CERTIFICATION TESTING OF UNITED STATES DEPARTMENT OF ENERGY ATLAS TRAIN MULTIPLE CAR TEST REPORT

for the U.S. Department of Energy

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Proprietary Report

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Executive Summary

As part of the United States Department of Energy (DOE) Atlas Railcar Project, the Atlas and Buffer railcars were developed to meet the need for future large-scale rail transport of spent nuclear fuel and high-level radioactive waste. The DOE collaborated with the United States Naval Nuclear Propulsion Program (NNPP) to purchase a rail escort vehicle (REV) designed and tested by the NNPP. The DOE contracted MxV Rail to perform multiple-car railcar certification testing and modeling s according to the certification requirements in the Association of American Railroads (AAR) *Manual of Standards and Recommended Practices (MSRP)*, Section C, Standard S-2043[1], "Performance Specification for Trains Used to Carry High-Level Radioactive Material (HLRM)." This report describes multiple car testing results in accordance with the S-2043 certification for the Multiple-Car Test (paragraph 6.0). The work was performed as part of Phase 5 under DOE Contract 89243218CNE000004/P00022.

The test train consisted of a leading Buffer car, a 12-axle cask car, a trailing Buffer car, and a REV. The 12-axle cask car, known as the Atlas railcar, is equipped with fittings to accommodate cradles and end stops designed to allow the railcar to carry various casks used for the transportation of spent nuclear fuel and high-level radioactive waste. During testing, depending on the requirements, the Atlas railcar was loaded with either the minimum test load (198,975 pounds) or the maximum test load (490,400 pounds). The Buffer cars were four-axle flatcars with permanent loads attached to achieve a gross rail load of 263,000 pounds. The REV was a four-axle car with facilities for personnel to escort the shipment.

Except for the second revenue service 10-degree curve test and the demonstration test run, all tests were performed with AAR-1B narrow flange wheel profiles. After the first revenue service test in October 2022, the wheel tread profiles on the train were changed from AAR-1B narrow flange profiles to AAR-2A narrow flange profiles to improve curving performance. In June 2023, a repeat of the revenue service 10-degree curve test with the AAR-2A narrow flange profiles showed improved performance. A demonstration test run using the AAR-2A narrow flange profiles was completed in September 2023.

Tests were performed in several locations including the Transportation Technology Center (TTC) in Pueblo, Colorado; the Pueblo Chemical Depot (PCD) in Pueblo, Colorado; BNSF railroad tracks between Avondale, Colorado and Folsom, New Mexico; and Union Pacific (UP) railroad tracks between Avondale, Colorado and Scoville, Idaho. The table below shows the test performed, the results of the tests, and data where criteria were not met.

S-2043 Section	Critical Data (S-2043 Criteria and Loading Condition	Met/Did not Meet
6.1 Dynamic Tests at the Controlled Test Site		
6.1.1.1 Stop Distance (Loaded)	The jerk rate did not match to within 0.5 mph/sec^2 from car to car during three of the 12 emergency and two of the 14 full service application stop distance test runs.	Not Met
6.1.1.1 Stop Distance (Empty)	The Atlas railcar did not meet the wheel slip criteria (63.4%, limit = 15%) during one (wet) of the 18 (wet and dry) full service braking run at 50 mph The jerk rate did not match to within 0.5 mph/sec^2 from car to car during two of the 16 emergency application stop distance test runs.	Not Met
6.1.1.2 Braking in Curves		Met
6.1.2 Hand Brake	No established criteria	NA
6.1.3 Buff and Draft Curving	Buffer car 20001 Maximum vertical acceleration = 0.94 g (0.9 g) Buffer car 20002 Maximum lateral acceleration = 1.77 g (0.75 g) Buffer car 20002 Maximum lateral peak to peak acceleration = 1.89 g (1.3 g)	Not Met
6.2 System Monitoring Tests		
6.2.1 System Functional Tests		Met
6.2.2 Failure Simulations		Met
6.3 Revenue Service Tests		
6.3.1 Turnouts, Crossovers		Met
6.3.1 Tight Curves: 12-degree curve at the TTC		Met
6.3.1 Tight Curves: 10- and 12-degree curves at PCD		Met
6.3.1 Tight Curves: 10-degree curve at Alps, New Mexico	Atlas railcar maximum truck side lateral force/vertical force (L/V) ratio = 0.53 (0.5)	Not Met
6.3.2 Class 2 Maintained Track (5 miles no better than FRA class 2)		Met
6.3.2 Class 2 Maintained Track (additional revenue service track)	Atlas railcar maximum truck side L/V ratio = 0.57 (0.5) Atlas railcar maximum wheel L/V ratio = 0.82 (0.8) REV maximum truck side L/V ratio = 0.55 (0.5)	Mot Met
6.3.3 Ride Quality	No established criteria	NA
6.3.4 Demonstration run	No established criteria	NA

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1.0 INTRODUCTION

The Atlas and Buffer railcars were developed and are being tested as part of the U.S. Department of Energy (DOE) Atlas Railcar Project to meet the need for future large-scale rail transport of spent nuclear fuel and high-level radioactive waste. The DOE collaborated with the United States Naval Nuclear Propulsion Program (NNPP) to purchase a rail escort vehicle (REV) that the NNPP had designed and tested. MxV Rail, a subsidiary of the Association of American Railroads (AAR), performed multiple-car certification testing and modeling of a train consisting of a DOE Atlas 12-axle cask-carrying railcar, two four-axle Buffer railcars, and a REV.

The testing and modeling were performed to determine whether the train meets the requirements for certification according to the Association of American Railroads (AAR) *Manual of Standards and Recommended Practices (MSRP)*, Standard S-2043, "Performance Specification for Trains Used to Carry High-Level Radioactive Material," revised 2017[1] (S-2043). This report provides a summary of the testing and modeling results for the Multiple-Car Test (paragraph 6.0) phase of certification for the Atlas and Buffer railcars.

Tests were performed at the Transportation Technology Center (TTC) in Pueblo, Colorado; at the Pueblo Chemical Depot (PCD) in Pueblo, Colorado; on BNSF railroad tracks between Avondale, Colorado, and Folsom, New Mexico; and on Union Pacific (UP) railroad tracks between Avondale, Colorado and Scoville, Idaho. The work was performed as part of Phase 5 under DOE Contract 89243218CNE000004/P00022.

2.0 OBJECTIVE

The objective of this report is to provide a summary of the testing and modeling results from the Multiple-Car Test (paragraph 6.0).

3.0 TEST TRAIN DESCRIPTION

The test train included the following vehicles:

- IDOX 20002 Buffer car
- IDOX 10001 Atlas cask car
- IDOX 20001 Buffer car
- IDOX 30001 REV

The Buffer cars, cask car, and REV represent at least one of each type of railcar that an anticipated consist would employ to transport various casks used for the transportation of spent nuclear fuel and high-level radioactive waste. The three railcar types use 100-ton Swing Motion® trucks (Figure 1) supplied by Amsted Rail. Each truck uses two wheelsets with AAR-type K axles (K-axles) and AAR-2A narrow flange wheels. During the multiple car test program, the AAR-1B narrow flange profiles were replaced with AAR-2A narrow flange profiles to improve curving performance of the train in revenue service curving tests. The change in wheel tread profile is described in detail in Section 4.0. Narrow flange wheels were specified for these cars because the increased gage clearance allowed more lateral movement for better high-speed stability and extremely tight curve performance. The trucks were specially designed to use a polymer element between the bearing adapter and the side frame, thereby giving the truck a passive steering capability. Figure 2 shows a bearing adapter pad.

During the Atlas railcar single car testing program, MxV Rail tested the car with a total of four primary suspension pad models. The pads are made from chlorosulfonated polyethylene (CSM) and are categorized by the Shore D durometer hardness value. The car arrived with CSM 58 (Shore D hardness = 58) production pads, ASF-Keystone part number 10522A, and these pads were found to have the best balance of curving and hunting performance. All three test car types used the CSM 58 10522A pads, and all test results presented in this report are based on these test cars.

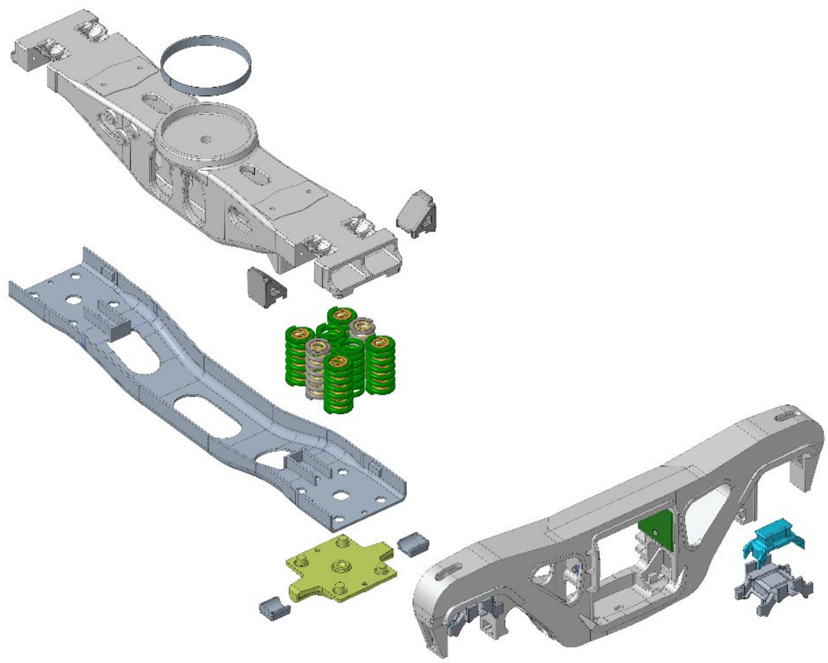

Figure 1. Exploded view of Swing Motion® truck

Figure 2. Bearing adapter pad used on the Atlas and Buffer cars and the REV

3.1 Atlas Railcar Description

The Atlas railcar is a 12-axle span bolster railcar built by Kasgro Rail Corporation and completed for DOE in February 2019. The car is equipped with fittings to accommodate cradles and end stops designed to allow the railcar to carry various casks used for the transportation of spent nuclear fuel and high-level radioactive waste. The railcar deck is supported on two span bolsters. Each span bolster rests on three (3) two-axle trucks.

Figure 3 shows the railcar with the minimum test load installed. Table 1 lists the railcar dimensions, and Table 2 shows the truck configuration used for testing. The secondary suspension is made up of special non-AAR springs.

