the commissioning from speeds of 45, 50, and 80 mph.

The results, included in **Table 2.1**, showed an average deceleration on the order of 0.10 g (2 mph/sec) for service braking and 0.15 g (3 mph/sec) for emergency braking. By measuring both stopping distance and stopping time, two values of average deceleration were calculated independently. Differences in the two values indicate that the braking force and deceleration were not constant but varied during the braking process.

After the commissioning period, other stop distance tests were performed and are included in this Section for completeness. During the high speed stability tests, on

8 December 1992, a stop test was conducted from a speed of 152 mph to confirm operation at high speed. The measured stopping distance indicated an average deceleration rate of 0.077 g (1.7 mph/sec).

Following removal of the instrumented wheelsets, a series of additional stop tests were conducted on 5 January 1993 at the same location and on the same track as for the commissioning runs. These tests were conducted using the **air brake equipment only** from speeds of 30 mph to 135 mph to ensure that stopping distances were within the allowable limits established for Amtrak's NEC signaling system. To simulate conditions for a fully loaded trainset, disc brakes on one axle were disabled.

Results of these tests are included in **Table 2.1**. A plot of the braking distances is shown in **Figure 2.1**, together with Amtrak's maximum braking distance specification, Amtrak Standard S-603. The maximum acceptable braking distance for unrestricted operation throughout the NEC signaling system is 7848 feet. The plot indicates the X2000 braking performance is well within the acceptable envelope for speeds up to 135 mph.

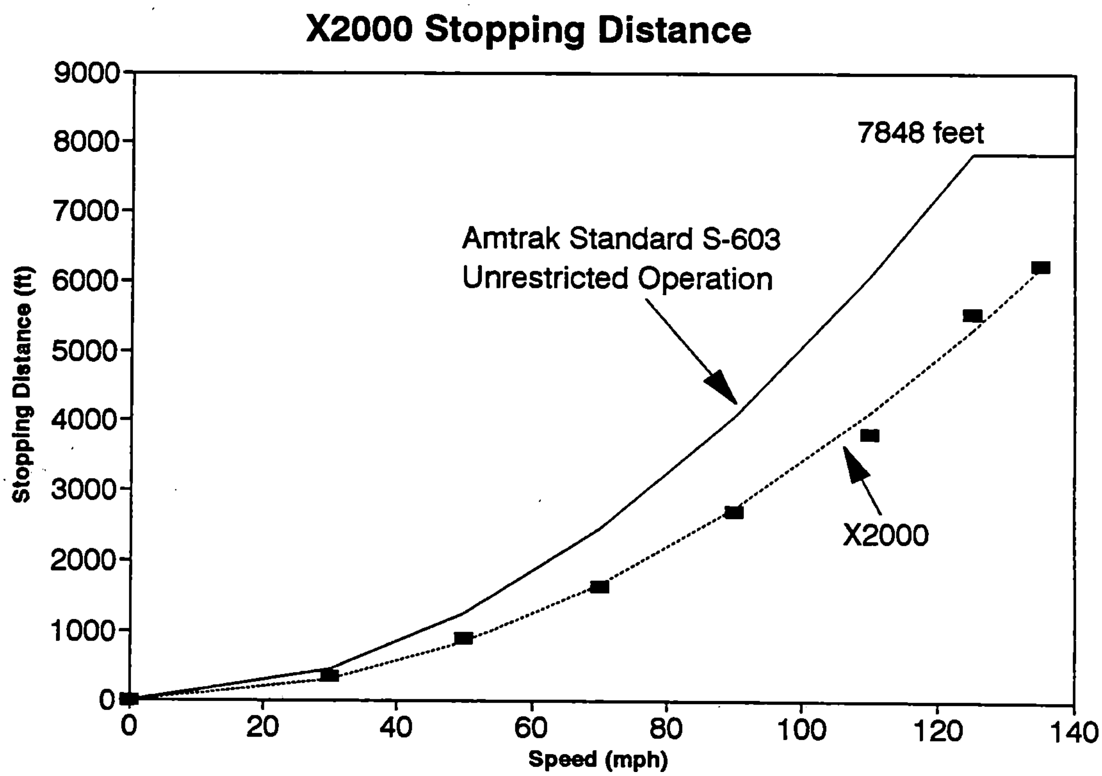


Figure 2.1: X2000 Stopping Distances, Air (Disc) Brakes Only

TABLE 2.1 SUMMARY OF X2000 BRAKING TESTS

Distance Measurement: Pulse Counter
Time Measurement: Watch, Hand Held

X2000 Normal Braking: Blend of Air Disc Brakes and Regenerative on Power Car
X2000 Emergency Braking: Air Disc Brakes, Tread Brakes, and Magnetic Track Brakes (No Regenerative except as noted)

Safety Requirement: Fail-safe, air brakes only
Brakes on 1 axle disabled to simulate fully loaded trainset condition

Date	Initial Speed		Service/	Stopping	Stopping Distance		Avg Deceleration [g] based on	
	mph	km/h	Emergency	Time [s]	ft	m	time v/t	distance $v^2/2d$
Nov 13	30	48	Service	15	420	128	0.091	0.072
	49	79	Service	23	922	281	0.097	0.087
	70	113	Service	31	1782	543	0.103	0.092
	89	143	Service	-	2834	864	--	0.093
	113	182	Service	56	4748	1,447	0.092	0.090
	32	51	Emergency	-	288	88	--	0.119
	50	80	Emergency	14	642	196	0.163	0.130
	69	111	Emergency	20	1226	374	0.157	0.130
	70	113	Emergency	23	1314	401	0.139	0.125
	90	145	Emergency	27	1659	506	0.152	0.163
	114	183	Emergency	36	3296	1,005	0.144	0.132
	114	183	Emergency (Regen On)	34	3383	1,031	0.153	0.128
Dec 8	151	243	Service	89	11339	3,456	0.077	0.067
Jan 5	30	48	Service	13	357	109	0.105	0.084
	50	80	Service	22	899	274	0.104	0.093
	70	113	Service	29	1641	500	0.110	0.100
	90	145	Service	34	2712	827	0.121	0.100
	110	177	Service	46	3825	1,166	0.109	0.106
	125	201	Service	58	5549	1,691	0.098	0.094
	135	217	Service	61	6250	1,905	0.101	0.097

2.5.2 CLEARANCES

Clearance verification was carried out at New York Penn Station. No problems were experienced.

2.5.3 OTHER TESTS

Other commissioning tests undertaken by Amtrak in readying the trainset for test and demonstration included:

1. Interior and exterior sound level.
2. Pantograph uplift forces.
3. Transformer inrush currents.
4. Input voltage wave shape.
5. Electro-magnetic interference.
6. Acceleration tests and current draw.
7. Tight curve negotiation.
8. Headlight intensity.
9. Cab signal system.

Dynamic testing began at the successful completion of the commissioning program.

3. SAFETY REQUIREMENTS AND ASSURANCE

The fundamental basis for safe operation at higher cant deficiencies and speeds is the satisfactory control of forces acting at and across the wheel/rail interface. Safety criteria are concerned with assessing the risk of vehicle derailment through vehicle overturning, wheel climb, track gage widening, including rail rollover and lateral deflection, lateral track panel shift and truck instability. Since a particular design feature of the X2000 trainset was the ability to traverse curves at high speed or cant deficiency, safe curving performance was a principal focus of the dynamic tests.

3.1 SAFETY CRITERIA

A total of four instrumented wheelsets were installed on the locomotive and the driving trailer (cab car) of the X2000 trainset to directly measure wheel/rail forces during the tests. The measured wheel forces were assessed against safety criteria established prior to testing based on experience, judgement, and previous tests conducted in the NEC[1]. The following parameters and limits were used to monitor all test operations:

1) **Track Panel Shift: Net Axle Lateral Force (NAL) < 0.5 x Static Axle Load**

- for the X2000 locomotive, NAL < 90 kN
- for the X2000 cab car, NAL < 78 kN

2) **Wheel Climb Derailment[2]: L/V Ratio (Nadal), Single Wheel < 0.8**

- conditions considered safe if each wheel L/V is less than 0.8; if any wheel exceeds 0.8, then:

  Axle Sum L/V Ratio (Weinstock) < 1.0
  - examine axle sum if single wheel L/V exceeds 0.8; conditions are considered safe if sum is less than 1.0

3) **Rail Rollover: Truck Side L/V Ratio (T-L/V) < 0.5**

4) **Vehicle Overturn: Minimum Vertical Wheel Force (Vmin) > 10% of Static Wheel Load**

- for the X2000 locomotive, Vmin > 9.0 kN
- for the X2000 cab car, Vmin > 7.8 kN

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[1] Railroad Passenger Safety, Report No. DOT-FRA/ORD-89/06, April 1989.

[2] A Review of Literature and Methodologies in the Study of Derailments Caused by Excessive Forces at the Wheel/Rail Interface, AAR Report No. R-717, December 1990.

5) **Truck Hunting: Truck Frame Lateral Acceleration < 0.8 g peak to peak**

- no peak-to-peak oscillations at or above this level should be sustained

Measurements of wheel/rail forces, safety parameters 1) through 4), were low-pass filtered at 25 Hz. Force transients occurring in time frames less than 40 milliseconds were not of primary interest. Measurements of truck frame lateral accelerations, parameter 5), were band-pass filtered at 2 - 8 Hz, the frequency range over which truck hunting might be expected to occur. The band-pass filter helped to discriminate truck hunting from high frequency shock loadings and vibrations and from low frequency steady-state curving accelerations.

During each test run, these safety criteria were monitored to ensure that none of the above limits were exceeded. Data projections had been used to minimize the likelihood that any safety limit would be exceeded. Prior to each run above five inches of cant deficiency, the track was visually inspected by Amtrak. If any stop test criterion was met or exceeded during the test period, that condition was used to define the limiting speed for that particular curve.

Vertical and lateral accelerations were also recorded at various locations on the car body. Although the vehicle's suspension, by design, isolates to a large extent the carbody from the track disturbances, any **changes** in the carbody acceleration levels over time could give an early warning indication of potential problems. Since acceleration measurements could be easily performed again at a later date, it was desirable to compare carbody acceleration response to certain types of vehicle behavior which are approaching unsafe conditions.

3.2 DYNAMIC ANALYSIS AND PREDICTIONS

To support Amtrak in their waiver application to the FRA, ABB carried out extensive computer simulations to establish whether the X2000, as modified for the U.S. demonstration, would be capable of safe operation during the tests at cant deficiencies up to and including 12" in 2° and 4° curves and at speeds in tangent track up to 150 mph.

A test zone of the Harrisburg Line, including 4 principal curves, was referenced for the presentation of simulation predictions. Using a mathematical model of the X2000, ABB provided projections of the anticipated forces and L/V ratios using, as input, measured track data with perturbations in space-curve form (specifically Track 4) from this test zone and representative rail-head profiles, both new and worn, provided by Amtrak. Significant track alignment deviations measured by Amtrak at the beginning and end of curve transition spirals were included in the input.

Simulation results included time histories of the predicted wheel-rail force signals on perturbed track, filtered at 25 Hz, and plots of the relevant safety parameters as a function of cant deficiency.

The results indicated that:

- For new rail, no proposed safety criteria would be exceeded for the range of conditions outlined above.
- A 2-point wheel-rail contact condition could occur in most curves of the Harrisburg Line, given the worn track profile; projections for both single and 2-point contact conditions were reviewed. Although 2-point contact would reduce safety margins somewhat, and accurate model predictions of vehicle response under this condition is difficult, it was concluded that the safety criteria would not be exceeded in this situation.
- The critical speed (hunting), at equivalent conicities up to 0.4, is predicted to be well above 150 mph (~165 - 175 mph).

Complete details of the predicted results were given in ABB Report TRP 9224 and proprietary ABB Report TRP 9226. The vehicle data used in these simulations were representative of the X2000 vehicle types included in the trainset that was tested in the United States. These reports explained the main parameters used in the simulations and gave proprietary data for the mathematical model of the different vehicles in the trainset.

In addition, other safety-related background data was provided by ABB in note form, including test results from previous X2000 test runs carried out in Germany. It was demonstrated that, during these tests, no safety criteria limits were reached and that a substantial margin of safety was evident for all cant deficiencies. Issues of note included:

- o Top speed was 251 km/h (157 mph); maximum cant deficiency was 12 inches.
- o Track in Germany is of good quality; measured lateral forces on U.S. track might be expected to be somewhat higher, but allowable loads are higher also.
- o Radial steering made a significant contribution to the reduction of wheel/rail forces in curves of 500 m radius and greater; for curve radii less than 500 m, partial radial steering was purported to reduce wear and wheel/rail noise.

Comparisons of simulation predictions and measurements taken from tests in Sweden were also provided in note form. Agreement was good, given the limitations of the simulation, and a good margin of safety was both predicted and observed.

Other supporting evidence for test safety was noted from measurements taken during previous tests on the NEC of the "banking Amcoach"[3], a vehicle quite similar in characteristics to the X2000. Tests of this vehicle at cant deficiencies up to 12 inches indicated a good margin of safety.

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[3] High Cant Deficiency Test of the F40PH Locomotive and the Prototype Banking Amcoach, Report No. DOT-FR-83-03, (NTIS: PB 83-219139), January 1983.

4. VEHICLE PERFORMANCE TEST PROCEDURES

Test instrumentation was installed on the trainset in Washington, DC, by SJ technical personnel. The test methods, procedures, locations, and the sequence of events for the vehicle performance tests are described in this Section. Included are the methods for measurement and determination of cant deficiency, the particular test zones chosen, and a summary list of conducted test runs.

4.1 INSTRUMENTATION

Four instrumented wheelsets were installed in Sweden before the X2000 trainset was shipped to the U.S. These wheelsets were of the load measuring wheel type, as developed in Sweden. The wheels were strain-gauged to measure both vertical and lateral forces. Two instrumented wheelsets were installed on truck 1 at the driver's end of the locomotive and two were installed on truck 12 at the driver's end of the cab car. These wheelsets were removed and replaced with regular wheelsets at the conclusion of the 400 series tests in mid-December, 1992.

Accelerometers were installed to measure selected carbody and truck frame accelerations and cant deficiency. A description of the measurement transducers and their locations on the vehicle are depicted in **Figure 4.1** and detailed in Appendix B.

Safety criteria parameters were displayed in real time during the test runs using five 6-channel strip chart recorders, each using a constant, time-based chart speed. The channel allocations and descriptions are given in **Appendix B.** An onboard computer system was used for digital data recording and onboard data analysis.

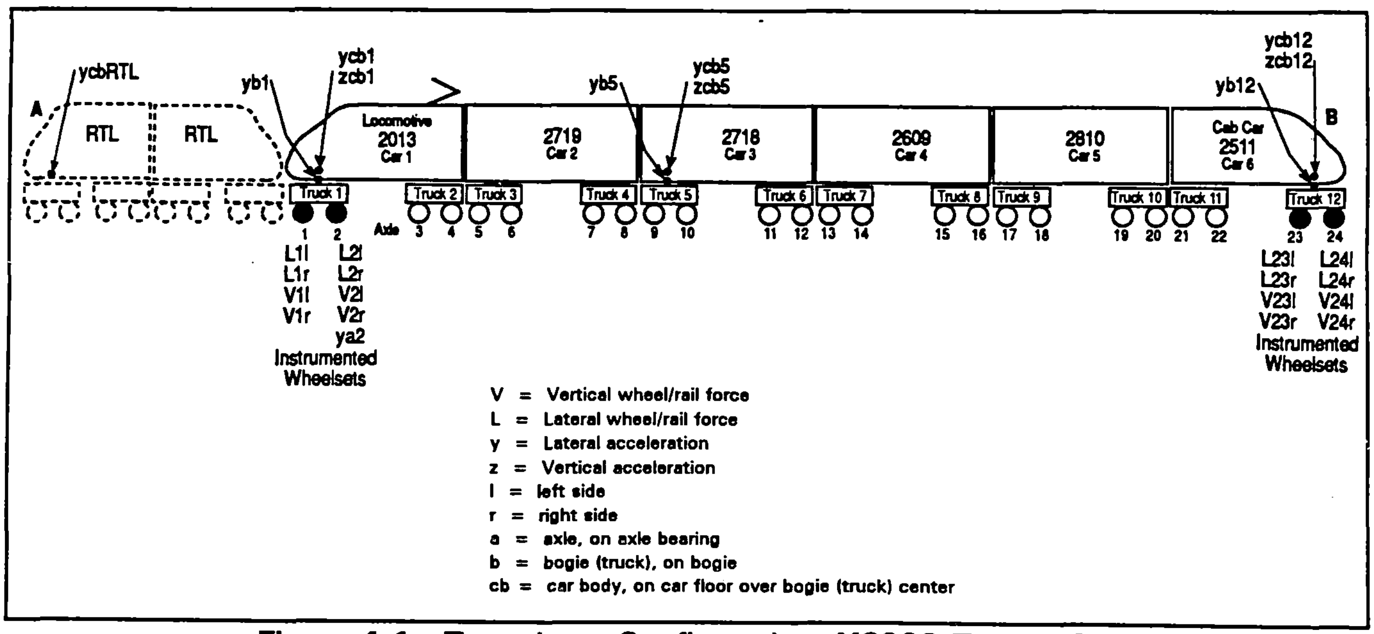


Figure 4.1: Transducer Configuration, X2000 Tests USA

4.2 METHOD FOR DETERMINATION OF CANT DEFICIENCY/UNBALANCE

Unbalance was calculated from the lateral acceleration signal generated by an accelerometer installed on the axlebox lower damper bracket of wheelset (axle) number 2 of the locomotive. Location magnets were installed on the track at the entry and exit spirals of each test curve on which a detailed analysis was to be performed. These magnets were detected by the passing train and informed the onboard computer of the time each curve was entered and exited for each test run on a consistent basis. From such acceleration signals it was possible to determine the duration of wheelset 2 in the full body of each test curve. The portion of the axlebox lateral acceleration signal so identified was averaged in order to determine the mean track-plane lateral acceleration or average cant deficiency of the train in the full body of each curve. Peak cant deficiency was obtained from the peak lateral acceleration recorded.

It was assumed that the wheelset and accelerometer remained parallel to the track-plane; the effect of wheelset lateral displacement relative to the track causing a slight roll of the wheelset ($<0.2°$) on the track due to conical type wheel profiling was ignored. Where magnets did not identify curves, manual inspection of the signal was used to determine the duration of the full body of the curve.

The full body of any curve is judged to exist where the steady state values of both curvature and superelevation have been reached at two points in the curve between which the sum of the fluctuations of the actual curvature and actual superelevation from their intended steady state values respectively tend to zero.

4.3 TEST ZONES

The tests were conducted over five main test zones as follows:

100 Series Philadelphia - Harrisburg Line **between Parkesburg and Lancaster;** Cant Deficiency Tests up to 110 mph

200 Series Northeast Corridor (NEC) Mainline (Philadelphia - New York) **between New Brunswick and Metro Park;** Cant Deficiency Tests up to 125 mph

300 Series NEC Mainline (Philadelphia - New York) **between Trenton and New Brunswick;** High Speed Stability Tests up to 150 mph

400 Series NEC Mainline **between Washington, DC and New York Penn Station;** Demonstration Revenue Service Runs up to 125 mph

1000 Series NEC Mainline **between Boston, MA and New Haven, CT;** Cant Deficiency Tests

Amtrak supplied track data in space-curve form for various portions of the test zones.

4.3.1 100 Series Test Runs, Philadelphia - Harrisburg Line, MP 44 - 68

The test zone between Parkesburg (MP 44) and Lancaster (MP 68) comprised 24 miles (39 km) of electrified double track on wooden ties with tie-plates and cut spike rail fasteners. The majority of the track incorporated continuous welded rail (CWR) with a 140 RE profile. Some sections of jointed rail existed with 39 foot rail lengths and staggered joints. 155 RE rail profiles also occurred in the test zone. At approximate intervals of two miles, a 30 foot cut section with an insulated joint was welded into the track for signaling purposes. The track was well bedded in stone ballast. Although the wooden ties fully met the FRA safety standards for the speeds run, there were several isolated locations where individual ties were providing little gauge widening restraint.

There were 23 curves encountered within this test zone on each track as described in **Appendix D**. Four particular test curves were selected for more detailed computer analyses in two groups of reversed pairs for each track. Travelling West in the direction of Lancaster on Track #4, these particular test curves were encountered as follows:

Curve Number	Curve Name	Location MP	Curvature/ [Radius]	Super Elevation	Posted Speed	12" UB Speed	Direction
662 A&B	Gap	51	4° 10' [419 m]	5 1/2"	55 mph	77 mph	Left
663	Eby's	52 - 53	4° 12' [416 m]	6"	55 mph	78 mph	Right
671	Ronks	60 - 61	2° 4' [845 m]	6"	75 mph	112 mph	Right
672	Bird-in-Hand	61 - 62	2° 2' [859 m]	6"	75 mph	112 mph	Left

Travelling East in the direction of Parkesburg on Track #1, the corresponding test curves were encountered as follows:

Curve Number	Curve Name	Location MP	Curvature/ [Radius]	Super elevation	Posted Speed	12" UB Speed	Direction
672	Bird-in-Hand	62 - 61	2° 4' [845 m]	5 3/4"	75 mph	111 mph	Right
671	Ronks	61 - 60	2° 1' [866 m]	5 3/4"	75 mph	112 mph	Left
663	Eby's	53 - 52	4° 6' [426 m]	5 1/2"	50 mph	78 mph	Left
662 A&B	Gap	51	4° 16' [409 m]	5 1/2"	50 mph	77 mph	Right

4.3.2 200 Series Test Runs, New Brunswick to Metro Park, MP 31 - 21

The test zone, situated approximately between New Brunswick (MP 31) and Metro Park (MP 21) comprised 10 miles (16 km) of electrified quadruple track. The two center high speed tracks utilized concrete mono-block ties with Pandrol rail fasteners.

The majority of the rail was CWR with a 140 RE profile. The interlockings (cross-overs) were carried on wooden ties with tieplates and cut spike rail fasteners. At approximate intervals of two miles, a 30 foot cut section with an insulated joint was welded into the track for signaling purposes. The track was well bedded in stone ballast. The maximum line speed in the zone was 125 mph.

There were 12 curves encountered within this test zone on each track as described in **Appendix D.** Three particular test curves were selected for more detailed analyses in two groups comprising one reversed pair and a singlet for each of the high speed Tracks # 2 and 3. Travelling East in the direction of Metro Park on Track #2, the particular test curves were encountered as follows:

Curve Number	Curve Name	Location MP	Curvature/ [Radius]	Super elevation	Posted Speed	12" UB Speed	Direction
268	1st Curve west of Lincoln	27 - 26	1° 52' [934 m]	6"	80 mph	117 mph	Left
266	Curve west of MP 24	25 - 24	1° 33' [1127 m]	5 3/4"	90 mph	128 mph	Right
265	Curve east of MP 24	24 - 23	1° 27' [1204 m]	5 1/4"	90 mph	130 mph	Left

Travelling West in the direction of New Brunswick on Track #3, the corresponding test curves were encountered as follows:

Curve Number	Curve Name	Location MP	Curvature/ [Radius]	Super elevation	Posted Speed	12" UB Speed	Direction
265	Curve east of MP 24	23 - 24	1° 26' [1221 m]	6"	90 mph	134 mph	Right
266	Curve west of MP 24	24 - 25	1° 30' [1164 m]	5 1/4"	90 mph	128 mph	Left
268	1st Curve west of Lincoln	26 - 27	1° 56' [905 m]	6"	80 mph	115 mph	Right

4.3.3 300 Series Test Runs, Trenton to New Brunswick, MP 55 - 32

The test zone between Trenton (MP 55) and New Brunswick (MP 32) comprised 22 miles (35 km) of electrified quadruple track. The two center high speed tracks incorporated concrete mono-block ties with Pandrol rail fasteners. The majority of the rail was CWR with a 140 RE profile. The interlockings (cross-overs) were laid on wooden ties with tieplates and cut spike rail fasteners. At approximate intervals of two miles, a 30 foot cut section including an insulated joint was welded into the track for signaling purposes. The track was well bedded in stone ballast. The maximum line speed was normally 125 mph, but was raised to 150 mph for the X2000 tests.

Of the 6 curves within the test zone, two large radius curves were located at the Eastern one-third of the test zone on each of the high speed Tracks # 2 and 3. Travelling East in the direction of New Brunswick on Track # 2, these large radius curves were encountered as follows:

Curve Number	Location MP	Curvature/ [Radius]	Super elevation	Ord Speed	UB at 150 mph	Direction
276	41 - 39	0° 32' [3274 m]	3 5/8"	125 mph	4.6"	Left
275	39	0° 19' [5514 m]	2"	125 mph	2.9"	Right

Travelling West in the direction of Trenton on Track #3, the corresponding large radius curves were encountered as follows:

Curve Number	Location MP	Curvature/ [Radius]	Super elevation	Ord Speed	UB at 150 mph	Direction
275	39	0° 20' [5238 m]	2 1/8"	125 mph	3.0"	Right
276	39 - 41	0° 31' [3379 m]	3 1/2"	125 mph	4.5"	Left

4.3.4 400 Series Test Runs, Washington DC to New York Penn Station

The test zone between Washington and New York comprised 225 miles (362 km) of electrified double track, quadrupled where possible between Washington DC and Newark, New Jersey. The two high speed tracks were supported predominantly by concrete mono-block ties with Pandrol rail fasteners. The majority of rail was CWR with a 140 RE profile. All but a few interlockings (cross-overs) were laid on wooden ties with tieplates and cut spike rail fasteners. At approximate intervals of two miles, a 30 foot cut section with an insulated joint was welded into the track for signaling purposes. The track was well bedded in stone ballast. The maximum line speed was normally 125 mph. Line speed was often restricted to less than this figure due to Metroliner trains not being allowed to operate at more than 4 inches of unbalance in curves. The 150 mph test speed for the X2000 between Trenton and New Brunswick was not in force during the 400 Series long distance test runs. Turnouts, crossovers and numerous curves of different radii and superelevation were encountered along the route. **Appendix D** provides comprehensive track and curve data.

4.3.5 1000 Series Test Runs, Boston, MA to New Haven, CT.

A series of cant deficiency tests were performed over Amtrak's Northeast Corridor between Boston, Massachusetts, and New Haven, Connecticut. The objective of these tests was to demonstrate the performance and potential of the X2000 trainset over this heavily curved route. These tests were performed with two Rohr Turboliner (RTL) power cars coupled to the X2000 trainset for propulsion over the non-electrified territory. An accelerometer was placed at the center of the carbody floor over the leading truck of one RTL power car to measure lateral carbody acceleration. Round trip runs were made at 5, 7 and 8 inches of cant deficiency on the curves.

Stop test criteria for these tests were determined by the overturning limitations of the RTL power cars, tested previously in the NEC ("Amtrak Evaluation of Tilt and Turbo Train Technologies", Amtrak Report, 1989). Carbody lateral accelerations of the RTL power car, correlated to vehicle overturn, were not to exceed 0.23g steady state and 0.37g transient. Values used for 75% of the stop test criteria were 0.17g steady state and 0.28g transient.

4.4 TEST SEQUENCE

The overall test sequence for the program is described in the Test Event Log included in **Appendix C** and summarized in **Table 4.1.**

4.5 HIGH SPEED BRAKE TESTS

Stops were made periodically during the course of the test runs at speeds up to 152 mph using only the air brake equipment to assess the braking performance and to ensure that stopping distances were within the allowable limits established for the NEC signaling system. Stop distance measurements are reported in **Section 2.5.1.**

4.6 CARBODY ACCELERATIONS AND RIDE QUALITY TESTS

Carbody accelerations in the lateral and vertical directions on the locomotive, the cab car, and a coach car were measured and recorded during the technical tests and during the demonstration revenue service runs between Washington and New York. The measurements were selectively displayed on strip charts during the course of the tests. The specific locations on the trainset at which these measurements were made were:

- Over truck 1 in the locomotive;
- Over truck 5 in the second coach (Car 2718);
- Over truck 12 in the cab car.

Immediately prior to revenue service (31 January 1993), accelerations were measured on the cab car during a round-trip test run at 135 mph maximum speed between Washington and New York Penn Station. These measurements were made at the following locations on the cab car vehicle:

- Truck frame, lateral acceleration, Truck 12
- Carbody, lateral acceleration, over Truck 12
- Carbody, vertical acceleration, over Truck 12

Carbody acceleration measurements were continued at selected locations on the vehicle on a weekly basis during the revenue service period as a condition of the waiver.

TABLE 4.1 X2000 TEST RUNS IN CHRONOLOGICAL ORDER

Date	Run #	Line	Direction/ Track	Track Condit	Scheduled Unbalance/Speed	Leading Car/ Axle
Nov 30/92	101	Ph - Hrsbg	W / Trk 4	Dry	3"	Cab Car / Axle 24
"	102	Hrsbg - Ph	E / Trk 1	Dry	5"	Locomotive / Axle 1
"	103	Ph - Hrsbg	W / Trk 4	Dry	6"	Cab Car / Axle 24
"	104	Hrsbg - Ph	E / Trk 1	Dry	6"	Locomotive / Axle 1
"	105	Ph - Hrsbg	W / Trk 4	Dry	7"	Cab Car / Axle 24
"	106	Hrsbg - Ph	E / Trk 1	Dry	7"	Locomotive / Axle 1
Dec 1/92	107	Ph - Hrsbg	W / Trk 4	Damp	7"	Cab Car / Axle 24
"	108	Hrsbg - Ph	E / Trk 1	Damp	7"	Locomotive / Axle 1
"	109	Ph - Hrsbg	W / Trk 4	Wet	8"	Cab Car / Axle 24
"	110	Hrsbg - Ph	E / Trk 1	Wet	8"	Locomotive / Axle 1
"	111	Ph - Hrsbg	W / Trk 4	Wet	9"	Cab Car / Axle 24
"	112	Hrsbg - Ph	E / Trk 1	Wet	9"	Locomotive / Axle 1
"	113	Ph - Hrsbg	W / Trk 4	Wet	10"	Cab Car / Axle 24
"	114	Hrsbg - Ph	E / Trk 1	Wet	10"	Locomotive / Axle 1
Dec 2/92	115	Ph - Hrsbg	W / Trk 4	Dry	10"	Cab Car / Axle 24
"	116	Hrsbg - Ph	E / Trk 1	Dry	10"	Locomotive / Axle 1
"	117	Ph - Hrsbg	W / Trk 4	Dry	11"	Cab Car / Axle 24
"	118	Hrsbg - Ph	E / Trk 1	Dry	11"	Locomotive / Axle 1
"	119	Ph - Hrsbg	W / Trk 4	Dry	12"	Cab Car / Axle 24
"	120	Hrsbg - Ph	E / Trk 1	Dry	12"	Locomotive / Axle 1
Dec 3/92	121	Ph - Hrsbg	W / Trk 4	Dry	9"	Locomotive / Axle 1
"	122	Hrsbg - Ph	E / Trk 1	Dry	10"	Cab Car / Axle 24
"	123	Ph - Hrsbg	W / Trk 4	Dry	10"	Locomotive / Axle 1
"	124	Hrsbg - Ph	E / Trk 1	Dry	11"	Cab Car / Axle 24
"	125	Ph - Hrsbg	W / Trk 4	Dry	9"	Locomotive / Axle 1
"	126	Hrsbg - Ph	E / Trk 1	Dry	9"	Cab Car / Axle 24
"	127	Ph - Hrsbg	W / Trk 4	Dry	12"	Locomotive / Axle 1
"	128	Hrsbg - Ph	E / Trk 1	Dry	12"	Cab Car / Axle 24
"	129	Ph - Hrsbg	W / Trk 4	Dry	9"	Locomotive / Axle 1
"	130	Hrsbg - Ph	E / Trk 1	Dry	9"	Cab Car / Axle 24
Dec 7/92	300	Ph - NYP	E / Trk 3	Dry	130 mph	Cab Car / Axle 24
"	200	Ph - NYP	E / Trk 3	Dry	5"	Cab Car / Axle 24
"	201	NYP - Ph	W / Trk 3	Dry	7"	Locomotive / Axle 1
"	202	Ph - NYP	E / Trk 3	Dry	9"	Cab Car / Axle 24

Date	Run #	Line	Direction/ Track	Track Condit	Scheduled Unbalance/Speed	Leading Car/ Axle
"	203	NYP - Ph	W / Trk 3	Dry	10"	Locomotive / Axle 1
"	204	Ph - NYP	E / Trk 3	Dry	11"	Cab Car / Axle 24
"	205	NYP - Ph	W / Trk 3	Dry	12"	Locomotive / Axle 1
"	301	NYP - Ph	W / Trk 3	Dry	140 mph	Locomotive / Axle 1
Dec 8/92	302	Ph - NYP	E / Trk 3	Dry	150 mph	Cab Car / Axle 24
"	206	Ph - NYP	E / Trk 3	Dry	9"	Cab Car / Axle 24
"	207	NYP - Ph	W / Trk 2	Dry	9"	Locomotive / Axle 1
"	208	Ph - NYP	E / Trk 2	Dry	10"	Cab Car / Axle 24
"	209	NYP - Ph	W / Trk 2	Dry	11"	Locomotive / Axle 1
"	210	Ph - NYP	E / Trk 2	Dry	12"	Cab Car / Axle 24
"	211	NYP - Ph	W / Trk 3	Dry	at profile	Locomotive / Axle 1
"	303	NYP - Ph	W / Trk 3	Dry	150 mph	Locomotive / Axle 1
Dec 12/92	304	Ph - NYP	E / Trk 3	Wet	140 mph	Cab Car / Axle 24
"	305	NYP - Ph	W / Trk 3	Wet	150 mph	Locomotive / Axle 1
Dec 14/92	400	Wa - Ph	N / Trk 2	Dry	9"	Cab Car / Axle 24
"	402	Ph - NYP	E / Trk 2	Dry	9"	Cab Car / Axle 24
"	401	NYP - Ph	W / Trk 3	Dry	9"	Locomotive / Axle 1
"	403	Ph - Wa	S / Trk 3	Dry	9"	Locomotive / Axle 1
Dec 15/92	404	Wa - Ph	N / Trk 2	Dry	9" + 5 mph	Cab Car / Axle 24
"	406	Ph - NYP	E / Trk 1,2	Dry	9" + 5 mph	Cab Car / Axle 24
"	405	NYP - Ph	W / Trk 3	Dry	9" + 5 mph	Locomotive / Axle 1
"	410	Ph - Tren	E / Trk 2	Dry	9" + 5 mph	Cab Car / Axle 24
"	411	Tren - Ph	W / Trk 3,4	Dry	9" + 5 mph	Locomotive / Axle 1
"	407	Ph - Wa	S / Trk 3	Dry	9" + 5 mph	Locomotive / Axle 1
Jan 12/93	1201	Bo - NH	W / Trk 1	Dry	5"	RTL trailing/Axle 24
"	1202	NH - Bo	E / Trk 2	Dry	5"	RTL leading / Axle 1
Jan 13/93	1301	Bo - NH	W / Trk 1	Dry	7"	RTL leading / Axle 1
"	1302	NH - Bo	E / Trk 2	Dry	7"	RTL trailing/Axle 24
Jan 15/93	1501	Bo - NH	W / Trk 1	Dry	8"	RTL leading / Axle 1
"	1502	NH - Bo	E / Trk 2	Dry	8"	RTL trailing/Axle 24
Jan 31/93		Wa - NY (ret)	Trk 2 N,E Trk 3 W,S	Dry	135 mph, 9"	Cab Car leading N,E trailing W,S

5. DYNAMIC TEST RESULTS

Test results are presented herein to examine the safety aspects and the safety margin involved with the high cant deficiency operation of the X2000 train. During each test run, measured peak values of the safety parameters were compiled on a mile by mile basis. A summary of the peak values, closest to the safety limits, recorded over all the cant deficiency and high speed test runs and over all test zones is given in **Table 5.1**. Each safety parameter will be addressed in turn in this Section.

5.1 MAXIMUM UNBALANCE AND MAXIMUM SPEED RECORDED

The lateral accelerometer installed adjacent to axle #2 of the locomotive was used to indicate the degree of unbalance or cant deficiency. The maximum quasi-steady lateral acceleration recorded from all test runs was 2.07 m/s^2. This occurred during Test Run 128 on the Philadelphia - Harrisburg line while travelling east on Track #1 in curve 662 (Gap, 4° curvature) at a speed of 78 mph. This lateral acceleration translates to an unbalance or cant deficiency of 12.5 inches.

The maximum speed recorded during the high speed test runs was 154 mph. This occurred during Test Run 305 on the NEC Philadelphia - New York line while travelling West on Track #3 at MP 51 near Trenton, NJ. This was a scheduled 150 mph run under wet track conditions, in which a 150 mph or greater speed was sustained for over 8 miles. A speed of 152 mph was also recorded at the same location under dry track conditions during Test Run 303.

5.2 MINIMUM VERTICAL WHEEL-RAIL FORCE (VEHICLE OVERTURN), Vmin

To examine the safety from vehicle overturn in high cant deficiency operation, the vertical wheel force measured on each of the 8 instrumented wheels was monitored for the minimum (peak) values, **Vmin**, indicating the peak unloading (on the low rail side in curves). From each cant deficiency and high speed test run, the single-most minimum vertical wheel force peak measured on any of the 8 wheels and anywhere within the test zone for that test run was tabulated. A composite plot of these minimum vertical wheel force peaks measured from the cant deficiency and high speed test runs on both the Philadelphia - Harrisburg and NEC mainlines is shown in **Figure 5.1**.