Figure 3. IDOX10001 during testing with minimum test load

Table 1. Atlas railcar dimensions

Dimension	Value
Length over pulling faces	78 feet 1 1/4 inches
Length over strikers	73 feet 5 1/4 inches
Span bolster spacing	38 feet 6 inches
Axle spacing on trucks	72 inches
Distance between adjacent truck centers	10 feet 6 inches
Coupler length	37 inches
Cushion unit length	15 inches

Table 2. Atlas railcar configuration

Component	Description	
Secondary suspension springs at end trucks (A,B,D,E)	Kasgro part numbers: (2) 1-94, (2) 1-95, (2) 1-96, (4) 1-97, (4) 1-92, (4) 1-99	
Secondary suspension springs at middle trucks (C,F)	Kasgro part numbers: (2) 1-88, (2) 1-89, (2) 1-90, (4) 1-91, (4) 1-92, (2) 1-93, (4) 1-99	
Primary suspension	Adapter Plus pads, ASF-Keystone part number 10522A	
Side frames	F9N-10FH-UB	
Bolsters	B9N-714N-HJ	
Truck side bearings	Miner TCC-III 60LT	
Span bolster side bearings	Gap type (1/8 to 3/16-inch clearance)	
Friction wedge, composition faced (four per truck)	ASF-Keystone Part number 48446	
Bearings and adapters	AAR Class K 6 1/2 x 9 bearings with 6 1/2 x 9 Special Adapter ASF-Keystone Part number 10523A	
Truck center bowl plate	Metal Horizontal Liner	
	End Truck Average	Middle Truck Average
Minimum test load spring nest height measured May 19, 2023	8.98 inches	9.20 inches
Maximum test load spring nest height measured June 30, 2022	8.30 inches	8.30 inches
	Actual weight on rail used during testing	
TTC scale weight empty car measured April 1, 2019	222,050 (lbs.)	
TTC scale weight car plus minimum test load measured June 6, 2022	421,025 (lbs.)	
TTC scale weight car plus maximum test load measured July 12, 2022	712,450 (lbs.)	

Figure 4 shows the convention for wheel and truck identification. The B-end of a railroad freight car is normally the end with the hand brake, but because the Atlas railcar has two hand brakes, the railcar manufacturer designated and stenciled the B-end. The right and left sides of the railcar are designated from the perspective of standing at the B-end of the railcar looking toward the A-end of the car. Axles are numbered starting from the B-end. For axle numbers greater than nine, the locations are stenciled with letters descending from Z.

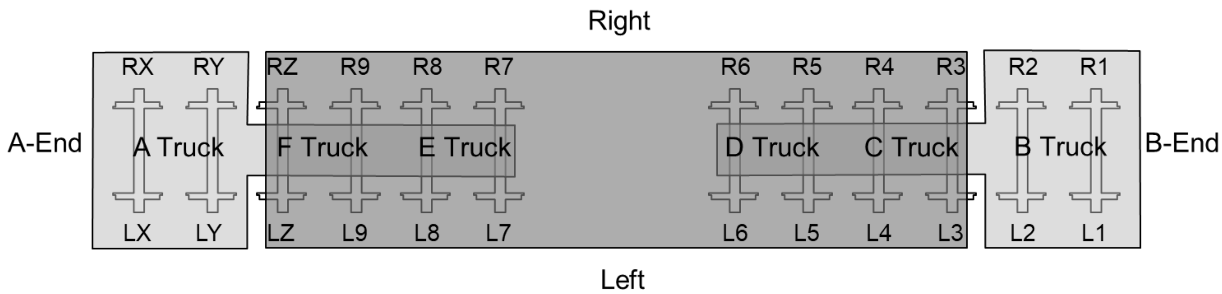

Figure 4. Axle and side naming convention

3.2 Buffer Railcar Description

The S-2043 compliant Buffer car is a four-axle flatcar with a steel plate load permanently attached. In 2019, Kasgro completed the manufacture of IDOX 20001 and IDOX 20002, two prototype Buffer cars that were delivered for Standard S-2043 testing alongside the Atlas cask car program.

Each Buffer car truck uses two Koni 04A 2032 vertical dampers to control the vertical motion of the railcar suspension. Table 3 lists the car dimensions, and Figure 3 shows the general arrangement of the car. Table 4 shows the truck configuration used for testing.

Table 3. IDOX 20001 and 20002 Buffer car dimensions

Dimension	Value
Length over pulling faces	66 feet, 4 5/8 inches
Length over strikers	61 feet, 8 5/8 inches
Truck center spacing	44 feet 6 inches
Axle spacing on trucks	72 inches
Coupler length	43 inches
Cushion unit length	15 inches

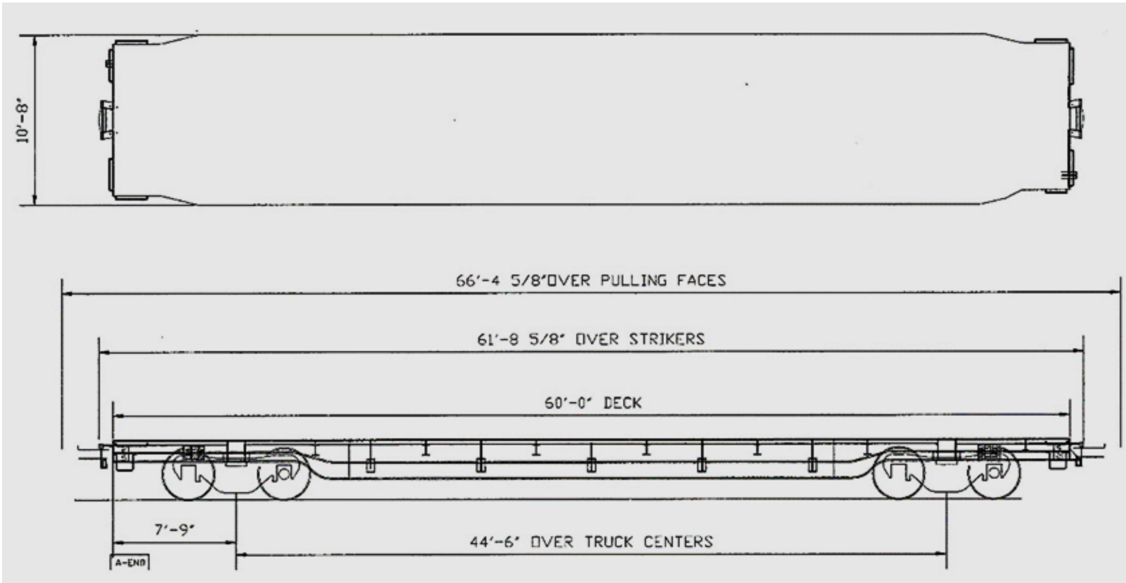

Figure 5. IDOX 20001, 20002 Buffer car arrangement drawing

Table 4. IDOX 20001, 20002 Buffer car truck configuration

Component	Description	
Secondary suspension	Five D7 outer coils, five D6 inner coils, five D6A inner inner coils, two 49427-1, two 49427-2	
Primary suspension	Adapter plus pads, ASF part number 10522A	
Side bearings	Miner TCC-III 60LT	
Friction wedge	Amsted part number 1-9249	
Bearings and adapters	K class 6 ½ x 9 bearings with 6 ½ x 9 special adapter ASF Part number 10523A	
Center bowl plate	Metal horizontal liner	
Vertical hydraulic dampers	KONI damper 04a 2032	
Side frames	F9N-10FH-UB	
Bolsters	B9N-714N-FS	
	A-end truck average	B-end truck average
Spring nest height IDOX 20001	7.66 inches	7.69 inches
Spring nest height IDOX 20002	7.78 inches	7.84 inches
TTC scale weight – June 2, 2022 IDOX 20001	131,725 pounds	131,800 pounds
TTC scale weight – June 2, 2022 IDOX 20002	131,050 pounds	131,725 pounds

3.3 Rail Escort Vehicle Description

The REV is a four-axle car built by Vigor Works and completed for DOE in January 2022 to house escorts during shipments. Figure 6 shows the general arrangement drawing of the REV, and the basic car dimensions are listed in Table 5. The REV uses 100-ton Swing Motion® trucks from Amsted Rail. Amsted Rail designed the trucks to use primary pads to improve steering performance and vertical KONI dampers (model 04A 2032) to control carbody motion. The REV car's truck configuration is summarized in Table 6. The REV has a light rail load of 175,000 pounds and a gross rail load of 185,000 pounds.

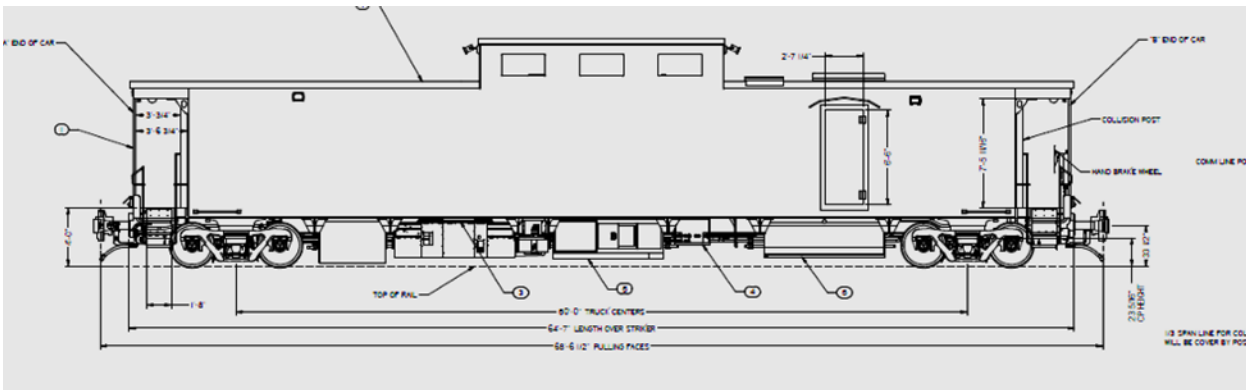

Figure 6. IDOX 30001 REV general arrangement

Table 5. REV dimensions

Dimension	Value
Length over pulling faces	68 feet 11 inches
Truck center spacing	50 feet
Axle spacing	72 inches
Coupler length (pin to coupling line)	43 inches
Cushion unit travel	10 inches

Table 6. IDOX 30001 REV configuration

Component	Description	
Secondary suspension	Five 52596-1 outer coils, five D7 inner coils, five D6A inner inner coils, two 49427-1 outer control coils, two 49427-2 inner control coils	
Primary suspension	Adapter plus pads, ASF part number 10522A	
Side bearings	Miner TCC-III 80LT	
Friction wedge	Amsted part number 1-9249	
Bearings and adapters	K class 6 1/2 x 9 bearings with 6 1/2 x 9 special adapter ASF part number 10523A	
Center bowl plate	Metal horizontal liner	
Vertical hydraulic dampers	KONI damper 04A 2032	
Side frames (AAR design feature code)	F9N-10FH-UB	
Bolsters (AAR design feature code)	B9N-714N-FS	
	A-end truck	B-end truck
Loaded spring nest height	8.06 inches (average)	8.06 inches (average)
TTC scale weight - June 6, 2022	89,675 pounds	87,450 pounds

4.0 WHEEL PROFILE CHANGE

All tests except the second revenue service 10-degree curve test and the demonstration test run were performed with AAR-1B narrow flange wheel profiles. After the first revenue service test in October 2022, the wheel tread profiles on the train were changed from AAR-1B narrow flange profiles to AAR-2A narrow flange profiles (current standard) to improve curving performance, as discussed in this section. In June 2023, the revenue service 10-degree curve test was repeated with AAR-2A narrow flange profiles, and the test showed improved performance. The demonstration test run was completed in September 2023 with AAR-2A narrow flange profiles.

In October 2022, the train, with the Atlas railcar loaded with the minimum test load, traveled from Avondale, Colorado, to the 10-degree curve at Milepost 274 of the BNSF's Twin Peaks subdivision. This 10-degree curve is referred to as the Alps curve in this report. Truck side L/V ratios on the Atlas and REV exceeded the S-2043 criterion in many of the 4-degree or tighter curves between Trinidad, Colorado and the siding at Folsom, New Mexico. The siding at Folsom is approximately 10 miles beyond the Alps curve.

MxV Rail investigated several possible solutions to reduce the truck side L/V ratios using the vehicle dynamics models developed and validated during both the design phase and the single car testing phase of the S-2043 process. The potential solutions investigated include:

- Changing longitudinal and lateral pedestal clearance
- Changing center plate friction
- Changing primary suspension longitudinal stiffness
- Changing primary suspension lateral stiffness

- Changing from the AAR-1B narrow flange wheel profiles to the AAR-2A narrow flange wheel profile.

Based on the modeling results, the only potential solution that appeared to have a significant effect on the vehicle curving performance was the change from the AAR-1B narrow flange wheel profile to the AAR-2A narrow flange wheel profile.[2,3] Figure 7 shows the difference between how the two wheel-tread profiles contact the outside rail in the Alps curve. The AAR-1B narrow flange design profile has two distinct points of contact between the wheel and rail, one on the tread and one on the flange, with nearly 1.4 inches in between where no contact occurs. Having two contact points limits the steering forces generated by the wheelset. The reduced steering forces are not adequate to rotate the trucks and axles into the proper position to best negotiate the curve. The AAR-2A profile has single-point contact with the high rail of the Alps curve, allowing for larger steering forces that result in better positioning of the trucks and axles, thereby improving the steering performance.

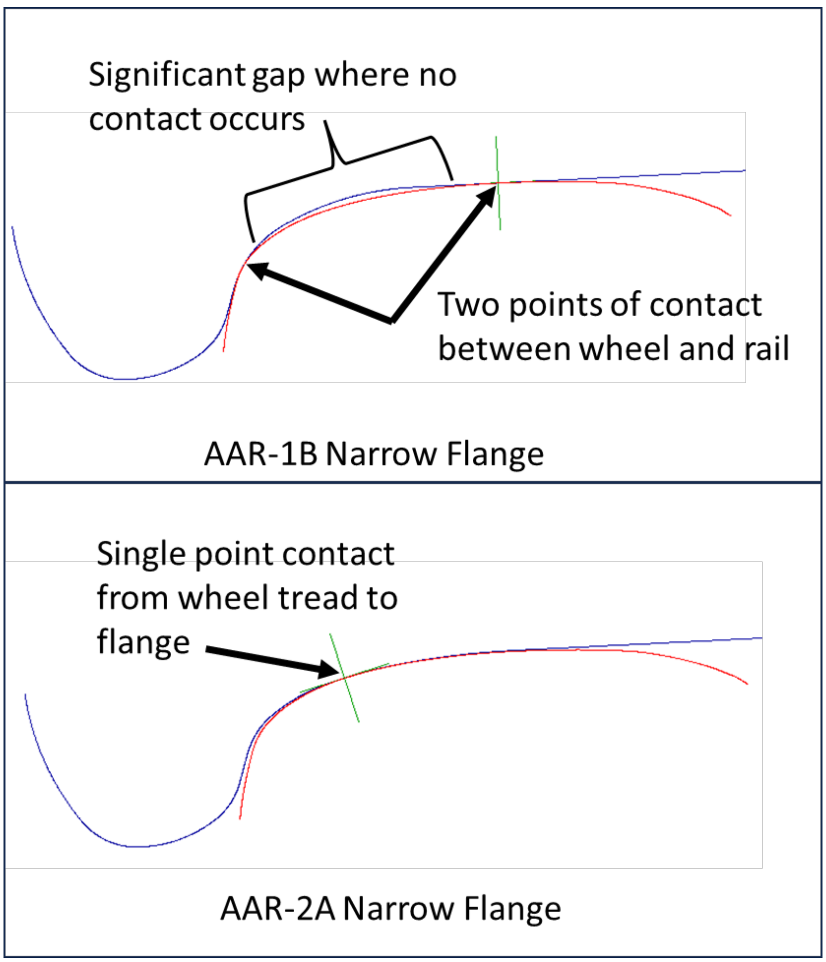

Figure 7. Comparison of the contact conditions of the AAR-1B narrow flange and the AAR-2A narrow flange wheel profiles on the outside rail profile measured in the Alps curve

Changing from the AAR-1B narrow flange wheel profile to the AAR-2A narrow flange wheel profile significantly improved the test results. Figure 8 shows:

- A histogram of the track curvature between Trinidad and the Alps curve
- The number of curves where the REV did not meet the truck side L/V ratio criterion with AAR-1B narrow flange wheel profiles
- The number of curves where the REV did not meet the truck side L/V ratio criterion with AAR-2A narrow flange wheel profiles

The truck side L/V ratio results shown were measured while traveling south with the B-ends of the cars leading. During this portion of the test, the REV did not meet the truck side L/V ratio criterion for two out of 88 total curves with the AAR-2A narrow flange profile; this was a still a significant improvement over the AAR-1B narrow flange profile in which the REV did not meet the criterion for 30 out of 88 total curves.

The tests with AAR-2A profiles were conducted several months after the tests with AAR-1B profiles. Wheel-rail friction conditions can affect curving performance, but friction conditions were similar for the two tests. Average friction measured on October 26, 2022, (the day after the AAR-1B test) was 0.44 (top of low rail), 0.53(top of high rail), and 0.29 (gage face of high rail). Average friction measured on June 27 and 29, 2023, (the days of AAR-2A test) was 0.44 (top of low rail), 0.49 (top of high rail), and 0.35 (gage face of high rail). Simulations showed that the truck side L/V ratio curving performance was more sensitive to wheel and rail shape than wheel-rail friction conditions.

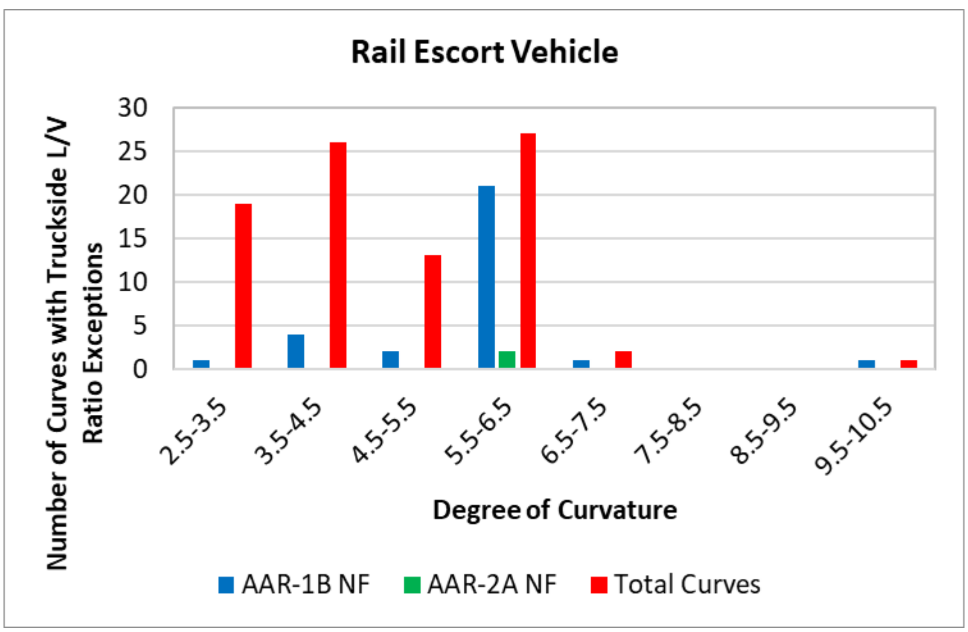

Figure 8. REV truck side L/V ratio curving performance going from Trinidad to the Alps curve with the B-end leading

Figure 9 shows a plot of the truck side L/V ratios for the Atlas car while it operates in the Alps curve for B-end-leading southbound runs in buff and A-end-leading northbound runs in draft. These runs were performed with AAR-1B narrow flange profiles and repeated with AAR-2A narrow flange profiles. The graph shows the results from approximately a quarter of the runs in the Alps curve performed with the AAR-2A narrow flange profile to complete the runs required by the test plan. Due to these exceptions, testing with the AAR-1B narrow flange profile was suspended following these test runs. For this portion of the runs performed, the graph shows that the Atlas railcar did not meet the truck side L/V ratio criterion for any of the runs with the AAR-1B narrow flange profile, but it did meet the criterion for all the runs with the AAR-2A narrow flange profile.

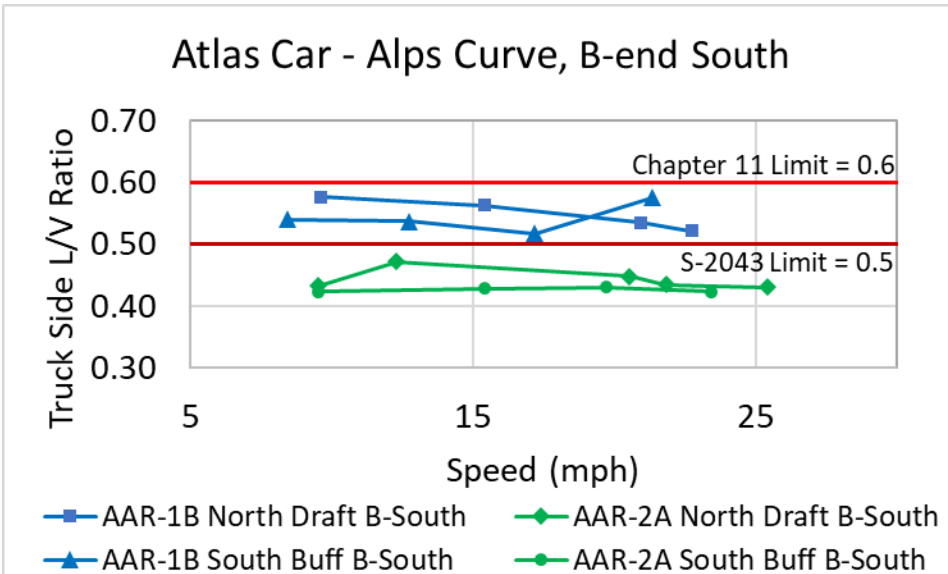

Figure 9. Comparison of Atlas railcar truck side L/V ratios with AAR-1B narrow flange wheel profiles and with AAR-2A narrow flange wheel profiles in the Alps test curve

5.0 TEST PLANS AND INSTRUMENTATION SUMMARY

The tests reported here were described in six test plans. One test plan covered activity related to Standard S-2043 paragraph 6.1; another test plan covered activities related to Standard S-2043 paragraph 6.2; and four test plans covered different activities related to Standard S-2043 paragraph 6.3. Table 7 lists the S-2043 sections, the report sections, and the associated test plans, all of which are included as appendices to this report.