It should be noted in this plot that individual wheels are not distinguished; these peak values were drawn from each test run at any location within the test zone, not necessarily in a curve, and may be for any wheel of the 8 instrumented wheels. In addition, the peak values are plotted against the intended or scheduled test run cant deficiency and not necessarily the actual cant deficiency when the peak was recorded. No trend line should be drawn from this composite; it merely conveys the number of tests carried out and the magnitudes of the minimum wheel forces experienced over a wide range of track alignments, geometries, and conditions.

TABLE 5.1 PEAK VALUES MEASURED FROM ALL TEST ZONES, HARRISBURG and NEC LINES

Safety Criteria	Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Intended Cant Def	Measured Cant Def	Measured Speed	Leading Axle	Comments
Min Vertical Wheel Force Vmin	23 kN	83%	Left Wheel Axle 1 (Loco)	101 Hrsbg	West Track 4	51 - 52	Dry	3"	3.1"	57 mph	Axle 24 (Cab)	In curve 662 (Gap - 4°)
	20 kN	86%	Left Wheel Axle 1 (Loco)	113 Hrsbg	West Track 4	60 - 61	Wet	10"	11"	108 mph	Axle 24 (Cab)	In curve 671 (Ronks - 2°)
	22 kN	84%	Left Wheel Axle 1 (Loco)	119 Hrsbg	West, Track 4	60 - 61	Dry	12"	11.7"	111 mph	Axle 24 (Cab)	In curve 671 (Ronks - 2°)
	23 kN	83%	Left Wheel Axle 1 (Loco)	204 NEC	East Track 3	25 - 24	Dry	11"	12.4"	125 mph	Axle 24 (Cab)	In curve 266 (1.5°)
Max Net Axle Lateral Force NAL	66 kN	84%	Axle 24 (Cab)	113 Hrsbg	West Track 4	51 - 52	Wet	10"	11"	77 mph	Axle 24 (Cab)	In curve 662 (Gap - 4°)
	66 kN	84%	Axle 24 (Cab)	113 Hrsbg	West Track 4	61 - 62	Wet	10"	10.1"	107 mph	Axle 24 (Cab)	In curve 672 (Bd Hnd - 2°)
	68 kN	87%	Axle 24 (Cab)	114 Hrsbg	East Track 1	62 - 61	Wet	10"	10"	106 mph	Axle 1 (Loco)	In curve 672 (Bd Hnd - 2°)
	-66 kN	85%	Axle 24 (Cab)	120 Hrsbg	East Track 1	53 - 52	Dry	12"	12.1"	80 mph	Axle 1 (Loco)	In Curve 663 (EBYs - 4°)
	63 kN	70%	Axle 1 (Loco)	204 NEC	East Track 3	25 - 24	Dry	11"	12.4"	125 mph	Axle 24 (Cab)	In curve 266 (1.5°)
Max Wheel L/V Ratio L/V	0.61	76%	Left Wheel Axle 1 (Loco)	120 Hrsbg	East Track 1	53 - 52	Dry	12"	12.1"	80 mph	Axle 1 (Loco)	In Curve 663 (EBYs - 4°)
	0.60	75%	Left Wheel Axle 24 (Cab)	122 Hrsbg	East Track 1	53 - 52	Dry	10"	9.8"	75 mph	Axle 24 (Cab)	In Curve 663 (EBYs - 4°)
	0.60	75%	Left Wheel Axle 24 (Cab)	128 Hrsbg	East Track 1	53 - 52	Dry	12"	10.9"	78 mph	Axle 24 (Cab)	In Curve 663 (EBYs - 4°)
	0.56	70%	Right Wheel Axle 1 (Loco)	205 NEC	West Track 3	23 - 24	Dry	12"	8.8"	125 mph	Axle 1 (Loco)	In curve 265 (1.5°)

TABLE 5.1 (con't): PEAK VALUES MEASURED FROM ALL TEST ZONES, HARRISBURG and NEC LINES

Safety Criteria	Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Intended Cant Def	Measured Cant Def	Measured Speed	Leading Axle	Comments
Max Truck Side L/V T-L/V	0.44	88%	Left Side Truck 12 (Cab)	113 Hrsbg	West Track 4	61 - 62	Wet	10"	10.1"	108 mph	Axle 24 (Cab)	In curve 672 (Bd Hnd - 2°)
	0.46	92%	Left Side Truck 12 (Cab)	122 Hrsbg	East Track 1	53 - 52	Dry	10"	9.8"	75 mph	Axle 24 (Cab)	In Curve 663 (EBYs - 4°)
	0.45	90%	Left Side Truck 12 (Cab)	126 Hrsbg	East Track 1	53 - 52	Dry	9"	9.2"	72 mph	Axle 24 (Cab)	In Curve 663 (EBYs - 4°)
	0.45	90%	Left Side Truck 12 (Cab)	128 Hrsbg	East Track 1	53 - 52	Dry	12"	10.9"	78 mph	Axle 24 (Cab)	In Curve 663 (EBYs - 4°)

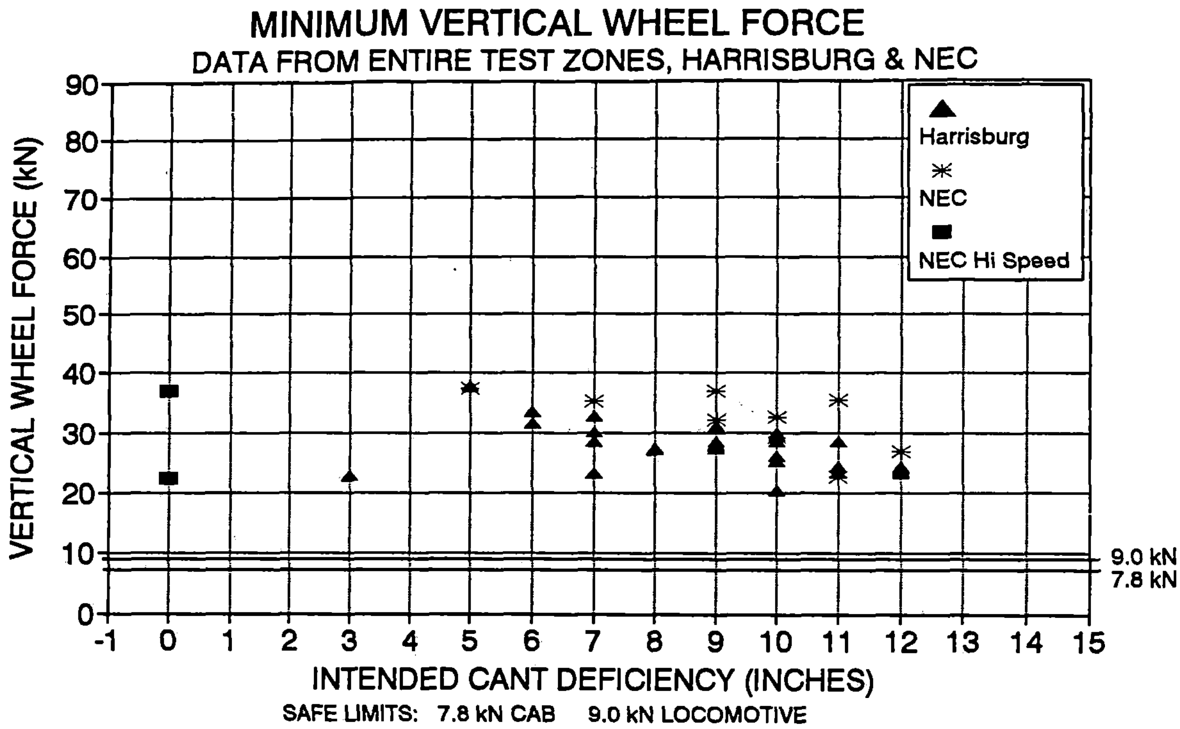


Figure 5.1: Minimum Vertical Wheel Forces Measured During X2000 Test Runs

The composite plot shows that no measured wheel approached the minimum allowable vertical wheel force (maximum unloading) at any time throughout these test runs, which included cant deficiencies up to 12.5 inches, speeds up to 154 mph, and curvatures from tangent to 4° in both dry and wet conditions. From the lowest values recorded, a safety margin of about 14% from the allowable limit is apparent for cant deficiencies up to 12.5 inches on representative track. No appreciable crosswinds were encountered during these test runs.

The lowest value recorded for **Vmin** occurred during test run 113 (wet rail) in test curve 671 (Ronks, 2° curvature) of the Harrisburg Line, travelling westbound on Track #4, measured on the left wheel of trailing axle #1 of the locomotive (locomotive was trailing the consist; left wheel was on the low rail side). A more detailed examination of the vertical wheel forces measured from 10 test runs in this curve, on this track, and on this wheel in the trailing condition is given in **Figure 5.2.** Both the average value and the minimum peak value are plotted as a function of the quasi-steady cant deficiency measured in the circular portion of this curve. This plot includes values measured under both wet and dry track conditions, which has little or no effect.

Extrapolation of the minimum vertical force measurements, assuming linearity, indicates that the safety limit of 9 kN would be reached at a cant deficiency of about 15 inches for similar conditions.

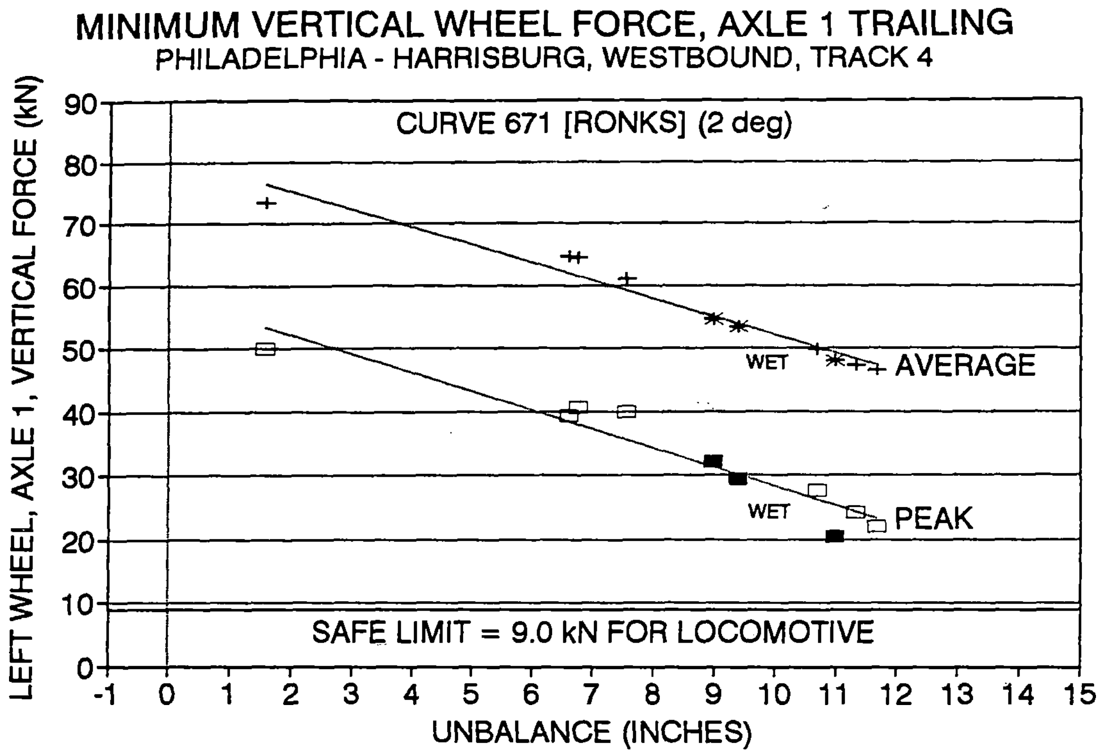


Figure 5.2: Minimum Vertical Wheel Force, Measured In Curve 671, Westbound

5.3 NET AXLE LATERAL FORCE (TRACK PANEL SHIFT), NAL

Lateral track shift forces were examined by measuring the net lateral force on each axle. The maximum (peak) net axle lateral force, **NAL**, measured during each cant deficiency and high speed test run was tabulated for each axle. A composite plot of the peak net axle lateral forces measured for the locomotive axles #1 and #2 from each test run and over all test zones is given in **Figure 5.3a**. A similar plot for the peak net axle lateral forces on cab car axles #23 and #24 is given in **Figure 5.3b**.

The individual axles are not distinguished in these plots; the peak values were drawn from each test run at any location within the test zone, and are plotted against the intended or scheduled cant deficiency. No trend lines can be gained from these composite plots; they merely convey the number of tests carried out and the magnitudes of the maximum net axle lateral forces experienced over a wide range of track geometries and conditions.

In **Figure 5.3a**, it is evident that the net lateral forces measured for the locomotive axles were significantly lower than the allowable safety limit of 90 kN, with a substantial margin of safety. For the axles of the lighter weight cab car (**Figure 5.3b**), similar forces were observed although the allowable safety limit for the cab car is less at 78 kN. A margin of safety below the 78 kN limit of about 15% is evident in this case.

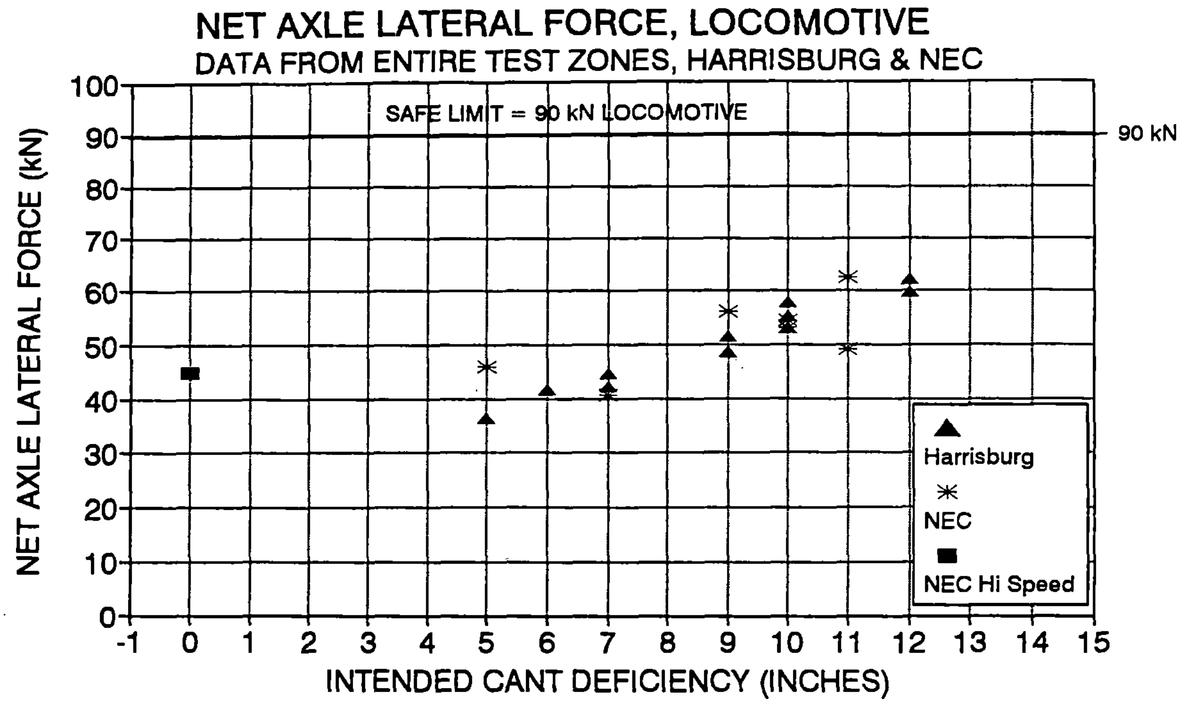


Figure 5.3a: Peak Net Axle Lateral Forces, Locomotive (Composite of Test Runs)

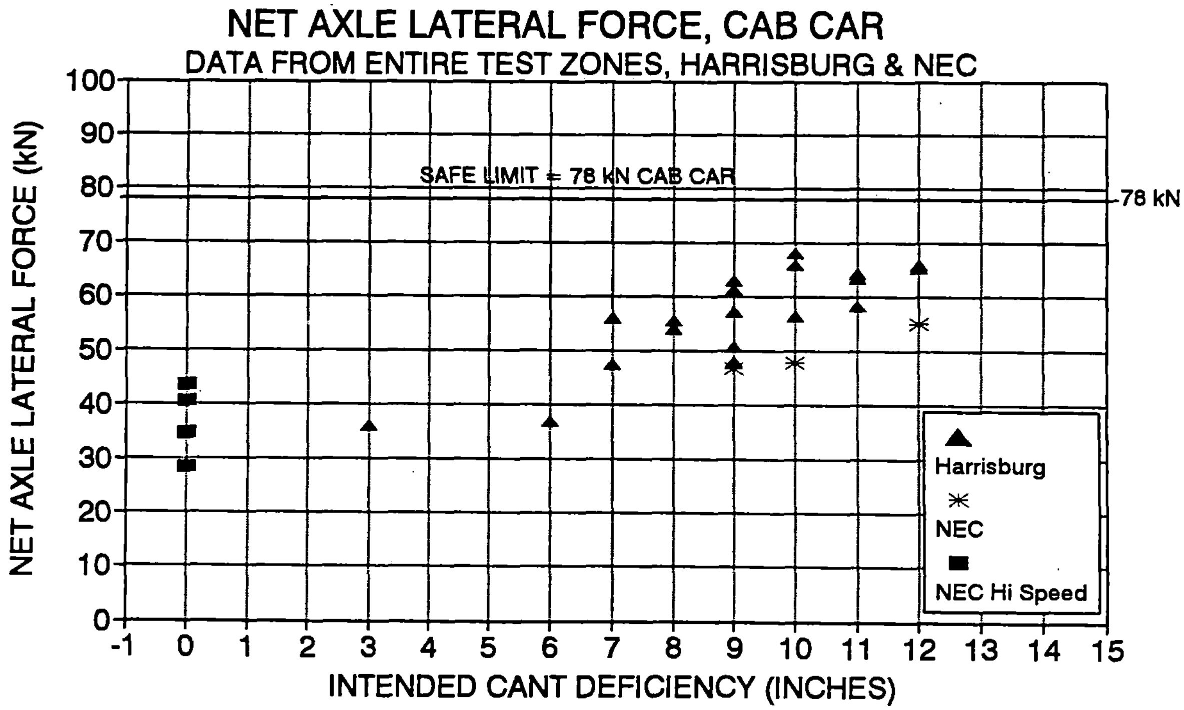


Figure 5.3b: Peak Net Axle Lateral Forces, Cab Car (Composite of Test Runs)

One of the highest peaks recorded for the net axle lateral force, **NAL**, was on axle #24 of the cab car, the leading axle of the leading car, during test run 113 (wet rail) in test curve 672 (Bird-in-Hand, 2° curvature) of the Philadelphia - Harrisburg line, westbound on Track #4. To examine this peak and the trends associated with higher speed curving, the net axle lateral forces measured on axle #24, in the leading position, during 10 test runs through this curve 672, on Track #4, westbound are plotted in **Figure 5.4** as a function of the quasi-steady cant deficiency measured in the circular portion of the curve.

This plot includes test runs under both dry and wet conditions. A linear extrapolation of the measured peak values of **NAL** in the curve indicates that the safety limit of 78 kN would be reached at a cant deficiency of about 15 inches.

There is some scatter in the average values and in the peak values measured at higher cant deficiencies. The peak of 66 kN at 10.1" cant deficiency was measured in wet conditions, as were the peaks of 49 kN and 50 kN at 8.4" and 8.9" cant deficiency respectively. Peaks of 50 kN, 50 kN and 60 kN, at cant deficiencies of 10", 11" and 11.2" respectively, were measured in consecutive test runs in dry conditions. Although the distinction between wet and dry conditions is not obvious, the scatter might, in some part, be attributed to the steering effectiveness of the truck under varying conditions. Additional testing would be necessary to fully quantify the effects, if any, of wet versus dry rail conditions on radial steering and overall trainset performance.

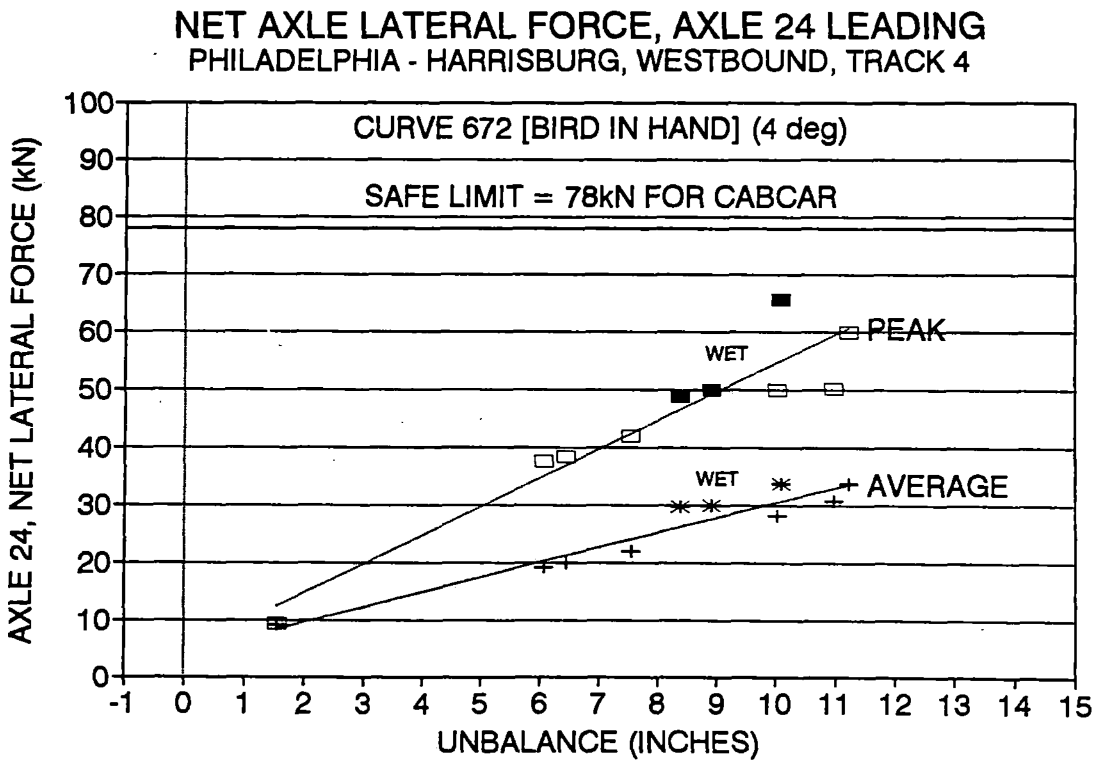


Figure 5.4: Net Axle Lateral Force, Axle 24, In Curve 672, Track 4

5.4 L/V DERAILMENT QUOTIENT (WHEEL CLIMB), L/V

To assess the safety from wheel climb in high cant deficiency operation, the lateral to vertical force ratio, **L/V**, on each of the 8 instrumented wheels was monitored for the maximum peak values. A composite plot of the maximum peak single wheel L/V ratios measured from each cant deficiency and high speed stability test run and over all test zones is shown in **Figure 5.5**. In this plot, individual wheels are not distinguished; these peak values were drawn from each test run and may be for any wheel of the 8 instrumented wheels in a leading or trailing position, left side or right side. In addition, the peak values are plotted as a function of the intended or scheduled test run cant deficiency and not necessarily the actual cant deficiency when the peak was recorded.

The plot illustrates the number of test runs carried out and the representative magnitudes of the peak wheel L/V ratios measured over a wide range of track alignments, geometries and conditions, both on the Harrisburg line and on the NEC. The highest wheel L/V ratios measured during the cant deficiency and high speed runs were about 0.6, approximately 75% of the allowable Nadal single wheel limit of 0.8. As a result, the second safety criterion, the axle sum L/V ratio due to Weinstock, was not examined in any detail. A safety margin of about 25% is apparent for cant deficiencies up to 12.5 inches for similar track and vehicle conditions.

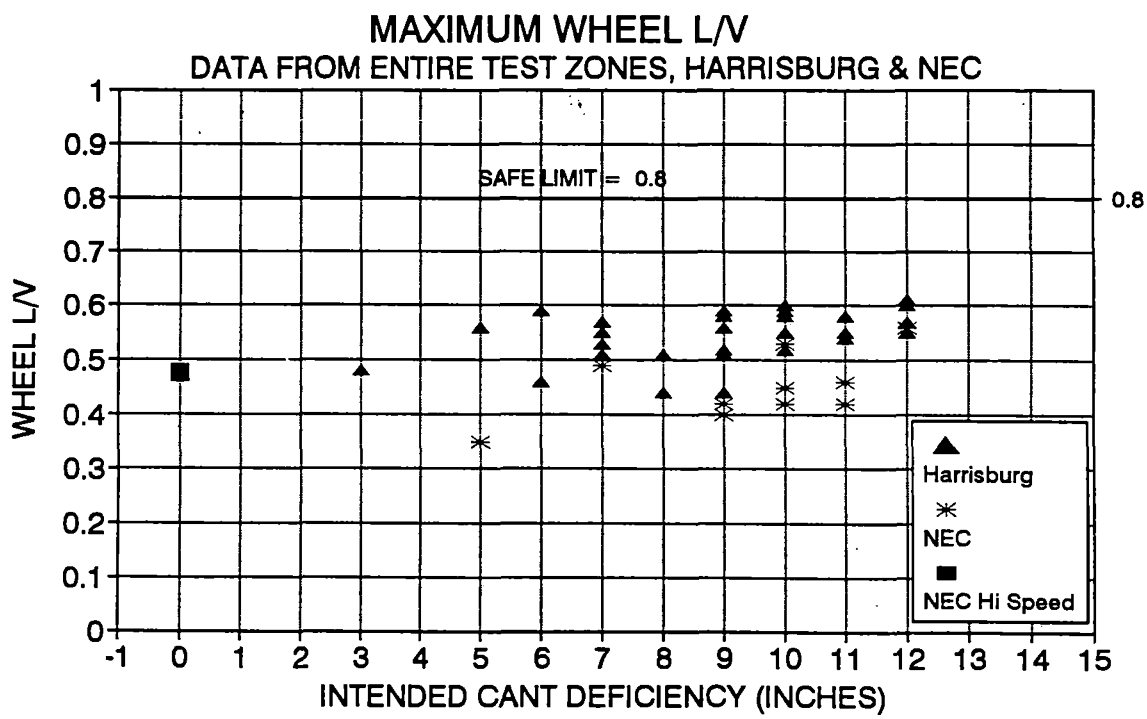


Figure 5.5: Peak Maximum Wheel L/V Ratios (Composite, All Wheels, Test Runs)

The highest peaks recorded for single wheel L/V were measured on the wheels of the leading axle of the consist in test curve 663 (Eby's, 4° curvature) of the Harrisburg line, travelling eastbound on Track #1. The leading axle, depending on the orientation of the train, was either axle #1 (locomotive) with the high side wheel on the right side of the train (looking to the locomotive), or axle #24 (cab car) with the high side wheel on the left side of the train (looking to the locomotive). A plot of the single wheel L/V ratios taken from 10 test runs in which the locomotive was leading in test curve 663, eastbound on Track #1, is given in **Figure 5.6** for the right wheel (high side wheel) of the leading axle #1. Both the peak value measured in the curve and the average value while in the curve are plotted as a function of the quasi-steady cant deficiency measured in the circular portion of the curve.

This plot includes test runs under both dry and wet conditions; the three test runs under wet conditions are evident at cant deficiencies of 8.3", 9.2" and 9.5". Both the average and peak values under wet conditions are lower than those measured in dry conditions at similar cant deficiencies. Otherwise, there is a very gradual increase of the measured single wheel L/V ratios as cant deficiency increases. This might be an indication of two-point wheel/rail contact in this curve under dry conditions. Nevertheless, the measured values are well below the safety limit of 0.8.

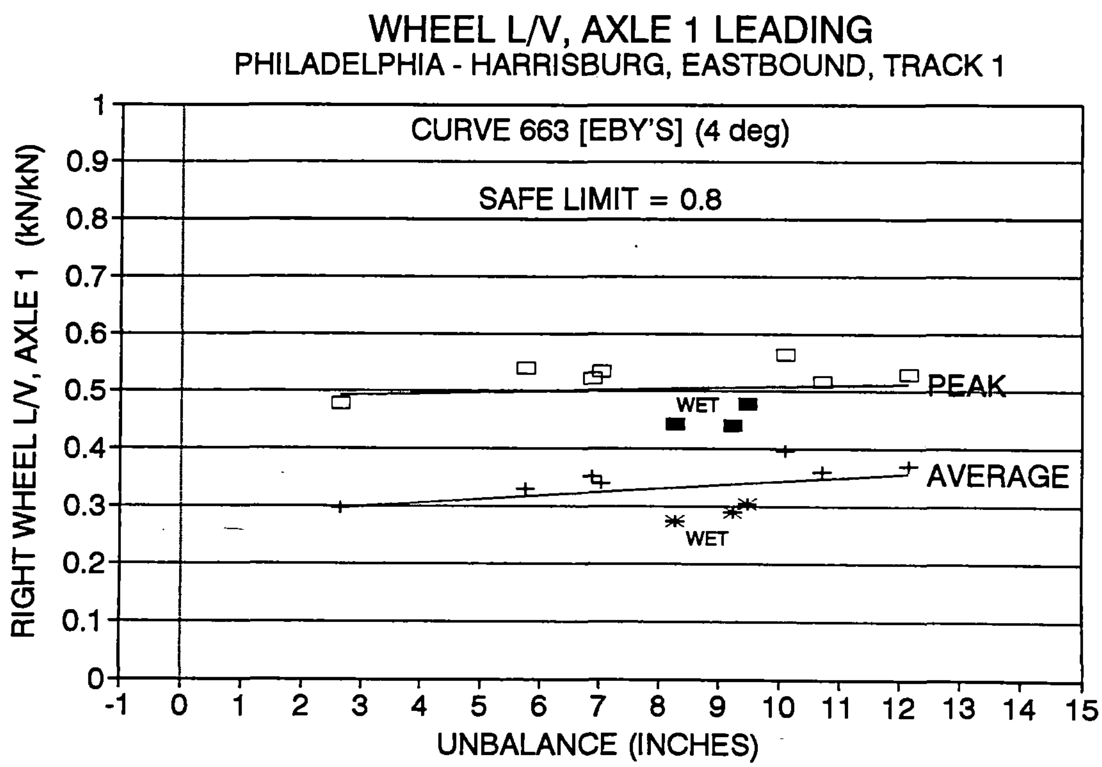


Figure 5.6: Wheel L/V Ratios, Right Wheel, Axle 1, Curve 663

5.5 TRUCK-SIDE L/V RATIO (RAIL ROLL-OVER), T-L/V

To assess safety from rail roll-over, the truck-side lateral force to vertical force ratio (sum of the lateral forces on the wheels of one side of the truck divided by the sum of the vertical forces on the same side of the truck), **T-L/V**, was monitored for the maximum peak values. A composite plot of the maximum peak truck side L/V ratios measured from each cant deficiency and high speed stability test run and over all test zones, is given in **Figure 5.7**. This plot includes both left and right sides for truck #1 of the locomotive and truck #12 of the cab car; the points are not distinguished. In addition, the peak values are plotted against the intended or scheduled test run cant deficiency and not necessarily the actual cant deficiency when the peak was measured.

The composite plot illustrates the magnitudes of peak truck-side L/V ratios encountered over a range of track alignments, geometries, and conditions. No peak values were measured in these test runs that exceeded the allowable limit of 0.5. At cant deficiencies above 9 inches, some peak values of truck side L/V were observed around 90% of the allowable limit during test runs on the Philadelphia - Harrisburg line.

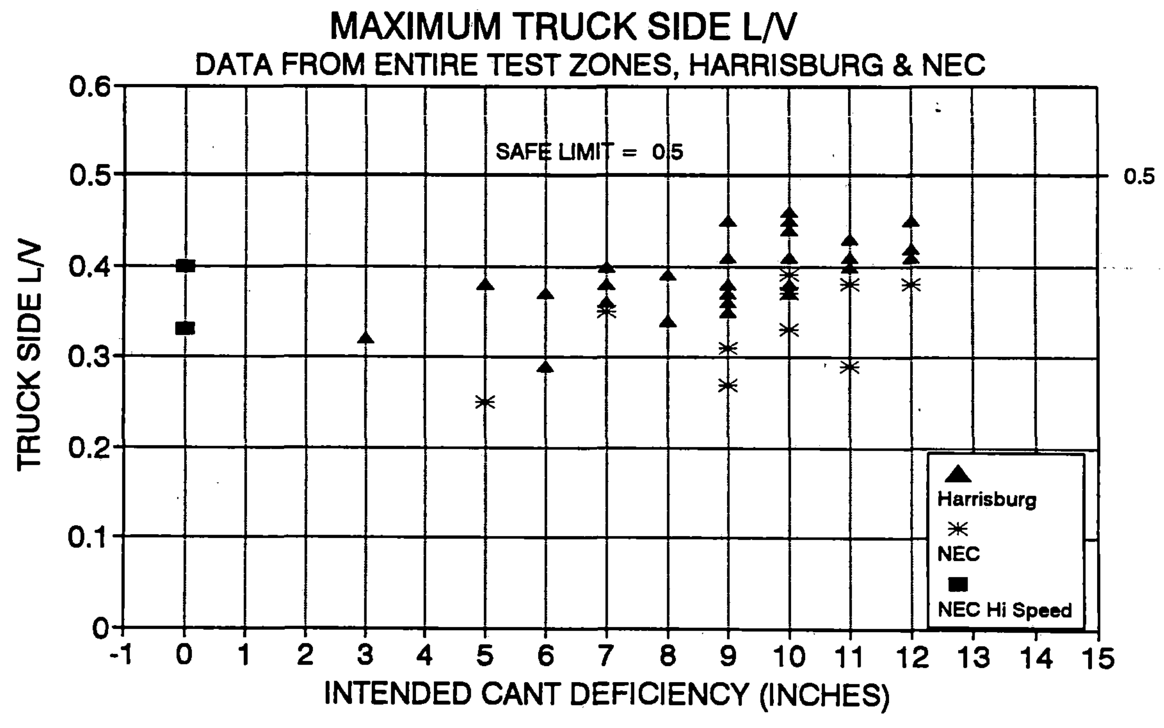


Figure 5.7: Peak Maximum Truck Side L/V Ratios (Composite of Test Runs)

One of the highest peaks recorded for truck-side L/V was measured on the left side of leading truck #12 of the cab car during test run 113 (wet rail), at the beginning of test curve 672 (Bird-in-Hand, 2° curvature) of the Harrisburg Line, westbound on track #4. A plot of truck-side L/V for the left side of truck #12, taken from 10 test runs (including test run 113) at this location in test curve 672 is given in **Figure 5.8.** Both the peak values and the average values in the curve are plotted as a function of the quasi-steady cant deficiency measured in the circular portion of the curve.

This plot includes test runs in both dry and wet conditions. The average values of truck-side L/V in the curve under wet conditions (at cant deficiencies of 8.4", 8.9", and 10.1") are consistently higher than those measured at similar cant deficiencies under dry conditions. The measured peak values showed little difference between wet and dry conditions. A margin of safety of about 10% below the safety criterion of 0.5 is apparent for cant deficiencies up to 12 inches under wet or dry conditions.

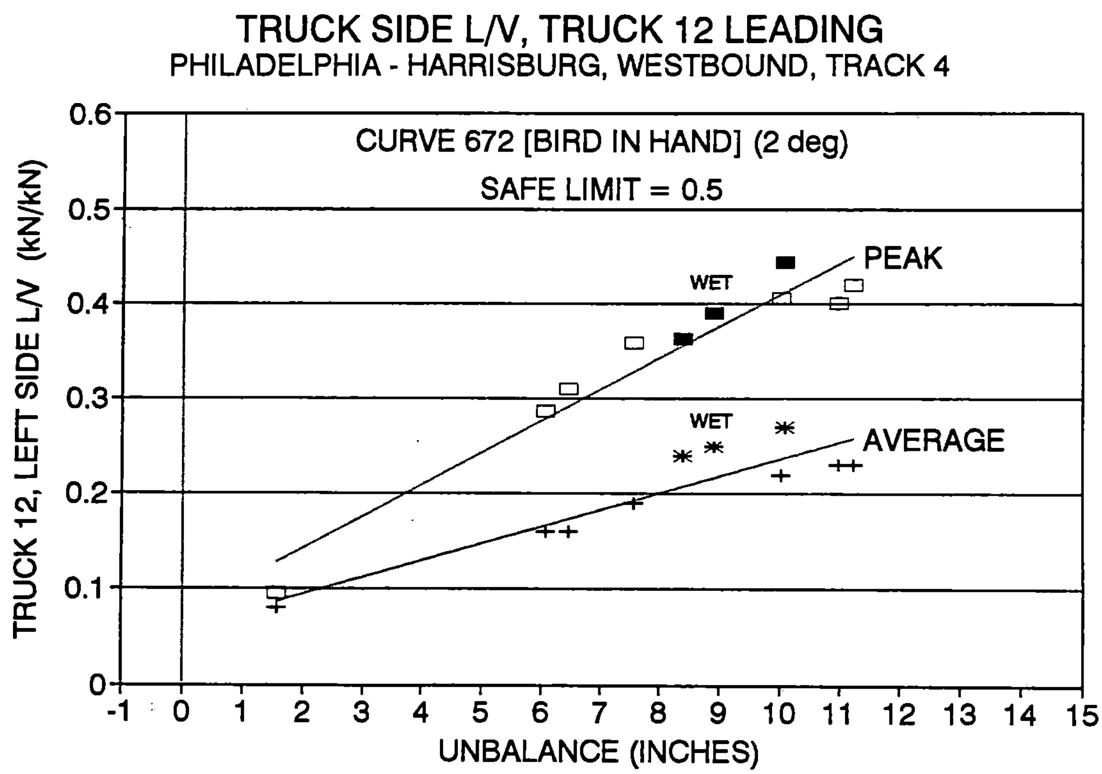


Figure 5.8: Truck Side L/V Ratios, Truck 12 (Cab) in Curve 672

5.6 FIELD OBSERVATIONS OF LATERAL RAIL DISPLACEMENT

Track panel shift and rail movement were monitored during high cant deficiency test runs by surveying from lineside structures. No permanent deformation of track or rail was registered during any of the trials on both wooden ties with cut spikes and tie plates or concrete monoblock ties with Pandrol fasteners.