Table 7. Test plans

Standard S-2043 Paragraph	Report Section	Test Plan
6.1	6.0 Dynamic Tests at the Controlled Test Site	Appendix A: TP-20-001rev2 Test Implementation PlanMultiple Car Test of The Atlas HLRM Train in Accordance with Association Of American Railroads Standard S-2043 Paragraph 6.1 -- Tests at Controlled Test Site. May 27, 2021
6.2	7.0 System Monitoring Tests	Appendix B: TP-21-002rev2 Test Implementation Plan System Safety Monitoring Tests as Part of Multiple Car Test of The Atlas Railcar Consist in Accordance with Association Of American Railroads Standard S-2043, Paragraph 6.2. December, 2021
6.3.1, 6.3.2	8.0 Revenue Service Tests (8.1.1, 8.1.3, 8.2.1)	Appendix C: TP-21-003rev4 Test Implementation Plan Multiple Car Test of The Atlas HLRM Train in Accordance With Association Of American Railroads Standard S-2043 (Revenue Service At Pueblo Chemical Depot) for the U.S. Department Of Energy (DOE). July 12, 2022
6.3.1, 6.3.3	8.0 Revenue Service Tests (8.1.2, 8.3)	Appendix D: TP-21-004rev3 Test Implementation Plan Multiple Car Test of the Atlas HLRM Train In Accordance With Association Of American Railroads Standard S-2043 (Revenue Service at Controlled Site Portions) for the U.S. Department of Energy (DOE). July 12, 2022
6.3.1, 6.3.3	8.0 Revenue Service Tests (8.1.4, 8.2.2, 8.3)	Appendix E: TP-23-001rev2 Test Implementation Plan: Multiple Car Test Of The HLRM Train in Accordance with Association Of American Railroads Standard S-2043 (Revenue Service BNSF Portions) for the U.S. Department Of Energy (DOE). April 6, 2023
6.3.4	8.0 Revenue Service Tests (8.4)	Appendix F: TP-23-002 Test Implementation Plan: Multiple Car Test of the HLRM Train in Accordance with Association Of American Railroads Standard S-2043 (Revenue Service Test Demonstration Run) for The U.S. Department Of Energy (DOE). August 15, 2023

The following measurements were made on each car for all tests except the demonstration test run (Standard S-2043, paragraph 6.3.4).

- Carbody lateral acceleration (above the carbody centerplate) on the A- and B-end
- Carbody vertical acceleration (above the carbody centerplate) on the A- and B-end
- Carbody roll angle on the A- and B-end
- Spring nest vertical displacement on each side of each truck

Additional measurements made for individual tests are described in the corresponding test section.

6.0 DYNAMIC TESTS AND THE CONTROLLED TEST SITE

The dynamic tests at the controlled site were conducted at the TTC. The test plan, included as Appendix A, contains additional details describing the tests, including the instrumentation used.

6.1 Braking Tests

MxV Rail conducted the braking tests according to the requirements of Standard S-2043, paragraph 6.1.1.

6.1.1 Stop Distance Tests

MxV Rail performed stop distance tests using the minimum test load between June 2 and 16, 2022, and using the maximum test load on July 7 and 8, 2022. These tests were performed per Standard S-2043, paragraph 6.1.1.1 and observed by the personnel listed in Table 8 per Standard S-2043 requirements.

Table 8. Official observers for stop distance tests

Dates	Observer
June 2 and 6, 2022	Matt DeGeorge, MxV Rail Senior Engineer II
June 13 and 16, 2022	Adam Klopp, MxV Rail Principal Investigator II
July 7, 2023	Heath Bushel, MxV Rail Manager Braking Systems
July 8, 2023	Steve Belport, MxV Rail Principal Investigator II

MxV Rail performed stop distance tests that demonstrated the test consist could stop without any wheel sliding in both the minimum and maximum test load condition with both dry and wet rails. The Standard S-2043 criterion of maximum wheel slip less than 15 percent was met for all test conditions except one (run name 2022_06_06_133053). The train met the rate of change for the deceleration (jerk) service braking criterion having a maximum value less than 1.9 mph/sec^2 for full-service braking runs and 2.5 mph/sec^2 for emergency braking runs. The jerk rate data is unavailable for minimum load runs conducted on June 2 and 6, 2022, because the accelerometers were inadvertently oriented in the vertical (z) direction as opposed to the longitudinal (x) direction, resulting in the loss of this data. Selected test runs were repeated on June 13 and 16, 2022, to make up for the loss of data. The measured wheel tread temperatures were well below levels that would be expected to cause damage to the wheels.

The tests were performed with both the minimum and maximum test load (Figure 10) at nominal speeds of 30, 50, and 70 mph. Standard S-2043, paragraph 6.1.1.1 requires the stop distance tests to be done with both full-service and emergency brake applications and in both dry and wet rail conditions. These tests included wheel temperature measurements on Axle 1 of each of the four cars plus an additional measurement on Axle 7 of the Atlas railcar. The wheel temperature was measured by embedding a brass plug attached to a thermocouple inside the brake shoes on these wheels. The axle rotation was measured using a reflective sensor together with a sticker with 20 evenly spaced reflective surfaces wrapped around the axle. The data from the reflective sensor was processed to calculate axle speed for all axles of IDOX 20002, 10001, and 30001 and axle 1 of 20001. These axle speeds were compared to the global positioning system (GPS) speed to measure wheel slip.

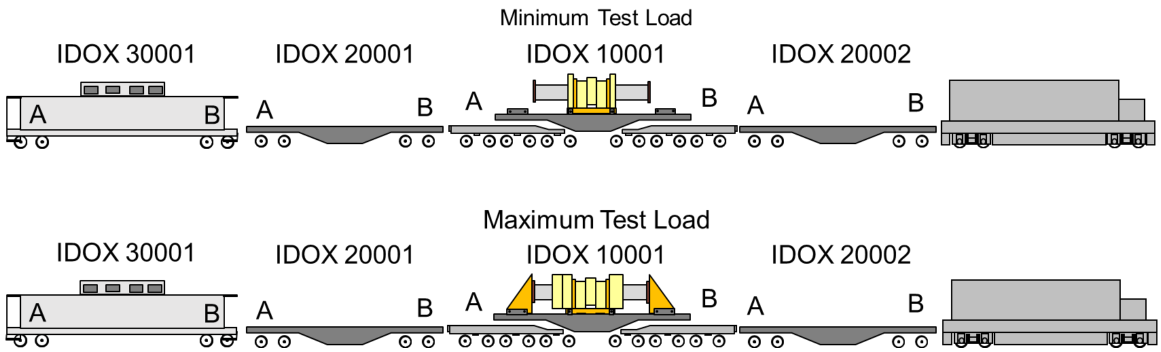

Figure 10. Minimum and maximum load train configurations for the stop distance tests

The area between station markers T30 and T34 clockwise (CW) on the Transit Test Track (TTT) was set as the test zone. This section of track is level tangent. For the 70-mph runs, the train generally passed through the level tangent section onto track that has a 0.69 percent uphill grade. These runs were repeated in the counterclockwise (CCW) direction to measure the effect of the grade. The Test Implementation Plan (Appendix A) assumed the test would be performed on a steady grade; however, the tests were performed on level track because it was determined a level track would allow easier control of the test conditions. During testing, the stop distances were calculated by integrating the speed signal from the time when the trainline pressure dropped 2 psi from nominal to the stop.

Jerk is defined as the rate of change of deceleration and is reported here in units of mph/sec^2. One of the vertical accelerometers on each car was repositioned to measure longitudinal acceleration for these tests. To calculate jerk, the measured acceleration was differentiated with respect to time. To eliminate spikes, the data was filtered at 1 Hz using a 4-pole Butterworth filter at each step. The results changed significantly based on the filter rate and the type of filter used. The 1-Hz filter rate was chosen because it produced an acceleration trace that had characteristics similar to the data that MxV Rail had processed previously for passenger trains. The Butterworth filter was chosen because it produced less ringing than other filter types. Figure 11 shows an example of how the jerk rate was calculated, highlighting the section where either the full-service or the emergency brakes were applied (between the red lines). The example shows the slope of the acceleration was determined by applying a linear regression through the data within this region to determine the linear jerk rate. This steady slope is difficult to see in the jerk rate data. The peak jerk values were a characteristic of shorter wavelength changes in the acceleration data rather than the longer, steadier change in acceleration as the brakes were applied. There is a jump in the data at the very end of the run when the train stops, but this was ignored for the determination of the maximum jerk rate.

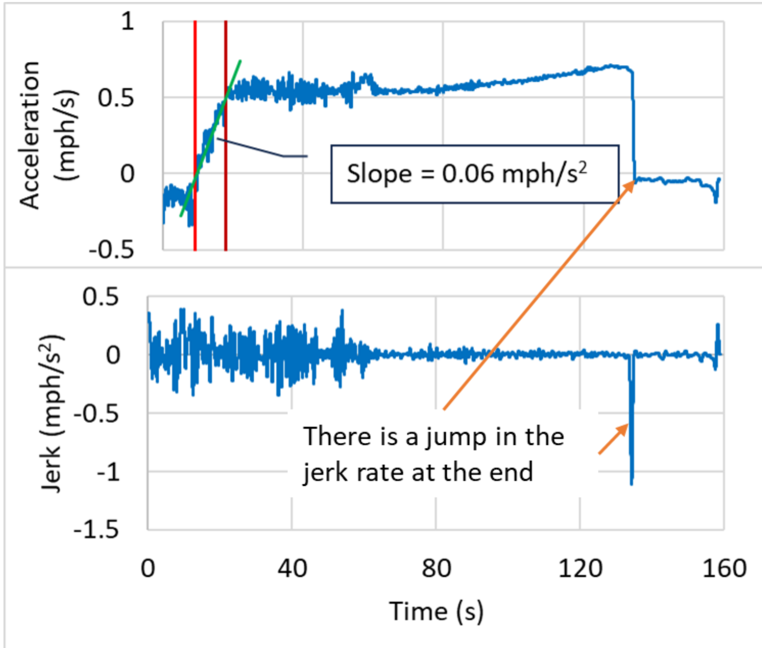

Figure 11. Example of jerk rate calculation

MxV Rail has reported the jerk rate and the difference in jerk rate between coupled cars as indicated in Standard S-2043, paragraph 4.4.2. It is clear that the jerk rate could affect passenger comfort as a large jerk could cause a passenger to lose their balance. It is not clear how the jerk rate would affect a non-passenger carrying rail car or its lading. Furthermore, it is not clear how the match of jerk from car to car would affect either the passenger carrying or non-passenger carrying railcar.

Table 9 shows data from minimum test load stop distance tests. Although no criterion is given in S-2043 for this measurement, the stop distances are reported as required by S-2043. As expected, stop distances from the minimum test load wet rail tests were generally somewhat longer than stop distances from the dry rail tests. Figure 12 shows a plot of minimum test load stop distances versus speed for wet and dry rail.

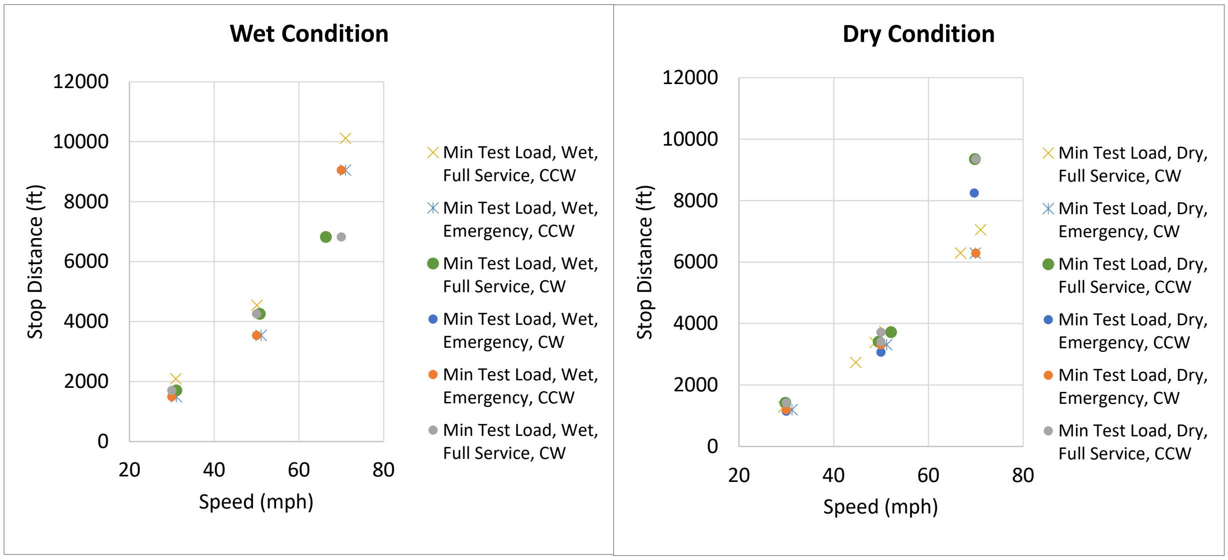

Figure 12. Plots of minimum load train stop distance versus speed

The wheel tread temperatures are reported as required by S-2043, although no criterion is given for this measurement. The test plan (Appendix A) set a maximum limit of 700° F for wheel tread temperature to prevent damage to the wheels. Wheel tread temperature exceeded 700° F on nine of the 34 test runs. The maximum temperature measured was 846° F on the Atlas railcar, and the temperature remained above 700° F for 55 seconds. The wheels were inspected following the test and no bluing or other damage was noted.

The wheel slip data met the S-2043 criterion of 15 percent with the exception of the 50-mph, full-service braking, CCW, wet condition run with a wheel slip percentage of 64.3 percent measured on the Atlas railcar. Figure 13 shows the time history speed and wheel slip plots for this exceedance. On behalf of the DOE, MxV Rail requests an exception from the AAR EEC to approve the Atlas train because the wheel slip occurred on only one of the six minimum test load, emergency application, wet rail runs.

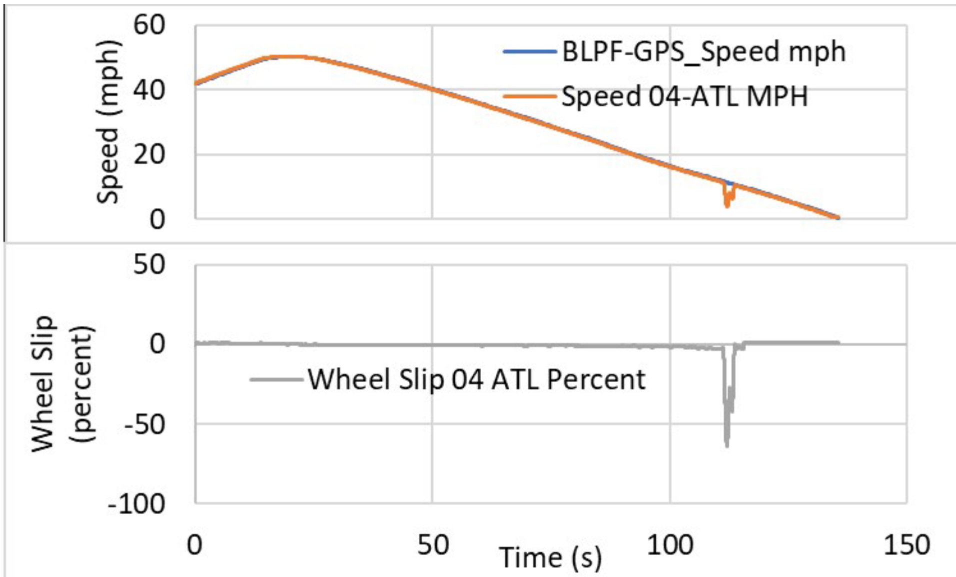

Figure 13. Atlas railcar wheel slip, 50 mph, full-service brake, CCW, wet condition

The train met the Standard S-2043 jerk criterion of 1.9 mph/sec^2 for service braking runs and the Standard S-2043 jerk criterion of 2.5 mph/sec^2 for the emergency braking runs. Standard S-2043 requires that the jerk from car-to-car shall match to within 0.5 mph/sec^2. The jerk rate column in Table 9 is highlighted for two cases where the car-to-car jerk match did not meet the maximum 0.5 mph/sec^2 limit. On behalf of the DOE, MxV Rail requests an exception from the AAR EEC to approve the Atlas train because it is unclear how the exception to the jerk rate car-to-car match criteria will affect train operations or safety.

Table 9. Minimum test load stop distance results

Run Name (year-month-day-time)	Speed (mph)	Brake Appl.	Direction	Wet/ Dry	Stop Dist. (ft)	Max. Wheel Tread Temp (°F)				Max. Slip (percent, S-2043 limit 15%)				Jerk Rate (mph/s^2) (1.9 full, 2.5 Emer.)			
						BC1	Atl	BC2	Rev	BC1	Atl	BC2	Rev	BC1	Atl	BC2	Rev
2022_06_02_154418	30.0	Emerg.	CCW	Dry	1,148	334	438	381	316	4.6%	4.4%	4.4%	4.7%				
2022_06_02_155408	50.0	Emerg.	CCW	Dry	3,065	416	710	680	352	5.3%	5.1%	5.0%	5.3%				
2022_06_02_160747	69.7	Emerg.	CCW	Dry	8,246	617	761	705	526	4.5%	4.3%	4.1%	4.4%				
2022_06_13_124212	30.8	Emerg.	CCW	Dry	1,353	434	193	261	95	4.7%	4.5%	4.6%	4.7%	1.0	0.6	0.4	0.5
2022_06_13_130210	48.8	Emerg.	CCW	Dry	3,285	593	486	562	99	3.5%	6.8%	3.2%	3.5%	0.6	0.7	0.8	0.7
2022_06_13_134015	71.0	Emerg.	CCW	Dry	8,182	735	609	682	588	5.0%	4.9%	4.6%	5.2%	0.3	0.6	0.6	1.2
2022_06_02_134106	31.2	Emerg.	CW	Dry	1,194	423	378	345	418	6.4%	6.2%	5.6%	6.4%				
2022_06_02_135550	51.2	Emerg.	CW	Dry	3,309	485	616	427	489	4.3%	4.2%	4.2%	4.4%				
2022_06_02_141311	69.9	Emerg.	CW	Dry	6,289	553	631	581	596	4.4%	4.5%	4.3%	4.5%				
2022_06_06_141428	31.1	Emerg.	CCW	Wet	1,491	206	162	213	205	3.5%	8.6%	3.3%	13.4%				
2022_06_06_142334	51.1	Emerg.	CCW	Wet	3,535	309	173	362	306	4.5%	4.4%	4.4%	4.7%				
2022_06_13_142004	71.0	Emerg.	CCW	Wet	9,050	812	846	787	466	4.3%	3.8%	3.8%	4.2%	0.2	0.4	0.5	0.6
2022_06_13_155923	31.9	Emerg.	CW	Wet	1,474	320	228	233	432	4.7%	4.6%	4.5%	5.1%	0.3	0.3	0.4	0.4
2022_06_13_161137	51.0	Emerg.	CW	Wet	3,564	639	535	201	503	4.5%	4.3%	4.1%	4.6%	0.5	0.4	0.3	0.5
2022_06_13_162433	67.2	Emerg.	CW	Wet	5,784	717	539	443	612	5.2%	5.2%	5.0%	5.1%	0.4	0.6	0.5	0.6
2022_06_16_093847	70.1	Emerg.	CW	Wet	6,065	611	638	538	553	5.8%	5.6%	5.4%	5.7%	0.4	1.0	0.7	0.8
2022_06_02_145657	29.8	Full Srv.	CCW	Dry	1,422	473	436	438	312	3.7%	3.4%	3.2%	3.4%				
2022_06_02_150443	52.1	Full Srv.	CCW	Dry	3,717	679	682	526	393	4.3%	4.3%	4.1%	4.3%				
2022_06_02_151455	49.5	Full Srv.	CCW	Dry	3,407	491	650	562	496	4.3%	4.2%	4.0%	4.3%				
2022_06_02_152739	69.8	Full Srv.	CCW	Dry	9,351	689	733	716	670	3.2%	3.1%	2.9%	3.2%				
2022_06_13_135629	71.6	Full Srv.	CCW	Dry	10,536	683	702	750	580	3.2%	3.2%	3.0%	3.5%	0.8	0.8	0.7	0.9
2022_06_02_111016	29.5	Full Srv.	CW	Dry	1,284	331	196	214	176	4.0%	4.1%	4.1%	4.3%				
2022_06_02_111839	44.7	Full Srv.	CW	Dry	2,732	427	254	241	214	3.9%	3.9%	3.8%	3.9%				
2022_06_02_112738	48.8	Full Srv.	CW	Dry	3,385	440	288	287	305	4.1%	3.9%	3.7%	4.2%				
2022_06_02_113815	50.8	Full Srv.	CW	Dry	3,745	465	321	310	396	4.2%	4.2%	4.2%	4.6%				
2022_06_02_131442	66.8	Full Srv.	CW	Dry	6,294	555	457	330	383	4.9%	5.0%	4.8%	4.9%				
2022_06_02_133017	71.0	Full Srv.	CW	Dry	7,052	594	525	412	460	4.0%	4.0%	4.0%	4.0%				
2022_06_06_131904	31.0	Full Srv.	CCW	Wet	2,084	142	139	161	138	3.3%	3.3%	3.2%	3.3%				
2022_06_06_133053	50.1	Full Srv.	CCW	Wet	4,541	346	138	220	153	3.7%	63.4%	3.2%	3.4%				
2022_06_06_135820	71.0	Full Srv.	CCW	Wet	10,108	692	585	582	442	3.9%	3.9%	4.0%	4.1%				
2022_06_13_152700	31.1	Full Srv.	CW	Wet	1,698	277	363	229	343	3.6%	3.5%	3.3%	3.6%	0.3	0.3	0.3	0.3
2022_06_13_153604	50.8	Full Srv.	CW	Wet	4,256	364	496	210	226	3.9%	3.8%	4.0%	4.1%	0.3	0.5	0.4	0.6
2022_06_13_154929	66.4	Full Srv.	CW	Wet	6,819	766	670	317	373	4.4%	4.3%	4.1%	4.2%	0.3	0.5	0.5	0.4
2022_06_16_092108	69.8	Full Srv.	CW	Wet	6,975	754	577	319	383	4.4%	4.4%	4.1%	4.5%	0.5	0.5	0.5	0.7

Table 10 shows data from maximum-loaded train stop distance tests. Although no criterion is given for this measurement, the stop distances are reported as required by S-2043. For the maximum-loaded tests, the stop distances for dry and wet rail tests were very similar. Figure 14 shows a plot of stop distances with maximum test load versus speed.