One instance of "plate movement on deteriorated ties" was detected using surveyor's tacks by the field survey crew during the test period. The observations were made in Gap curve (662), Track #4 (Harrisburg line) on the night of 1 December 1992 after a day of "wet" test runs 107 - 114 at measured cant deficiencies up to 11". Approximately 0.25" of plate movement and 0.125" plate wear was detected at an isolated location; movement did not occur on two consecutive ties and there were many good ties in the vicinity.

This movement could not be directly attributed to the passage of the X2000 as apart from other general traffic on the line. The wheel/rail force data measured in Gap curve for the relevant preceding test runs 111 and 113 did not reveal the occurrence of any excessive forces, although the net axle lateral force on the leading axle 24 of the cab car (leading car) did exhibit a peak of 66 kN (84% of the safety limit) during test run 113, with a corresponding truck side L/V ratio of 0.42 (also 84% of the safety limit). However, this location was carefully monitored and no further movement was observed during the remainder of the test runs at cant deficiencies up to 12".

5.7 TRUCK FRAME ACCELERATION (HUNTING), TA

The truck frame lateral accelerations of truck #1 of the locomotive, truck #5 of the coach car, and truck #12 of the cab car were monitored throughout the test period.

A review of the chart recordings gave no indications of truck instability at any speed within the speed range covered during the tests, which included operation at up to 154 mph. There was no evidence of sustained high lateral accelerations of the truck, and no reported observations of truck hunting by experienced onboard test personnel. This was consistent with predictions made by ABB that the critical hunting speed for the range of anticipated wheel/rail contact conditions is well above 150 mph.

A final check of truck frame lateral accelerations was made during a pre-revenue service round trip, 31 January 1993, from Washington to New York City, at speeds up to 135 mph. A summary of the chart-recorded results is given in **Table 5.2.**

There was no evidence of truck hunting, and the recorded values of truck lateral acceleration are representative of truck response to track perturbations in high speed operation on existing track. The test results demonstrate the types and levels of lateral loading which must be taken by the truck design. Specifications for trucks should include requirements for such lateral loading, in addition to vertical loading, and require confirmation that truck design is satisfactory for these lateral loading conditions.

TABLE 5.2: TRUCK FRAME LATERAL ACCELERATIONS, TRUCK 12

135 MPH RUN, NEC, WASHINGTON - NEW YORK R/t, 31 January 1993

- No evidence of truck hunting during entire test run; no sustained oscillations of lateral acceleration above 0.6 g peak to peak.
- Characteristic single peaks observed as responses from track perturbations; maximum measured peak to peak of single occurrences was 1.15 g (N.B. signal low-pass filtered at 10 Hz).

Track	Milepost	Direct/Track	Speed	Min Accel	Max Accel	Peak to Peak	Comments
Wa-Ph	129	North, Trk 2	131 mph	-0.35 g	+0.55 g	0.90 g	
Wa-Ph	122	North, Trk 2	130 mph	-0.5 g	+0.45 g	0.95 g	
Wa-Ph	106	North, Trk 2	124 mph	-0.25 g	+0.25 g	0.50 g	Sustained for ~ 15 sec
Wa-Ph	103.5	North, Trk 2	~130 mph	-0.5 g	+0.4 g	0.9 g	at north end exit of curve #387 (1°, 4.75" SE), Winans interlocking (just past BWI) at Halethorpe
Wa-Ph	80	North, Trk 2	135 mph	-0.75 g	+0.4 g	1.15 g	
Wa-Ph	77	North, Trk 2	136 mph	-0.6 g	+0.4 g	1.0 g	
Wa-Ph	76	North, Trk 2	136 mph	-0.4 g	+0.6 g	1.0 g	
Wa-Ph	47	North, Trk 2	~130 mph	-0.2 g	+0.2 g	0.4 g	Sustained for 15 sec
Wa-Ph	38.5	North, Trk 2	~120 mph	-0.4 g	+0.5 g	0.9 g	
Wa-Ph	33	North, Trk 2	136 mph	-0.35 g	+0.55 g	0.9 g	
Wa-Ph	4	North, Trk 2	101 mph	-0.4 g	+0.3 g	0.7 g	Several irregular peaks
Ph-NYP	77.5	East, Trk 2	111 mph	-0.55 g	+0.4 g	0.95 g	
Ph-NYP	65	East, Trk 2	136 mph	-0.65 g	+0.25 g	0.90 g	Several irregular peaks
Ph-NYP	33	East, Trk 2	136 mph	-0.4 g	+0.45 g	0.95 g	Several irregular peaks
Ph-NYP	26	East, Trk 2	112 mph	-0.45 g	+0.5 g	0.95 g	
Ph-NYP	20.5	East, Trk 2	113 mph	-0.6 g	+0.35 g	0.95 g	
NYP-Ph	88	West, Trk 3	32 mph	-0.4 g	+0.3 g	0.7 g	
Ph-Wa	38	South, Trk 2*	128 mph	-0.55 g	+0.4 g	0.95 g	
Ph-Wa	57.5	South, Trk 3	126 mph	-0.55 g	+0.35 g	0.70 g	Several irregular peaks
Ph-Wa	112.5	South, Trk 3	132 mph	-0.35 g	+0.3 g	0.70 g	
Ph-Wa	128.5	South, Trk 3	120 mph	-0.4 g	+0.35 g	0.90 g	

* Note: Track 2 used Southbound from MP3 to MP51

5.8 BOSTON - NEW HAVEN TESTS

Tests over this heavily curved, non-electrified line were limited by the performance of the RTL power cars used to tow the X2000 trainset. Accelerations on the RTL power car exceeding 75% of the stop test criteria were measured on a number of occasions. The values and locations of these accelerations are given in **Table 5.3**.

TABLE 5.3 RTL CARBODY ACCELERATIONS EXCEEDING 75% OF STOP TEST CRITERIA

Track No. 1

Run No. 1201 (1/12/93), 5" Cant Deficiency, RTL Trailing

- o MP 168 ("Davisville Intlg."), .28g transient at 90 mph.

Run No. 1301 (1/13/93), 7" Cant Deficiency, RTL Leading

- o MP 188.8 (Curve No. 28 "Lawn Intlg."), .19g steady state at 62 mph.
- o MP 112.5 (Curve No. 109), .30g transient at 72 mph.
- o MP 106.3 (Curve No. 116 "Conn."), .40g transient, .16g transient, and .17g steady state at 67 mph.
- o MP 81.6 (Curve No. 141), .18g steady state at 64 mph.
- o MP 81.3 (Curve No. 142), .34g transient at 64 mph.
- o MP 75.8 (Curve No. 148A), .30g transient at 52 mph.

Run No. 1501 (1/15/93), 8" Cant deficiency, RTL Leading

- o MP 133.8 (Curve No. 79), .17g steady state at 69 mph.

Track No. 2

Run No 1202 (1/12/93), 5" Cant Deficiency, RTL Leading

- o MP 188.8 (Curve No. 28 "Lawn Intlg."), .28g transient at 53 mph.
- o MP 118.8 (Curve No 101), .30g transient at 58 mph.

Run No. 1302 (1/13/93), 7" Cant Deficiency, RTL Trailing

- o MP 174.1 (Curve No. 50), .30g transient at 94 mph.
- o MP 132.4 (Curve No. 81), .30g transient at 58 mph.
- o MP 112.3 (Curve No. 110), .28g and .28g transient at 73 mph.

Run No. 1502 (1/15/93), 8" Cant Deficiency, RTL Trailing

- o MP 174.1 (Curve No. 50), .31g transient at 95 mph.
- o MP 141.4 (Curve No. 71), .28g transient 79 mph.
- o MP 136.3 (Curve No. 75), .17g steady state at 69 mph.
- o MP 112.3 (Curve No. 110), .28g and .29g transient at 73 mph.
- o MP 108.7 (Curve No. 114), .29g transient at 74 mph.
- o MP 105.1 (Curve No. 117), .40g transient at 83 mph.
- o MP 94.8 (Curve No. 126), .29g, .30g, .28g, and .28g transient at 88 mph.

Two other items of interest were noted during the testing as follows:

1. During the 8" Cant Deficiency Run No. 1502 (RTL trailing), RTL No. 154 exhibited a pronounced "yaw" response at several locations. Between MP 89 and MP 92, this "yaw" response resulted in lateral accelerations, measured on the RTL car, up to .25 g peak-to-peak at 83 mph.

2. In several instances, the response of the RTL power car to track anomalies was more severe in the leading configuration than in the trailing configuration. For example, at curve No. 116 ("Conn.") during Run No. 1201 (RTL trailing), the maximum vehicle response was 0.18g transient at 63 mph. In comparison, during Run No. 1301 (RTL leading), the vehicle response at the same curve was 0.40g and 0.46g transient, and 0.17g steady state at 67 mph. The track anomalies were indicated by the same basic signature, but vehicle response was greatly increased in the leading configuration for only a 4 mph increase in speed.

5.9 DEMONSTRATION REVENUE SERVICE RUNS

After a data review of the cant deficiency and high speed test runs, a speed profile was prepared by Amtrak for a demonstration revenue service round trip from Washington to New York Penn Station. This speed profile was based on a maximum cant deficiency of 9 inches and accounted for actual allowable speeds dependent on signal spacings and other local restrictions.

5.9.1 Demonstration Revenue Service Run, 125 mph, 9" Cant Deficiency

Using this speed profile, a demonstration revenue service round trip was made with full instrumentation. For data recording, the trip was segmented into 4 test zones as follows:

1) Washington - Philadelphia, Northbound, principally on track 2
2) Philadelphia - New York Penn, Eastbound, principally on track 2
3) New York Penn - Philadelphia, Westbound, principally on track 3
4) Philadelphia - Washington, Southbound, principally on track 3

On a mile-by-mile basis, the peak values of each safety parameter were recorded in each test zone. A composite plot of the four highest recorded values of each safety parameter in each test zone is shown in **Figures 5.9 - 5.12** as a function of vehicle speed. More detailed information on the location and conditions for these peak values is given in **Table 5.4**.

A maximum top speed of 125 mph was attained during the demonstration revenue service round trip and no violations of any safety limits were observed.

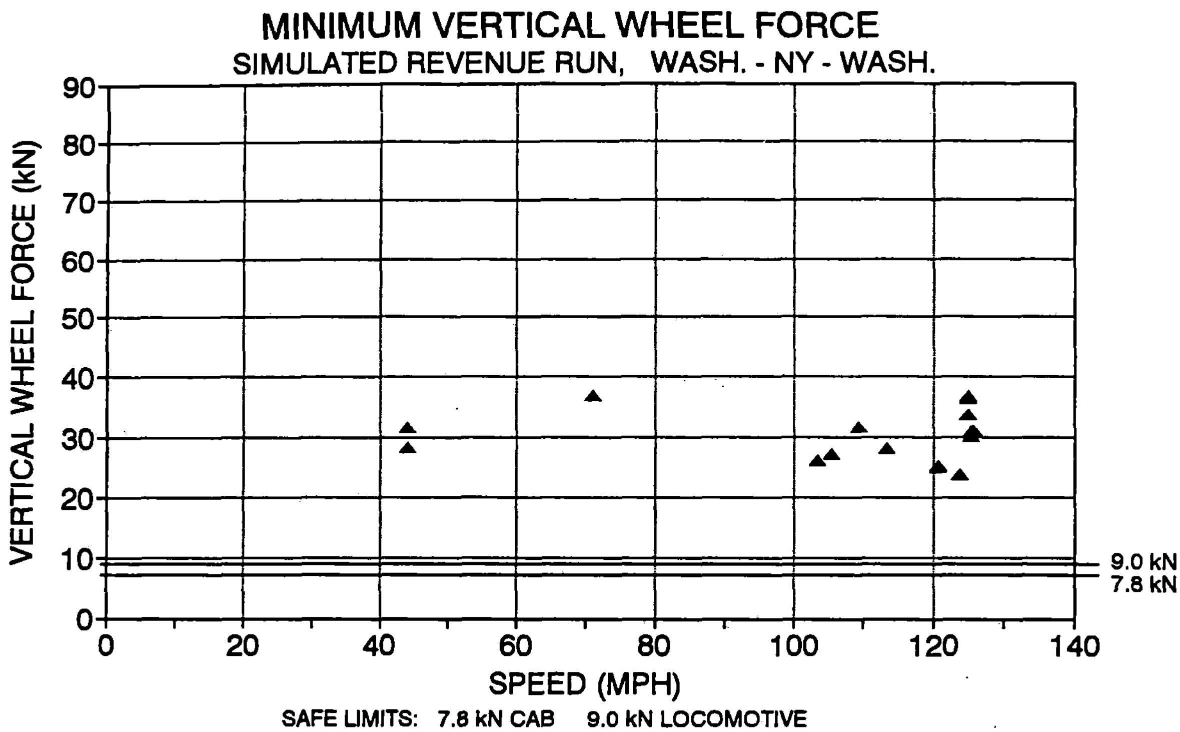


Figure 5.9: Minimum Vertical Wheel Forces, Demonstration Revenue Service Run

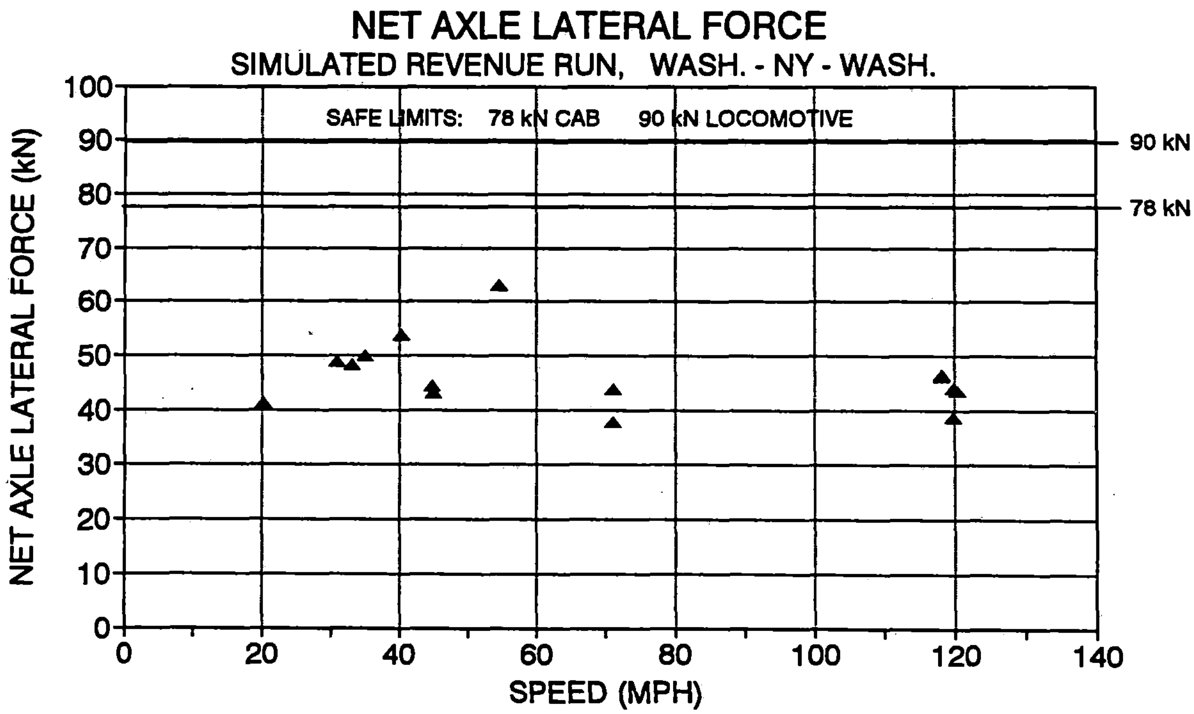


Figure 5.10: Peak Net Axle Lateral Forces, Demonstration Revenue Service Run

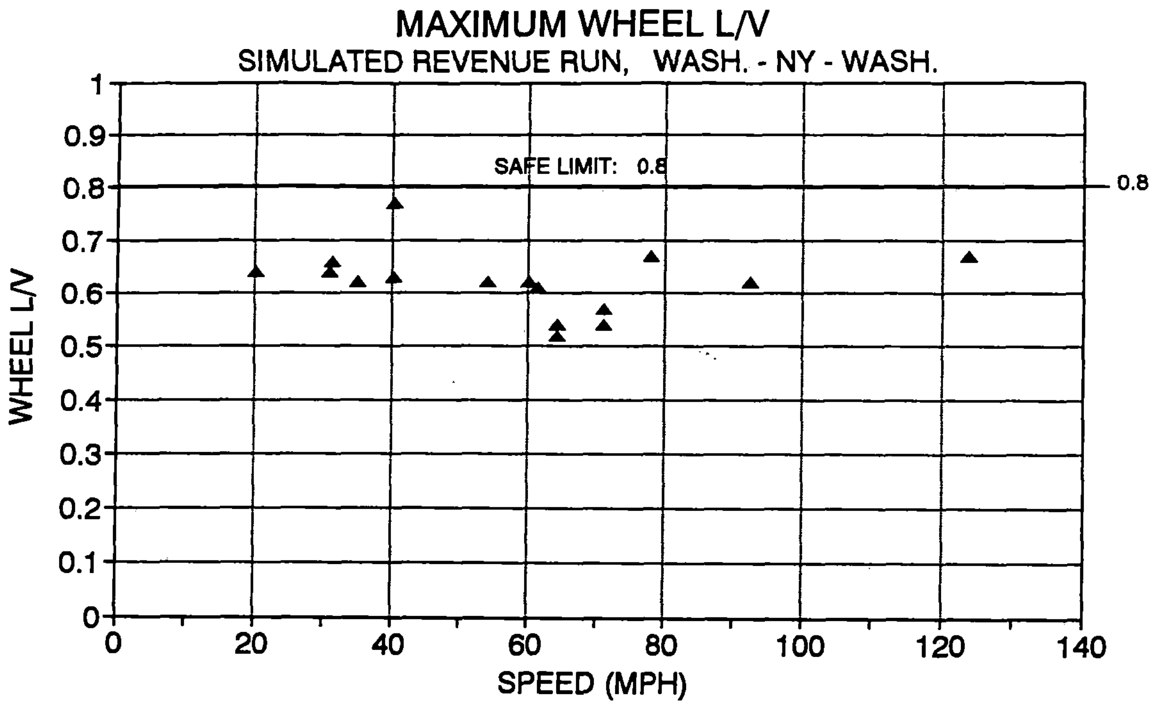


Figure 5.11: Maximum Wheel L/V Ratios, Demonstration Revenue Service Run

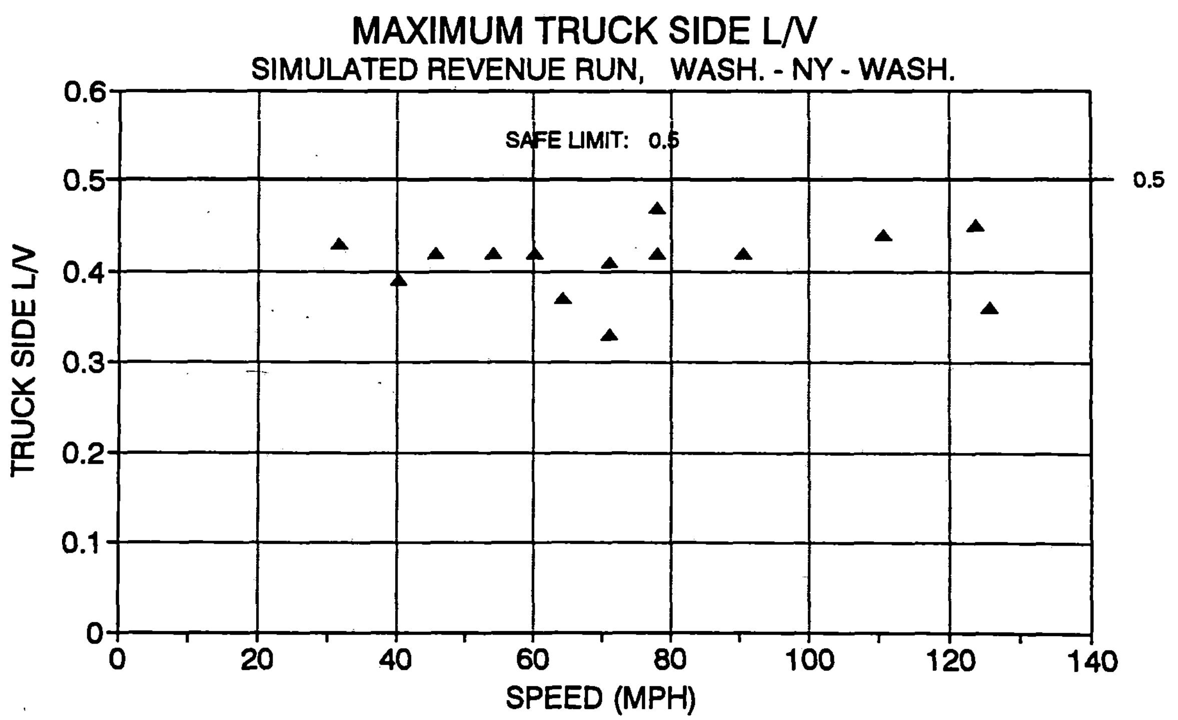


Figure 5.12: Maximum Truck Side L/V Ratios, Demonstration Revenue Service Run

TABLE 5.4 PEAK VALUES, DEMONSTRATION REVENUE RUN, NEC, WASHINGTON - NEW YORK R/t

A) MINIMUM VERTICAL WHEEL FORCE, Vmin

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
30 kN	74%	Right Wheel Axle 1 (Loco)	400 Wa-Ph	North Track 2	76 - 75	Dry		125 mph	Axle 24 (Cab)	Tangent track
31 kN	73%	Left Wheel Axle 1 (Loco)	400 Wa-Ph	North Track 1	63 - 62	Dry		126 mph	Axle 24 (Cab)	
27 kN	72%	Left Wheel Axle 23 (Cab)	400 Wa-Ph	North Track 2	59 - 58	Dry		105 mph	Axle 24 (Cab)	
31 kN	73%	Left Wheel Axle 1 (Loco)	400 Wa-Ph	North Track 2	39 - 38	Dry		126 mph	Axle 24 (Cab)	
37 kN	66%	Right Wheel Axle 1 (Loco)	402 Ph-NYP	East Track 2	66 - 65	Dry		125 mph	Axle 24 (Cab)	
36 kN	66%	Left Wheel Axle 2 (Loco)	402 Ph-NYP	East Track 2	66 - 65	Dry		125 mph	Axle 24 (Cab)	
28 kN	76%	Left Wheel Axle 1 (Loco)	401 NYP-Ph	West Track 3	22 - 23	Dry		44 mph	Axle 1 (Loco)	
32 kN	72%	Left Wheel Axle 2 (Loco)	401 NYP-Ph	West Track 3	22 - 23	Dry		44 mph	Axle 1 (Loco)	
26 kN	74%	Left Wheel Axle 24 (Cab)	401 NYP-Ph	West Track 3	57 - 58	Dry		103 mph	Axle 1 (Loco)	
24 kN	77%	Right Wheel Axle 24 (Cab)	403 Ph-Wa	South Track 3	35 - 36	Dry		124 mph	Axle 1 (Loco)	
25 kN	80%	Right Wheel Axle 1 (Loco)	403 Ph-Wa	South Track 3	55 - 56	Dry		121 mph	Axle 1 (Loco)	
25 kN	80%	Right Wheel Axle 2 (Loco)	403 Ph-Wa	South Track 3	55 - 56	Dry		121 mph	Axle 1 (Loco)	
28 kN	76%	Left Wheel Axle 23 (Cab)	403 Ph-Wa	South Track 4	62 - 63	Dry		114 mph	Axle 1 (Loco)	

TABLE 5.4 (con't) PEAK VALUES, DEMONSTRATION REVENUE RUN, NEC, WASHINGTON - NEW YORK R/t

B) MAXIMUM NET AXLE LATERAL FORCE, NAL

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
63 kN	70%	Axle 1 (Loco)	400 Wa-Ph	North Track 2	99 - 98	Dry		55 mph	Axle 1 (Loco)	
48 kN	62%	Axle 24 (Cab)	400 Wa-Ph	North Track 2	98 - 97	Dry		33 mph	Axle 1 (Loco)	
50 kN	64%	Axle 24 (Cab)	400 Wa-Ph	North Track 2	27 - 26	Dry		35 mph	Axle 24 (Cab)	
44 kN	49%	Axle 1 (Loco)	402 Ph-NYP	East Track 2	75 - 74	Dry		120 mph	Axle 24 (Cab)	
39 kN	50%	Axle 23 (Cab)	402 Ph-NYP	East Track 2	75 - 74	Dry		120 mph	Axle 24 (Cab)	
45 kN	49%	Axle 1 (Loco)	401 NYP-Ph	West Track 3	7 - 8	Dry		45 mph	Axle 1 (Loco)	
47 kN	52%	Axle 2 (Loco)	401 NYP-Ph	West Track 3	74 - 75	Dry		118 mph	Axle 1 (Loco)	
46 kN	59%	Axle 24 (Cab)	401 NYP-Ph	West Track 3	74 - 75	Dry		118 mph	Axle 1 (Loco)	
54 kN	60%	Axle 1 (Loco)	401 NYP-Ph	West Track 4	87 - 88	Dry		40 mph	Axle 1 (Loco)	
47 kN	60%	Axle 24 (Cab)	403 Ph-Wa	South Track 3	50 - 51	Dry		120 mph	Axle 1 (Loco)	
43 kN	48%	Axle 1 (Loco)	403 Ph-Wa	South Track 3	94 - 95	Dry		45 mph	Axle 1 (Loco)	
41 kN	46%	Axle 1 (Loco)	403 Ph-Wa	South Track 3	95 - 96	Dry		20 mph	Axle 1 (Loco)	
49 kN	54%	Axle 1 (Loco)	403 Ph-Wa	South Track 3	96 - 97	Dry		31 mph	Axle 1 (Loco)	

TABLE 5.4 (con't) PEAK VALUES, DEMONSTRATION REVENUE RUN, NEC, WASHINGTON - NEW YORK R/t

C) MAXIMUM WHEEL L/V RATIO, L/V

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
0.66	83%	Right Wheel Axle 24 (Cab)	400 Wa-Ph	North Track 2	97 - 96	Dry		31 mph	Axle 24 (Cab)	
0.62	78%	Left Wheel Axle 24 (Cab)	400 Wa-Ph	North Track 2	94 - 93	Dry		60 mph	Axle 24 (Cab)	
0.62	78%	Right Wheel Axle 2 (Loco)	400 Wa-Ph	North Track 1	27 - 26	Dry		35 mph	Axle 24 (Cab)	
0.57	71%	Left Wheel Axle 24 (Cab)	402 Ph-NYP	East Track 2	82 - 81	Dry		71 mph	Axle 24 (Cab)	
0.67	84%	Right Wheel Axle 1 (Loco)	401 NYP-Ph	West Track 3	10 -11	Dry		78 mph	Axle 1 (Loco)	
0.61	76%	Left Wheel Axle 1 (Loco)	401 NYP-Ph	West Track 3	81 - 82	Dry		62 mph	Axle 1 (Loco)	
0.77	96%	Right Wheel Axle 1 (Loco)	401 NYP-Ph	West Track 4	87 - 88	Dry		40 mph	Axle 1 (Loco)	In "Zoo" interlocking, approaching 30th St. Station, Phil.
0.63	79%	Right Wheel Axle 23 (Cab)	401 NYP-Ph	West Track 4	87 - 88	Dry		40 mph	Axle 1 (Loco)	In "Zoo" interlocking, approaching 30th St. Station, Phil.
0.67	84%	Right Wheel Axle 1 (Loco)	403 Ph-Wa	South Track 3	35 - 36	Dry		124 mph	Axle 1 (Loco)	
0.62	78%	Right Wheel Axle 1 (Loco)	403 Ph-Wa	South Track 4	60 - 61	Dry		93 mph	Axle 1 (Loco)	
0.64	80%	Right Wheel Axle 1 (Loco)	403 Ph-Wa	South Track 3	95 - 96	Dry		20 mph	Axle 1 (Loco)	
0.64	80%	Right Wheel Axle 1 (Loco)	403 Ph-Wa	South Track 3	96 - 97	Dry		31 mph	Axle 1 (Loco)	
0.62	78%	Right Wheel Axle 1 (Loco)	403 Ph-Wa	South Track 3	98 - 99	Dry		54 mph	Axle 1 (Loco)	

TABLE 5.4 (con't) PEAK VALUES, DEMONSTRATION REVENUE RUN, NEC, WASHINGTON - NEW YORK R/t

D) MAXIMUM TRUCK SIDE L/V RATIO, T-L/V

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
0.42	84%	Left Side Truck 12 (Cab)	400 Wa-Ph	North Track 2	95 - 94	Dry		46 mph	Axle 24 (Cab)	
0.42	84%	Left Side Truck 12 (Cab)	400 Wa-Ph	North Track 2	94 - 93	Dry		60 mph	Axle 24 (Cab)	
0.42	84%	Left Side Truck 12 (Cab)	400 Wa-Ph	North Track 1	13 - 12	Dry		91 mph	Axle 24 (Cab)	
0.37	74%	Left Side Truck 12 (Cab)	402 Ph-NYP	East Track 2	86 - 85	Dry		64 mph	Axle 24 (Cab)	
0.41	82%	Left Side Truck 12 (Cab)	402 Ph-NYP	East Track 2	82 - 81	Dry		71 mph	Axle 24 (Cab)	
0.42	84%	Left Side Truck 1 (Loco)	401 NYP-Ph	West Track 3	10 - 11	Dry		78 mph	Axle 1 (Loco)	
0.47	94%	Right Side Truck 1 (Loco)	401 NYP-Ph	West Track 3	10 - 11	Dry		78 mph	Axle 1 (Loco)	
0.39	78%	Left Side Truck 1 (Loco)	401 NYP-Ph	West Track 4	87 - 88	Dry		40 mph	Axle 1 (Loco)	
0.39	78%	Right Side Truck 1 (Loco)	401 NYP-Ph	West Track 4	87 - 88	Dry		40 mph	Axle 1 (Loco)	
0.45	90%	Right Side Truck 1 (Loco)	403 Ph-Wa	South Track 3	35 - 36	Dry		124 mph	Axle 1 (Loco)	
0.43	86%	Right Side Truck 1 (Loco)	403 Ph-Wa	South Track 3	97 - 98	Dry		32 mph	Axle 1 (Loco)	
0.42	84%	Right Side Truck 1 (Loco)	403 Ph-Wa	South Track 3	98 - 99	Dry		54 mph	Axle 1 (Loco)	
0.44	88%	Left Side Truck 1 (Loco)	403 Ph-Wa	South Track 3	128 - 129	Dry		111 mph	Axle 1 (Loco)	

5.9.2 Demonstration Revenue Service Run, 125 mph, 9" Cant Deficiency + 5 mph

A second demonstration revenue service round trip was made between Washington and New York Penn Station. In this case, the trip was made at speeds 5 mph above the 9 inch cant deficiency baseline speeds, except where other restrictions applied. A composite plot of the four highest recorded values of each safety parameter in each test zone is shown in **Figures 5.13 - 5.16** as a function of vehicle speed. More detailed information on the location and conditions for these peak values is given in **Table 5.5.**

For this second higher speed round trip, no violations of any safety limits were observed while traversing any of the approximately 400 different curves at or below the intended +5 mph speed profile. Of the total of 448 miles of track tested, there were three instances where the locomotive truck-side L/V exceeded the limit of 0.5 as follows:

1) 0.57 at 60 mph, 1 mile South of 30th Street Station in Philadelphia, past a turnout at the end of a curved section (curve 305) adjacent to a bridge.

2) 0.54 at 81.5 mph, near MP 10 (NY - Ph), intentionally run at 6.5 mph above the simulated engineer 5 mph excess-speed profile to examine track effects in a section of 1° (1746m radius) curve with four switches in the curve at Hunter interlocking.

3) 0.51 at 126 mph, on tangent track near MP 35 (Ph - Wa) while transiting a switch for the Harmony Industrial Track, south of Stanton

No exceptions of any other safety limit were recorded.

It should be noted that the force ratio required to roll over a rail on tangent track, even if worn, is likely to be closer to the new rail limit of 0.6 than the 0.5 limit used in the tests for worn curve rail. Any rail bolted to a nearby switch crossing will probably tolerate force ratios in excess of 0.6 without rolling over.

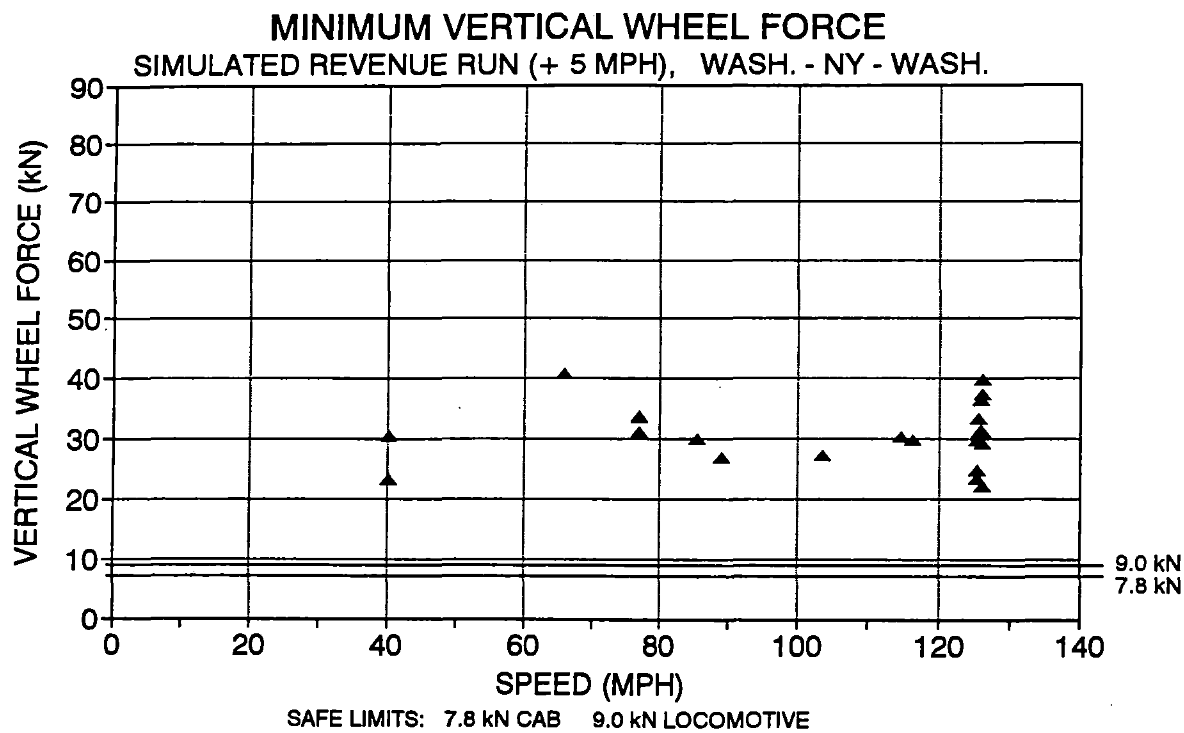


Figure 5.13: Minimum Vertical Wheel Forces, Demonstration Revenue Run + 5mph

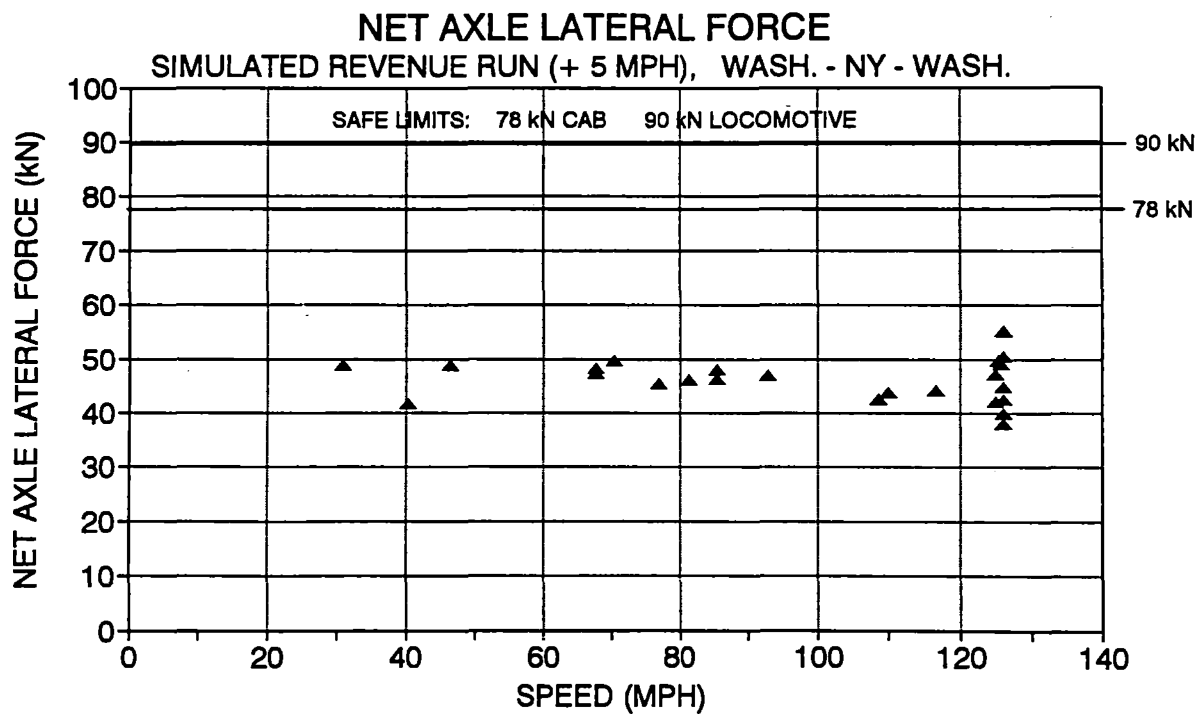


Figure 5.14: Peak Net Axle Lateral Forces, Demonstration Revenue Run + 5mph

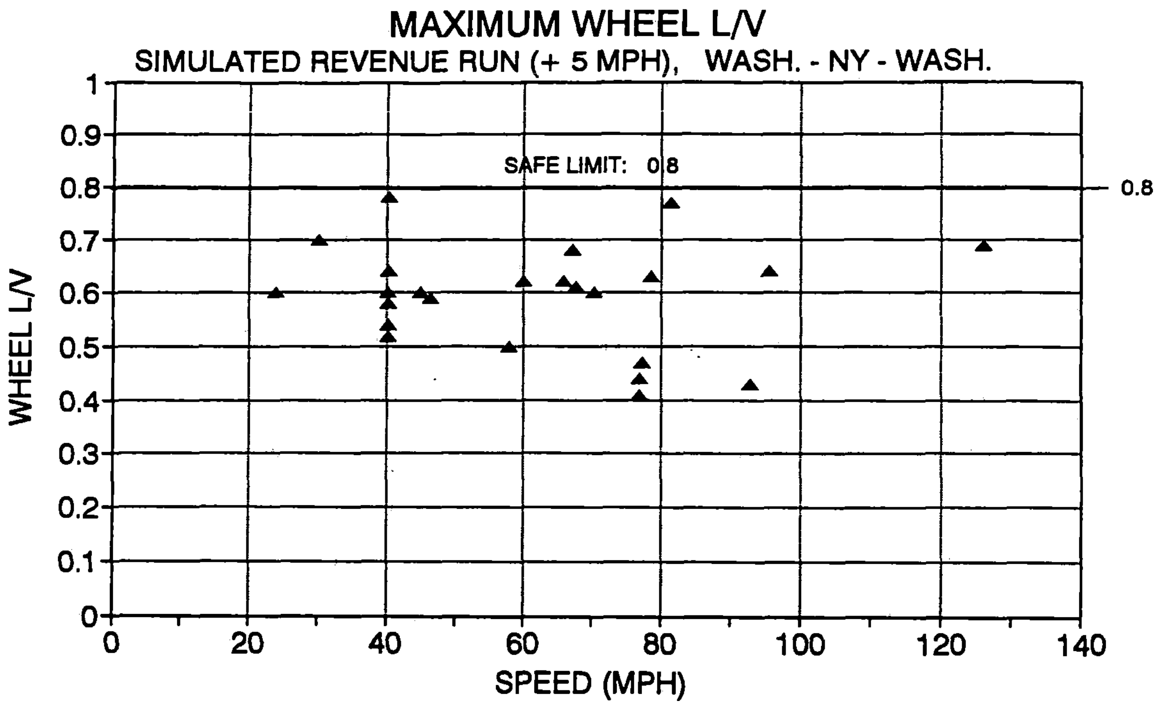


Figure 5.15: Maximum Wheel L/V Ratios, Demonstration Revenue Run + 5mph

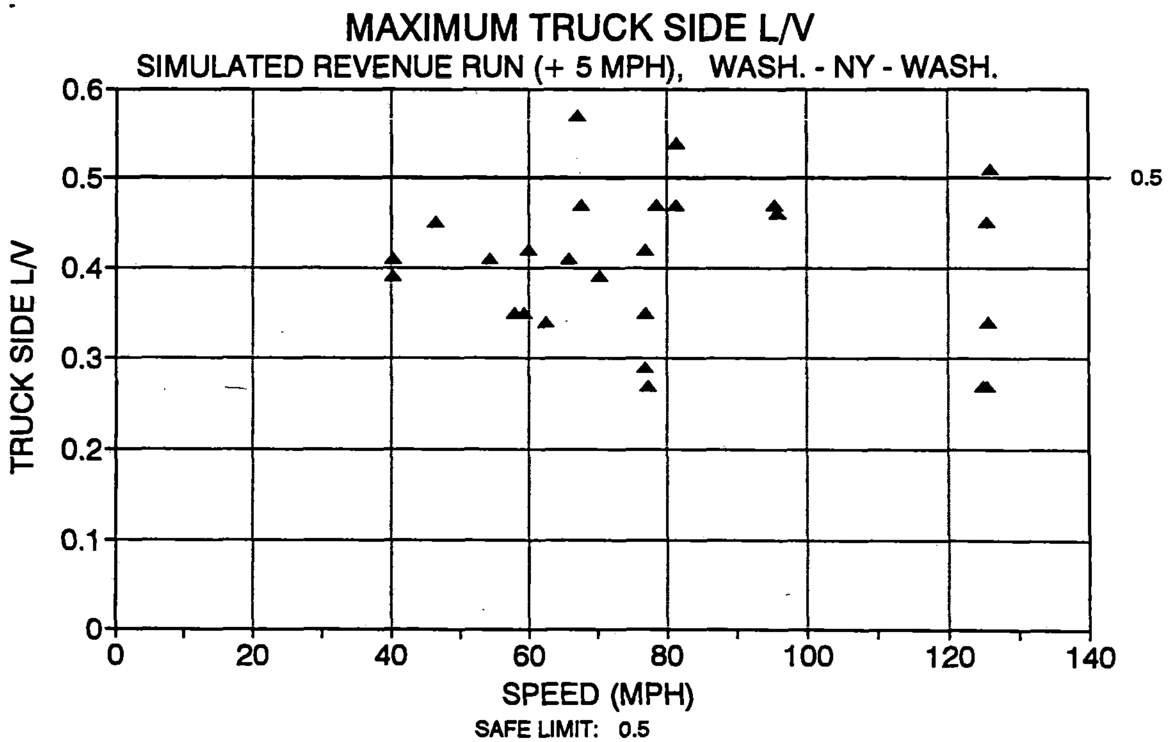


Figure 5.16: Maximum Truck Side L/V Ratios, Demonstration Revenue Run + 5 mph

TABLE 5.5 PEAK VALUES, SIMULATED REVENUE RUN (+5 mph), NEC, WASHINGTON - NEW YORK R/t

A) MINIMUM VERTICAL WHEEL FORCE, Vmin

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
31 kN	73%	Right Wheel Axle 1 (Loco)	404 Wa-Ph	North Track 2	75 - 74	Dry	0.0"	126 mph	Axle 24 (Cab)	
31 kN	73%	Left Wheel Axle 1 (Loco)	404 Wa-Ph	North Track 1	62 - 61	Dry	6.0"	126 mph	Axle 24 (Cab)	
30 kN	75%	Left Wheel Axle 1 (Loco)	404 Wa-Ph	North Track 2	50 - 49	Dry	9.0"	125 mph	Axle 24 (Cab)	
27 kN	78%	Left Wheel Axle 1 (Loco)	404 Wa-Ph	North Track 2	29 - 28	Dry	4.8"	89 mph	Axle 24 (Cab)	
23 kN	82%	Left Wheel Axle 2 (Loco)	406 Ph-NYP	East Track 1	88 - 87	Dry	1.2"	40 mph	Axle 24 (Cab)	
31 kN	68%	Left Wheel Axle 24 (Cab)	406 Ph-NYP	East Track 1	88 - 87	Dry	1.2"	40 mph	Axle 24 (Cab)	
27 kN	77%	Left Wheel Axle 1 (Cab)	406 Ph-NYP	East Track 1	71 - 70	Dry	3.0"	104 mph	Axle 24 (Cab)	
30 kN	74%	Left Wheel Axle 2 (Loco)	406 Ph-NYP	East Track 2	11 - 10	Dry	0.0"	86 mph	Axle 24 (Cab)	
30 kN	68%	Right Wheel Axle 24 (Cab)	405 NYP-Ph	West Track 3	24 - 25	Dry	10.8"	115 mph	Axle 1 (Loco)	
30 kN	69%	Left Wheel Axle 24 (Cab)	405 NYP-Ph	West Track 3	25 - 26	Dry	6.0"	116 mph	Axle 1 (Loco)	
31 kN	66%	Left Wheel Axle 23 (Cab)	405 NYP-Ph	West Track 3	32 - 33	Dry	0.0"	126 mph	Axle 1 (Loco)	
31 kN	73%	Right Wheel Axle 2 (Loco)	405 NYP-Ph	West Track 3	74 - 75	Dry	10.8"	126 mph	Axle 1 (Loco)	

A) MINIMUM VERTICAL WHEEL FORCE, Vmin

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
29 kN	70%	Left Wheel Axle 24 (Cab)	407 Ph-Wa	South Track 3	35 - 36	Dry	0.0"	126 mph	Axle 1 (Loco)	
22 kN	80%	Right Wheel Axle 24 (Cab)	407 Ph-Wa	South Track 3	35 - 36	Dry	0.0"	126 mph	Axle 1 (Loco)	
23 kN	82%	Right Wheel Axle 2 (Loco)	407 Ph-Wa	South Track 3	55 - 56	Dry	0.0"	126 mph	Axle 1 (Loco)	
25 kN	76%	Right Wheel Axle 24 (Cab)	407 Ph-Wa	South Track 3	55 - 56	Dry	0.0"	126 mph	Axle 1 (Loco)	
33 kN	70%	Right Wheel Axle 1 (Loco)	410 Ph-Tre	East Track 2	82 - 81	Dry	6.0"	77 mph	Axle 24 (Cab)	
31 kN	73%	Right Wheel Axle 2 (Loco)	410 Ph-Tre	East Track 2	82 - 81	Dry	6.0"	77 mph	Axle 24 (Cab)	
34 kN	63%	Right Wheel Axle 24 (Cab)	410 Ph-Tre	East Track 2	82 - 81	Dry	6.0"	77 mph	Axle 24 (Cab)	
33 kN	70%	Left Wheel Axle 2 (Loco)	410 Ph-Tre	East Track 2	66 - 65	Dry	4.8"	126 mph	Axle 24 (Cab)	
36 kN	59%	Left Wheel Axle 24 (Cab)	411 Tre-Ph	West Track 3	65 - 66	Dry	3.6"	126 mph	Axle 1 (Loco)	
40 kN	62%	Left Wheel Axle 2 (Loco)	411 Tre-Ph	West Track 3	70 - 71	Dry	9.0"	126 mph	Axle 1 (Loco)	
37 kN	58%	Left Wheel Axle 24 (Cab)	411 Tre-Ph	West Track 3	70 - 71	Dry	9.0"	126 mph	Axle 1 (Loco)	
41 kN	61%	Right Wheel Axle 1 (Loco)	411 Tre-Ph	West Track 3	85 - 86	Dry	0.0"	66 mph	Axle 1 (Loco)	

TABLE 5.5 (con't) PEAK VALUES, SIMULATED REVENUE RUN (+5 mph), NEC, WASHINGTON - NEW YORK R/t

B) MAXIMUM NET AXLE LATERAL FORCE, NAL

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
49 kN	63%	Left Wheel Net Axle 24 (Cab)	404 Wa-Ph	North Track 2	94 -93	Dry	0.0"	46 mph	Axle 24 (Cab)	
48 kN	53%	Left Wheel Net Axle 1 (Loco)	404 Wa-Ph	North Track 2	93 - 92	Dry	4.2"	68 mph	Axle 24 (Cab)	
48 kN	62%	Left Wheel Net Axle 24 (Cab)	404 Wa-Ph	North Track 2	93 - 92	Dry	4.2"	68 mph	Axle 24 (Cab)	
50 kN	64%	Left Wheel Net Axle 24 (Cab)	404 Wa-Ph	North Track 2	50 - 49	Dry	9.0"	125 mph	Axle 24 (Cab)	
43 kN	48%	Left Wheel Net Axle 1 (Loco)	406 Ph-NYP	East Track 2	27 - 26	Dry	9.0"	109 mph	Axle 24 (Cab)	
44 kN	49%	Left Wheel Net Axle 1 (Loco)	406 Ph-NYP	East Track 2	25 - 24	Dry	10.8"	117 mph	Axle 24 (Cab)	
48 kN	53%	Left Wheel Net Axle 1 (Loco)	406 Ph-NYP	East Track 2	11 - 10	Dry	0.0"	86 mph	Axle 24 (Cab)	
46 kN	59%	Left Wheel Net Axle 24 (Cab)	406 Ph-NYP	East Track 2	11 - 10	Dry	0.0"	86 mph	Axle 24 (Cab)	
46 kN	51%	Left Wheel Net Axle 1 (Loco)	405 NYP-Ph	West Track 3	10 - 11	Dry	3.0"	82 mph	Axle 1 (Loco)	
55 kN	61%	Left Wheel Net Axle 2 (Loco)	405 NYP-Ph	West Track 3	74 - 75	Dry	10.8"	126 mph	Axle 1 (Loco)	
51 kN	65%	Left Wheel Net Axle 24 (Cab)	405 NYP-Ph	West Track 3	74 - 75	Dry	10.8"	126 mph	Axle 1 (Loco)	
50 kN	64%	Left Wheel Net Axle 24 (Cab)	405 NYP-Ph	West Track 3	81 - 82	Dry	9.0"	70 mph	Axle 1 (Loco)	

B) MAXIMUM NET AXLE LATERAL FORCE, NAL

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
44 kN	49%	Left Wheel Net Axle 2 (Loco)	407 Ph-Wa	South Track 3	23 - 24	Dry	8.4"	110 mph	Axle 1 (Loco)	
49 kN	63%	Left Wheel Net Axle 24 (Cab)	407 Ph-Wa	South Track 3	50 - 51	Dry	11.4"	126 mph	Axle 1 (Loco)	
43 kN	48%	Left Wheel Net Axle 1 (Loco)	407 Ph-Wa	South Track 3	75 - 76	Dry	0.0"	126 mph	Axle 1 (Loco)	
49 kN	54%	Left Wheel Net Axle 1 (Loco)	407 Ph-Wa	South Track 3	97 - 96	Dry		31 mph	Axle 1 (Loco)	
46 kN	59%	Left Wheel Net Axle 24 (Cab)	410 Ph-Tre	East Track 2	82 - 81	Dry	6.0"	77 mph	Axle 24 (Cab)	
47 kN	52%	Left Wheel Net Axle 1 (Loco)	410 Ph-Tre	East Track 2	81 - 80	Dry	6.0"	93 mph	Axle 24 (Cab)	
47 kN	52%	Left Wheel Net Axle 1 (Loco)	410 Ph-Tre	East Track 2	75 - 74	Dry	11.4"	125 mph	Axle 24 (Cab)	
42 kN	54%	Left Wheel Net Axle 23 (Cab)	410 Ph-Tre	East Track 2	75 - 74	Dry	11.4"	125 mph	Axle 24 (Cab)	
38 kN	42%	Left Wheel Net Axle 1 (Loco)	411 Tre-Ph	West Track 3	70 - 71	Dry	9.0"	126 mph	Axle 1 (Loco)	
45 kN	50%	Left Wheel Net Axle 2 (Loco)	411 Tre-Ph	West Track 3	70 - 71	Dry	9.0"	126 mph	Axle 1 (Loco)	
40 kN	51%	Left Wheel Net Axle 24 (Cab)	411 Tre-Ph	West Track 3	70 - 71	Dry	9.0"	126 mph	Axle 1 (Loco)	
42 kN	47%	Left Wheel Net Axle 1 (Loco)	411 Tre-Ph	West Trck 3,4	87 - 88	Dry	0.0"	40 mph	Axle 1 (Loco)	

TABLE 5.5 (con't) PEAK VALUES, SIMULATED REVENUE RUN (+5 mph), NEC, WASHINGTON - NEW YORK R/t

C) MAXIMUM WHEEL L/V RATIO, L/V

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
0.70	88%	Right Wheel Axle 24 (Cab)	404 Wa-Ph	North Track 2	96 - 95	Dry	0.0"	30 mph	Axle 24 (Cab)	
0.60	75%	Right Wheel Axle 2 (Loco)	404 Wa-Ph	North Track 2	95 - 94	Dry	4.8"	24 mph	Axle 24 (Cab)	
0.59	74%	Left Wheel Axle 24 (Cab)	404 Wa-Ph	North Track 2	94 - 93	Dry	0.0"	46 mph	Axle 24 (Cab)	
0.61	76%	Left Wheel Axle 24 (Cab)	404 Wa-Ph	North Track 2	93 - 92	Dry	4.2"	68 mph	Axle 24 (Cab)	
0.60	75%	Left Wheel Axle 2 (Loco)	406 Ph-NYP	East Track 1	88 - 87	Dry	1.2"	40 mph	Axle 24 (Cab)	
0.52	65%	Left Wheel Axle 24 (Cab)	406 Ph-NYP	East Track 1	88 - 87	Dry	1.2"	40 mph	Axle 24 (Cab)	
0.54	68%	Right Wheel Axle 24 (Cab)	406 Ph-NYP	East Track 1	88 - 87	Dry	1.2"	40 mph	Axle 24 (Cab)	
0.50	63%	Left Wheel Axle 24 (Cab)	406 Ph-NYP	East Track 1	86 - 85	Dry	0.0"	58 mph	Axle 24 (Cab)	
0.62	78%	Right Wheel Axle 1 (Loco)	405 NYP-Ph	West Track 2	1-2	Dry	4.8"	60 mph	Axle 1 (Loco)	
0.60	75%	Right Wheel Axle 1 (Loco)	405 NYP-Ph	West Track 3	7-8	Dry	3.0"	45 mph	Axle 1 (Loco)	
0.77	96%	Right Wheel Axle 1 (Loco)	405 NYP-Ph	West Track 3	10-11	Dry	3.0"	82 mph	Axle 1 (Loco)	
0.60	75%	Left Wheel Axle 1 (Loco)	405 NYP-Ph	West Track 3	81-82	Dry	9.0"	70 mph	Axle 1 (Loco)	

C) MAXIMUM WHEEL L/V RATIO, L/V

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
0.68	85%	Right Wheel Axle 1 (Loco)	407 Ph-Wa	South Track 3	2-3	Dry	3.0"	67 mph	Axle 1 (Loco)	
0.63	79%	Right Wheel Axle 1 (Loco)	407 Ph-Wa	South Track 3	3-4	Dry	3.0"	79 mph	Axle 1 (Loco)	
0.64	80%	Right Wheel Axle 1 (Loco)	407 Ph-Wa	South Track 3	13-14	Dry	0.0"	96 mph	Axle 1 (Loco)	
0.69	86%	Right Wheel Axle 1 (Loco)	407 Ph-Wa	South Track 3	35-36	Dry	0.0"	126 mph	Axle 1 (Loco)	
0.47	59%	Left Wheel Axle 24 (Cab)	410 Ph-Tre	East Track 2	83-82	Dry	0.0"	77 mph	Axle 24 (Cab)	
0.41	51%	Left Wheel Axle 2 (Loco)	410 Ph-Tre	East Track 2	82-81	Dry	6.0"	77 mph	Axle 24 (Cab)	
0.44	55%	Right Wheel Axle 24 (Cab)	410 Ph-Tre	East Track 2	82-81	Dry	6.0"	77 mph	Axle 24 (Cab)	
0.43	54%	Right Wheel Axle 24 (Cab)	410 Ph-Tre	East Track 2	81-80	Dry	6.0"	93 mph	Axle 24 (Cab)	
0.62	78%	Right Wheel Axle 1 (Loco)	411 Tre-Ph	West Track 3	85-86	Dry	0.0"	66 mph	Axle 1 (Loco)	
0.58	73%	Left Wheel Axle 1 (Loco)	411 Tre-Ph	West Trck 3,4	87-88	Dry	0.0"	40 mph	Axle 1 (Loco)	
0.78	98%	Right Wheel Axle 1 (Loco)	411 Tre-Ph	West Trck 3,4	87-88	Dry	0.0"	40 mph	Axle 1 (Loco)	
0.64	80%	Right Wheel Axle 23 (Cab)	411 Tre-Ph	West Trck 3,4	87-88	Dry	0.0"	40 mph	Axle 1 (Loco)	

TABLE 5.5 (con't) PEAK VALUES, SIMULATED REVENUE RUN (+5 mph), NEC, WASHINGTON - NEW YORK R/t

D) MAXIMUM TRUCK SIDE L/V RATIO, T-L/V

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
0.45	90%	Left Side Truck 12 (Cab)	404 Wa-Ph	North Track 2	94-93	Dry	4.8"	46 mph	Axle 24 (Cab)	
0.47	94%	Left Side Truck 12 (Cab)	404 Wa-Ph	North Track 2	93-92	Dry	4.2"	68 mph	Axle 24 (Cab)	
0.45	90%	Left Side Truck 12 (Cab)	404 Wa-Ph	North Track 2	62-61	Dry	6.0"	126 mph	Axle 24 (Cab)	
0.46	92%	Left Side Truck 12 (Cab)	404 Wa-Ph	North Track 2	12-11	Dry	2.4"	96 mph	Axle 24 (Cab)	
0.35	70%	Left Side Truck 12 (Cab)	406 Ph-NYP	East Track 1	86-85	Dry	0.0"	58 mph	Axle 24 (Cab)	
0.35	70%	Left Side Truck 12 (Cab)	406 Ph-NYP	East Track 1	85-84	Dry	0.0"	59 mph	Axle 24 (Cab)	
0.41	82%	Left Side Truck 12 (Cab)	406 Ph-NYP	East Track 1	82-81	Dry	1.2"	54 mph	Axle 24 (Cab)	
0.34	68%	Left Side Truck 12 (Cab)	406 Ph-NYP	East Track 2	42-41	Dry	0.0"	126 mph	Axle 24 (Cab)	
0.42	84%	Right Side Truck 1 (Loco)	405 NYP-Ph	West Track 2	1-2	Dry	4.8"	60 mph	Axle 1 (Loco)	
0.47	94%	Left Side Truck 1 (Loco)	405 NYP-Ph	West Track 3	10-11	Dry	3.0"	82 mph	Axle 1 (Loco)	70 mph posted speed, Class 4 Track, interlocking in middle of 1° curve, Hunter
0.54	108%	Right Side Truck 1 (Loco)	405 NYP-Ph	West Track 3	10-11	Dry	3.0"	82 mph	Axle 1 (Loco)	70 mph posted speed, Class 4 Track, interlocking in middle of 1° curve, Hunter
0.39	78%	Left Side Truck 1 (Loco)	405 NYP-Ph	West Track 3	81-82	Dry	9.0"	70 mph	Axle 1 (Loco)	

D) MAXIMUM TRUCK SIDE L/V RATIO, T-L/V

Measured Value	% of Limit	Vehicle Element	Run No/ Line	Direct/ Track	Track Milepost	Track Condit	Measured Cant Def	Measured Speed	Leading Axle	Comments
0.57	114%	Right Side Truck 1 (Loco)	407 Ph-Wa	South Track 3	2-3	Dry	0.6"	60 mph	Axle 1 (Loco)	Switch, in a spiral adjacent to bridge. Posted Class 3
0.47	94%	Right Side Truck 1 (Loco)	407 Ph-Wa	South Track 3	3-4	Dry	3.0"	79 mph	Axle 1 (Loco)	
0.47	94%	Right Side Truck 1 (Loco)	407 Ph-Wa	South Track 3	13-14	Dry	0.0"	96 mph	Axle 1 (Loco)	
0.51	102%	Right Side Truck 1 (Loco)	407 Ph-Wa	South Track 3	35-36	Dry	0.0"	126 mph	Axle 1 (Loco)	Switch, tangent track, Class 5 profile exception
0.27	54%	Left Side Truck 12 (Cab)	410 Ph-Tre	East Track 2	83-82	Dry	0.0"	77 mph	Axle 24 (Cab)	
0.35	70%	Left Side Truck 12 (Cab)	410 Ph-Tre	East Track 2	82-81	Dry	6.0"	77 mph	Axle 24 (Cab)	
0.42	84%	Left Side Truck 12 (Cab)	410 Ph-Tre	East Track 2	82-81	Dry	6.0"	77 mph	Axle 24 (Cab)	
0.29	58%	Right Side Truck 12 (Cab)	410 Ph-Tre	East Track 2	82-81	Dry	6.0"	77 mph	Axle 24 (Cab)	
0.27	54%	Left Side Truck 12 (Cab)	410 Ph-Tre	East Track 2	75-74	Dry	11.4"	125 mph	Axle 24 (Cab)	
0.27	54%	Left Side Truck 12 (Cab)	410 Ph-Tre	East Track 2	66-65	Dry	4.8"	126 mph	Axle 24 (Cab)	
0.34	68%	Right Side Truck 1 (Loco)	411 Tre-Ph	West Track 3	84-85	Dry	0.0"	63 mph	Axle 1 (Loco)	
0.41	82%	Right Side Truck 1 (Loco)	411 Tre-Ph	West Track 3	85-86	Dry	0.0"	66 mph	Axle 1 (Loco)	
0.41	82%	Left Side Truck 1 (Loco)	411 Tre-Ph	West Track 3	87-88	Dry	0.0"	40 mph	Axle 1 (Loco)	

5.10 CARBODY ACCELERATION RESULTS

During the instrumented wheelset test runs, carbody lateral and vertical accelerations were measured on the locomotive, the cab car, and a coach car, and recorded on digital tape. Since carbody acceleration was not considered a primary safety criterion, the vertical accelerations were not displayed in real time on strip chart recordings, and only in selected test runs were the carbody lateral accelerations displayed. The principle stop test criteria, involving the direct measurement of the wheel/rail forces and the truck accelerations (hunting), utilized all the available real-time display channels. An analysis of the digital recordings has not yet been done and would be beneficial in future studies.

Since acceleration measurements are easily performed, it is both useful and practical to correlate carbody acceleration response to certain types of vehicle behavior which may indicate unsafe conditions. While not all unsafe conditions can be correlated, monitoring of the carbody accelerations could be used to give a good first indication of the state of the track and vehicles.

Prior to beginning revenue service, a round-trip, 135 mph maximum speed test run was made between Washington and New York in which the carbody lateral and vertical accelerations were recorded. The carbody accelerations were used to assess the passenger environment and to identify any events that exceeded Amtrak's own ride quality standard which evaluates the peak-to-peak accelerations of specific events typically related to track anomalies. Accelerations which exceed Amtrak's thresholds, particularly in the lateral direction, are those which might indicate potential track or vehicle problems, and also which might hinder walking or standing on the train and affect passenger safety.

A summary of the results from this test run is included in **Tables 5.6 and 5.7** and highlighted below.

1) **Carbody, Lateral Acceleration, Cab Car** over Truck 12

- o No observed peak to peak accelerations (jolts) > 0.25 g (Amtrak "Level 1" exceptions") throughout the test run

- o Maximum jolt observed was 0.25 g (one only)

2) **Carbody, Vertical Acceleration, Cab Car** over Truck 12

- o Approximately 9 peak to peak accelerations (jolts) > 0.30 g (Amtrak "Level 1" exceptions) were measured during the entire test run

- o 2 peak to peak accelerations > 0.4 g (Amtrak "Level 2" exceptions) were measured; however subjective observations of ride comfort at these occurrences did not reflect undue levels of discomfort

TABLE 5.6: CARBODY LATERAL ACCELERATIONS, CAB CAR OVER TRUCK 12

135 MPH RUN, NEC, WASHINGTON - NEW YORK R/t, 31 January 1993

Track	Milepost	Direct/Track	Speed	Min Accel	Max Accel	Peak to Peak	Comments
Wa-Ph	103.5	North, Trk 2	~130 mph	-0.08 g	+0.10 g	0.18 g	at north end exit of curve #387 (1°, 4.75" SE), Winans interlocking (just past BWI) at Halethorpe
Wa-Ph	95	North, Trk 2	~90 mph	-0.13 g	+0.04 g	0.17 g	
Wa-Ph	12	North, Trk 2	90 mph	-0.10 g	+0.08 g	0.18 g	
Ph-NYP	85	East, Trk 2	62 mph	-0.10 g	+0.12 g	0.22	
Ph-NYP	55	East, Trk 2	111 mph	-0.07 g	+0.10 g	0.17 g	
Ph-NYP	10	East, Trk 2	75 mph	-0.11 g	+0.06 g	0.17 g	
NYP-Ph	12	West, Trk 3	104 mph	-0.12 g	+0.12 g	0.23 g	
NYP-Ph	22	West, Trk 3	109 mph	-0.11 g	+0.14 g	0.25 g	
NYP-Ph	25.5	West, Trk 3	109 mph	-0.11 g	+0.12 g	0.23 g	Through 1st switch (east side), Lincoln interlocking, at Metuchen
Ph-Wa	55	South, Trk 3	120 mph	-0.09 g	+0.15 g	0.24 g	
Ph-Wa	57	South, Trk 3	126 mph	-0.12 g	+0.10 g	0.22 g	
Ph-Wa	71	South, Trk 3	135 mph	-0.14 g	+0.10 g	0.24 g	
Ph-Wa	102	South, Trk 3	130 mph	-0.10 g	+0.12 g	0.22 g	
Ph-Wa	123	South, Trk 3	128 mph	-0.12 g	+0.10 g	0.22 g	
Ph-Wa	128	South, Trk 3	115 mph	-0.10 g	+0.12 g	0.22 g	

The majority of the peaks appear to be related to track irregularities, such as turnouts, crossovers and crossings.

The FRA requested that Amtrak conduct regular carbody acceleration measurements on the X2000 trainset during its revenue service operation on the NEC as a condition of the waiver. It had been verified that the wheel/rail forces were within safe limits during the test runs for the characteristic signatures of carbody accelerations on record. Periodic measurements of the accelerations experienced over the same track areas and at similar vehicle speeds would provide some level of assurance of safe conditions if levels did not increase. Although the vehicle's suspension, by design, isolates to a large extent the carbody from the track disturbances (this varies from car to car), any changes in the carbody acceleration levels over time would give an early warning indication of potential problems in track or vehicle condition.

TABLE 5.7: CARBODY VERTICAL ACCELERATIONS, CAB CAR OVER TRUCK 12

135 MPH RUN, NEC, WASHINGTON - NEW YORK R/t, 31 January 1993

Track	Milepost	Direct/Track	Speed	Min Accel	Max Accel	Peak to Peak	Comments
Wa-Ph	126	North, Trk 2	126 mph	-0.17 g	+0.18 g	0.35 g	
Wa-Ph	103.5	North, Trk 2	~130 mph	-0.18 g	+0.27 g	0.45 g	at north end exit of curve #387 (1°, 4.75" SE), Winans interlocking (just past BWI) at Halethorpe
Wa-Ph	72	North, Trk 2	136 mph	-0.18 g	+0.15 g	0.33 g	
Wa-Ph	25	North, Trk 2	~70 mph	-0.16 g	+0.17 g	0.33 g	
Wa-Ph	13	North, Trk 2	91 mph	-0.13 g	+0.17 g	0.30 g	
Ph-NYP	58	East, Trk 2	100 mph	-0.11 g	+0.18 g	0.29 g	
Ph-NYP	20.5	East, Trk 2	113 mph	-0.15 g	+0.15 g	0.30 g	
NYP-Ph	25.5	West, Trk 3	109 mph	-0.17 g	+0.27 g	0.44 g	Through 2nd switch (west side), Lincoln interlocking, at Metuchen
NYP-Ph	28	West, Trk 3	120 mph	-0.08 g	+0.20 g	0.28 g	
NYP-Ph	40	West, Trk 3	125 mph	-0.15 g	+0.13 g	0.28 g	
NYP-Ph	65	West, Trk 3	135 mph	-0.15 g	+0.18 g	0.33 g	
Ph-Wa	13	South, Trk 2*	90 mph	-0.15 g	+0.20 g	0.35 g	
Ph-Wa	57.5	South, Trk 3	126 mph	-0.18 g	+0.17 g	0.35 g	
Ph-Wa	79	South, Trk 3	133 mph	-0.17 g	+0.11 g	0.28 g	
Ph-Wa	84	South, Trk 3	120 mph	-0.11 g	+0.17 g	0.28 g	
Ph-Wa	102	South, Trk 3	135 mph	-0.20 g	+0.15 g	0.35 g	

* Note: Track 2 used southbound from MP3 to MP51

5.11 REVENUE SERVICE EXPERIENCE

The X2000 trainset performed in revenue service on a regularly scheduled basis from 1 February, 1993, for approximately 3 months on the Northeast corridor. Maintenance and oversight support was provided by ABB. No significant problems were reported.

The carbody acceleration/ride quality measurements were performed by ABB on a weekly basis. To monitor the vehicle or vehicle equipment related performance as well as track condition, measurements were made at different locations on the trainset each week over a monthly rotation using both a "MacMeter" to survey for exceptions to Amtrak's ride criteria and a portable chart recorder to evaluate ride comfort.

Locations on the trainset were monitored according to:

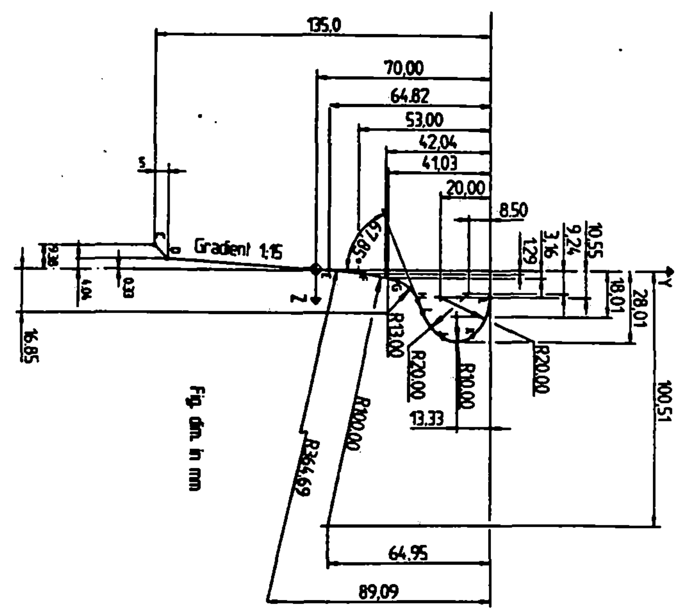
Week 1:	Cab Car, B end, Wash - NY;	Cab Car, B end, NY - Wash
Week 2:	Locomotive, Wash - NY;	Coach 2718, B end, NY - Wash
Week 3:	Coach 2719, A end, Wash - NY;	Coach 2719, B end, NY - Wash
Week 4:	Bistro 2609, A end, Wash - NY;	Coach 2810, B end, NY - Wash

Track sections of principal interest were predefined as:

MacMeter:	MP 90 - 30, Baltimore - Wilmington; MP 80 - 20, Philadelphia - Newark
Chart Recorder:	MP 95-91 (after Union Tunnel), MP 80 - 78 (Gunpowder), MP 64 - 60 (Susquehanna River), MP 51 - 49, Baltimore - Wilmington; MP 76 - 73 (Torresdale), MP 46 - 44 (Princeton Jct), Philadelphia - Newark

On occasion, carbody lateral (yaw) oscillations, at frequencies of about 1.2 - 1.3 Hz, in some instances reaching magnitudes of 0.2 g peak-to-peak, were observed on the trainset at speeds in the range of around 100 - 120 mph. This was more evident on the locomotive when in the trailing position. Although these accelerations did not exceed Amtrak's ride criteria and were not a direct safety concern, ABB took steps to enhance the ride comfort during the revenue service period by re-profiling the wheels of the entire trainset from the original S1002 profile to a "PKB-036" profile shown in **Figure 5.17**. The principal difference in the profiles was a change to a 1 in 15 taper on the wheel tread from the taping point outwards compared with the 1 in 40 taper of the S1002 profile (this change would have little effect on the integrity of the wheel force measurements made during the testing phase). The re-profiling was carried out at Amtrak's Ivy City Maintenance Facility in Washington DC during March 1993, without interruption to the revenue service schedule.