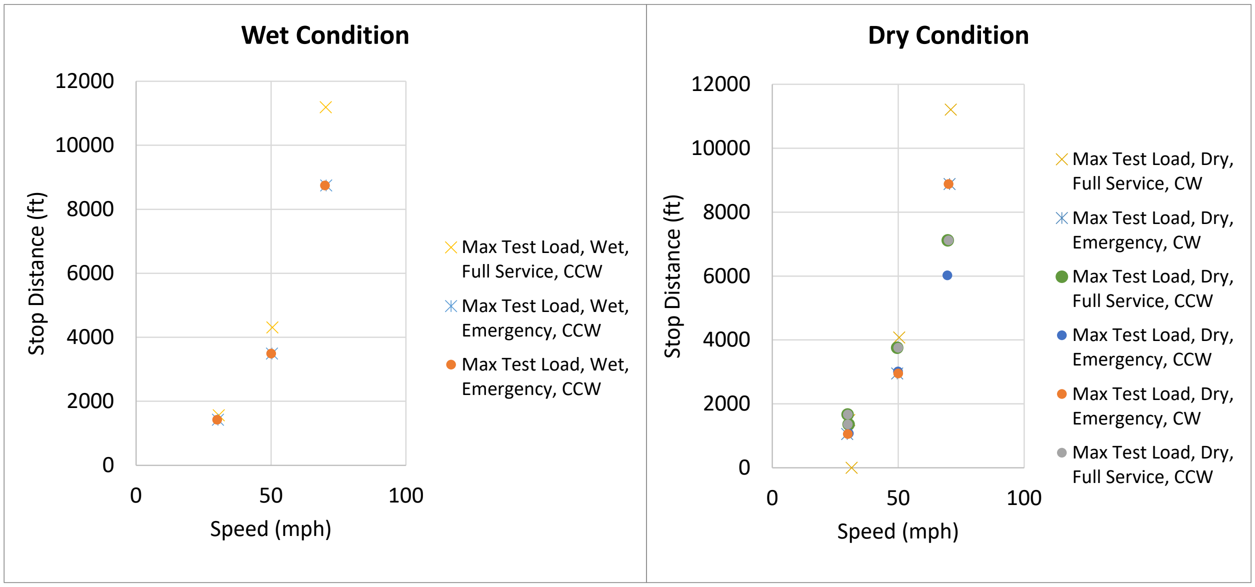

Figure 14. Plots of maximum test load train stop distance versus speed

The wheel tread temperatures are reported as required by Standard S-2043, although no criterion is given for this measurement. The test plan (Appendix A) set a maximum limit of 700° F for wheel tread temperature to prevent damage to the wheels. Wheel tread temperature exceeded 700° F on nine of the 26 test runs. The maximum temperature measured was 823° F on the leading buffer railcar, and the temperature remained above 700° F for 39 seconds. The wheels were inspected following the test, and no bluing or other damage was noted. The wheel slip data met the Standard S-2043 criterion of 15 percent.

The maximum loaded train met the Standard S-2043 jerk criterion of 1.9 mph/sec^2 for service braking runs and 2.5 mph/sec^2 for emergency braking runs. Standard S-2043 requires that the jerk shall match to within 0.5 mph/sec^2 from car to car. The jerk rate column in Table 10 is highlighted for the seven cases where the car-to-car jerk did not meet the maximum 0.5 mph/sec^2 limit. On behalf of the DOE, MxV Rail requests an exception from the AAR EEC to approve the Atlas train because it is unclear how the exception to the jerk rate car-to-car match criteria will affect train operations or safety.

Table 10. Maximum test load stop distance results

Run Name (year-month-day-time)	Speed (mph)	Brake Appl.	Direction	Wet/ Dry	Stop Dist. (ft)	Max. Wheel Tread Temp (°F)				Max. Slip (percent,S-2043 limit 15%)				Jerk Rate (mph/s^2) (1.9 full, 2.5 Emer.)			
						BC1	Atl	BC2	Rev	BC1	Atl	BC2	Rev	BC1	Atl	BC2	Rev
2022_07_07_122845	29.7	Emerg.	CCW	Dry	1,058	377	373	518	365	4.5%	4.4%	4.3%	4.5%	0.8	0.5	1.1	1.6
2022_07_07_123751	49.6	Emerg.	CCW	Dry	2,950	823	762	722	558	5.2%	5.2%	5.2%	5.5%	0.9	0.5	0.8	0.6
2022_07_07_125109	70.4	Emerg.	CCW	Dry	8,880	807	722	737	634	4.2%	4.1%	3.9%	4.2%	0.6	0.4	0.6	0.5
2022_07_08_121445	30.4	Emerg.	CW	Dry	1,080	457	641	457	320	4.9%	5.1%	5.1%	5.2%	0.3	0.5	0.5	0.5
2022_07_08_122513	49.9	Emerg.	CW	Dry	3,017	778	677	629	520	4.8%	4.8%	4.6%	5.1%	1.4	0.9	0.4	0.5
2022_07_08_123933	69.5	Emerg.	CW	Dry	6,025	806	660	629	628	4.9%	4.8%	4.6%	5.0%	0.4	1.2	0.4	0.8
2022_07_07_154637	30.3	Emerg.	CCW	Wet	1,427	158	176	252	172	9.3%	5.1%	4.8%	5.4%	0.5	0.3	0.7	0.9
2022_07_07_155452	50.3	Emerg.	CCW	Wet	3,493	455	182	173	274	6.8%	5.2%	5.0%	5.4%	0.5	0.6	0.6	0.8
2022_07_07_160814	70.4	Emerg.	CCW	Wet	8,747	644	540	562	641	5.0%	4.5%	4.4%	5.0%	0.5	0.3	0.6	0.7
2022_07_08_143935	30.2	Emerg.	CW	Wet	1,139	233	338	172	262	5.7%	5.9%	7.6%	11.5%	0.3	0.3	0.3	0.3
2022_07_08_143034	49.9	Emerg.	CW	Wet	3,181	588	519	228	604	5.0%	5.0%	4.7%	5.3%	0.3	0.3	0.5	0.5
2022_07_08_141904	69.3	Emerg.	CW	Wet	6,091	716	471	449	546	5.9%	5.9%	5.5%	6.0%	0.3	0.9	0.4	0.6
2022_07_07_110600	31.5	Full Srv.	CCW	Dry	0	303	173	205	172	2.7%	2.8%	2.6%	2.9%	0.7	0.5	0.5	0.7
2022_07_07_112002	30.5	Full Srv.	CCW	Dry	1,494	448	179	271	194	4.2%	4.1%	4.0%	8.9%	0.8	0.8	1.1	1.3
2022_07_07_115042	50.4	Full Srv.	CCW	Dry	4,077	641	500	431	361	3.9%	3.9%	3.8%	4.1%	1.3	1.0	1.1	0.9
2022_07_07_120533	70.9	Full Srv.	CCW	Dry	11,210	728	733	663	590	3.6%	3.3%	3.3%	3.8%	0.8	0.5	0.8	0.8
2022_07_08_102349	29.9	Full Srv.	CW	Dry	1,669	164	314	158	306	3.7%	3.5%	3.5%	4.1%	0.3	0.3	0.3	0.4
2022_07_08_110947	30.3	Full Srv.	CW	Dry	1,363	384	412	327	150	4.2%	3.9%	4.0%	4.0%	0.2	0.2	0.3	0.3
2022_07_08_112440	49.6	Full Srv.	CW	Dry	3,757	615	581	277	307	4.9%	4.8%	4.7%	5.1%	0.2	0.4	0.3	0.6
2022_07_08_115659	69.7	Full Srv.	CW	Dry	7,118	703	691	713	624	4.8%	4.4%	4.1%	4.3%	0.3	1.0	0.5	0.6
2022_07_07_130808	30.6	Full Srv.	CCW	Wet	1,564	282	348	323	330	3.9%	3.8%	3.7%	3.9%	0.6	0.9	0.6	0.5
2022_07_07_132547	50.5	Full Srv.	CCW	Wet	4,309	570	247	277	552	4.3%	3.9%	4.2%	4.2%	0.7	0.8	0.7	0.8
2022_07_07_134208	70.3	Full Srv.	CCW	Wet	11,189	822	660	402	627	4.7%	4.2%	4.3%	4.6%	0.7	0.6	0.5	0.5
2022_07_08_125817	30.4	Full Srv.	CW	Wet	1,678	315	279	330	222	3.8%	3.8%	4.1%	3.9%	0.3	0.3	0.3	0.3
2022_07_08_130740	50	Full Srv.	CW	Wet	4,262	599	314	212	223	4.1%	3.9%	3.6%	4.1%	0.3	0.5	0.3	0.4
2022_07_08_132158	69.7	Full Srv.	CW	Wet	7,391	728	590	220	446	4.9%	4.9%	4.5%	5.0%	0.4	1.5	0.5	0.8

6.1.2 Braking in Curves

The braking in curves test was performed according to the requirements of Standard S-2043, paragraph 6.1.1.2 to verify that the braking system does not adversely affect truck steering. The test results met all applicable Standard S-2043 criteria, demonstrating that brake forces did not cause adjacent axles to become significantly misaligned. Per Standard S-2043 requirements, the test was performed May 31 and June 1, 2022, and observed by Matt DeGeorge, MxV Rail Senior Engineer II.

The test was performed on dry rails with the Atlas railcar in its minimum test load condition (Figure 15), which produced the highest L/V ratios in the single-car constant curving test. This test was performed with the same onboard instrumentation as the stop distance testing with the addition of wayside instrumentation to measure the wheel/rail forces and the axle angle of attack (AOA). Instrumented wheelsets were not used, instead strain gages on the rails were monitored from wayside to measure vertical and lateral forces. An optical measurement system was installed to measure AOA.

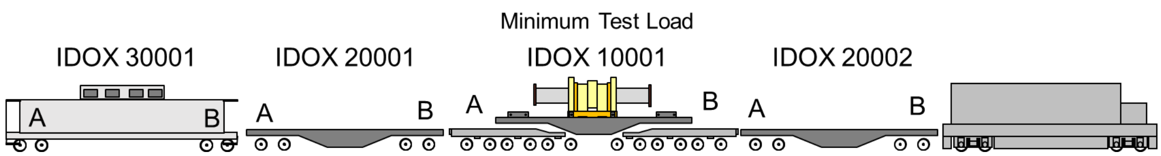

Figure 15. Train configured for the braking in curves test

The test train was operated through the 7.5-degree curve on the Wheel/Rail Mechanisms Loop (WRM) loop starting at 32 mph (maximum allowable speed for this track section, see the test plan, Appendix A, Section 4.2.3, for more information). A full-service brake application was made before the leading car entered the spiral, and test measurement data was collected until the train stopped. The test was repeated at various speeds between 12 and 32 mph and with the brakes applied at different positions throughout the curve. Test runs were made in both the CW and CCW directions around the WRM loop and with both the A- and B-end of each car leading for a total of 36 total runs.

Table 11 through Table 14 summarize the worst-case results from the braking in curves test of the Atlas railcar, the leading Buffer car (IDOX 20002), the trailing Buffer car (IDOX 20001), and the REV (IDOX 30001), respectively. Each car met all Standard S-2043 requirements. In general, all the measured axle AOA results were well below the Standard S-2043 limits, indicating good steering performance despite braking loads.

Table 11. Atlas railcar braking in curves results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.2	0.2	0.2	0.2
Maximum wheel L/V ratio	0.8	0.12	0.18	0.09	0.12
Maximum truck side L/V ratio	0.5	0.08	0.13	0.06	0.08
Minimum vertical wheel load	25 (% of static)	66%	69%	63%	69%
Lateral peak-to-peak acceleration	1.3 (g)	0.10	0.14	0.13	0.11
Maximum lateral acceleration	0.75 (g)	0.08	-0.12	0.15	0.12
Lateral acceleration standard deviation	0.13 (g)	0.03	0.03	0.03	0.03
Maximum vertical acceleration	0.90 (g)	0.20	-0.15	-0.15	-0.15
Maximum vertical suspension deflection	95 (%)	18%	18%	21%	16%
Axle Angle of Attack (AoA)	12.5 (mrad)	8.3	2.5	1.1	1.4

Table 12. Buffer car (IDOX 20002) braking in curves results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.3	0.3	0.3	0.3
Maximum wheel L/V ratio	0.8	0.15	0.18	0.09	0.12
Maximum truck side L/V ratio	0.5	0.08	0.13	0.05	0.07
Minimum vertical wheel load	25 (% of static)	83%	83%	89%	85%
Lateral peak-to-peak acceleration	1.3 (g)	0.14	0.18	0.21	0.17
Maximum lateral acceleration	0.75 (g)	-0.09	-0.12	0.15	0.11
Lateral acceleration standard deviation	0.13 (g)	0.03	0.02	0.04	0.03
Maximum vertical acceleration	0.90 (g)	0.29	-0.28	0.20	-0.21
Maximum vertical suspension deflection	95 (%)	28%	31%	45%	23%
Axle Angle of Attack (AoA)	12.5 (mrad)	12.3	3.1	2.0	1.5

Table 13. Buffer car (IDOX 20001) braking in curves results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.3	0.2	0.3	0.3
Maximum wheel L/V ratio	0.8	0.23	0.18	0.08	0.11
Maximum truck side L/V ratio	0.5	0.13	0.11	0.04	0.07
Minimum vertical wheel load	25 (% of static)	84%	80%	86%	82%
Lateral peak-to-peak acceleration	1.3 (g)	0.27	0.23	0.24	0.20
Maximum lateral acceleration	0.75 (g)	-0.17	-0.16	0.17	0.14
Lateral acceleration standard deviation	0.13 (g)	0.03	0.03	0.03	0.04
Maximum vertical acceleration	0.90 (g)	-0.20	0.72	-0.19	-0.20
Maximum vertical suspension deflection	95 (%)	38%	40%	51%	30%
Axle Angle of Attack (AoA)	12.5 (mrad)	11.0	2.5	1.3	1.5

Table 14. REV braking in curves results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.3	0.2	0.4	0.2
Maximum wheel L/V ratio	0.8	0.16	0.24	0.10	0.14
Maximum truck side L/V ratio	0.5	0.11	0.13	0.06	0.07
Minimum vertical wheel load	25 (% of static)	65%	76%	78%	79%
Lateral peak-to-peak acceleration	0.60 (g)	0.21	0.48	0.32	0.18
Maximum lateral acceleration	0. 35 (g)	-0.13	-0.28	-0.23	0.12
Lateral acceleration standard deviation	0.13 (g)	0.03	0.03	0.03	0.03
Maximum vertical acceleration	0. 60 (g)	-0.36	-0.40	0.33	-0.36
Maximum vertical suspension deflection	95 (%)	27%	29%	35%	25%
Axle Angle of Attack (AoA)	12.5 (mrad)	10.8	4.0	2.0	6.5

6.2 Hand Brake Test

MxV Rail conducted the hand brake test according to the requirements of Standard S-2043, paragraph 6.1.2. Standard S-2043 does not specify limiting criteria for this test. However, the test results can be used to determine the number of cars that must have the hand brakes set to hold a train on a grade. The results show that, with hand brakes set on all cars, the train should not move by itself on a 2.8-percent grade. The test was performed July 12, 2022, and observed by Steven Belport, MxV Rail Principal Investigator II, per Standard S-2043 requirements.

The torque applied to the hand brakes varied by car due to the difference in equipment and equipment location. A member of the test team first applied the hand brakes by hand, and then measured the amount of torque at which the mechanism would just begin to move after the application of a torque wrench. The measured torque was 135 foot-pounds for each of the Buffer cars, 120 foot-pounds for the REV, 105 foot-pounds on each end of the Atlas railcar for the first application, and 100 foot-pounds on each end of the Atlas railcar for the second application.

An instrumented coupler was installed between the REV, and a hopper car was coupled to the locomotive (Figure 16). The force required to move the train was recorded for various hand brake application scenarios, starting with setting all hand brakes and ending with setting only the leading car hand brake. The grade-holding capability was calculated for each hand brake configuration. The test was performed with Atlas railcar loaded with the maximum test load. Table 15 shows a summary of hand brake test results.

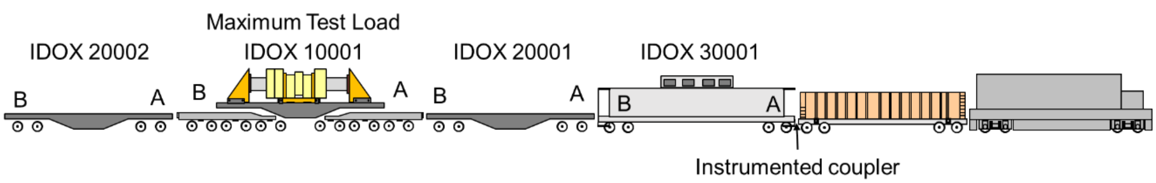

Figure 16. Train configured for the hand brake test

Table 15. Hand brake test results

Run	IDOX 20002	Atlas B-end	Atlas A-end	IDOX 20001	REV	Adjusted Coupler Force (kips)	Percent Grade Holding Capacity
1	Released	Released	Released	Released	Released	1.96	
2	Set	Set	Set	Set	Set	41.14	2.8%
3	Set	Set	Set	Set	Released	35.69	2.4%
4	Set	Set	Set	Released	Released	29.11	1.9%
5	Set	Set	Released	Released	Released	19.93	1.3%
6	Set	Released	Released	Released	Released	8.92	0.5%
7	Released	Set	Set	Released	Released	22.84	1.5%

The test was conducted on the level tangent section of the TTT between markers T30 and T33.9. A locomotive only has eight discrete throttle positions thereby making it impossible to match traction force to braking force precisely. Therefore, it is necessary to account for the acceleration of the train after it begins to move. Longitudinal accelerometers mounted on each car of the train were used to account for small accelerations or decelerations of the train by summing the acceleration of each car, measured in g's multiplied, and the weight of the car. The summed acceleration force was subtracted from the measured coupler force for each run. To measure the rolling resistance of the train, the first test was conducted with no hand brakes applied, and the train rolling resistance was subtracted from the measured force. Figure 17 shows the coupler force, the coupler force adjusted for acceleration, and the average coupler force calculated in the top graph. The bottom graph of Figure 17 shows a tachometer signal from each car, and when the tachometer signal moves from 0 to 4.3 volts or from 4.3 volts to 0 volts, it indicates the cars are moving.

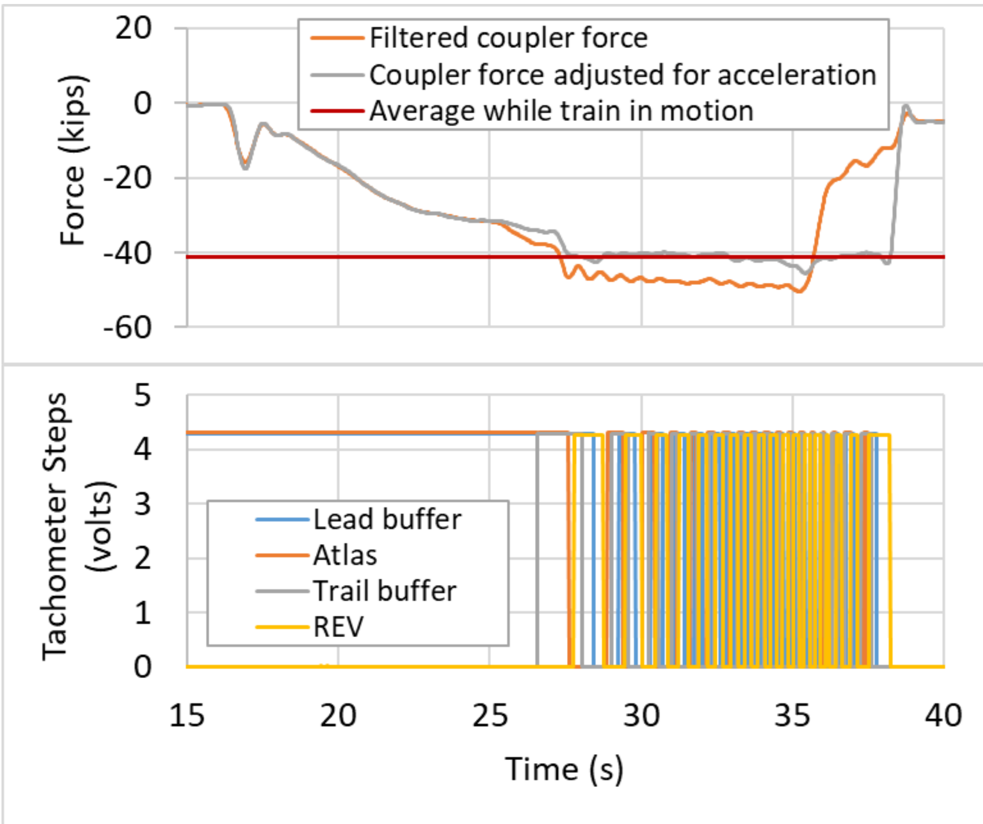

Figure 17. Time history of coupler force, coupler force adjusted for acceleration, and the tachometer pulses for the four Atlas train cars

6.3 Buff and Draft Curving

The buff and draft curving test was performed per Standard S-2043, paragraph 6.1.3 and the procedures of the test plan (Appendix A). Tests were performed through the 12-degree curve in both the CW and CCW directions with both the A-end and the B-end of the Atlas railcar leading. The Atlas railcar was loaded with the minimum test load. Buff and draft loads of approximately 50, 100, 150, 200, and 250 kips were created on the consist by coupling the train between two to four locomotives on one end and up to 35 braking cars on the other end. The force was changed by adjusting the brake setting and by adding 125-ton loaded hopper braking cars to the consist or removing them from the consist as needed. During the test runs, the buff and draft loads were sometimes controlled at the expense of controlling the test speed. The test speeds ranged from 9 to 18 mph. Twenty test runs were performed under buff loads, and 20 test runs were performed under draft loads. Table 16 lists the AAR observer and the rail coefficient of friction measured on each day of testing. The data for each car under test are summarized in Sections 6.3.1 to 6.3.4.

Table 16. Buff and draft curving official observers and rail friction measurements

Date	Observer	Rail coefficient of friction		
		Low rail	High rail	Gage face
June 8, 2022	Matt DeGeorge, Senior Engineer II	0.55	0.45	0.48
June 9, 2022	Matt DeGeorge, Senior Engineer II	0.53	0.48	0.49
June 10, 2022	Jon Hannafious, Director Technical Standards & EEC Manager	0.40	0.48	0.46
June 14, 2022	Daniel Gutscher, Mgr. Coupling Systems and Castings	0.57	0.52	0.51
June 15, 2022	Adam Klopp, Principal Investigator II	0.54	0.49	0.50

6.3.1 Atlas Car

Table 17 summarizes the worst-case values measured on the Atlas railcar during all buff curving test runs compared to the limiting criteria of S-2043. The Atlas railcar met S-2043 criteria for buff curving runs.