Ride comfort recordings of the carbody lateral accelerations after re-profiling confirmed that the oscillations were substantially reduced.



Courtesy of ABB Traction

Figure 5.17: Modified Wheel Profile During Revenue Service

6. DISCUSSION OF RESULTS AND COMPARISON WITH ANALYSES

The carefully controlled test program was conducted to examine the limits of safe performance under more extreme conditions than those to be used in revenue service. A considerable amount of valuable data was gathered, particularly from the instrumented wheelset measurements, on which to base limits and procedures for the revenue service demonstration. This Section provides a review of the test highlights and a discussion of the results, with some insight into the basis for establishing the safety limits for revenue service operation. Effects of carbody tilt, wet rail, side wind, track condition variance, speed variance, and vehicle condition on attainable cant deficiency are included for discussion.

6.1 TEST HIGHLIGHTS AND SIGNIFICANT EVENTS

Approximately 56 instrumented wheelset test runs were conducted over test zones on the Philadelphia - Harrisburg line and on the NEC from Washington to New York City, with remarkably few problems and favorable results. Highlights include:

- 12.5" average cant deficiency sustained in a test curve representative of U.S. track conditions; no safety criteria exceeded.

- 154 mph maximum speed attained; no truck instability observed.

- No safety criteria exceeded during cant deficiency test runs on the Harrisburg line and the NEC test zone between Trenton and Newark.

- The main circuit breaker, left open for an extended time, resulted in loss of tilting on one occasion during a test; an examination of the recordings showed that no safety criteria were exceeded.

6.2 COMPARISON OF SAFETY-RELATED RESULTS WITH ANALYSES

Extensive computer simulations were carried out by ABB to predict the safety-related performance parameters of the X2000 trainset operating on U.S. track before any tests were performed, as discussed in **Section 3.** Predictions were made using a mathematical model of the X2000, equipped with S1002 profiled wheels, responding to space-curve track geometry data measured and provided by Amtrak for Track #4 of the Harrisburg line. While a complete comparison and discussion of the measured results with the predictions is beyond the scope of this report, an example is included to give some sense of the predictive capabilities and value for future considerations.

Results measured from Curve 663 (Eby's, 4° curvature), travelling westbound on track #4, for test runs in which the cab car was leading the trainset (test runs 101, 103,... 119) were chosen for comparison with the predicted results in **Figures 6.1(a)-(d).** The predictions given assume single-point wheel/rail contact conditions, although ABB also made some predictions for two-point contact. Both the average value and the peak value of each safety parameter for the leading truck and axle of the cab car are compared as a function of quasi-steady cant deficiency in the circular portion of the curve.

As shown in **Figure 6.1(a)**, the prediction of the minimum vertical wheel force, **Vmin**, on the inner-rail wheel of the leading axle of the cab car as a function of cant deficiency shows excellent agreement with measured results, for both the average and peak values in this curve. The agreement of the peak values indicates that the track geometry has been accommodated in the model predictions.

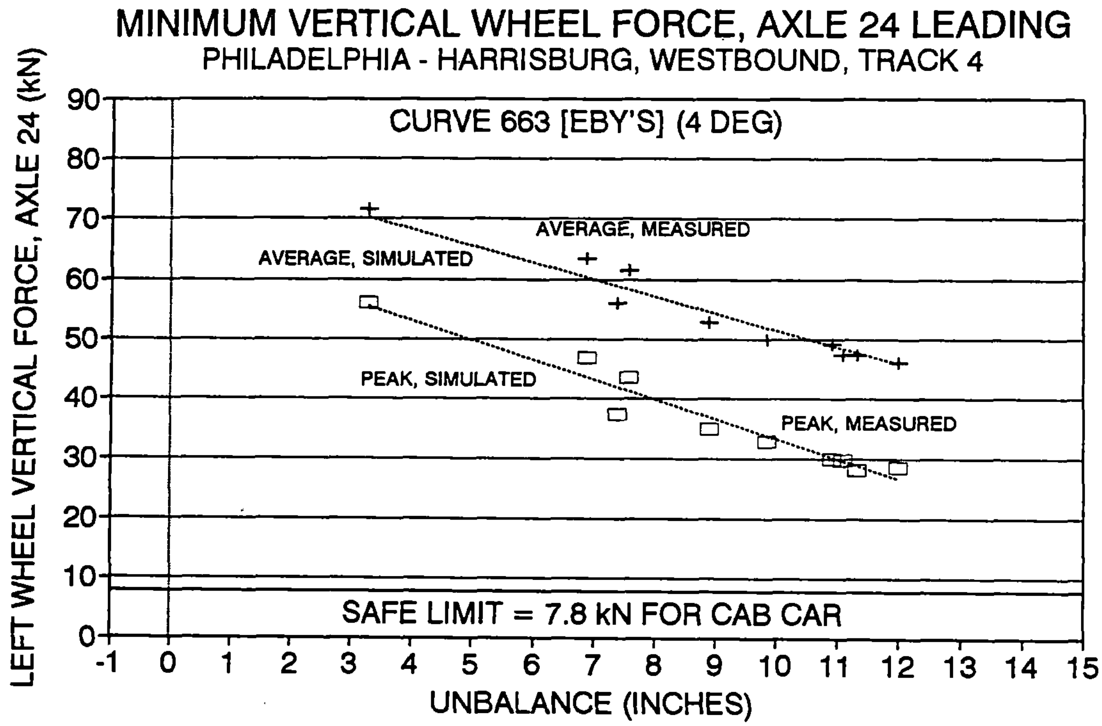


Figure 6.1(a): Measurement vs Prediction, Minimum Vertical Wheel Force

Predictions of the net axle lateral force, **NAL**, on the leading axle of the cab car (**Figure 6.1(b)**) gave the correct trends, although the measured forces, both average and peak, were about 15-20% higher in magnitude. (The negative sign for the forces in this plot merely indicate force direction). The differences could be the result of radial steering effectiveness under actual conditions and the potential effects of two-point contact conditions at the wheel/rail interface.

For the single wheel **L/V** ratio on the right wheel of the leading axle, **Figure 6.1(c)**, the predictions under-estimate the measured values by about the same margin as for the lateral force prediction. For the truck-side **T-L/V** ratio on the right side, **Figure 6.1(d)**, the predictions are low by a factor of about 20%.

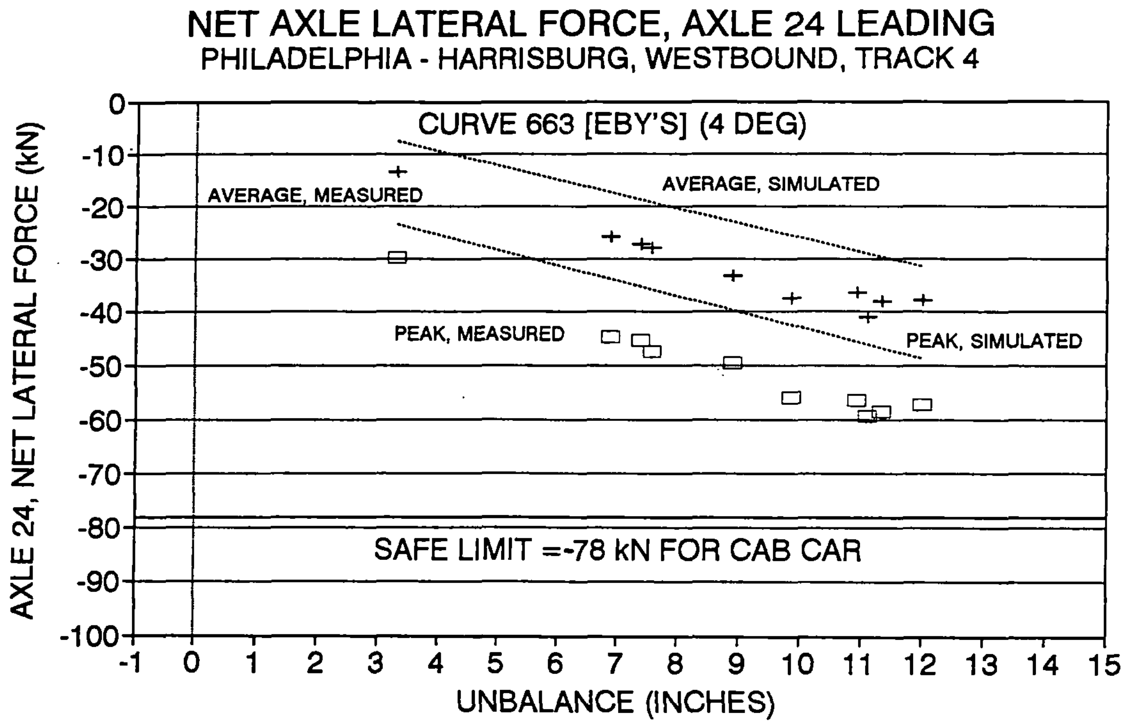


Figure 6.1(b): Measurement vs Prediction, Net Axle Lateral Force

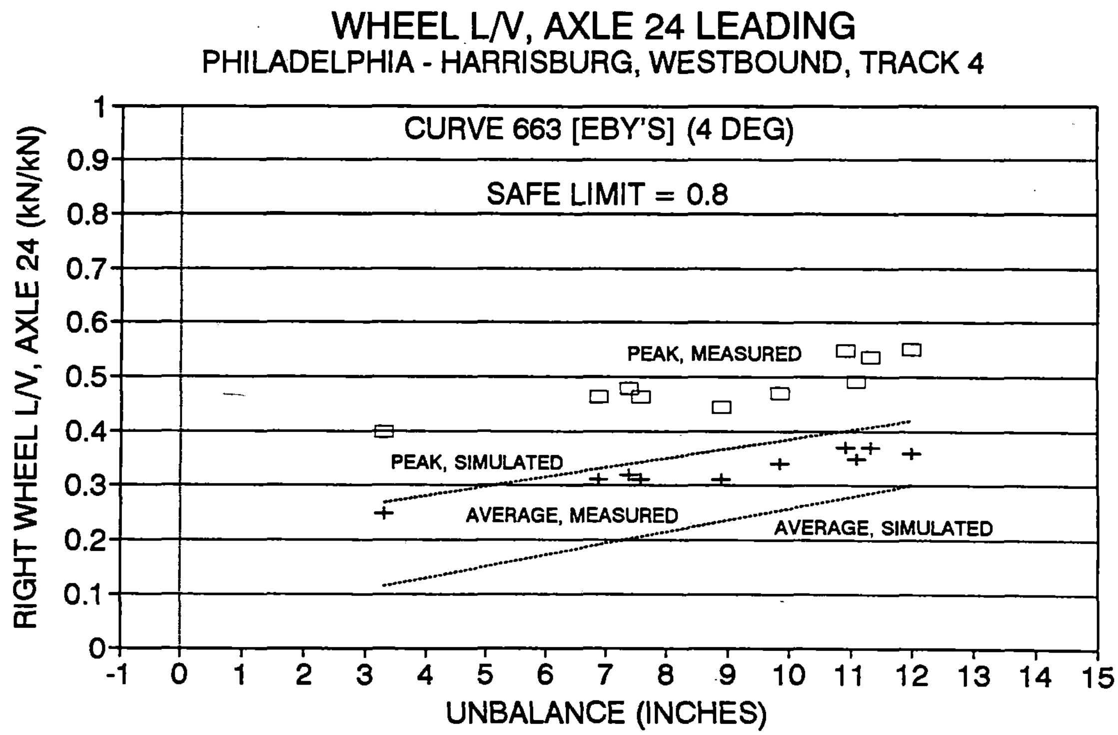


Figure 6.1(c): Measurement vs Prediction, Single Wheel L/V Ratio

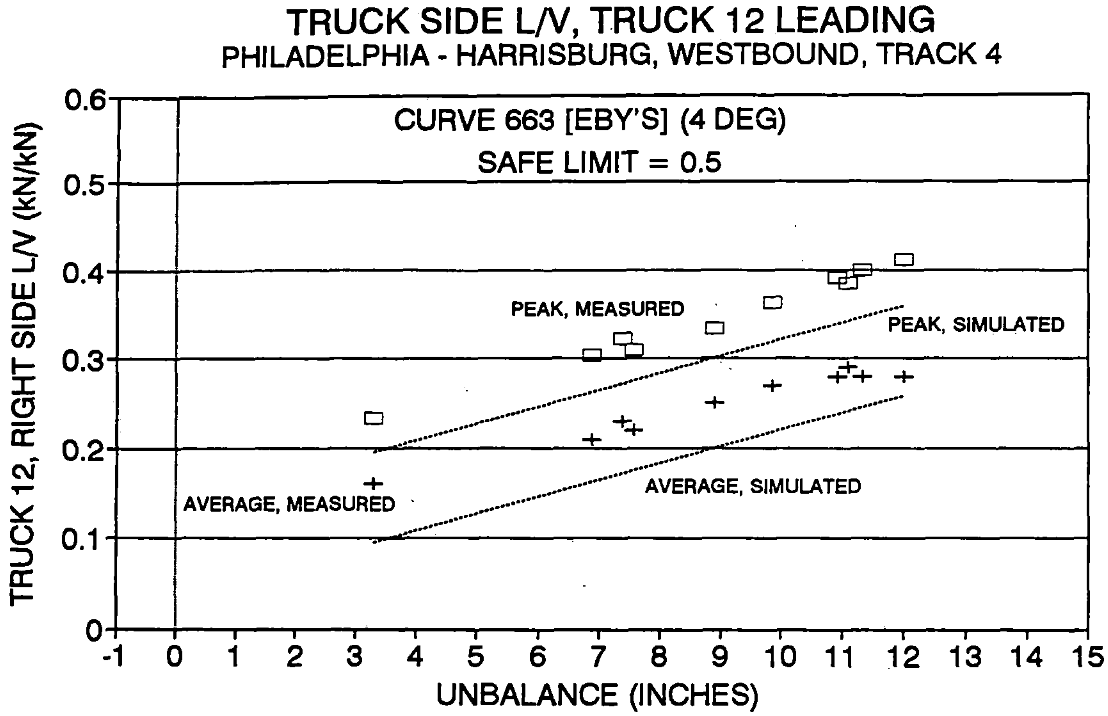


Figure 6.1(d): Measurement vs Prediction, Truck-Side L/V Ratio

This example comparison shows that the model predictions do provide reasonable estimates of the safety-related derailment parameters and are a valuable contribution to assessing and establishing safe operating limits in high speed rail operation.

6.3 EFFECTS OF STEERABLE TRUCKS

The tilting concept permits the X2000 trainset to run through curves at higher speeds than for a conventional trainset without subjecting passengers to excessive lateral accelerations. However, it is the suspension design and lateral force sharing characteristics of the steerable truck which ultimately determine the maximum speeds or cant deficiencies which can be achieved in curves without incurring undue risk of derailment. A comprehensive examination of the design trade-offs and benefits of steerable trucks versus rigid trucks is beyond the scope of this report. However, the effectiveness of the steering in reducing the lateral forces at the wheel/rail interface on a consistent basis for the X2000 trainset is of importance in assuring safety in high cant deficiency operation. It would be reasonable to permit tilting trains to operate at higher speeds on curves provided that lateral forces are not greater than for conventional trains and derailment safety is always maintained.

6.3.1 OBJECTIVES OF STEERABLE TRUCK CONCEPTS

The primary objective of the steerable truck configuration is to minimize the lateral forces at the wheel/rail interface during curve negotiation. A general representation of the wheel-rail forces expected in higher radius curves for both a conventional rigid truck and a steerable (radial) truck is given in **Figure 6.2**. The force vectors illustrate the direction and relative magnitudes (the length of the vector lines) of the typical forces experienced at the wheel-rail interface and the net axle lateral forces.

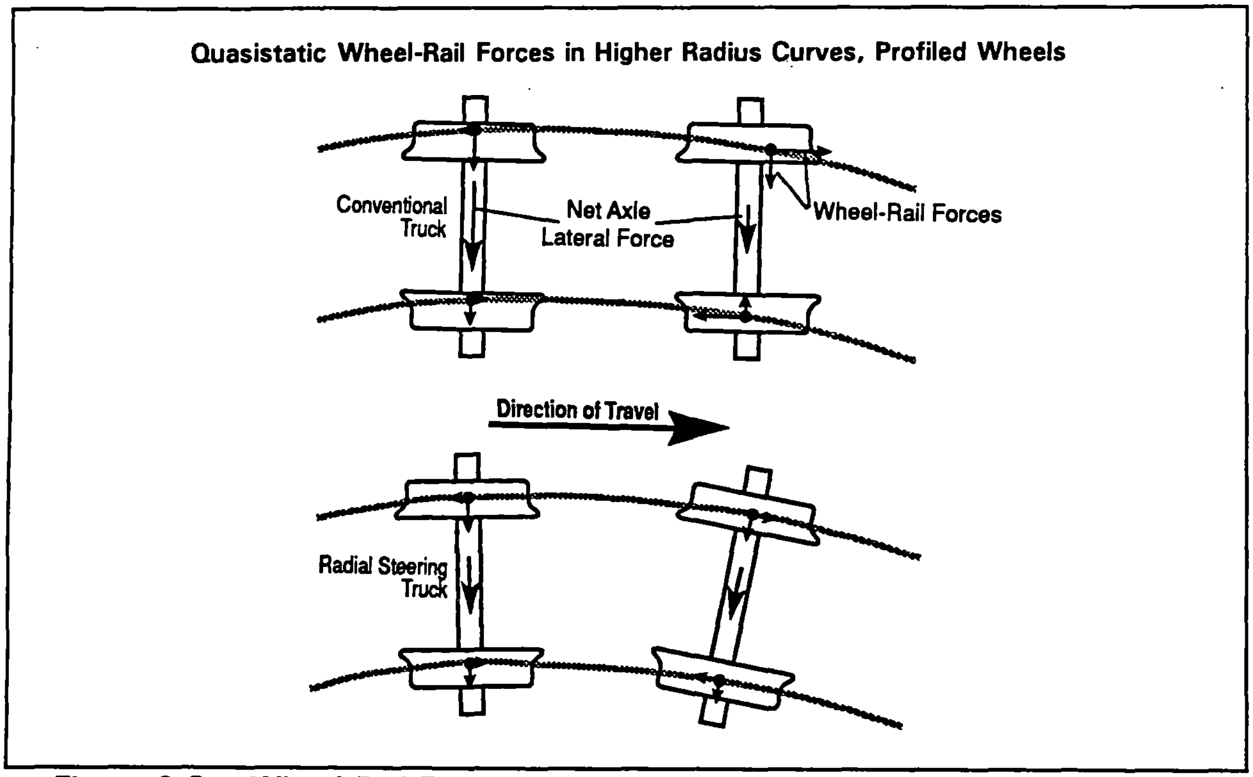


Figure 6.2: Wheel-Rail Forces, Rigid vs Steered Truck, Large Radius Curves

For a rigid truck, the wheelsets are constrained both parallel and in line; the constraints prevent the wheelsets from conforming to the track optimally on curved track to sustain good rolling contact. Typically, in a curve, the leading wheelset of a rigid truck runs against the outer rail in a skewed position while the trailing wheelset runs towards the inner rail in a position which is approximately radial. The skewed position of the leading wheelset results in it being forced to slide sideways as it rolls forwards, producing significant lateral force against the outer rail. Meanwhile, the trailing wheelset is running on unsuitable contact diameters for the curve, resulting in the inner wheel tending to run ahead while the outer wheel drags back. This produces a turning moment in the truck which is reacted by lateral force on the inner rail for the trailing wheelset and additional lateral force against the outer rail for the leading wheelset.

Actual values for these lateral forces depend on specific conditions involving a number of factors including angle of attack, adhesion and contact geometry. When the cant deficiency or centrifugal force resulting from traversing the curve at speeds above balance is added to these lateral forces produced by poor tracking, the combined lateral force at a wheel-rail interface may become excessive in terms of derailment safety, wheel wear and rail wear. Quasi-statically, of course, the net lateral force on the truck as a whole must balance the cant deficiency or centrifugal force.

Ideally, the axles should be radial to the curve to provide good rolling characteristics and minimize lateral forces, and not constrained to slide laterally or run on unsuitable contact diameters. The steerable trucks on the X2000 are of the flexible wheelset type; the axle-boxes are connected to the truck frame by elastomeric springs (rubber chevrons), which are capable of elasticity in the longitudinal and lateral directions, in addition to vertically. With this type, the longitudinal and lateral friction-generated forces at the wheel/rail interface react against the longitudinal and lateral stiffnesses of the axle-box springs, resulting in each wheelset taking up a position which is approximately radial on curves of large radius, where the conicity of the wheels can provide the necessary steering forces and the spring deflections required are small. Traction and braking forces will affect the degree of self-steering obtained with this type of truck.

The steerable truck should reduce the severity of lateral forces in two ways: firstly by reducing the forces resulting from poor tracking of the axles and secondly by permitting both axles to share the centrifugal force.

6.3.2 LATERAL LOAD SHARING BETWEEN AXLES ON CURVES DURING TEST RUNS

In order to assess the degree and consistent behavior of the lateral load sharing achieved in practice, the results of test runs in curves 662, 663, 671, and 672 on the Harrisburg line were tabulated. The average net axle lateral forces measured in these curves on the axles of truck 1 of the locomotive and on the axles of truck 12 of the cab car have been listed and compared in **Table 6.1**. Representative results for test runs intended at 6", 9" and 12" cant deficiency under dry rail conditions are given, as are the results for 9" cant deficiency under wet conditions for comparison. For each test run curve, the ideal lateral force that would be on each axle of the truck to balance the centrifugal force, if shared equally, is given for reference purposes, computed from the measured average cant deficiency in that curve.

The results show a certain degree of scatter. In the case of the locomotive, the degree of traction power being provided is likely to be a variable and might account for some of the variation in results, although the effect of power application in the case of the X2000 flexible wheelset type steerable truck is uncertain. In the case of the cab car, there is some interaction between the carbody tilt system and the truck. The geometry of the traction links between truck and carbody are such that tilting tends to provide a more even distribution of axle forces in the leading truck and less in the trailing truck.

TABLE 6.1: QUASISTATIC NET AXLE LATERAL FORCES MEASURED DURING CURVING

Curve/ Unit Leading	Run #	Track #	Track Condition	Cant Deficiency* Intended [in]	Cant Deficiency* Actual [in]	Net Axle Lateral Force* Locomotive, Truck #1 Ideal [kN]	Locomotive, Truck #1 Axle 1 [kN]	Locomotive, Truck #1 Axle 2 [kN]	Net Axle Lateral Force* Cab Car, Truck #12 Ideal [kN]	Cab Car, Truck #12 Axle 23 [kN]	Cab Car, Truck #12 Axle 24 [kN]
Curve 662 Locomotive Leading	104	1	Dry	6	5.4	17	17	19	14	11	21
	121	4	Dry	9	-9.3	-28	-30	-26	-25	-18	-34
	125	4	Dry	9	-9.0	-28	-28	-25	-24	-13	-38
	129[nt]	4	Dry	9	-9.1	-28	-28	-23	-24	-18	-34
	112	1	Wet	9	8.9	27	28	29	24	16	33
	120	1	Dry	12	12.2	37	34	41	32	23	43
	127	4	Dry	12	-11.9	-36	-36	-33	-31	-25	-39
Curve 662 Cab Car Leading	103	4	Dry	6	6.0	18	23	14	16	18	19
	126	1	Dry	9	-10.5	-32	-37	-22	-28	-26	-33
	130[nt]	1	Dry	9	-9.8	-30	-34	-20	-26	-27	-29
	111	4	Wet	9	9.9	30	37	25	26	23	36
	119	4	Dry	12	12.0	37	42	30	32	34	38
Curve 663 Locomotive Leading	104	1	Dry	6	-5.8	-18	-19	-15	-15	-8	-28
	121	4	Dry	9	8.6	26	26	29	23	15	33
	125	4	Dry	9	8.4	26	26	28	22	16	32
	129[nt]	4	Dry	9	8.7	27	28	31	23	21	28
	112	1	Wet	9	-9.2	-28	-32	-23	-24	-17	-36
	120	1	Dry	12	-12.2	-37	-39	-34	-32	-24	-44
	127	4	Dry	12	11.7	36	37	40	31	22	42
Curve 663 Cab Car Leading	103	4	Dry	6	-6.9	-21	-28	-15	-18	-19	-26
	130[nt]	1	Dry	9	8.6	26	32	26	23	24	26
	126	1	Dry	9	9.3	28	34	25	25	24	33
	111	4	Wet	9	-9.9	-30	-36	-22	-26	-22	-37
	119	4	Dry	12	-12.0	-37	-44	-29	-32	-32	-38
Curve 671 Locomotive Leading	104	1	Dry	6	-3.3	-10	-8	-11	-9	-10	-28
	121	4	Dry	9	6.2	19	15	24	16	11	23
	125	4	Dry	9	8.8	27	22	31	23	19	32
	129[nt]	4	Dry	9	8.7	27	23	33	23	24	29
	112	1	Wet	9	-9.3	-28	-27	-28	-25	-18	-36
	120	1	Dry	12	11.6	-35	-30	-38	-31	-24	-41
	127	4	Dry	12	11.2	34	29	40	30	25	38
Curve 671 Cab Car leading	103	4	Dry	6	-6.6	-20	-27	-14	-17	-18	-20
	130[nt]	1	Dry	9	7.3	22	30	19	19	24	20
	126	1	Dry	9	8.5	26	34	20	22	26	26
	111	4	Wet	9	-9.4	-29	-33	-22	-25	-23	-33
	128	1	Dry	12	10.7	33	40	28	28	32	33
	119	4	Dry	12	-11.7	-36	-43	-28	-31	-33	-32

Curve/ Unit Leading	Run #	Track #	Track Condition	Cant Deficiency* Intended [in]	Cant Deficiency* Actual [in]	Net Axle Lateral Force* Locomotive, Truck #1 Ideal [kN]	Axle 1 [kN]	Axle 2 [kN]	Net Axle Lateral Force* Cab Car, Truck #12 Ideal [kN]	Axle 23 [kN]	Axle 24 [kN]
Curve 672 Locomotive leading	104	1	Dry	6	5.4	17	12	21	14	9	20
	121	4	Dry	9	-7.2	-22	-19	-25	-19	-13	-29
	125	4	Dry	9	-9.1	-28	-23	-30	-24	-16	-34
	129[nt]	4	Dry	9	-9.1	-28	-23	-27	-24	-17	-31
	112	1	Wet	9	8.9	27	24	31	24	17	30
	120	1	Dry	12	-11.4	35	28	41	30	23	39
	127	4	Dry	12	-10.8	-33	-28	-34	-29	-19	-38
Curve 672 Cab Car leading	103	4	Dry	6	6.1	19	23	13	16	19	19
	130[nt]	1	Dry	9	-8.5	-26	-31	-17	-22	-27	-21
	126	1	Dry	9	-8.9	-27	-33	-18	-24	-24	-25
	111	4	Wet	9	8.9	27	33	23	24	24	30
	119	4	Dry	12	11.2	34	38	28	30	34	34
	128	1	Dry	12	-11.5	-35	-41	-25	-30	-32	-30

* The "-" sign indicates lateral force direction to the right, relative to the trainset, looking forward to the locomotive
nt No Tilt on Cab Car during this test run (tilting disabled)

The results for truck #1 of the locomotive show that, when the locomotive (and truck #1) was leading (and pulling the train), the lateral forces were more nearly equal between axles 1 and 2. When the locomotive was trailing (and pushing the train), the trailing axle (axle 1 in this case) generally took approximately 40% more lateral load than the leading axle (axle 2). The results show considerable variation between runs and specific curves.

The same trend is true for the cab car. With truck #12 in the leading position (and leading the trainset), the lateral forces were generally more equally shared by axles 23 and 24. When the cab car was at the rear of the train, the trailing axle (axle 24 in this case) tended to carry about twice the lateral load of the leading axle 23. The results show wide variation between test runs and particular curves.

Wet rail conditions did not appear to affect the locomotive significantly as far as load sharing between wheelsets was concerned. As before, the differences between test runs and curves make comparison difficult. Results for the cab car, when leading, show that the leading axle carried significantly more load in the wet condition than in the dry condition. No significant difference can be seen when the cab car was trailing; however, this might be expected if the rail had been dried by the passage of the locomotive and coaches before the cab car reached the area.

Although the differences between similar runs are not easily explained, the assessment shows that the quasistatic lateral forces were more or less shared between axles of a truck on a consistent basis, in a leading or trailing position, for various curve radii and track conditions, such that no unacceptably high net axle lateral forces were ever observed.

Comparison with the performance of rigid trucks under similar conditions would be desirable to fully appreciate the overall effectiveness of the steerable truck. A detailed examination of the lateral force contributions, high rail side wheel to low rail side wheel of an axle, would also be beneficial.

6.4 MAXIMUM CANT DEFICIENCY LIMIT

Based on the trends exhibited from the dynamic tests for the safety related criteria discussed in **Section 5**, it is to be expected that the X2000 would not exceed any of the safety criteria in the test curves for cant deficiencies up to 15 inches. While extrapolation of the test data to this extent assumes linearity which is not truly valid, it is useful in assessing the relative margin of safety which is likely to exist for the proposed revenue service.

6.5 EFFECTS OF CARBODY TILT

During two test runs on the Philadelphia - Harrisburg line, the tilt system was deactivated on the cab car and on the 2 adjacent cars, #2810 and #2609. These test runs (129,130) were carried out at 9 inches of cant deficiency, with the locomotive leading westbound and the cab car leading eastbound. A comparison of results for the cab car with those obtained from similar 9 inch cant deficiency test runs (125,126) with normal tilting shows little difference in the derailment related safety parameters.

The small interaction effect of the tilt system with the trucks is evident in **Table 6.1** for the average net axle lateral forces on the axles of Truck #12 of the cab car in the curves. When Truck #12 was in the trailing position, there was a slight improvement in the lateral load sharing between the axles when the tilt was disabled. With the cab car leading, the differences were inconsistent.

The maximum steady state carbody lateral acceleration recorded with the tilt system deactivated was 0.19g on the cab car above truck #12 while traversing curve 662 (4°). The maximum peak lateral acceleration observed with no tilting was 0.33g while traversing curve 672 (2°).

6.6 EFFECTS OF WET RAIL

As noted in **Section 5**, the effects of wet rail conditions and lower adhesion levels were not pronounced; there were modest increases observed in the net axle lateral forces of the leading axle (particularly for the cab car), and of the truck side L/V, and yet decreases in the high rail wheel L/V. In some instances, but not always, it was observed that the amount of lateral load sharing by the wheel on the low rail, due to radial steering, was reduced when the rail was wet. The resulting increase in the lateral force applied to the high rail, however, was felt to have little or no impact regarding wheel climb due to the reduction in the coefficient of friction on the high rail. While no hazards are anticipated in any way, further analysis to determine the effect on truck side L/V ratio is recommended to fully describe the effect of wet rail conditions on performance.

6.7 EFFECTS OF SIDE WIND ON ATTAINABLE CANT DEFICIENCY

The effect of side winds on vehicle overturning can be expressed in terms of vertical wheel force unloading. For the X2000 trainset, the vehicle most susceptible to side winds is the cab car when leading the trainset; the side wind in combination with aerodynamic forces on the leading, lighter weight vehicle at higher speeds gives the worst case condition. The locomotive, being heavier and shorter in length, is less affected by side wind.

Measured results for vertical wheel load, **Vmin**, from the 7 test curves on the Harrisburg line and the NEC (e.g. **Figures 5.2, 6.1**), under little or no side wind conditions, indicate that the inner wheel on the leading axle of the cab car in the leading position consistently unloads by about 2.9 kN for every 1" increase in cant deficiency. This trend is roughly the same for both the average and peak values measured for **Vmin**; the measurements were made in the presence of track irregularities and lift forces (due to vehicle forward speed) experienced by the cab car in the leading position. Simulated results provided by ABB for the cab car indicated a similar level of unloading as cant deficiency increases with no sidewinds present.

For a 45 mph sidewind applied to the cab car in a static condition, a simple model estimate of unloading predicts that the vertical wheel force will unload by about 5.7 kN (1300 lb). From the above measurements, this would be roughly equivalent to the unloading experienced by the X2000 cab car when operating at 2" of cant deficiency around a curve.

ABB conducted a very detailed evaluation of sidewind loading at higher speeds for the X2000 cab car in the leading position. Rather than vertical unloading on a wheel, the sidewind effect on attainable cant deficiency was expressed by the vector intercept (VI) value (the intercept of the resultant vector of the car's weight and the lateral forces on the car with the rail plane); the main difference is that the vertical forces from both wheels on one side of the truck are averaged to determine the VI. A safety limit of 26.5" for the VI assumes a 10% margin remaining on the inner wheels before total unloading occurs, and is equivalent to the safety limit for **Vmin** $\geq$ 10% of static wheel load. Use of the VI assists in discriminating between situations truly developing a risk of vehicle overturn from others such as running across a dipped rail joint.

Since the wind conditions during the tests were negligible, the measured VI values were low. To assess the influence of higher sidewinds on the VI, ABB conducted a simulation to compute the effects of a sidewind (in an ideal curve) based on wind tunnel test results. Preliminary results for the cab car were then derived by adding the computed effect of a 45 mph sidewind on the VI to the measured values for the curves 662, 663, 671, and 672 on the Harrisburg line, as well as for the curves 265, 266, and 268 on the Trenton-Newark line. With this method, the maximum expected dynamic value of the VI for a 45 mph sidewind and at 10" cant deficiency was determined to be about 24.5" (equivalent to Vmin ~ 17% of static axle load) for curve 663, and about 23" for the other curves on the Harrisburg line. On the Trenton-Newark curves, the maximum expected VI is about 22".

Complete calculations from a specific curve including track irregularities (e.g. from the NEC) should be done to prove that the dynamic variation of the VI with sidewind is not higher than without sidewind, as in the tests. This is likely to be true since the essential dynamics related to vehicle overturning are of rather low frequency (a very short duration wheel unloading will not result in overturning).

6.8 EFFECT OF TRACK CONDITION VARIANCE ON ATTAINABLE CANT DEFICIENCY

To describe the full effect of various track geometry variations on the performance relative to the safety criteria is a major task well beyond the scope of this effort. Realistic, performance-based limits for track geometry for high speed passenger train operations in the United States have yet to be developed and need to be addressed. An anomaly which reduces the crosslevel by one inch in the body of a curve will be used as a convenient estimate of the likely contribution of the 'realistic worst case' track geometry. Although it is unlikely such an anomaly would exist on Amtrak's high speed track, it is considered a reasonable indicator of the maximum track geometry related effect. The net effect of such an anomaly would be to increase the actual cant deficiency by 1 inch. Deviations in curvature or crosslevel could realistically be expected to increase the cant deficiency by this amount.

6.9 EFFECT OF SPEED VARIANCE ON ATTAINABLE CANT DEFICIENCY

Operating at speeds greater than intended due to speedometer or operator error is a likely occurrence. The effect of overspeed operation is a function of both the curve geometry and the planned operating speed. In general, the higher the degree of curvature and the greater the operating speed, the greater the effect overspeed operation will have on safety. The change in cant deficiency for an overspeed of 5 mph is shown as a function of operating speed for various curvatures in **Figure 6.3.**

6.10 EFFECT OF VEHICLE CONDITION ON ATTAINABLE CANT DEFICIENCY

Obviously the range of possible effects of vehicle maintenance condition on performance is unlimited. As a realistic worst case condition, it is conceivable that the radial steering ability of the truck would be lost.

Much experience gained from a wide variety of radial steering trucks in service (in particular, the X2000) has indicated that the components most likely to suffer from sub-standard maintenance are the dampers. Extensive trials were carried out during 1989 in Sweden to verify the effects of removing up to half of any one group of dampers, often in combinations of several groups together. It was found that under

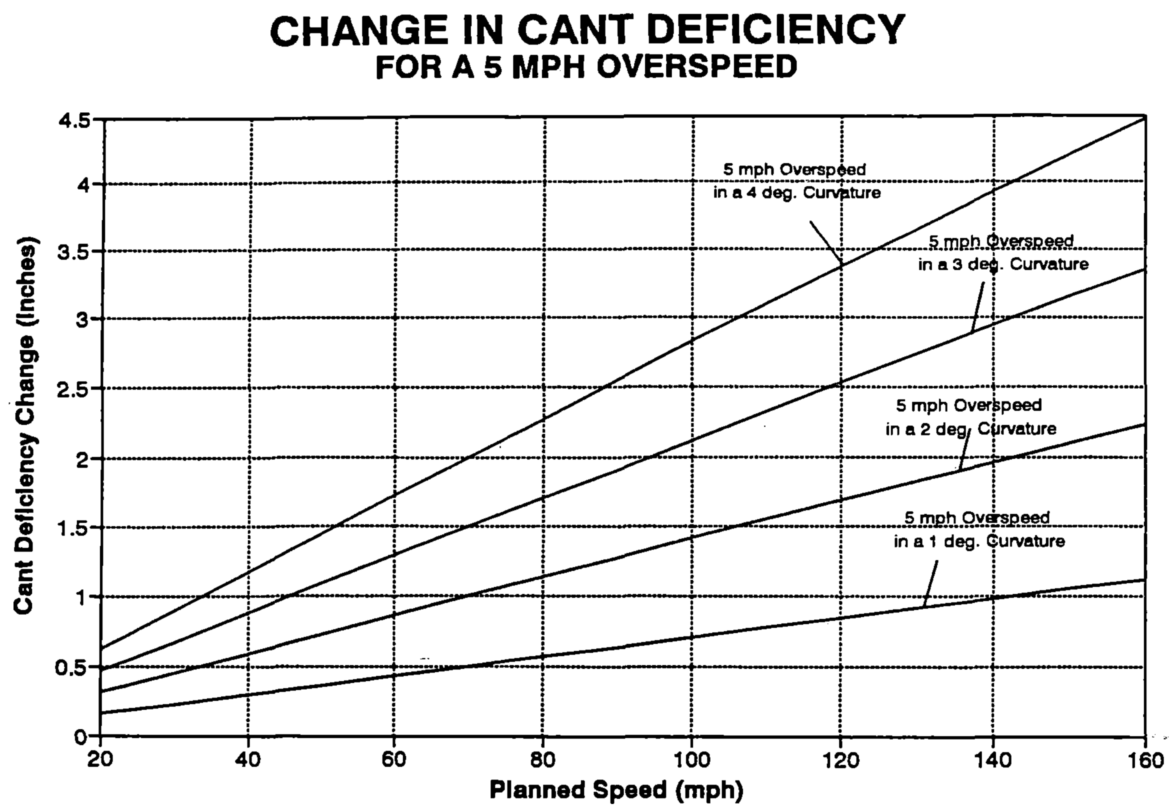


Figure 6.3: Effect of 5 mph Overspeed on Cant Deficiency

such conditions of only 50% of the dampers effective, safety criteria at high cant deficiencies in curves were little affected.

Stability at high speed on tangent was affected negatively, but even with truck hunting, all safety criteria were still fulfilled. However, ride comfort did degenerate more significantly with 50% of the dampers ineffective. This supports the conclusion that damper failure is primarily a comfort and wear problem rather than a safety risk. A 1 inch cant deficiency margin should be ample to account for damper degradation.

Another area requiring maintenance is the profile of the wheels. Careful follow-up programs in Sweden during X2000 revenue service have shown that the wheel profiles maintain a fairly stable worn shape after an initial period of wear-in. Inspection of the profiles chosen for running in the U.S. after some 5000 miles suggests this pattern would be repeated for Amtrak track conditions. Again, a 1 inch cant deficiency margin on safety should provide adequate margin for the unlikely possibility of turning different wheel diameters and other such errors, and for a likely worst case worn wheel profile contour.

6.11 SUMMARY OF EFFECTS ON SUSTAINABLE OPERATIONAL CANT DEFICIENCY

The sum total of the above effects would be to increase the effective cant deficiency by 5.9 inches. A discussion of these effects is presented in **Section 7.**

7. RECOMMENDATIONS AND CONCLUSIONS

As previously stated, the purpose of this report is to document the process, events, and results of a test program that provided a basis for establishing procedures and limits for the safe operation of the X2000 by Amtrak in the NEC. In developing the conclusions and recommendations presented here the authors have attempted to strike a balance between performance and safety. Where either the available data or time for analysis was limited, conservative judgement has been applied in the interest of safety.

The X2000 has been thoroughly analyzed and tested in Europe and has compiled a successful operating and safety record in service in Sweden. The fundamental question addressed by the tests and analysis supporting operations in the United States is how the X2000 would respond to the track conditions here.

The tests in the United States were conducted by Amtrak over specific test zones on Amtrak's Harrisburg line and on the NEC between Trenton and Newark. Specific test curves chosen for detailed analysis ranged from 4° 16' (409m radius) to 1° 26' (1221m radius) giving a theoretical cant deficiency of 12" at speeds ranging from 77 mph to 134 mph respectively. Trials were carried out in each of these selected curves at up to 12" of cant deficiency or at a maximum of 125 mph, whichever limit was reached first. During the 42 test runs, from which 156 curve transits were analyzed in detail, not one safety limit was exceeded. The highest average cant deficiency recorded by the axle mounted accelerometer through an entire curve during trials was 12.5". The test runs were made in conditions varying from dry to wet and with the tilt activated and deactivated on separate runs.

Following successful completion of the tests and a review of results, approval was given by the FRA for revenue service operation of the tested X2000 trainset in the NEC at speeds up to 135 mph in selected locations and cant deficiencies up to 9 inches.

The following recommendations were developed from the preliminary analysis of the test results on which the FRA based its decisions. A brief reference to the relevant and supporting analysis, test results and conclusions is included with each recommendation.

7.1 TRACK GEOMETRY AND VEHICLE MAINTENANCE STANDARDS FOR HIGH SPEED RAIL OPERATION

Prior to the introduction of regular high speed revenue service, track geometry standards for the intended speed range must be developed. As is done in other countries with high speed rail service, vehicle response (i.e. wheel/rail force, axle/truck/carbody accelerations) should be evaluated on a scheduled basis.

7.2 RECOMMENDATION FOR OPERATION AT 9" OF CANT DEFICIENCY

Test results showed the X2000 radial truck to be effective in transferring lateral loads from the high rail to the low rail and between axles at elevated cant deficiency. Vertical load transfer and vehicle overturning were effectively controlled by the truck design which incorporates a roll stabilizer. These design features allowed the X2000 to operate in regular service at 9.6 inches of cant deficiency in Sweden (1.6 m/s^2 lateral acceleration), based on the design curve geometry.

The test results from both the Harrisburg line and the NEC test zones indicate the peak dynamic responses for the safety relevant parameters never reached more than 92% of the stop test criteria at up to 12" of cant deficiency.

The Harrisburg test zone was believed by the Amtrak test planners to be representative of the 'realistic worst case' Amtrak track conditions. A linear projection of the trends established from the test data suggest that, for the conditions tested, somewhere around 15 inches of cant deficiency could be attained before the safety criteria would have been exceeded.

Several factors, which were not evaluated during the test, affect the margin of safety for high cant deficiency operation. A summary of these factors and their estimated likely contributions, in terms of equivalent cant deficiency, is shown below.

Primary Factors Influencing the Margin of Safety for High Cant Deficiency Operations

Factor	Calculated/Estimated Equivalent Cant Deficiency
- 45 mph Side Wind	2.0"
- Track Geometry Variations (FRA cant deficiency enforcement limit)	1.0"
- 5 mph Overspeed	1.4"
- Vehicle Maintenance Condition (Preliminary estimate based on worst likely vehicle condition with sub-standard maintenance)	1.5"

Taken in combination these effects would yield an equivalent increase in cant deficiency of 5.9 inches. While the probability of each of these negative factors existing simultaneously is considered extremely remote, planned operations at 9 inches of cant deficiency based on average geometry might conceivably produce a total equivalent cant deficiency of just below 15 inches.

While it is impossible to know the precise contribution of each of these factors and their combinations under actual service conditions, this type of assessment demonstrates that operating the X2000 at 9 inches of cant deficiency over Amtrak track can be considered safe with the conditions described below.

7.3 RECOMMENDED CONDITIONS FOR 9 INCH CANT DEFICIENCY OPERATION

Condition #1 - Track Geometry/Structure for 9" Cant Deficiency - The track geometry in the curves over which operation at 9" cant deficiency is allowed should meet all applicable FRA Track Safety Standards. The limiting speed for each curve is to be calculated based on a 9 inch cant deficiency using average geometry with a 1 inch tolerance limit for the worst case combination of curvature and crosslevel as measured by monthly inspections by an automated track geometry measurement car.

Track structure, ballast, ties and fasteners must meet the appropriate FRA regulations for the planned operating speed.

Condition #2 - Wind - When speeds are predicted to be in excess of 45 mph, X2000 line speeds should be restricted to those applicable to Metroliner operations under the same conditions.

Condition #3 - Vehicle Conditions - While wheel wear has been reported from service experience in Sweden to be very light, it is considered prudent, due to the different rail profiles which exist on Amtrak rail, that wheel profiles be monitored to ensure that accelerated wheel tread and flange wear do not occur.

Dampers are used more extensively on the X2000 than on existing Amtrak equipment to limit undesired vehicle response. Evaluating the effect of degraded dampers was not part of the test program; therefore it is considered prudent that the condition of all vehicle suspension dampers be monitored to ensure that they are functioning properly by measuring vehicle carbody accelerations on a regular basis .

Condition #4 - Speed Control - Amtrak should take steps to ensure that the combined effects of speedometer error and engineer error will not result in more than 5 mph overspeed in the worst case. It is recommended that this be accomplished by careful implementation of Amtrak's and the equipment manufacturer's existing procedures for speedometer calibration and engineer training.

7.4 RECOMMENDATIONS FOR OPERATION AT 10" OF CANT DEFICIENCY IN SELECTED CURVES

From observations of both the measured track geometry and corresponding vehicle response, it is clear that some curves on the NEC could safely support operation at even higher cant deficiency. Curves which meet the following conditions should be considered for operation at 10" cant deficiency.

Condition #1 - Track Geometry/Dynamic Response Analysis -
Analog plots of both the track geometry and vehicle response should be analyzed to confirm that the following conditions exist:

- Relatively smooth and coordinated spirals and spiral/curve transitions
- No special track work or structures within 200 feet of the curve along the track (i.e.- switches, crossings, undergrade bridges, etc.)
- Limited dynamic response during demonstration revenue test runs.

Condition #2 - Strict Speed Control - Steps should be taken to ensure that the 10" unbalance speed, based on the limiting track geometry conditions, is never exceeded. In this way, overspeed operation is prevented from impacting the margin of safety.

7.5 RECOMMENDATION FOR 135 MPH MAXIMUM OPERATION SPEED

The X2000 demonstrated stable operation at 150 mph over the NEC high speed stability test zone. Analysis performed by the equipment manufacturer has predicted stable performance, under normal conditions, for speeds up to 165 mph.

Both the data and the analysis support the operation at elevated speeds. Operation at speeds up to 135 mph would be considered conservatively safe under conditions 2, 3 and 4 of Section 7.4 together with the following additional conditions.

Condition #1 - Track Geometry/Structure for 125 mph - The track must meet the conditions currently approved for 125 mph Metroliner operations.

Condition #2 - Instability in Service - Any indications of instability during operation must be reported to the FRA. Speed for the X2000 would be restricted to 125 mph until the cause(s) of instability were identified and corrected.

7.6 CONCLUSIONS

Based upon the experimental work described in this Report and the results obtained, the following conclusions can be drawn:

o 9" cant deficiency operation can be safely achieved on NEC track

o 10" cant deficiency operation can be permitted for selected curves with good track structure and geometry

o 135 mph operation can be permitted in limited locations where track structure, geometry and rail profile are good

o Track structure and geometry should be monitored before revenue service begins, 1 week after service has been in operation, and henceforth on a monthly basis; examine for changes particularly in the high cant deficiency and high speed zones

- o Vehicle wheel profiles and damper elements should be monitored for condition on a monthly basis
- o Operation should be limited to 5" cant deficiency when wind conditions exceed 45 mph
- o Effects of wet rail are still to be resolved
- o Specific effects of track geometry and rail profile are still to be resolved
- o An audible alarm should be installed to signal power loss
- o Specifics of engineer training should be considered; precise control of overspeed may be required

APPENDIX A

STEPS TO OBTAIN WAIVER FOR THE X2000 U.S. TEST AND DEMONSTRATION, AND THE FEDERAL REGISTER NOTICE

A.1 WAIVER PROCESS DESCRIPTION

Since the X2000 trainset did not meet a number of the requirements specified by FRA regulations, a waiver of these requirements by the FRA was necessary before the train could be operated for test purposes only in the United States. The subject areas which were included in the waiver for the X2000 trainset are given below, together with the applicable regulation numbers:

		CFR
1.	Operation at 125 mph for test purposes.	213.9
2.	No hand-holds, uncoupling levers and steps.	231.12
3.	Lack of proper test documentation for glazing.	223 App. A
4.	Operation at speeds producing more than 3" of cant deficiency on curves.	213.57
5.	Operation of either RTL power cars or F40 locomotives at 8" of cant deficiency.	213.57
6.	Operation with tread brakes removed from instrumented wheel sets.	232.1
7.	No conventional hand brake.	231.12
8.	Emergency brake application not providing increase in cylinder pressure of 15- 20%.	232 App. A
9.	200,000 candela headlight.	229.125
10.	No sanding equipment on power car.	229.131

The procedure for requesting, processing and obtaining the waiver is described below.

The test sponsor, Amtrak, submitted a petition to the FRA requesting the necessary waiver. Based on the text of the petition, the FRA published a notice in the Federal Register. This notice provided information regarding the receipt of the petition, its content, and explained how the FRA proposed to ensure safety during the tests. A period of 45 days was provided for comment by interested parties.

Taking into account any comments received, the FRA prepared a brief for consideration by the FRA Safety Board. The brief provided complete details of the tests proposed, described measures to be taken to minimize the risk of an accident and gave the justification for such measures. The brief included a description of the measures to be taken by the test sponsor, Amtrak, to ensure that the performance limits of the test trainset had been estimated through analysis prior to the actual testing and that as these limits were approached incrementally during the test operations, test direction personnel were provided the opportunity to terminate testing if it appeared that one or more limits were likely to be exceeded.

Subsequently, the Board approved the petition. The test sponsor, Amtrak, was then able to proceed with the tests as proposed, while adhering precisely to the conditions stated in the notice of approval and under the critical observation of an FRA test monitor.

The test sponsor prepared a detailed test plan. The plan included the following items:

a. Test objectives; one objective was confirmation of the test trainset performance as predicted analytically.
b. Test procedures, including data to be collected, instrumentation to be employed, data analysis techniques to be used and the general test methodology.
c. Test safety constraints, including consideration of the safety requirements of previous cant deficiency testing and the applicable conditions contained in the FRA test approval document.
d. Recognition of the need to prepare clear and precise train operating instructions for locomotive engineers that give the speed restriction for each particular curve, based on the analysis of data from a track geometry measurement car, including curvature and superelevation data.
e. Designation of responsibilities.
f. Test schedule.

Testing was undertaken in two stages. The first stage was the validation of the simulated dynamic behavior of the train. This data was reviewed by FRA staff before further testing was undertaken. The second stage consisted of full-scale testing of train performance, within the limitations specified.

Before the prototype trainset was operated in revenue service, a second petition for a waiver of the applicable FRA regulations was filed. The receipt and contents of this additional petition were published in the Federal Register. Subsequently, the FRA Safety Board issued a favorable ruling on the petition.

A.2 Summary of Waiver Process Essential Steps

The essential steps that must be taken by a test sponsor, such as Amtrak, in order to obtain a waiver of applicable FRA regulations are summarized below:

1. Submission of petition for waiver of FRA regulations to cover train operation for test purposes only.

2. Notice published by FRA in Federal Register informing public of receipt of petition, contents of petition and FRA plan for ensuring safety.

3. Comment from interested parties during 45 day period.

4. Brief prepared by FRA for Safety Board describing nature of tests, recommendation for minimizing risk of accident and justification of such

recommendations, together with details of measures that test sponsor will take to ensure limits of vehicle performance are estimated in advance and such limits are not exceeded during testing.

5. FRA Safety Board issues ruling approving or denying petition.

6. In case of approval, test sponsor proceeds with tests, in accordance with conditions stated in notice of approval and under observation of FRA Test Monitor, if so specified.

7. Assuming successful completion of tests and desire to operate prototype trainset in revenue service, additional petition filed for waiver of FRA regulations to cover train operation during revenue service, based on successful completion of test program covered by initial waiver.

8. Publication of notice in Federal Register by FRA, as before.

9. Comments from interested parties, as before.

10. Brief prepared for FRA Safety Board, including successful results of tests carried out under initial waiver, together with FRA plan for ensuring train safety.

11. Ruling by FRA Safety Board concerning additional petition for waiver to allow train operation in revenue service.

APPENDIX B

TEST INSTRUMENTATION DETAILS

B.1 TRANSDUCERS

Four instrumented wheelsets were installed in Sweden before the X2000 trainset was shipped to the U.S. These wheelsets were of the load measuring wheel type, as developed in Sweden. The wheels were strain-gauged to measure both vertical and lateral forces. Two instrumented wheelsets were installed on truck 1 at the driver's end of the locomotive and two were installed on truck 12 at the driver's end of the cab car.

A description of the measurement transducers and their locations on the vehicle is given below in **Table B.1** and depicted in **Figure B.1**.

The nomenclature used to define each signal name was as follows:

V = Vertical wheel/rail force
L = Lateral wheel/rail force
y = Lateral acceleration
z = Vertical acceleration
l = left side
r = right side
a = axle, on axle bearing
b = bogie (truck), on bogie
cb = car body, on car floor over bogie (truck) center

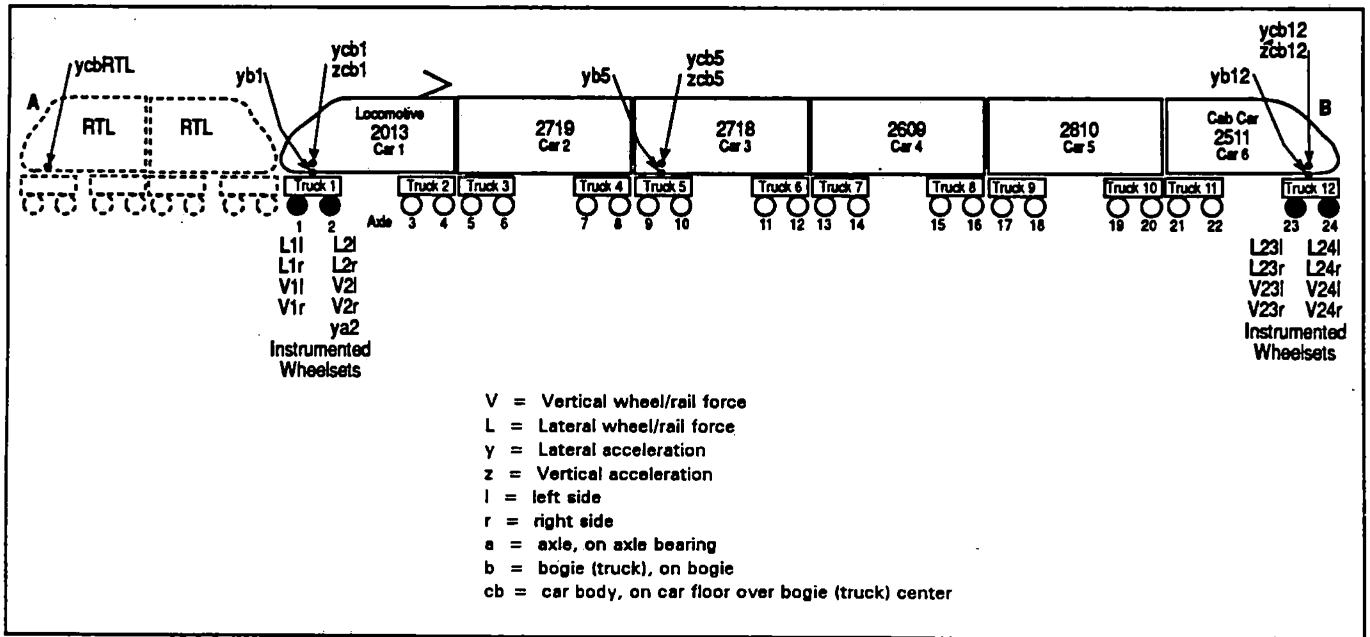


Figure B.1: Transducer Configuration, X2000 Tests USA

TABLE B.1 TRANSDUCERS AND SIGNAL NAMES FOR X2000 TEST RUNS

Signal #	Transducer Type	Signal Name	Description
1	Instrumented Wheelset	L1l	W/R Lateral Force, Axle 1, Left Wheel (Locomotive)
2	Instrumented Wheelset	L1r	W/R Lateral Force, Axle 1, Right Wheel (Locomotive)
3	Instrumented Wheelset	V1l	W/R Vertical Force, Axle 1, Left Wheel (Locomotive)
4	Instrumented Wheelset	V1r	W/R Vertical Force, Axle 1, Right Wheel (Locomotive)
5	Instrumented Wheelset	L2l	W/R Lateral Force, Axle 2, Left Wheel (Locomotive)
6	Instrumented Wheelset	L2r	W/R Lateral Force, Axle 2, Right Wheel (Locomotive)
7	Instrumented Wheelset	V2l	W/R Vertical Force, Axle 2, Left Wheel (Locomotive)
8	Instrumented Wheelset	V2r	W/R Vertical Force, Axle 2, Right Wheel (Locomotive)
9	Instrumented Wheelset	L23l	W/R Lateral Force, Axle 23, Left Wheel (Cab Car)
10	Instrumented Wheelset	L23r	W/R Lateral Force, Axle 23, Right Wheel (Cab Car)
11	Instrumented Wheelset	V23l	W/R Vertical Force, Axle 23, Left Wheel (Cab Car)
12	Instrumented Wheelset	V23r	W/R Vertical Force, Axle 23, Right Wheel (Cab Car)
13	Instrumented Wheelset	L24l	W/R Lateral Force, Axle 24, Left Wheel (Cab Car)
14	Instrumented Wheelset	L24r	W/R Lateral Force, Axle 24, Right Wheel (Cab Car)
15	Instrumented Wheelset	V24l	W/R Vertical Force, Axle 24, Left Wheel (Cab Car)
16	Instrumented Wheelset	V24r	W/R Vertical Force, Axle 24, Right Wheel (Cab Car)
17	Servo Accelerometer	ycb1	Lateral Acceleration in Car Over Bogie 1 (Locomotive)
18	Servo Accelerometer	zcb1	Vertical Acceleration in Car Over Bogie 1 (Locomotive)
19	Servo Accelerometer	yb1	Lateral Acceleration, Bogie 1 (Locomotive)
20	Variable Capacitance Accelerometer	ya2	Lateral Acceleration, Axle 2 (Locomotive); used to measure unbalance or cant deficiency
21	Servo Accelerometer	ycb5	Lateral Acceleration in Car Over Bogie 5 (Coach)
22	Servo Accelerometer	zcb5	Vertical Acceleration in Car Over Bogie 5 (Coach)
23	Servo Accelerometer	yb5	Lateral Acceleration, Bogie 5 (Coach)
24	Servo Accelerometer	ycb12	Lateral Acceleration in Car Over Bogie 12 (Cab Car)
25	Servo Accelerometer	zcb12	Vertical Acceleration in Car Over Bogie 12 (Cab Car)
26	Servo Accelerometer	yb12	Lateral Acceleration, Bogie 12 (Cab Car)
27	Servo Accelerometer	ycbRTL	Lateral Acceleration in Car Over Front Bogie of Leading RTL unit (Boston - New Haven tests only)
28	Speed Pickup	v	Trainset forward speed

B.2 CHANNEL DESIGNATION

Safety criteria parameters were displayed in real time during the test runs using five 6-channel strip chart recorders. The channel allocations and descriptions are given below in **Table B.2.**

TABLE B.2 STRIP CHART RECORDER CHANNEL DESIGNATIONS

Stripchart Channel #	Signal Name	Description
1.1	NA1L	Net Axle Lateral Force, Axle 1 (Locomotive) [kN] {0 to ± 100 kN}
1.2	V1l	Vertical Wheel Force, Axle 1, Left Wheel (Locomotive) [kN] {0 to 200 kN}
1.3	V1r	Vertical Wheel Force, Axle 1, Right Wheel (Locomotive) [kN] {0 to 200 kN}
1.4	NA2L	Net Axle Lateral Force, Axle 2 (Locomotive) [kN] {0 to ± 100 kN}
1.5	V2l	Vertical Wheel Force, Axle 2, Left Wheel (Locomotive) [kN] {0 to 200 kN}
1.6	V2r	Vertical Wheel Force, Axle 2, Right Wheel (Locomotive) [kN] {0 to 200 kN}
2.1	L/V1l	Wheel L/V Ratio, Axle 1, Left Wheel (Locomotive) {-0.1 to 0.9}
2.2	L/V1r	Wheel L/V Ratio, Axle 1, Right Wheel (Locomotive) {-0.1 to 0.9}
2.3	L/V2l	Wheel L/V Ratio, Axle 2, Left Wheel (Locomotive) {-0.1 to 0.9}
2.4	L/V2r	Wheel L/V Ratio, Axle 2, Right Wheel (Locomotive) {-0.1 to 0.9}
2.5	T1-L/Vl	Truck Side L/V Ratio, Truck 1, Left Side (Locomotive) {-0.1 to 0.9}
2.6	T1-L/Vr	Truck Side L/V Ratio, Truck 1, Right Side (Locomotive) {-0.1 to 0.9}
3.1	NA23L	Net Axle Lateral Force, Axle 23 (Cab Car) [kN] {0 to ± 100 kN}
3.2	V23l	Vertical Wheel Force, Axle 23, Left Wheel (Cab Car) [kN] {0 to 200 kN}
3.3	V23r	Vertical Wheel Force, Axle 23, Right Wheel (Cab Car) [kN] {0 to 200 kN}
3.4	NA24L	Net Axle Lateral Force, Axle 24 (Cab Car) [kN] {0 to ± 100 kN}
3.5	V24l	Vertical Wheel Force, Axle 24, Left Wheel (Cab Car) [kN] {0 to 200 kN}
3.6	V24r	Vertical Wheel Force, Axle 24, Right Wheel (Cab Car) [kN] {0 to 200 kN}
4.1	L/V23l	Wheel L/V Ratio, Axle 23, Left Wheel (Cab Car) {-0.1 to 0.9}
4.2	L/V23r	Wheel L/V Ratio, Axle 23, Right Wheel (Cab Car) {-0.1 to 0.9}
4.3	L/V24l	Wheel L/V Ratio, Axle 24, Left Wheel (Cab Car) {-0.1 to 0.9}
4.4	L/V24r	Wheel L/V Ratio, Axle 24, Right Wheel (Cab Car) {-0.1 to 0.9}
4.5	T12-L/Vl	Truck Side L/V Ratio, Truck 12, Left Side (Cab Car) {-0.1 to 0.9}
4.6	T12-L/Vr	Truck Side L/V Ratio, Truck 12, Right Side (Cab Car) {-0.1 to 0.9}
5.1	ya2	Lateral Acceleration, Axle 2 (Locomotive) [m/s^2] {0 to ± 2.5 m/s^2}
5.2	ycb5	Lateral Acceleration, Car Over Truck 5 (Coach) [m/s^2] {0 to ± 2.5 m/s^2}
5.3	ycb12	Lateral Acceleration, Car Over Truck 12 (Cab) [m/s^2] {0 to ± 2.5 m/s^2}
5.4	yb12	Lateral Acceleration, Truck 12 (Cab Car) [m/s^2] {0 to ± 10 m/s^2}
5.5	v	Vehicle Forward Speed [mph] {0 to 150 mph}
5.6		Tractive Effort

APPENDIX C

TEST EVENT LOG, X2000 U.S. DEMONSTRATION

TEST EVENT LOG
X2000 US Demo

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LR 9223-12m

Date	Time	MP	Run #	Direction	Un Balance	Track #	Rail Dry Wet	X2 2013 direction	Remarks
30/11	12^{30}	[illegible]	101	W	3"	3	D	E	Old col. in computer
		11							Lateral forces OK
		20				4			Accelerometer signals OK
									Problem with magnets, cab car
									No filter on Truck acc.
	13^{30}								stop Lancaster
	15^{25}		102	E	5"	1	D	E	Problem with magnets
	15^{50}								stop Park
	16^{20}		103	W	6"	4	D	E	
	16^{35}								stop Lancaster
	16^{50}		104	E	6"	1	D	E	
	17^{10}								stop Thorndale
	18^{10}		105	W	7"	4	D	E	Y612 Lad, tilt problems
	18^{20}								stop Lancaster
	18^{50}		106	E	7"	1	D	E	
	19^{10}								stop Parksburg.

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TEST EVENT LOG
X2000 US Demo

LR.9223-12m

Date	Time	MP	Run #	Direction	Un Balance	Track #	Rail Dry Wet	X2 2013 direction	Remarks
1/12	11^{50}		107	W	7"	4	D ½W	E	False magnets Cabcar.
	12^{05}								
	13^{05}		108	E	7"	1	½W	E	
	13^{20}								
	13^{40}		109	W	8"	4	W	E	
	13^{55}								
	14^{20}		110	E	8"	1	W	E	
	14^{35}								
	14^{50}		111	W	9"	4	W	E	
	15^{05}								
	15^{20}		112	E	9"	1	W	E	
	15^{40}								
	16^{11}		113	W	10"	4	W	E	
	16^{25}								
	17^{10}		114	E	10"	1	W	E	
	17^{25}								

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TEST EVENT LOG
X2000 US Demo

LR 9223-12m

Date	Time	MP	Run #	Direction	Un Balance	Track #	Rail Dry Wet	X2 2013 direction	Remarks
2/12	10^{25}		115	W	10"	4	D	E	
	$11^{[illegible]}$								
	11^{20}		116	E	10"	1	D	E	
	11^{35}								
	12^{40}		117	W	11"	4	D	E	
	12^{55}								
	14^{05}		118	E	11"	1	D	E	
	14^{20}								
	15^{20}		119	W	12"	4	D	E	
	15^{35}								
	16^{05}		120	E	12"	1	D	E	
	16^{15}								

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TEST EVENT LOG
X2000 US Demo

LR 9223-12m

Date	Time	MP	Run #	Direction	Un Balance	Track #	Rail Dry Wet	X2 2013 direction	Remarks
3/12	10^{50}		121	W	9"	4	D	W	Train turned.
	11^{05}								No Y-kompensation bottom MP54
									on axle 23 and 24
	11^{25}		122	E	10"	1	D	W	
	11^{40}								
	12^{40}		123	W	10"	4	D	W	
	12^{55}								
	14^{25}		124	E	11"	1	D	W	
	14^{40}								
4/12	11^{15}		125	W	9"	4	D	W	Ripple on V24 before 48
	11^{30}								
	12^{35}		126	E	9"	1	D	W	
		57							Stem stop
		52-57							False MP
	13^{45}								
	14^{50}		127	W	12"	4	D	W	
	15^{05}								
	15^{30}		128	E	12"	1	D	W	
		56							L23r, L23l adjusted
	15^{45}								
	16^{20}		129	W	9"	4	D	W	No 1:11 car 4, 5 and 6
		53							L23r, L23l adjusted
	16^{35}								
			130	E	9"	1	D	W	
	17^{15}	56							L24r, L24v adjusted.
	17^{20}								

TEST EVENT LOG
X2000 US Demo

LR 9223-12m

Date	Time	MP	Run #	Direction	(speed) Un Balance	Track #	Rail Dry Wet	X2 2013 direction	Remarks
7/12	0^{45}	56	200	E	130	3	D	rear	
	0^{55}	34	"						
7/12	2^{07}	33/23	200	E	5"	3	D	rear	1 false magnet M4 (loco)
	2^{16}								
7/12	2^{25}	23/32	201	W	7"	3	D	front	1 double magnet M1 (loco)
	2^{35}								1 false " M4 "
7/12	2^{52}	32/21	202	E	9"	3	D	rear	
	3^{01}								
7/12	3^{12}	21/31	203	W	10"	3	D	front	1 missing magnet
	3^{20}							\	1 false " M4 (loco)
									Waiting for freight train
7/12	3^{45}	31/21	204	E	11"	3	D	rear	
	3^{55}								
7/12	4^{20}	21/31	205	W	12"	3	D	front	
	4^{27}								
7/12	4^{28}		301	W	140	3	D	"	change during run
	4^{40}								

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TEST EVENT LOG
X2000 US Demo

LR 9223-12m

Date	Time	MP	Run #	Direction	speed/ Un Balance	Track #	Rail Dry Wet	X2 2013 direction	Remarks
8/12	0.25		302	E	150	3	D	rear	
	0.37								
8/12	0.39		206	E	9"	3	D	rear	Changed during run
	0.50								1 false magnet M4 after 5. (loco)
									No data on computer
									Chart recorders OK
8/12	1.05		–	W	–	2	–	front	Clearence run
8/12	1.12		207	W	9"	2	D	front	v.113 instead of 117
	1.25								restricted signal
8/12	2.17		208	E	10"	2	D	rear	One vertical hit
	2.28?								
8/12	2.35		209	W	11"	2	D	front	v<115 mph instead
	2.45								
8/12	2.55		210	E	12"	2	D	rear	
	3.05								
8/12	3.18		211	W	linespeed	2	D	front	v≈95 mph
8/12	3.33		303	W	150	3	D	"	Changed during run
	3.55								at mp 31
10/12	10.00		131	W	9"	3?	D	rear	Pressrun
	10.45		131	W	9"	4	Snow	"	Dep from Downingtown
	11.08								
10/12	12.00		132	E	9"	1	Snow	front	Dep from Lancaster
	13.15								2nd last non tilted
									First curve in linespeed
									due to low adhesion

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TEST EVENT LOG
X2000 US Demo

LR 9223-12m

Date	Time	MP	Run #	Direction	Un Balance	Track #	Rail Dry Wet	X2 2000 direction	Remarks
12/12	9:05	54	304	E	140	3	W	rear	
	9:15	34							End of run 304
12/12	9:55	24	305	W	150	3	W	front	Extra for Thomas Edwards
	10:01	34							153 mph
	10:09	54							End of run 305

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TEST EVENT LOG
X2000 US Demo

LR 9223-12m

Date	Time	MP	Run #	Direction	Un Balance	Track #	Rail Dry/Wet	X2 2013 direction	Remarks
14/12	8^{14}	132	400	N	9"	2	D	rear	Washington-Philadelphia
									channel 17-32 are
									recorded with lower sample
									freq. (100Hz) due to long runs
									(Run number 400 – 411)
		121							Penalty for overspeed
	8^{35}	113							–"–
									First time ever this
									driver is driving!!
		70/69							High L/V1L on "TRAS", not on Brush
	9^{10}	63				1			L/L false from 945-985 sek.
	9^{12}	60				2			
	9^{22}	42							MP synchronized
	9^{50}	0				1 in i		Phy	
									The train starts be-
14/12	10^{15}	88	402	E	9"	1	D	rear	fore the measurement
									car is ready AGAIN!
									without information
		87				2			
		8				1			Same track, new number
									after Newark
	11^{08}	900				5			Stop at Penn Cen
									MP lost numbers
									906 → 900, 906
									resynchronised
	The start	8^{14}		was			nearly		one minute
	early & without			any			notice.		

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TEST EVENT LOG X2000 US Demo

LR 9223-12m

Date	Time	MP	Run #	Direction	Un Balance	Track #	Rail Dry Wet	X2 2013 direction	Remarks
14/12	12^{11}	900	401	W	9"	5	D	front	V23L false from
									901 – 903
		905				2			
12^{12}	1220	6				3			
my notes	12^{25}	23							Stop Newark
Thomas Edison		'							" Metro Park
	1317	87				4			
	1322					5			" Philadelphia
									Check V23L + V24L
									Pantograph down for
									10 s. No change in
									signals.
									Grounding problems
									to the Q-shaper.
									Fixed
14/12	14^{28}	0	403	S	9"	3	D	front	Track 5 ; Philadelphia
		60				4			
		72				3			
	15^{26}					7			Stop Baltimore
									Slipringdevice 4 (axle 23)
									changed to 5. Train moved to #1
	16^{07}					1			
	1608					3			
	16^{27}								Red signal. Caught up train 95
	16^{46}					16			Stop at Washington
									Slipringdevice 10 (axle 24)
									canged to 6.

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TEST EVENT LOG
X2000 US Demo

LR 9223-12m

Date	Time	MP	Run #	Direction	Un Balance	Track #	Rail Dry/Wet	X2 2013 direction	Remarks
15/12	8^{15}	135	404	N	9"5 mph	2	D	rear	Recorded from start
									L23 & 24 L & r not OK from start
		133							All signals OK
		128							Temporary stop
		122							Penalty overspeed 129 mph
	8^{47}	96							Stop at Baltimore track #6. 2min
		67	and north		→ mp ~			25	Frost
		64				1			
		60				2			
		58				1			Arrival Willmington
	9^{29}					1			Stop at Willmington 1min
	9^{31}	26				2			
	9^{49}	0				4			Stop at Philladelphia
	10^{00}		406			1			Dep "
						1			We are on wrong TK
									and miss the high UB.
	10^{35}	58				2			Back to #2
									Channel 17-32 lost
									mp 60-57 on TRAS
									but not on Brush
									Changed 15V supply
									False signal mp 57 → 906
									for channel 17-32. Un-
									filtered signals are (1-16) OK
		49				2			Reached 125 mph
									Slow acceleration due to
									low line voltage 10kV
	10^{58}	9				2			Stop at Newark Open Bridge
	10^{59}								Dep "
Dep	11^{02}								Stop on bridge "
	11^{23}					6			Stop in New York
	11^{24}								Channel 17-32 OK

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TEST EVENT LOG
X2000 US Demo

LR.9223-12m

Date	Time	MP	Run #	Direction	Un Balance	Track #	Rail Dry Wet	X2 2013 direction	Remarks
15/12	12^{12}	[illegible]	405	W	9°+5mph	6	D	front	Leave NYP
	12^{14}					2			
		6				3			
		1/26							One false magnet before M5
	12^{55}	~58				3			Stop for restrictive signal 2min
	13^{17}	85				3			Just before Philadelphia
15/12	13^{28}	85	410	E	9°+5mph	2	D	rear	Repetition of the
									morning test run
									but on the right Track
	13^{44}	60				2			Finish
15/12	13^{54}	58	411	W	9°+5mph	3	D	front	Crossover to # 3
	14^{17}	87				4			Stop at Philadelphia Track#6
15/12	14^{21}	1	407	S	9°+5mph	3	D	front	Dep Phy track #6
									One false mp before nr: 2
	14^{39}	25				3			Stop at Wilmington 2min
		60				4			
		73				3			
	15^{09}	95							Stop Baltimore TK#7 1min
		111/							Power-off twice to the
		/114							strip chart recorders.
									TRAS OK
	15^{48}	[illegible]							Stop 2min outside Washington
	15^{52}					16			Stop in Washington

APPENDIX D

TRACK CURVE INFORMATION

Eastbound

X2000 TEST PROGRAM
HARRISBURG LINE SPEEDS

Track No. 1

CV.#	TIMETABLE DESCRIPTION	MILEPOST LOCATION		CURVE GEOMETRY			PROPOSED CURVING SPEED FOR X-2000 TEST										PROPOSED MAXIMUM TESTING SPEED
		West	East	DEGREE [decimal]	RADIUS [feet]	S.E. [inches]	3"UB [mph]	4"UB [mph]	5"UB [mph]	6"UB [mph]	7"UB [mph]	8"UB [mph]	9"UB [mph]	10"UB [mph]	11"UB [mph]	12"UB [mph]	[mph]
677		66.58	66.26	0.60	9,549	1.875	108	110	110	110	110	110	110	110	110	110	110
676.1		66.22	66.17	0.37	15,626	0.750	110	110	110	110	110	110	110	110	110	110	"
676		65.52	64.79	0.32	18,094	0.750	110	110	110	110	110	110	110	110	110	110	"
675		63.87	63.51	1.00	5,730	3.375	95	103	109	110	110	110	110	110	110	110	"
674		63.21	62.97	0.45	12,733	0.500	105	110	110	110	110	110	110	110	110	110	"
673		62.10	61.64	1.02	5,636	3.250	94	101	108	110	110	110	110	110	110	110	"
672	Curve west of MP 61	61.48	60.97	2.03	2,818	5.250	76	81	85	89	93	97	100	104	107	110	"
671	Curve west of MP 60	60.62	59.97	2.00	2,865	5.500	78	82	87	91	95	98	102	105	109	110	"
670	Curve west of MP 59	59.69	59.53	1.10	5,209	3.000	88	95	102	108	110	110	110	110	110	110	"
669		58.99	58.42	1.52	3,778	5.500	90	95	99	104	109	110	110	110	110	110	"
668		57.64	57.36	0.65	8,815	1.250	97	107	110	110	110	110	110	110	110	110	"
667		56.64	55.79	0.98	5,827	2.250	87	95	103	110	110	110	110	110	110	110	"
666		54.58	54.38	0.45	12,733	0.875	110	110	110	110	110	110	110	110	110	110	"
665		53.99	53.66	0.47	12,278	0.875	109	110	110	110	110	110	110	110	110	110	"
664		53.25	52.74	2.05	2,795	5.625	78	82	86	90	94	97	101	104	108	110	"
663	Curve west of Gap	52.44	52.00	4.03	1,421	5.750	56	59	62	65	67	70	72	75	77	79	"
662	Curve at Gap	51.63	50.77	4.20	1,364	5.625	54	57	60	63	66	68	71	73	75	77	"
661		50.61	50.19	2.00	2,865	5.875	80	84	88	92	96	100	103	107	110	110	"
660		50.06	49.81	1.00	5,730	3.375	95	103	109	110	110	110	110	110	110	110	"
659		49.16	48.84	1.00	5,730	3.375	95	103	109	110	110	110	110	110	110	110	"
658		48.72	48.36	1.00	5,730	3.125	94	101	108	110	110	110	110	110	110	110	"
657	Curve west of Atglen	48.29	47.50	2.00	2,865	5.750	79	84	88	92	95	99	103	106	109	110	"
656		46.86	46.77	0.33	17,189	0.375	110	110	110	110	110	110	110	110	110	110	"
655		45.34	45.24	0.40	14,324	0.750	110	110	110	110	110	110	110	110	110	110	"
654.1		44.81	44.61	0.45	12,733	0.875	110	110	110	110	110	110	110	110	110	110	"
654		43.79	43.65	0.32	18,094	0.750	110	110	110	110	110	110	110	110	110	110	"
653.1		43.97	43.96	0.37	15,626	0.750	110	110	110	110	110	110	110	110	110	110	"
653		41.63	41.32	0.65	8,815	2.250	107	110	110	110	110	110	110	110	110	110	"
652		41.03	40.84	0.75	7,640	1.875	96	106	110	110	110	110	110	110	110	110	"
651		39.90	39.42	0.67	8,594	2.250	106	110	110	110	110	110	110	110	110	110	"
650		39.09	38.39	0.50	11,459	1.625	110	110	110	110	110	110	110	110	110	110	"
649		37.92	37.33	1.02	5,636	3.375	95	102	109	110	110	110	110	110	110	110	"

Eastbound

X2000 TEST PROGRAM
HARRISBURG LINE SPEEDS

Track No. 1

CV.#	TIMETABLE DESCRIPTION	MILEPOST LOCATION West	MILEPOST LOCATION East	CURVE GEOMETRY DEGREE [decimal]	RADIUS [feet]	S.E. [inches]	PROPOSED CURVING SPEED FOR X-2000 TEST 3"UB [mph]	4"UB [mph]	5"UB [mph]	6"UB [mph]	7"UB [mph]	8"UB [mph]	9"UB [mph]	10"UB [mph]	11"UB [mph]	12"UB [mph]	PROPOSED MAXIMUM TESTING SPEED [mph]
648		37.30	36.77	0.98	5,827	3.500	97	104	110	110	110	110	110	110	110	110	110
647		35.87	35.70	0.37	15,626	1.250	110	110	110	110	110	110	110	110	110	110	•
646		35.55	35.43	0.32	18,094	1.125	110	110	110	110	110	110	110	110	110	110	•
645		35.13	34.84	0.32	18,094	1.500	110	110	110	110	110	110	110	110	110	110	•
644		34.58	34.10	0.92	6,251	3.000	97	104	110	110	110	110	110	110	110	110	•
643		34.04	33.56	0.72	7,995	2.250	102	110	110	110	110	110	110	110	110	110	•
642		33.16	32.88	0.82	7,016	2.500	98	107	110	110	110	110	110	110	110	110	•
641		32.56	32.18	0.97	5,927	3.375	97	104	110	110	110	110	110	110	110	110	•
640		31.58	31.27	1.70	3,370	6.000	87	92	96	100	105	109	110	110	110	110	•
639	1st & 2nd curve 1200' west of Signal 295	30.84	30.34	2.37	2,421	5.625	72	76	80	84	87	91	94	97	100	103	•
638	1st & 2nd curve 1200' west of Signal 295	30.28	29.81	3.00	1,910	5.500	64	67	71	74	77	80	83	86	89	91	•
637		29.20	28.20	0.20	28,648	1.250	110	110	110	110	110	110	110	110	110	110	•
636		25.71	25.50	0.45	12,733	1.500	110	110	110	110	110	110	110	110	110	110	•
635		24.50	24.15	0.50	11,459	1.750	110	110	110	110	110	110	110	110	110	110	•
634		23.60	23.30	0.20	28,648	0.750	110	110	110	110	110	110	110	110	110	110	•
630	First 3 curves west of MP 21	22.74	22.35	2.05	2,795	5.500	77	81	86	90	93	97	101	104	107	110	•
629	First 3 curves west of MP 21	22.31	21.97	2.05	2,795	5.750	78	82	87	91	94	98	101	105	108	110	•
628	First 3 curves west of MP 21	21.85	21.60	2.12	2,707	5.625	76	81	85	89	92	96	99	103	106	109	•

X-2000 TEST PROGRAM
HARRISBURG LINE SPEEDS

Track No. 4/2

CV.#	TIMETABLE DESCRIPTION	MILEPOST LOCATION East	MILEPOST LOCATION West	CURVE GEOMETRY DEGREE [decimal]	RADIUS [feet]	S.E. [inches]	CALCULATED CURVING SPEEDS 3"UB [mph]	4"UB [mph]	5"UB [mph]	6"UB [mph]	7"UB [mph]	8"UB [mph]	9"UB [mph]	10"UB [mph]	11"UB [mph]	12"UB [mph]	PROPOSED MAXIMUM TESTING SPEED [mph]
628	First 3 curves west of MP 21	21.64	21.88	2.13	2,686	5.750	77	81	85	89	92	96	99	103	106	109	110
629	First 3 curves west of MP 21	22.01	22.32	2.10	2,728	5.750	77	81	86	89	93	97	100	104	107	110	•
630	First 3 curves west of MP 21	22.37	22.76	2.03	2,818	5.750	78	83	87	91	95	98	102	105	109	110	•
631		23.30	23.60	0.20	28,648	1.000	110	110	110	110	110	110	110	110	110	110	•
632		24.63	24.85	1.17	4,911	4.125	93	100	106	110	110	110	110	110	110	110	•
633		25.25	25.40	0.43	13,222	0.750	110	110	110	110	110	110	110	110	110	110	•
634		25.53	25.75	0.42	13,751	1.625	110	110	110	110	110	110	110	110	110	110	•
635		26.30	26.39	0.22	26,445	0.875	110	110	110	110	110	110	110	110	110	110	•
636		26.47	26.53	0.27	21,486	1.000	110	110	110	110	110	110	110	110	110	110	•
637		28.20	29.20	0.20	28,648	1.250	110	110	110	110	110	110	110	110	110	110	•
638	1st & 2nd curve 1200' west of Signal 295	29.81	30.25	3.07	1,868	5.625	63	67	70	74	77	80	83	85	88	91	•
639	1st & 2nd curve 1200' west of Signal 295	30.32	30.81	2.35	2,438	5.625	72	77	80	84	88	91	94	98	101	104	•
640		31.22	31.56	1.55	3,697	5.875	90	95	100	105	109	110	110	110	110	110	•
641		32.16	32.55	0.93	6,139	3.500	100	107	110	110	110	110	110	110	110	110	•
642		32.87	33.15	0.82	7,016	3.500	107	110	110	110	110	110	110	110	110	110	•
643		33.57	33.87	0.27	21,486	1.250	110	110	110	110	110	110	110	110	110	110	•
644		34.23	34.61	0.32	18,094	1.125	110	110	110	110	110	110	110	110	110	110	•
645		35.06	35.19	0.55	10,418	1.375	107	110	110	110	110	110	110	110	110	110	•
646		35.88	36.04	0.38	14,947	1.250	110	110	110	110	110	110	110	110	110	110	•
647		36.11	36.25	0.37	15,626	1.500	110	110	110	110	110	110	110	110	110	110	•
648		36.79	37.31	1.00	5,730	3.250	95	102	109	110	110	110	110	110	110	110	•
649		37.34	37.93	0.98	5,827	3.375	96	104	110	110	110	110	110	110	110	110	•
650		38.43	39.12	0.47	12,278	1.375	110	110	110	110	110	110	110	110	110	110	•
651		39.45	39.90	0.75	7,640	2.500	102	110	110	110	110	110	110	110	110	110	•
652		40.85	41.05	0.73	7,813	2.500	104	110	110	110	110	110	110	110	110	110	•
653		41.33	41.65	0.73	7,813	2.375	102	110	110	110	110	110	110	110	110	110	•
654		43.60	43.71	0.42	13,751	0.500	110	110	110	110	110	110	110	110	110	110	•
655		45.13	45.34	0.45	12,733	0.750	109	110	110	110	110	110	110	110	110	110	•
656		46.76	46.87	0.37	15,626	0.000	108	110	110	110	110	110	110	110	110	110	•
657	Curve west of Atglen	47.41	48.21	2.02	2,841	5.500	78	82	86	90	94	98	101	105	108	110	•
658		48.26	48.65	0.97	5,927	3.000	94	102	109	110	110	110	110	110	110	110	•
659		48.76	49.08	1.02	5,636	3.375	95	102	109	110	110	110	110	110	110	110	•
660		49.73	50.10	0.88	6,486	2.750	98	105	110	110	110	110	110	110	110	110	•

Westbound

Track No. 4/2

X-2000 TEST PROGRAM
HARRISBURG LINE SPEEDS

CV.#	TIMETABLE DESCRIPTION	MILEPOST LOCATION East	MILEPOST LOCATION West	CURVE GEOMETRY DEGREE [decimal]	CURVE GEOMETRY RADIUS [feet]	CURVE GEOMETRY S.E. [inches]	CALCULATED CURVING SPEEDS 3"UB [mph]	4"UB [mph]	5"UB [mph]	6"UB [mph]	7"UB [mph]	8"UB [mph]	9"UB [mph]	10"UB [mph]	11"UB [mph]	12"UB [mph]	PROPOSED MAXIMUM TESTING SPEED [mph]
661	Curve east of Gap	50.22	50.64	2.05	2,795	5.750	78	82	87	91	94	98	101	105	108	110	110
662	Curve at Gap	50.79	51.70	4.05	1,415	5.250	54	57	60	63	66	68	71	73	76	78	•
663	Curve west of Gap	52.02	52.46	4.13	1,386	5.875	55	58	61	64	67	69	72	74	76	79	•
664	Curve at MP 53	52.77	53.27	2.02	2,841	5.500	78	82	86	90	94	98	101	105	108	110	•
665		53.69	54.02	0.45	12,733	0.750	109	110	110	110	110	110	110	110	110	110	•
666		54.41	54.60	0.45	12,733	0.750	109	110	110	110	110	110	110	110	110	110	•
667		55.82	56.65	1.00	5,730	3.000	93	100	107	110	110	110	110	110	110	110	•
668		57.39	57.65	0.65	8,815	1.500	99	110	110	110	110	110	110	110	110	110	•
669		58.43	58.99	1.50	3,820	5.500	90	95	100	105	109	110	110	110	110	110	•
670		59.54	59.69	0.97	5,927	3.125	95	103	110	110	110	110	110	110	110	110	•
671	Curve west of MP 60	59.97	60.61	2.03	2,818	5.625	78	82	86	90	94	98	101	105	108	110	•
672	Curve west of MP 61	60.96	61.48	2.00	2,865	5.625	79	83	87	91	95	99	102	106	109	110	•
673		61.63	62.11	1.00	5,730	3.250	95	102	109	110	110	110	110	110	110	110	•
674		62.98	63.22	0.43	13,222	0.500	90	90	90	90	90	90	90	90	90	90	90
675		63.53	63.87	1.00	5,730	2.625	90	90	90	90	90	90	90	90	90	90	•
676		64.85	65.51	0.33	17,189	0.750	90	90	90	90	90	90	90	90	90	90	•
677		66.36	66.59	0.85	6,741	2.875	90	90	90	90	90	90	90	90	90	90	•

Eastbound

X-2000 TEST PROGRAM
NEC MAINLINE SPEEDS

Track No.2

CV.#	TIMETABLE DESCRIPTION	MILEPOST LOCATION West	MILEPOST LOCATION East	CURVE GEOMETRY DEGREE [decimal]	RADIUS [feet]	S.E. [inches]	CALCULATED CURVING SPEEDS 3"UB [mph]	4"UB [mph]	5"UB [mph]	6"UB [mph]	7"UB [mph]	8"UB [mph]	9"UB [mph]	10"UB [mph]	11"UB [mph]	12"UB [mph]	PROPOSED MAXIMUM TESTING SPEED [mph]
302		85.40	85.30	1.98	2,889	2.00	60	66	71	76	81	85	89	90	90	90	90
301		85.06	85.00	1.47	3,907	1.75	68	75	81	87	90	90	90	90	90	90	•
300	Curves at east & west ends of N. Phila. sta. pltfm.	84.93	84.84	0.83	6,876	2.00	90	90	90	90	90	90	90	90	90	90	•
299	Curves at east & west ends of N. Phila. sta. pltfm.	84.78	84.70	1.03	5,545	1.25	77	85	90	90	90	90	90	90	90	90	•
299	Curve MP 84.0 to 2nd Street overhead bridge	83.82	83.08	2.52	2,277	5.00	67	71	75	79	83	86	89	90	90	90	•
298	Curve between Shore and Ford	81.75	81.38	4.02	1,426	5.50	55	58	61	64	67	69	72	74	77	79	100
297	Curve eastward from Ford	81.30	80.89	1.80	3,183	2.00	63	69	75	80	85	89	93	98	100	100	•
296		79.68	79.18	0.60	9,549	2.25	100	100	100	100	100	100	100	100	100	100	•
295		78.51	78.20	0.32	18,094	1.50	100	100	100	100	100	100	100	100	100	100	•
294		77.04	76.68	1.00	5,730	4.75	105	112	118	124	125	125	125	125	125	125	125
293		76.47	76.11	0.68	8,385	3.25	114	123	125	125	125	125	125	125	125	125	•
292	First curve west of MP 75.0	75.40	75.08	0.75	7,640	4.00	115	123	125	125	125	125	125	125	125	125	•
291	Reverse curves between MP 74.0 and MP 75.0	75.08	74.62	1.55	3,697	5.75	90	95	100	104	108	113	117	120	124	125	•
290	Reverse curves between MP 74.0 and MP 75.0	74.47	74.07	1.47	3,907	5.25	90	95	100	105	109	114	118	122	125	125	•
289		72.57	72.17	0.33	17,189	1.75	125	125	125	125	125	125	125	125	125	125	•
288	Curve west of Croydon	70.61	70.06	1.18	4,842	5.75	103	108	114	119	124	125	125	125	125	125	•
287		68.70	68.60	0.17	34,378	0.50	150	150	150	150	150	150	150	150	150	150	150
286		67.69	66.72	0.47	12,278	2.25	127	138	149	150	150	150	150	150	150	150	•
285	Curve west of Grundy	66.33	65.62	0.72	7,995	4.75	124	132	139	146	150	150	150	150	150	150	•
284	Curve east of Grundy	64.94	64.60	0.65	8,815	3.75	122	131	139	146	150	150	150	150	150	150	•
283	Curve between MP 61.0 and MP 62.0	61.83	61.39	0.72	7,995	4.25	120	128	136	143	150	150	150	150	150	150	•
282		60.54	60.22	0.35	16,370	1.25	132	146	150	150	150	150	150	150	150	150	•
280	First curve west of Morris	57.13	57.00	0.57	10,111	2.00	112	123	133	142	150	150	150	150	150	150	•
279	First curve west of Trenton	56.33	56.05	0.67	8,594	2.25	106	116	125	133	141	148	150	150	150	150	•
278		50.46	50.36	0.30	19,099	1.00	138	150	150	150	150	150	150	150	150	150	•
277		40.24	39.48	0.30	19,099	1.50	146	150	150	150	150	150	150	150	150	150	•
276		39.36	41.94	0.52	11,090	3.25	131	142	150	150	150	150	150	150	150	150	•

Eastbound

X-2000 TEST PROGRAM
NEC MAINLINE SPEEDS

Track No.2

CV.#	TIMETABLE DESCRIPTION	MILEPOST LOCATION West	MILEPOST LOCATION East	CURVE GEOMETRY DEGREE [decimal]	RADIUS [feet]	S.E. [inches]	CALCULATED CURVING SPEEDS 3"UB [mph]	4"UB [mph]	5"UB [mph]	6"UB [mph]	7"UB [mph]	8"UB [mph]	9"UB [mph]	10"UB [mph]	11"UB [mph]	12"UB [mph]	PROPOSED MAXIMUM TESTING SPEED [mph]
275		34.21	33.75	0.30	19,099	1.25	142	150	150	150	150	150	150	150	150	150	150
274		31.34	31.12	0.45	12,733	2.75	135	146	150	150	150	150	150	150	150	150	•
273		30.65	30.25	0.43	13,222	2.75	138	149	150	150	150	150	150	150	150	150	•
272		28.97	28.85	0.47	12,278	2.25	127	138	149	150	150	150	150	150	150	150	•
271		27.65	27.43	0.28	20,222	1.75	150	150	150	150	150	150	150	150	150	150	•
270	Third curve west of Lincoln	27.17	26.74	0.77	7,473	3.75	112	120	128	135	142	148	150	150	150	150	•
269	Second curve west of Lincoln	26.65	26.38	1.45	3,951	5.75	93	98	103	108	112	116	121	125	125	125	125
268	First curve west of Lincoln	25.54	24.68	1.87	3,069	6.25	84	89	93	97	101	104	108	112	115	118	•
267	Curve at MP 25.0	24.53	24.11	1.18	4,842	4.75	97	103	108	114	119	124	125	125	125	125	•
266	First curve west of MP 24.0	23.86	23.61	1.55	3,697	5.75	90	95	100	104	108	113	117	120	124	125	•
265	First curve east of MP 24.0	23.51	22.86	1.45	3,951	5.25	90	95	100	105	110	114	118	123	125	125	•
264		22.81	22.45	0.77	7,473	4.50	118	125	125	125	125	125	125	125	125	125	•
263		22.04	21.86	0.72	7,995	4.25	120	125	125	125	125	125	125	125	125	125	•
262		21.84	21.68	0.72	7,995	3.25	112	120	125	125	125	125	125	125	125	125	•
261		20.80	20.71	0.67	8,594	3.25	116	125	125	125	125	125	125	125	125	125	•
260		20.69	20.39	0.25	22,919	0.50	125	125	125	125	125	125	125	125	125	125	•
259		19.74	19.64	0.42	13,751	1.75	125	125	125	125	125	125	125	125	125	125	•
258		19.41	19.28	0.28	20,222	1.75	125	125	125	125	125	125	125	125	125	125	•
256		18.94	18.84	0.42	13,751	3.00	125	125	125	125	125	125	125	125	125	125	•
255		18.50	18.20	0.20	28,648	0.50	125	125	125	125	125	125	125	125	125	125	•
254		15.10	14.70	0.20	28,648	0.50	125	125	125	125	125	125	125	125	125	125	•
253	Curves between Elizabeth & Elmora Block Station	14.26	14.03	2.37	2,421	2.50	58	63	67	72	76	80	83	87	90	94	110
252	Curves between Elizabeth & Elmora Block Station	13.10	13.05	1.97	2,913	4.25	73	77	82	86	90	94	98	102	105	109	•
251		12.54	12.29	0.20	28,648	0.50	110	110	110	110	110	110	110	110	110	110	•
250		10.49	10.21	0.32	18,094	2.00	110	110	110	110	110	110	110	110	110	110	•
249	Curve at Hunter	9.24	9.18	1.02	5,636	2.75	90	90	90	90	90	90	90	90	90	90	90
248		9.20	9.30	1.47	3,907	2.00	70	76	83	88	90	90	90	90	90	90	•

Westbound

X-2000 TEST PROGRAM
NEC MAINLINE SPEEDS

Track No.3

CV.#	TIMETABLE DESCRIPTION	MILEPOST LOCATION East	MILEPOST LOCATION West	CURVE GEOMETRY DEGREE [decimal]	RADIUS [feet]	S.E. [inches]	CALCULATED CURVING SPEEDS 3"UB [mph]	4"UB [mph]	5"UB [mph]	6"UB [mph]	7"UB [mph]	8"UB [mph]	9"UB [mph]	10"UB [mph]	11"UB [mph]	12"UB [mph]	PROPOSED MAXIMUM TESTING SPEED [mph]
248		9.20	9.30	0.95	6,031	1.000	78	87	90	90	90	90	90	90	90	90	90
249	Curve at Hunter	10.24	10.56	0.97	5,927	2.750	90	90	90	90	90	90	90	90	90	90	•
250		12.28	12.56	0.32	18,094	1.250	110	110	110	110	110	110	110	110	110	110	110
251		13.05	13.10	0.20	28,648	0.500	110	110	110	110	110	110	110	110	110	110	•
252	Curves between Elizabeth & Elmora Block Station	14.05	14.29	1.95	2,938	4.250	73	78	82	87	91	95	99	102	106	109	•
253	Curves between Elizabeth & Elmora Block Station	14.29	14.70	2.40	2,387	4.500	67	71	75	79	83	86	90	93	96	99	•
254		18.20	18.48	0.20	28,648	0.500	125	125	125	125	125	125	125	125	125	125	125
255		18.85	18.95	0.20	28,648	0.250	125	125	125	125	125	125	125	125	125	125	•
256		19.25	19.45	0.20	28,648	0.500	125	125	125	125	125	125	125	125	125	125	•
258		19.75	19.85	0.20	28,648	0.500	125	125	125	125	125	125	125	125	125	125	•
259		20.39	20.71	0.48	11,854	1.500	115	125	125	125	125	125	125	125	125	125	•
260		20.74	20.80	0.28	20,222	1.000	125	125	125	125	125	125	125	125	125	125	•
261		21.67	21.85	0.70	8,185	4.000	120	125	125	125	125	125	125	125	125	125	•
262		21.89	22.08	0.70	8,185	3.000	111	120	125	125	125	125	125	125	125	125	•
263		22.47	22.84	0.65	8,815	3.500	120	125	125	125	125	125	125	125	125	125	•
264		22.87	23.57	0.82	7,016	4.500	115	122	125	125	125	125	125	125	125	125	•
265	First curve east of MP 24.0	23.66	23.92	1.42	4,044	6.000	95	100	105	110	115	119	123	125	125	125	•
266	First curve west of MP 24.0	24.15	24.59	1.50	3,820	5.500	90	95	100	105	109	113	118	122	125	125	•
267	Curve at MP 25.0	24.73	25.52	1.20	4,775	4.750	96	102	108	113	118	123	125	125	125	125	•
268	First curve west of Lincoln	26.39	26.66	1.93	2,964	6.000	82	86	90	94	98	102	105	109	112	115	•
269	Second curve west of Lincoln	26.76	27.18	1.43	3,997	6.000	95	100	105	109	114	118	122	125	125	125	•
270	Third curve west of Lincoln	27.46	27.68	0.77	7,473	3.750	112	120	128	135	142	148	150	150	150	150	150
271		28.86	29.07	0.20	28,648	1.500	150	150	150	150	150	150	150	150	150	150	•
272		30.27	30.66	0.43	13,222	2.750	138	149	150	150	150	150	150	150	150	150	•
273		31.13	31.33	0.45	12,733	3.000	138	149	150	150	150	150	150	150	150	150	•
274		33.77	34.22	0.45	12,733	3.000	138	149	150	150	150	150	150	150	150	150	•
275		39.08	39.37	0.30	19,099	1.500	146	150	150	150	150	150	150	150	150	150	•

Westbound

X-2000 TEST PROGRAM
NEC MAINLINE SPEEDS

Track No.3

CV.#	TIMETABLE DESCRIPTION	MILEPOST LOCATION East	MILEPOST LOCATION West	CURVE GEOMETRY DEGREE [decimal]	CURVE GEOMETRY RADIUS [feet]	CURVE GEOMETRY S.E. [inches]	CALCULATED CURVING SPEEDS 3"UB [mph]	4"UB [mph]	5"UB [mph]	6"UB [mph]	7"UB [mph]	8"UB [mph]	9"UB [mph]	10"UB [mph]	11"UB [mph]	12"UB [mph]	PROPOSED MAXIMUM TESTING SPEED [mph]
276		39.49	40.26	0.52	11,090	3.250	131	142	150	150	150	150	150	150	150	150	150
277		50.38	50.50	0.30	19,099	1.000	138	150	150	150	150	150	150	150	150	150	"
278		56.13	56.35	0.27	21,486	1.000	146	150	150	150	150	150	150	150	150	150	"
279	First curve west of Trenton	56.99	57.12	0.67	8,594	2.500	109	118	127	135	143	150	150	150	150	150	"
280	First curve west of Morris	58.42	59.09	0.82	7,016	4.000	111	118	125	132	139	145	150	150	150	150	"
281		59.50	59.70	0.17	34,378	0.750	150	150	150	150	150	150	150	150	150	150	"
282		60.24	60.57	0.37	15,626	2.250	143	150	150	150	150	150	150	150	150	150	"
283	Curve between MP 61.0 and MP 62.0	61.40	61.94	0.73	7,813	4.500	121	129	136	143	150	150	150	150	150	150	"
284	Curve east of Grundy	64.62	64.95	0.65	8,815	4.000	124	133	141	148	150	150	150	150	150	150	"
285	Curve west of Grundy	65.63	66.33	0.73	7,813	4.500	121	129	136	143	150	150	150	150	150	150	"
286		66.72	67.68	0.47	12,278	2.250	127	138	149	150	150	150	150	150	150	150	"
287		68.60	68.70	0.17	34,378	0.500	150	150	150	150	150	150	150	150	150	150	"
288	Curve west of Croydon	70.03	70.59	1.17	4,911	6.000	105	111	116	121	125	125	125	125	125	125	125
289		72.21	72.60	0.35	16,370	1.500	125	125	125	125	125	125	125	125	125	125	"
290	Reverse curves between MP 74.0 and MP 75.0	74.08	74.49	1.45	3,951	5.750	93	98	103	108	112	116	121	125	125	125	"
291	Reverse curves between MP 74.0 and MP 75.0	74.64	75.11	1.42	4,044	5.000	90	95	100	105	110	115	119	123	125	125	"
292	First curve west of MP 75.0	75.14	75.41	0.75	7,640	3.500	111	120	125	125	125	125	125	125	125	125	"
293		76.14	76.46	0.70	8,185	3.250	113	122	125	125	125	125	125	125	125	125	"
294		76.70	77.04	1.00	5,730	4.000	100	107	113	120	125	125	125	125	125	125	"
295		78.21	78.50	0.33	17,189	1.250	100	100	100	100	100	100	100	100	100	100	100
296		79.23	79.73	0.62	9,291	1.500	100	100	100	100	100	100	100	100	100	100	"
298	Curve between Shore and Ford	81.39	81.75	4.07	1,409	5.000	53	56	59	62	65	68	70	73	75	77	"
299	Curve MP 84.0 to 2nd Street overhead bridge	83.14	83.83	2.47	2,323	5.000	68	72	76	80	83	87	90	90	90	90	90
299	Curves at east and west ends of N. Phila. station pl	84.74	84.81	1.08	5,289	1.000	73	81	89	90	90	90	90	90	90	90	"
300	Curves at east and west ends of N. Phila. station pl	84.88	85.01	0.80	7,162	2.250	90	90	90	90	90	90	90	90	90	90	"
301		85.07	85.14	1.37	4,192	1.500	69	76	82	89	90	90	90	90	90	90	"
302		85.38	85.49	1.90	3,016	2.250	63	69	74	79	83	88	90	90	90	90	"

EASTBOUND - TRACK NO.2

Washington DC to New York, NY

PREPARED BY : Conrad J. Ruppert, Jr.
Mgr. Field Engineering

REVISED : 1/20/93

NATIONAL RAILROAD PASSENGER CORPORATION

X-2000 Proposed Revenue Service Speed Profiles

(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED
					DEGREE [dec.degree]	SUPER-ELEV. [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	[mph]
ALL TRACKS		**136.00**	**134.50**	**WASHINGTON TERMINAL to AVENUE**								**TIMETABLE SPEED**
415	2	135.19	134.82		2.80	1.75	2.2	2.2	45	45	0	
TRACK # 2		**134.50**	**133.00**	**AVENUE to MILEPOST 133.0**								**85**
414	2	133.91	133.34		0.97	4.45	0.5	0.5	85	85	0	
TRACK # 2		**133.00**	**99.80**	**MILEPOST 133.0 to FREDERICK ROAD**								**125**
413	2	130.88	129.28		0.68	4.54	2.9	5.3	125	125	0	
412	2	128.90	128.79	Curve at Landover	0.35	0.99	2.8	5.3	100	125	25	
411	2	128.79	128.54	Curve at Landover	0.97	3.65	7.0	7.7	100	125	25	
410	2	127.74	127.42		0.37	2.40	1.6	1.6	110	125	15	
409 M	2	127.25	127.18		0.18	0.12	1.8	2.8	110	125	15	
409	2	126.95	126.67		1.10	6.40	5.6	6.3	110	125	15	
408	2	126.29	125.95		1.02	5.83	5.3	5.8	110	125	15	
407	2	125.55	125.21		1.03	5.85	5.4	6.2	110	125	15	
406	2	122.05	121.98		0.28	2.31	0.8	0.8	110	125	15	
405	2	120.25	119.96	Curve south of MP 120.0	0.82	6.18	2.8	3.9	115	125	10	
404	2	119.67	119.07		0.47	2.63	2.3	3.5	125	125	0	
403	2	118.37	118.11	First curve south of MP 118.0	0.62	4.14	2.6	3.9	120	125	5	
402	2	117.78	117.61	All curves MP 110.0 to MP 118.0	0.58	3.07	3.3	4.3	120	125	5	
401	2	117.49	116.72	All curves MP 110.0 to MP 118.0	0.85	5.97	3.3	4.2	120	125	5	
400	2	116.67	116.27	All curves MP 110.0 to MP 118.0	0.87	5.31	4.2	5.3	120	125	5	
399	2	115.62	115.16	All curves MP 110.0 to MP 118.0	0.87	5.40	4.1	5.2	120	125	5	
398	2	114.39	113.79	All curves MP 110.0 to MP 118.0	0.87	6.06	3.5	4.6	120	125	5	
397	2	113.51	113.17	All curves MP 110.0 to MP 118.0	0.80	5.81	2.9	4.0	120	125	5	
396	2	111.25	110.71	All curves MP 110.0 to MP 118.0	0.87	6.43	3.1	4.9	120	125	5	
395	2	110.46	110.16	All curves MP 110.0 to MP 118.0	0.65	4.52	2.6	4.6	120	125	5	
392	2	108.50	108.10		0.47	2.82	2.3	3.3	125	125	0	
391	2	106.93	106.48	Curve south of MP 106.0	1.53	6.59	8.8	9.3	90	120	30	
390	2	106.01	105.39		1.00	5.81	5.1	6.4	110	125	15	
389	2	104.74	104.43		0.42	2.54	2.1	3.0	110	125	15	
388	2	104.17	103.86		0.97	5.89	4.7	5.9	110	125	15	
387	2	103.71	103.45	Curve at Winans	1.08	5.01	6.8	6.9	100	125	25	
386	2	103.03	102.86		0.23	2.03	0.5	2.9	110	125	15	

X-2000 Proposed Revenue Service Speed Profiles
(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED
					DEGREE [dec.degrees]	SUPER-ELEV [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	[mph]
TRACK # 2		**133.00**	**99.80**	**MILEPOST 133.0 to FREDERICK ROAD (continued)**								**125**
385	2	102.13	101.45	First curve south of MP 101.0	1.02	4.80	6.4	7.3	105	125	20	
384	2	100.30	100.20		0.20	0.75	1.4	1.4	125	125	0	
383	2	99.97	99.81	First curve south of MP 100.0	1.12	3.91	7.4	9.0	100	120	20	
TRACK # 2		**99.80**	**98.10**	**FREDERICK ROAD to FULTON**								**80**
382	2	99.78	99.38	First curve north of Frederick Road Station	1.75	4.36	3.5	4.2	75	80	5	
381	2	98.59	98.18	First curve south of Bridge	3.75	4.77	4.7	5.3	50	60	10	
ALL TRACKS		**98.10**	**94.60**	**FULTON to NORTH PORTALS OF UNION TUNNEL**								**TIMETABLE SPEED**
380	2	98.10	97.63	Curve at Fulton	4.22	1.65	3.1	3.8	40	40	0	
379	2	97.43	97.38		0.80	0.10	0.4	0.5	30	30	0	
378	2	97.20	96.94		7.52	1.95	2.6	3.2	30	30	0	
377	2	96.34	95.71		7.87	1.88	3.1	3.6	30	30	0	
376	2	95.53	95.20		4.42	0.36	2.4	0.7	30	30	0	
TRACK # 2		**94.60**	**91.70**	**NORTH PORTALS OF UNION TUNNEL to BAY**								**60**
375	2	94.52	94.24	First curve north of Union Tunnels	5.00	2.58	6.2	7.1	45	50	5	
374	2	94.16	93.82	Curve at MP 94.0	4.20	4.53	6.1	6.7	50	60	10	
373	2	93.22	92.85		2.05	2.89	2.3	2.7	60	60	0	
372	2	92.41	91.96	Reverse curves at Bay Interlocking	1.90	3.04	1.7	2.7	60	60	0	
371	2	91.92	91.82	Reverse curves at Bay Interlocking	1.02	0.95	1.6	1.9	60	60	0	
TRACK # 2		**91.70**	**85.00**	**BAY to MILEPOST 85.0**								**110**
369	2	91.13	90.36		0.35	2.40	0.6	1.3	100	110	10	
365	2	89.90	89.76		0.52	3.68	0.7	1.5	110	110	0	
364	2	89.68	88.40		0.63	4.80	0.5	2.3	110	110	0	
362	2	88.15	86.59		0.90	5.47	2.2	3.1	110	110	0	
360	2	86.35	85.73		0.92	6.39	1.4	2.4	110	110	0	
TRACK # 2		**85.00**	**71.50**	**MILEPOST 85.0 to BUSH**								**125**
358	2	82.76	80.51		0.28	2.19	0.9	0.9	125	125	0	
357 N	2	79.79	79.73		0.25	1.25	1.5	2.8	125	125	0	
357 M	2	79.64	79.57		0.30	1.38	1.9	2.9	125	125	0	
357	2	78.40	77.88	First curve north of Gunpow	1.22	6.22	7.1	8.1	100	125	25	
356	2	77.67	77.57	First curve south of Magnolia	0.28	1.96	1.1	1.1	125	125	0	
355	2	73.80	73.65		0.20	0.75	1.4	1.4	125	125	0	

NATIONAL RAILROAD PASSENGER CORPORATION

X-2000 Proposed Revenue Service Speed Profiles
(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED
					DEGREE [dec degree]	SUPER-ELEV. [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	[mph]
TRACK # 2/1		71.50	60.70	BUSH to GRACE								125
354	2	71.30	69.74	Curve north of Bush	0.27	2.85	0.1	3.5	125	125	0	
352	2	66.71	66.21		0.50	3.14	2.3	3.1	125	125	0	
351	2	65.36	64.60		1.00	5.87	5.1	6.0	110	125	15	
350	1	62.81	62.07		0.65	4.33	2.8	4.0	125	125	0	
349	1	61.35	60.45	First curve south of Grace	0.72	1.17	3.9	5.1	95	100	5	
TRACK # 2		60.70	59.70	GRACE to SOUTHWARD LIMITS OF PERRY								90
TRACK # 2		59.70	28.30	SOUTHWARD LIMITS OF PERRY to YARD								125
348	2	57.90	57.59		0.45	1.75	3.2	4.2	110	125	15	
347	2	57.17	56.71	Curve at MP 57.0, north of Prince	1.40	6.07	8.0	8.7	95	120	25	
345	2	54.14	53.81	Curves MP 53.0 and 1,000 feet south of MP 54.0	0.50	2.91	2.6	3.4	110	125	15	
344	2	53.74	53.26	Curves MP 53.0 and 1,000 feet south of MP 54.0	1.12	6.02	6.2	7.3	110	125	15	
343	2	51.82	51.14		0.75	5.34	2.9	4.3	125	125	0	
342	2	50.66	49.90	Curve at MP 50.0	1.36	5.83	7.9	9.1	90	120	30	
341	2	49.12	48.62	Curve at MP 49.0	0.95	5.82	4.6	5.5	110	125	15	
340	2	47.26	46.71	Curve at MP 47.0	0.92	5.90	4.2	4.9	115	125	10	
339	2	45.85	45.26		0.53	3.69	2.1	3.1	125	125	0	
338	2	44.01	43.82		0.25	1.18	1.6	1.6	125	125	0	
337	2	41.94	41.78		0.38	2.36	1.8	3.7	125	125	0	
336	2	40.60	39.39	First curve south of Davis	0.52	2.62	3.1	4.2	110	125	15	
335	2	36.90	36.80		0.20	0.75	1.4	1.4	125	125	0	
334	2	34.66	34.53		0.40	2.58	1.8	2.8	125	125	0	
333	2	33.74	33.29		0.50	2.82	2.6	3.2	125	125	0	
332	2	33.05	32.59	Curve north of MP 33.0	1.05	5.73	5.8	7.0	110	125	15	
331	2	30.98	30.81		0.48	2.84	2.4	3.9	125	125	0	
330	2	30.39	30.03	Curve at MP 30.0	1.05	6.16	5.3	6.3	110	125	15	
329 N	2	29.60	29.55		0.27	0.39	2.6	3.2	125	125	0	
329 M	2	29.45	29.36		0.17	0.39	1.5	1.5	125	125	0	
329	2	29.29	28.60	Curve at MP 29.0	0.82	4.58	4.4	5.8	110	125	15	

NATIONAL RAILROAD PASSENGER CORPORATION

X-2000 Proposed Revenue Service Speed Profiles
(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED [mph]
					DEGREE [dec.degree]	SUPER-ELEV. [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	
TRACK # 2		**28.30**	**27.00**	**YARD to BRANDY**								**80**
328	2	27.53	26.98	Curve at MP 27.0	3.48	0.01	4.9	4.9	40	45	5	
TRACK # 2		**27.00**	**26.80**	**BRANDY to WINE**								**30**
TRACK # 2		**26.80**	**25.50**	**WINE to LANDLITH**								**80**
327	2	26.79	26.17	Curve north of Wilmington Station	4.77	1.76	5.0	5.4	40	45	5	
TRACK # 2		**25.50**	**16.50**	**LANDLITH to HOOK**								**110**
326	2	25.12	24.14		0.43	1.91	1.7	3.7	105	110	5	
325	2	23.78	22.92	First curve south of Bell	1.38	5.36	6.3	7.4	90	110	20	
323	2	22.27	21.92		0.80	4.18	2.6	4.0	110	110	0	
322	2	21.28	21.20		0.27	0.34	1.9	2.5	110	110	0	
321	2	21.03	20.59		0.72	3.47	2.6	3.8	110	110	0	
320 N	2	20.26	20.21		0.30	0.58	2.0	2.7	110	110	0	
320 M	2	20.20	20.10		0.30	0.58	2.0	2.7	110	110	0	
320	2	19.87	19.51		1.02	5.84	2.8	3.5	110	110	0	
319	2	18.48	17.97		1.02	5.54	3.1	3.7	110	110	0	
TRACK # 2		**16.50**	**11.50**	**HOOK to BALDWIN**								**90**
318	2	16.50	16.40		0.20	0.75	0.4	0.4	90	90	0	
317	2	15.95	15.80		0.20	0.75	0.4	0.4	90	90	0	
316	2	14.97	14.81		0.45	2.17	0.4	1.7	90	90	0	
315	2	13.92	13.69		0.80	2.62	1.9	3.3	90	90	0	
314	2	12.31	11.79		0.82	2.60	2.0	3.8	90	90	0	
TRACK # 2		**11.50**	**3.00**	**BALDWIN to MILEPOST 3.0**								**100**
313	2	11.02	10.45		1.00	5.23	1.8	2.3	100	100	0	
312	2	9.63	9.41		1.02	5.24	1.9	3.3	100	100	0	
311	2	7.21	6.78	Reverse curves between Brill and Sharon Hill	1.00	3.25	3.8	4.7	80	100	20	
310	2	6.78	6.00	Reverse curves between Brill and Sharon Hill	1.02	2.94	4.2	5.3	80	100	20	
308	2	6.00	5.38	Reverse curves between Brill and Sharon Hill	1.05	3.00	4.4	4.9	80	100	20	
307 N	2	3.31	3.20		0.20	0.44	1.0	1.9	100	100	0	
307 M	2	3.20	3.10		0.20	0.44	1.0	1.9	100	100	0	

NATIONAL RAILROAD PASSENGER CORPORATION

X-2000 Proposed Revenue Service Speed Profiles
(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED
					DEGREE [dec degree]	SUPER-ELEV. [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	[mph]
ALL TRACKS		**3.00**	**86.75**	**MILEPOST 3.0 to EASTWARDLIMITS OF ZOO**								**TIMETABLE SPEED**
307	2	2.98	2.85		1.42	2.78	2.1	2.7	70	70	0	
306	2	2.84	2.34		2.50	5.20	3.4	3.8	70	70	0	
305	2	2.31	1.98		2.05	3.00	2.2	2.6	60	60	0	
304	2	1.56	1.31		4.70	3.23	8.6	9.7	60	60	0	
303 H	2	1.23	1.14	All curves between 34th St. OH Bridge & Penn I/L Signal loc	4.78	0.21	5.1	4.3	40	40	0	
303 G	2	0.88	0.67	All curves between 34th St. OH Bridge & Penn I/L Signal loc	6.07	1.70	5.1	5.9	40	40	0	
303 F	1	88.99	88.79	All curves between Zoo and 34th St. OH Bridge	0.97	1.66	-1.0	-0.6	30	30	0	
303 E	1	88.73	88.44	All curves between Zoo and 34th St. OH Bridge	2.80	2.59	-0.8	-0.1	30	30	0	
303 C	1	88.30	87.71		6.50	1.94	2.2	2.4	30	30	0	
303 B	1	87.32	87.26		0.98	0.79	2.6	3.3	70	70	0	
303 A	1	87.26	87.17		0.65	0.98	1.2	2.2	70	70	0	
TRACK # 2		**86.75**	**85.50**	**EASTWARD LIMITS OF ZOO to NORTH PHILADELPHIA**								**70**
303	2	86.45	86.31	Curve at Bridge 86.11 (Ridge Ave.)	1.78	3.74	2.4	2.9	70	70	0	
TRACK # 2		**85.50**	**84.50**	**THROUGH NORTH PHILADELPHIA INTERLOCKING**								**60**
302	2	85.39	85.27		2.00	2.02	3.0	3.6	60	60	0	
301	2	85.05	84.99	Curve at west end North Philadelphia Sta. platform	1.42	1.82	1.8	2.2	60	60	0	
300	2	84.92	84.84		0.87	1.93	0.3	0.7	60	60	0	
299 W	2	84.77	84.70	Curve at east end North Philadelphia Sta. platform	1.00	1.36	1.2	1.9	60	60	0	
TRACK # 2		**84.50**	**82.00**	**NORTH PHILADELPHIA to SHORE**								**70**
299	2	83.82	83.08	Curve MP 84 to 2nd Street OH Bridge	2.55	5.06	3.7	4.9	65	70	5	
TRACK # 2		**82.00**	**76.00**	**SHORE to MILEPOST 76.0**								**110**
298	2	81.75	81.37	Curve between Shore and Ford	4.05	5.30	8.6	8.9	50	70	20	
297	2	81.30	80.89	Curve eastwrd from Ford	1.80	1.98	8.2	9.6	60	90	30	
296	2	79.69	79.19		0.60	2.31	2.8	4.3	100	110	10	
295	2	78.51	78.20		0.30	1.41	1.1	2.2	100	110	10	
294	2	77.04	76.68		0.62	4.54	2.4	3.7	100	110	10	
293	2	76.46	76.12		0.62	3.01	2.2	3.3	100	110	10	

NATIONAL RAILROAD PASSENGER CORPORATION

X-2000 Proposed Revenue Service Speed Profiles
(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED
					DEGREE [dec.degree]	SUPER-ELEV. [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	[mph]
TRACK # 2		**76.00**	**58.40**	**MILEPOST 76.0 to MORRIS**								**125**
292	2	75.40	74.95	First curve west of MP 75.0	0.75	4.63	3.6	4.3	120	125	5	
291	2	74.95	74.62	Reverse curves between MP 74.0 and MP 75.0	1.55	6.00	8.3	8.9	90	115	25	
290	2	74.47	74.05	Reverse curves between MP 74.0 and MP 75.0	1.48	5.49	8.2	8.7	90	115	25	
289	2	72.57	72.18		0.35	2.04	1.8	1.8	125	125	0	
288	2	70.61	70.06	Curve west of Croydon	1.20	5.93	7.2	7.6	105	125	20	
287	2	68.75	68.60		0.18	0.75	1.3	1.3	125	125	0	
286	2	67.09	66.72		0.47	2.57	2.6	3.3	125	125	0	
285	2	66.32	65.62	Curve west of Grundy	0.73	3.86	4.1	5.2	115	125	10	
284	2	64.94	64.60	Curve east of Grundy	0.65	3.71	3.4	4.1	120	125	5	
283	2	61.93	61.39	Curve between MP 61.0 and MP 62.0	0.72	5.21	2.7	3.8	110	125	15	
282	2	60.53	60.22		0.35	1.59	2.2	3.1	110	125	15	
280	2	59.24	59.05	First curve west of Morris	0.58	1.72	4.6	6.5	110	125	15	
TRACK # 2		**58.40**	**54.00**	**MORRIS to MILEPOST 54.0**								**110**
	2	58.40	58.00	Morris Interlocking					100	100	0	
279	2	57.10	56.74	First curve west of Trenton	0.92	2.61	5.2	6.0	110	110	0	
278	2	56.25	56.07		0.32	1.37	1.3	2.3	110	110	0	
TRACK # 2		**54.00**	**28.00**	**MILEPOST 54.0 to MILEPOST 28.0**								**125**
277	2	50.46	50.35		0.32	1.83	1.7	1.7	125	125	0	
276	2	40.23	39.45		0.50	3.62	1.6	2.5	125	125	0	
275	2	39.34	39.04		0.32	1.52	2.0	3.1	125	125	0	
274	2	34.20	33.74		0.47	3.09	2.1	2.8	125	125	0	
273	2	31.33	31.11		0.45	2.73	2.2	3.3	125	125	0	
272	2	30.65	30.25		0.47	2.34	2.8	3.6	125	125	0	
271	2	28.97	28.85		0.28	1.87	1.2	1.2	125	125	0	
TRACK # 2		**28.00**	**20.00**	**MILEPOST 28.0 to MILEPOST 20.0**								**110**
270	2	27.65	27.43	Third curve west of Lincoln	0.77	3.83	2.7	3.1	110	110	0	
269	2	27.17	26.75	Second curve west of Lincoln	1.47	5.89	6.6	7.2	90	110	20	
268	2	26.65	26.38	First curve west of Lincoln	1.87	6.38	8.1	8.5	80	105	25	
267	2	25.54	24.68	Curve at MP 25.0	1.20	4.90	5.3	5.8	95	110	15	
266	2	24.53	24.11	First curve west of MP 24.0	1.55	5.73	7.4	8.7	90	110	20	
265	2	23.92	23.65	First curve east of MP 24.0	1.46	5.22	7.1	8.0	90	110	20	

NATIONAL RAILROAD PASSENGER CORPORATION

X-2000 Proposed Revenue Service Speed Profiles

(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED
					DEGREE [dec degree]	SUPER-ELEV. [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	[mph]
TRACK # 2		28.00	20.00	MILEPOST 28.0 to MILEPOST 20.0 (continued)								110
264	2	23.55	22.85		0.78	4.72	1.9	3.3	110	110	0	
263	2	22.81	22.45		0.68	4.33	1.4	3.0	110	110	0	
262	2	22.03	21.89		0.53	2.24	2.2	3.9	110	110	0	
261	2	21.84	21.68		0.67	3.35	2.3	3.1	110	110	0	
260	2	20.80	20.71		0.27	0.53	1.8	2.2	110	110	0	
259	2	20.68	20.38		0.45	2.03	1.8	2.9	110	110	0	
TRACK # 2		20.00	15.10	MILEPOST 20.0 to ELMORA								125
258	2	19.74	19.67		0.32	1.85	1.7	2.7	125	125	0	
256	2	19.41	19.27		0.42	3.25	1.3	3.0	125	125	0	
255	2	18.94	18.84		0.20	0.44	1.7	3.0	125	125	0	
254	2	18.35	18.10		0.30	0.75	2.5	6.0	125	125	0	
TRACK # 2		15.10	10.50	ELMORA to HUNTER								110
	2	15.10	14.70	Elmora Interlocking					55	55	0	
253	2	14.65	14.25	Curve east of Elmora	2.37	2.68	3.3	3.5	55	60	5	
252	2	14.25	14.03	First curve west of MP 14.0	1.98	4.09	2.7	3.1	65	70	5	
251	2	13.05	13.20		0.25	0.75	1.4	1.4	110	110	0	
250	2	12.53	12.28		0.32	2.06	0.6	0.6	110	110	0	
249	2	10.49	10.21	Curve at Hunter	1.02	2.74	0.8	1.8	70	70	0	
ALL TRACKS		10.50	0.00	HUNTER to PENNSYLVANIA STATION, NEW YORK								TIMETABLE SPEED
248	2	9.24	9.18		1.00	0.50	2.9	5.5	70	70	0	
247 M	2	8.98	8.84		0.42	0.21	0.2	-0.4	35	35	0	
247	2	8.82	8.70		1.50	0.10	1.2	0.9	35	35	0	
246	2	8.63	8.51		1.57	0.29	1.1	0.6	35	35	0	
245	2	8.44	8.30		0.62	0.00	0.5	0.7	35	35	0	
244	2	8.30	8.11		0.67	0.81	0.1	1.0	45	45	0	
243	2	8.03	7.78		3.20	4.00	4.1	5.2	60	60	0	
242	1	6.71	6.33		0.45	2.25	0.3	1.0	90	90	0	
	1	W 6.10	W 6.10	Portal Movable Bridge					70	70	0	
241	1	W 5.75	W 5.50		0.47	1.81	0.9	1.3	90	90	0	
240	1	W 3.61	W 2.96	Curve west of the west portal North River Tunnels	2.02	4.12	3.8	5.8	75	75	0	
239	1	W 1.14	W 1.10		0.40	0.32	0.7	1.1	60	60	0	

WESTBOUND - TRACK NO.3

New York, NY to Washington DC

PREPARED BY : Conrad J. Ruppert, Jr.
Mgr. Field Engineering

REVISED : 1/20/93

NATIONAL RAILROAD PASSENGER CORPORATION

X-2000 Proposed Revenue Service Speed Profiles
(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED
					DEGREE [dec.degree]	SUPER-ELEV. [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	[mph]
ALL TRACKS		0.00	10.50	PENNSYLVANIA STATION, NEW YORK to HUNTER								CURRENT TIMETABLE
239	2	W 1.26	W 1.30		0.33	0.070	0.8	0.8	60	60	0	
240	2	W 3.03	W 3.65	Curve west of the west portal North River Tunnels	2.22	4.110	1.5	2.3	60	60	0	
241	2	W 5.51	W 5.79		0.43	1.710	0.7	1.9	90	90	0	
		W 6.10	W 6.10	Portal Movable Bridge					70	70	0	
242	2	W 7.38	W 8.11		0.47	1.850	0.8	1.3	90	90	0	
243	3	7.78	8.02		3.27	3.370	4.9	5.5	60	60	0	
244	3	8.11	8.44		0.67	0.180	0.8	0.5	45	45	0	
245	3	8.51	8.63		1.45	0.290	1.0	0.6	35	35	0	
246	3	8.69	8.82		1.47	0.300	1.0	1.4	35	35	0	
247	3	8.93	9.00		0.85	0.470	0.3	0.8	35	35	0	
248	3	9.20	9.30		0.97	0.820	2.5	3.1	70	70	0	
TRACK # 3		10.50	15.10	HUNTER to ELMORA								110
249	3	10.24	10.56	Curve at Hunter	0.97	3.040	0.3	1.9	70	70	0	
250	3	12.28	12.57		0.32	1.390	1.3	2.0	110	110	0	
251	3	13.00	13.15		0.25	0.750	1.4	1.4	110	110	0	
252	3	14.05	14.29	First curve west of MP 14.0	1.97	4.120	2.6	3.2	65	70	5	
253	3	14.29	14.70	Curve east of Elmora Interlocking	2.42	4.580	1.5	1.9	55	60	5	
		14.70	15.10	Elmora Interlocking					55	55	0	
TRACK # 3		15.10	20.00	ELMORA to MILEPOST 20.0								125
254	3	18.10	18.30		0.32	0.750	2.8	2.8	125	125	0	
256	3	19.10	19.25		0.38	1.500	2.7	2.7	125	125	0	
258	3	19.74	19.76		0.27	0.740	2.2	3.0	125	125	0	
TRACK # 3		20.00	28.00	MILEPOST 20.0 to MILEPOST 28.0								110
259	3	20.39	20.72		0.48	1.390	2.7	3.4	110	110	0	
260	3	20.74	20.81		0.30	1.100	1.4	2.2	110	110	0	
261	3	21.68	21.85		0.70	4.090	1.8	2.2	110	110	0	
262	3	21.90	22.05		0.68	2.920	2.8	3.9	110	110	0	
263	3	22.48	22.85		0.65	3.520	2.0	3.0	110	110	0	
264	3	22.88	23.55		0.77	4.540	2.0	3.0	110	110	0	
265	3	23.67	23.93	First curve east of MP 24.0	1.43	5.970	6.1	6.8	95	110	15	
266	3	24.15	24.59	First curve west of MP 24.0	1.50	5.130	7.6	7.9	90	110	20	
267	3	24.73	25.55	Curve at MP 25.0	1.18	4.260	5.7	6.8	95	110	15	

X-2000 Proposed Revenue Service Speed Profiles
(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED
					DEGREE [dec degree]	SUPER-ELEV. [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	[mph]
TRACK # 3		**20.00**	**28.00**	**MILEPOST 20.0 to MILEPOST 28.0 (continued)**								**110**
268	3	26.40	26.67	First curve west of Lincoln	1.93	6.190	8.7	9.4	80	105	25	
269	3	26.77	27.18	Second curve west of Lincoln	1.43	6.030	6.1	7.3	90	110	20	
270	3	27.48	27.87	Third curve west of Lincoln	0.77	3.900	2.6	3.3	110	110	0	
TRACK # 3		**28.00**	**54.00**	**MILEPOST 28.0 to MILEPOST 54.0**								**125**
271	3	28.87	29.07		0.20	1.680	0.5	0.5	125	125	0	
272	3	30.25	30.65		0.43	2.850	1.9	2.7	125	125	0	
273	3	31.13	31.34		0.45	3.000	1.9	2.8	125	125	0	
274	3	33.77	34.23		0.43	3.230	1.5	2.9	125	125	0	
275	3	39.08	39.35		0.30	1.630	1.7	2.8	125	125	0	
276	3	39.47	40.28		0.53	3.440	2.4	3.3	125	125	0	
277	3	50.38	50.52		0.28	1.080	2.0	3.0	125	125	0	
TRACK # 3		**54.00**	**58.40**	**MILEPOST 54.0 to MORRIS**								**110**
278	3	56.10	56.33		0.28	1.200	1.2	2.1	110	110	0	
279	3	56.99	57.12	First curve west of Trenton	0.68	2.510	3.2	3.9	95	110	15	
	3	58.00	58.40	Morris Interlocking					100	100	0	
TRACK # 3		**58.40**	**76.00**	**MORRIS to MILEPOST 76.0**								**125**
280	3	58.41	59.09	First curve west of Morris	0.77	3.680	4.7	6.2	110	125	15	
281	3	59.44	59.60		0.17	0.530	1.3	1.3	110	125	15	
282	3	60.24	60.56		0.38	2.490	1.7	1.7	110	125	15	
283	3	61.40	61.94	Curve between MP 61.0 and MP 62.0	0.75	4.920	3.3	3.9	110	125	15	
284	3	64.62	64.98	Curve east of Grundy	0.63	4.180	2.7	3.7	120	125	5	
285	3	65.63	66.33	Curve west of Grundy	0.75	4.990	3.2	4.1	115	125	10	
286	3	66.72	67.65		0.50	1.940	3.5	4.3	125	125	0	
288	3	70.03	70.60	Curve west of Croydon	1.05	5.330	6.2	8.2	105	125	20	
289	3	72.19	72.60		0.37	1.680	2.4	3.1	125	125	0	
290	3	74.08	74.50	Reverse curves between MP 74.0 and MP 75.0	1.45	5.820	7.6	7.9	90	115	25	
291	3	74.65	75.09	Reverse curves between MP 74.0 and MP 75.0	1.43	5.330	7.9	9.6	90	115	25	
292	3	75.13	75.42	First curve west of MP 75.0	0.73	4.030	4.0	4.9	110	125	15	

NATIONAL RAILROAD PASSENGER CORPORATION

X-2000 Proposed Revenue Service Speed Profiles

(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED
					DEGREE [dec.degree]	SUPER-ELEV. [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	[mph]
TRACK # 3		76.00	82.00	MILEPOST 76.0 to SHORE								110
293	3	76.13	76.47		0.70	3.460	2.4	3.4	100	110	10	
294	3	76.70	77.04		0.67	2.730	2.9	4.1	100	110	10	
295	3	78.21	78.50		0.35	1.490	1.5	2.6	100	110	10	
296	3	79.23	79.72		0.60	1.690	3.4	4.6	100	110	10	
297	3	80.90	81.32	Curve eastwrd from Ford	1.75	2.470	8.6	9.7	60	95	35	
298	3	81.39	81.79	Curve between Shore and Ford	4.10	5.320	8.7	9.5	50	70	20	
TRACK # 3		82.00	84.50	SHORE to NORTH PHILADELPHIA								70
299	3	83.16	83.84	Curve MP 84 to 2nd Street OH Bridge	2.47	5.190	3.3	3.9	65	70	5	
TRACK # 3		84.50	85.50	THROUGH NORTH PHILADELPHIA INTERLOCKING								60
299 M	3	84.74	84.81	Curve at east end North Philadelphia Station platform	1.27	0.880	2.3	2.8	60	60	0	
300	3	84.89	85.01		0.80	2.370	-0.4	0.1	60	60	0	
301	3	85.07	85.14	Curve at west end North Philadelphia Station platform	1.37	1.520	1.9	2.5	60	60	0	
302	3	85.38	85.49		1.90	2.300	2.5	3.1	60	60	0	
TRACK # 3		85.50	86.75	NORTH PHILADELPHIA to EASTWARD LIMITS OF ZOO INTERLOCKING								70
303	3	86.24	86.38	Curve at Bridge 86.11 (Ridge Ave.)	1.52	3.440	1.8	2.4	60	70	10	
ALL TRACKS		86.75	3.00	EASTWARD LIMITS OF ZOO to SOUTHWARD LIMITS OF PENN (MP 3.0)								CURRENT TIMETABLE
303 Z	4	87.68	89.76	All curves between Zoo and 34th St. OH Bridge	4.85	0.340	2.7	1.4	30	30	0	
304	3	89.80	90.04	All curves South St. OH Bridge to Signal Br. 2.0-2.1	4.32	1.340	3.5	4.2	40	40	0	
305	3	90.46	2.31	All curves South St. OH Bridge to Signal Br. 2.0-2.1	2.02	2.920	0.6	0.9	50	50	0	
306	3	2.31	2.84		2.47	6.130	2.3	2.8	70	70	0	
307	3	2.84	3.05		1.40	3.180	1.6	1.6	70	70	0	
TRACK # 3		3.00	11.50	MILEPOST 3.0 to BALDWIN								100
307 M	3	3.15	3.24		0.25	0.430	1.3	1.7	100	100	0	
308	3	5.38	6.02	Reverse curves between Brill and Sharon Hill	1.07	3.080	4.4	5.0	90	100	10	
309	3	6.02	6.81	Reverse curves between Brill and Sharon Hill	1.00	3.110	3.9	5.0	90	100	10	
311	3	6.81	7.22	Reverse curves between Brill and Sharon Hill	1.02	2.940	4.2	5.3	90	100	10	
312	3	9.41	9.66		1.02	5.650	1.5	2.4	100	100	0	
313	3	10.48	11.04		0.93	4.360	2.2	3.5	100	100	0	

NATIONAL RAILROAD PASSENGER CORPORATION

X-2000 Proposed Revenue Service Speed Profiles
(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED
					DEGREE [dec degree]	SUPER-ELEV. [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	[mph]
TRACK # 3		**11.50**	**16.50**	**BALDWIN to HOOK**								**90**
314	3	11.81	12.73		0.85	2.260	2.6	3.3	90	90	0	
315	3	13.69	13.94		0.75	2.630	1.6	3.3	90	90	0	
316	3	14.79	14.98		0.47	0.860	1.8	3.1	90	90	0	
317	3	15.80	15.95		0.20	1.000	0.1	0.1	90	90	0	
318	3	16.40	16.50		0.20	1.000	0.1	0.1	90	90	0	
TRACK # 3		**16.50**	**25.50**	**HOOK to LANDLITH**								**110**
319	3	17.98	18.51		1.00	5.800	2.7	4.1	110	110	0	
320	3	19.43	19.79		1.02	5.280	3.4	4.0	110	110	0	
320 M	3	20.07	20.15		0.20	0.840	0.9	0.9	110	110	0	
320 N	3	20.22	20.28		0.20	1.030	0.7	2.1	110	110	0	
321	3	20.80	21.03		0.70	3.410	2.5	3.4	110	110	0	
323	3	21.86	22.18		0.97	4.880	3.3	5.0	110	110	0	
324	3	22.94	23.77	First curve south of Bell	1.40	4.820	7.0	8.5	90	110	20	
326	3	24.20	25.16		0.42	2.030	1.5	2.6	105	110	5	
TRACK # 3		**25.50**	**26.80**	**LANDLITH to WINE**								**80**
327	3	26.19	26.80	Curve north of Wilmington Station	3.42	1.210	3.6	3.8	45	45	0	
TRACK # 3		**26.80**	**27.00**	**WINE to BRANDY**								**30**
327 M	3	26.88	26.93		1.37	0.580	0.3	0.6	30	30	0	
327 N	3	26.93	26.97		1.10	0.320	0.4	0.1	30	30	0	
TRACK # 3		**27.00**	**28.30**	**BRANDY to YARD**								**80**
328	3	27.09	27.53	Curve at MP 27.0	3.95	2.960	2.6	2.9	45	45	0	
TRACK # 3		**28.30**	**59.70**	**YARD to SOUTHWARD LIMITS OF PERRY**								**125**
329	3	28.63	29.30	Curve at MP 29.0	0.85	4.850	4.4	6.3	110	125	15	
330	3	30.07	30.41	Curve at MP 30.0	1.05	5.930	5.6	6.5	110	125	15	
331	3	30.84	30.99		0.47	3.530	1.6	2.8	125	125	0	
332	3	32.81	33.09	Curve north of MP 33.0	1.02	5.790	5.4	6.4	110	125	15	
333	3	33.33	33.75		0.50	2.950	2.5	3.3	125	125	0	
334	3	34.53	34.65		0.40	2.090	2.3	3.3	125	125	0	
335	3	35.80	35.90		0.20	0.750	1.4	1.4	125	125	0	
336	3	39.42	40.52	First curve south of Davis	0.50	3.110	2.4	3.5	125	125	0	
337	3	41.78	41.93		0.47	3.100	2.0	3.4	125	125	0	

X-2000 Proposed Revenue Service Speed Profiles
(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY DEGREE [dec degree]	CURVE GEOMETRY SUPER-ELEV. [inches]	UNBALANCE AVERAGE [inches]	UNBALANCE LIMITING [inches]	CURVING SPEEDS CURRENT [mph]	CURVING SPEEDS PROPOSED [mph]	CURVING SPEEDS INCREASE [mph]	MAXIMUM LINE SPEED [mph]
TRACK # 3		**28.30**	**59.70**	**YARD to SOUTHWARD LIMITS OF PERRY (continued)**								**125**
338	3	44.01	44.21		0.22	1.760	0.6	0.6	125	125	0	
339	3	45.27	45.83		0.57	3.520	2.7	3.7	125	125	0	
340	3	46.72	47.29	Curve at MP 47.0	0.95	6.040	4.4	5.1	115	125	10	
341	3	48.62	49.07	Curve at MP 49.0	0.83	4.800	4.3	6.6	110	125	15	
342	3	49.85	50.67	Curve at MP 50.0	1.40	5.170	8.9	9.6	90	120	30	
343	3	51.18	51.65		0.80	6.150	2.6	3.8	125	125	0	
344	3	53.28	53.76	Curves between MP 53.0 and 1,000 feet south of MP 54.0	1.12	5.780	6.5	7.9	105	125	20	
345	3	53.83	54.17	Curves between MP 53.0 and 1,000 feet south of MP 54.0	0.50	2.390	3.1	4.7	105	125	20	
346	3	55.62	55.84		0.30	0.500	2.8	4.4	125	125	0	
347	3	56.74	57.20	Curve at MP 57.0, north of Prince	1.37	6.130	8.9	9.3	95	125	30	
348	3	57.61	57.93		0.47	1.590	3.6	4.4	110	125	15	
TRACK # 3		**59.70**	**60.70**	**SOUTHWARD LIMITS OF PERRY to GRACE**								**90**
TRACK # 4		**60.70**	**71.50**	**GRACE to BUSH**								**125**
349	4	60.53	61.35	First curve south of Grace	0.77	2.110	3.8	6.2	95	105	10	
350	4	62.05	62.78		0.65	3.780	3.3	5.2	125	125	0	
351	4	64.63	65.40		0.97	5.980	4.6	5.4	110	125	15	
352	4	66.21	66.72		0.52	3.350	2.3	3.7	125	125	0	
353	4	69.83	71.30	Curve north of Bush	0.28	1.440	1.6	4.0	120	125	5	
TRACK # 3		**71.50**	**85.00**	**BUSH to MILEPOST 85.0**								**125**
355	3	73.65	73.80		0.20	0.500	1.7	1.7	125	125	0	
356	3	77.61	77.67	First curve south of Magnolia	0.25	1.940	0.8	0.8	125	125	0	
357	3	77.90	78.42	First curve north of Gunpow Interlocking	1.17	6.460	6.3	7.8	100	125	25	
357 M	3	79.48	79.52		0.25	0.940	1.8	2.7	125	125	0	
358	3	80.57	82.82		0.32	1.290	2.2	3.5	125	125	0	
TRACK # 3		**85.00**	**91.70**	**MILEPOST 85.0 to BAY**								**110**
359	3	85.78	86.37		0.95	5.360	2.7	3.8	110	110	0	
361	3	86.62	86.16		0.67	5.390	2.0	3.2	110	110	0	
363	3	88.41	89.71		0.65	3.840	1.7	4.5	110	110	0	
365	3	89.77	89.93		0.47	3.480	0.5	2.0	110	110	0	
369	3	90.18	91.03		0.37	0.790	2.3	4.9	100	110	10	
370	3	91.18	91.27		0.37	0.900	2.2	3.3	100	110	10	

NATIONAL RAILROAD PASSENGER CORPORATION

X-2000 Proposed Revenue Service Speed Profiles

(125 mph Maximum Speed)

CV#	TRK	MILEPOST LOCATION		TIMETABLE DESCRIPTION	CURVE GEOMETRY		UNBALANCE		CURVING SPEEDS			MAXIMUM LINE SPEED
					DEGREE [dec.degree]	SUPER-ELEV. [inches]	AVERAGE [inches]	LIMITING [inches]	CURRENT [mph]	PROPOSED [mph]	INCREASE [mph]	[mph]
TRACK # 3		**91.70**	**94.60**	**BAY to NORTH PORTALS OF UNION TUNNEL**								**60**
371	3	91.87	92.00	Reverse curves at Bay Interlocking	1.00	1.850	0.7	1.1	60	60	0	
372	3	92.00	92.42	Reverse curves at Bay Interlocking	2.02	3.040	2.1	2.9	60	60	0	
373	3	92.86	93.27		2.02	4.440	0.7	1.8	60	60	0	
374	3	93.85	94.12	Curve at MP 94.0	4.10	4.300	6.0	6.5	50	60	10	
375	3	94.22	94.53	First curve north of Union Tunnels	4.43	3.350	4.4	5.0	45	50	5	
ALL TRACKS		**94.60**	**98.10**	**NORTH PORTALS OF UNION TUNNEL to FULTON**								**CURRENT TIMETABLE**
376	3	95.25	95.48		4.95	0.420	2.7	2.6	30	30	0	
377	3	95.69	96.34		7.20	1.990	2.5	2.9	30	30	0	
378	3	96.98	97.12		7.65	1.510	3.3	3.7	30	30	0	
379	3	97.31	97.36		0.62	0.230	0.3	0.2	30	30	0	
380	3	97.59	98.10	Curve at Fulton	4.15	1.940	2.7	3.5	40	40	0	
TRACK # 3		**98.10**	**99.80**	**FULTON to FREDERICK ROAD**								**80**
381	3	98.19	98.60	First curve south of Bridge	3.88	2.820	7.0	7.5	50	60	10	
382	3	99.38	99.79	First curve north of Frederick Road Station	1.72	4.650	3.1	4.0	75	80	5	
TRACK # 3		**99.80**	**133.00**	**FREDERICK ROAD to MILEPOST 133.0**								**125**
383	3	99.83	99.99	First curve south of MP 100.0	1.18	3.360	8.5	8.8	100	120	20	
384	3	100.20	100.30		0.20	0.500	1.7	1.7	100	125	25	
385	3	101.46	102.10	First curve south of MP 101.0	1.00	4.320	6.6	7.8	105	125	20	
386	3	102.90	103.03		0.27	1.730	1.2	1.2	110	125	15	
387	3	103.48	103.74	Curve at Winans	1.10	5.500	6.5	7.9	100	125	25	
388	3	103.90	104.15		0,97	6.550	4.1	4.6	110	125	15	
389	3	104.43	104.74		0.47	2.620	2.5	3.3	110	125	15	
390	3	105.40	106.03		0.40	2.040	2.3	3.9	110	125	15	
391	3	106.49	106.95	Curve south of MP 106.0	1.55	6.000	8.3	8.3	90	115	25	
392	3	108.11	108.48		0.47	2.980	2.2	4.4	125	125	0	
395	3	110.17	110.46	All curves MP 110.0 to MP 118.0	0.80	5.570	3.2	4.4	120	125	5	
396	3	110.72	111.24	All curves MP 110.0 to MP 118.0	0.87	6.070	3.4	4.9	120	125	5	
397	3	113.18	113.54	All curves MP 110.0 to MP 118.0	0.83	5.820	3.3	4.1	120	125	5	
398	3	113.82	114.39	All curves MP 110.0 to MP 118.0	0.83	5.740	3.3	4.9	120	125	5	
399	3	115.15	115.63	All curves MP 110.0 to MP 118.0	0.80	5.550	3.2	3.9	120	125	5	
400	3	116.25	116.67	All curves MP 110.0 to MP 118.0	0.83	6.030	3.0	4.9	120	125	5	

X2000 US Demonstration Vehicle Dynamics Trials, Final Test Report, 1993
US DOT, FRA, Brian T Whitten, Brian T Scales