Table 17. Atlas railcar buff curving results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.1	0.1	0.1	0.1
Maximum wheel L/V ratio	0.8	0.40	0.31	0.31	0.33
Maximum truck side L/V ratio	0.5	0.34	0.29	0.28	0.32
Minimum vertical wheel load	25 (% of static)	53%	53%	54%	53%
Lateral peak-to-peak acceleration	1.3 (g)	0.15	0.15	0.10	0.11
Maximum lateral acceleration	0.75 (g)	0.12	-0.15	0.09	0.15
Lateral acceleration standard deviation	0.13 (g)	0.03	0.04	0.04	NC
Maximum vertical acceleration	0.90 (g)	0.18	-0.15	0.10	-0.11
Maximum vertical suspension deflection	95 (%)	39%	29%	30%	31%

* NC means Not Calculated because the length of this run was less that the 2000-foot distance of the lateral acceleration standard deviation calculation

Table 18 summarizes the worst-case values measured on the Atlas railcar during all draft curving test runs compared to the limiting criteria of S-2043. The Atlas railcar met S-2043 criteria for draft curving runs.

Table 18. Atlas Car Draft Curving Results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.1	0.1	0.1	0.1
Maximum wheel L/V ratio	0.8	0.50	0.46	0.40	0.40
Maximum truck side L/V ratio	0.5	0.42	0.42	0.35	0.38
Minimum vertical wheel load	25 (% of static)	45%	36%	43%	43%
Lateral peak-to-peak acceleration	1.3 (g)	0.15	0.11	0.17	0.15
Maximum lateral acceleration	0.75 (g)	0.15	-0.11	0.10	0.13
Lateral acceleration standard deviation	0.13 (g)	0.03	0.04	0.03	0.06
Maximum vertical acceleration	0.90 (g)	-0.24	-0.36	0.14	0.14
Maximum vertical suspension deflection	95 (%)	27%	46%	24%	30%

6.3.2 Leading Buffer Car

Table 19 summarizes the worst-case values measured on the leading Buffer car during all buff curving test runs compared to the limiting criteria of S-2043. The leading Buffer car met S-2043 criteria for buff curving runs.

Table 19. Leading Buffer car buff curving results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.2	0.2	0.2	0.2
Maximum wheel L/V ratio	0.8	0.34	0.16	0.23	0.14
Maximum truck side L/V ratio	0.5	0.23	0.12	0.16	0.13
Minimum vertical wheel load	25 (% of static)	87%	83%	85%	86%
Lateral peak-to-peak acceleration	1.3 (g)	0.33	0.11	0.10	0.16
Maximum lateral acceleration	0.75 (g)	0.33	-0.15	-0.12	-0.14
Lateral acceleration standard deviation	0.13 (g)	0.03	0.03	0.04	NC
Maximum vertical acceleration	0.90 (g)	0.66	0.43	-0.29	0.46
Maximum vertical suspension deflection	95 (%)	63%	47%	45%	54%

* NC means Not Calculated because the length of this run was less that the 2000-foot distance of the lateral acceleration standard deviation calculation

Table 20 summarizes the worst-case values measured on the leading Buffer car during all draft curving test runs compared to the limiting criteria of S-2043. While testing with the A-end leading CW through the 12-degree curve, the car did not meet the maximum vertical acceleration criteria during a single test run with an average draft force of 298 kips (11.9 mph). In this instance, the leading Buffer car's lateral and vertical acceleration data show discrete, short duration spikes near the entry and exit of the 12-degree curve. These spikes are not representative of the carbody's actual movement or dynamic behavior but rather a high frequency mechanical shock that rippled past the carbody accelerometers, as shown in Figure 18. The leading Buffer car met all other S-2043 criteria for draft curving runs.

The short duration lateral and vertical acceleration spikes occurred sporadically and with varying amplitude throughout the buff and draft curving test regimen. Out of 40 total datasets (buff curving and draft curving combined), the spikes caused only one vertical acceleration exception to the limiting criteria of S-2043. Among the distribution of all maximum lateral and vertical accelerations, this exception is considered an outlier. Within the complete dataset, there were three additional lateral acceleration outliers and one additional vertical acceleration outlier that did not cause exceptions to the limiting criteria. The average maximum lateral and vertical carbody accelerations were 0.13 g and 0.25 g, respectively.

At various times throughout testing, brief popping sounds were heard emanating from between the Atlas railcar and the two Buffer cars while entering or exiting the 12-degree curve. MxV Rail believes that components within the draft systems of the Buffer cars may have produced the popping noise and the resulting mechanical shockwave that briefly spiked the nearby carbody accelerometers, causing the maximum vertical acceleration exception. The moving draft system components may have become briefly bound by friction under large buff or draft forces and then rapidly freed when the couplers rotated while navigating the test curve. This binding and releasing of energy likely caused localized mechanical shocks that produced the popping sounds and acceleration spikes. On behalf of the DOE, MxV Rail requests an exception from the AAR EEC to approve the Atlas train because the exception to the carbody acceleration criteria was extremely short in duration and is not considered indicative of the gross motions of the carbody.

On behalf of the DOE, MxV Rail requests an exception from the AAR EEC to approve the Atlas train because the exception to the carbody acceleration criteria was extremely short in duration and is not considered indicative of the gross motions of the carbody.

Table 20. Leading Buffer car draft curving results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.2	0.2	0.2	0.2
Maximum wheel L/V ratio	0.8	0.46	0.44	0.40	0.44
Maximum truck side L/V ratio	0.5	0.41	0.43	0.35	0.40
Minimum vertical wheel load	25 (% of static)	61%	55%	59%	55%
Lateral peak-to-peak acceleration	1.3 (g)	0.13	0.17	0.17	0.87
Maximum lateral acceleration	0.75 (g)	0.14	0.13	-0.18	0.75
Lateral acceleration standard deviation	0.13 (g)	0.03	0.04	0.03	0.05
Maximum vertical acceleration	0.90 (g)	-0.33	0.50	-0.30	0.94
Maximum vertical suspension deflection	95 (%)	92%	89%	79%	92%

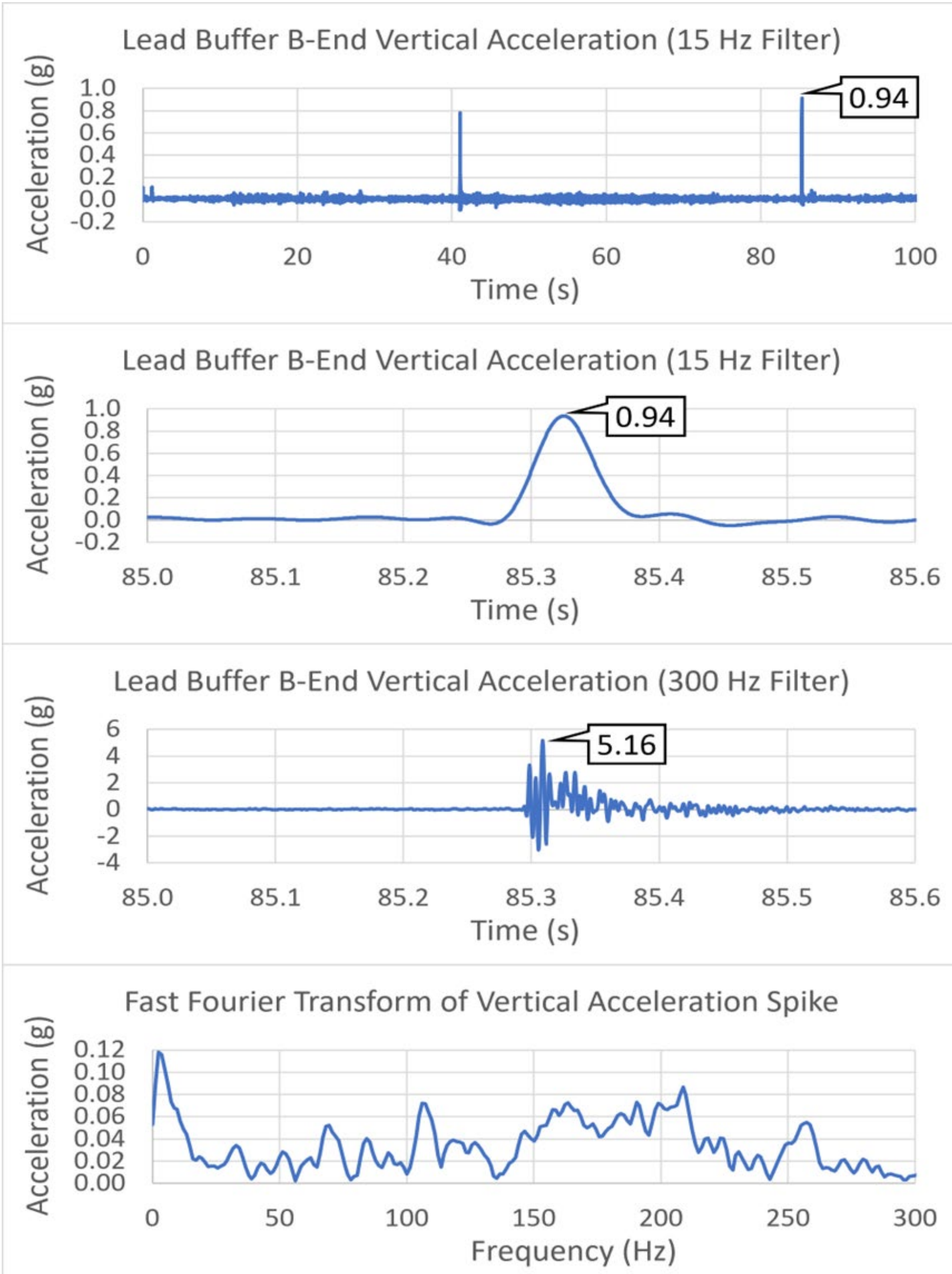

Figure 18. Leading Buffer car (IDOX 20002) vertical acceleration exception

6.3.3 Trailing Buffer Car

Table 21 summarizes the worst-case values measured on the trailing Buffer car during all buff curving test runs compared to the limiting criteria of S-2043. While testing with the A-end leading CW through the 12-degree curve, the car did not meet the maximum lateral acceleration criterion during a single test run with an average buff force of 260 kips (12.5 mph). The trailing Buffer car met all other S-2043 criteria for buff curving runs.

The maximum lateral acceleration exception was a single spike in the acceleration data within the 12-degree curve. This event is not representative of the trailing Buffer car's gross motion. The single exception is shown in Figure 19, and this exception is of the same nature as the acceleration spikes described in Section 6.3.2 for the leading Buffer car exceptions. On behalf of the DOE, MxV Rail requests an exception from the AAR EEC to approve the Atlas train because the exception to the carbody acceleration criteria was extremely short in duration and is not considered indicative of the gross motions of the carbody.

Table 21. Trailing Buffer car buff curving results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.2	0.2	0.2	0.2
Maximum wheel L/V ratio	0.8	0.37	0.29	0.24	0.30
Maximum truck side L/V ratio	0.5	0.30	0.16	0.15	0.28
Minimum vertical wheel load	25 (% of static)	76%	89%	87%	69%
Lateral peak-to-peak acceleration	1.3 (g)	0.34	0.50	0.19	0.83
Maximum lateral acceleration	0.75 (g)	0.32	-0.32	-0.13	0.79
Lateral acceleration standard deviation	0.13 (g)	0.03	0.04	0.04	NC
Maximum vertical acceleration	0.90 (g)	0.59	0.50	0.13	0.83
Maximum vertical suspension deflection	95 (%)	24%	30%	30%	25%

* NC means Not Calculated because the length of this run was less that the 2000-foot distance of the lateral acceleration standard deviation calculation

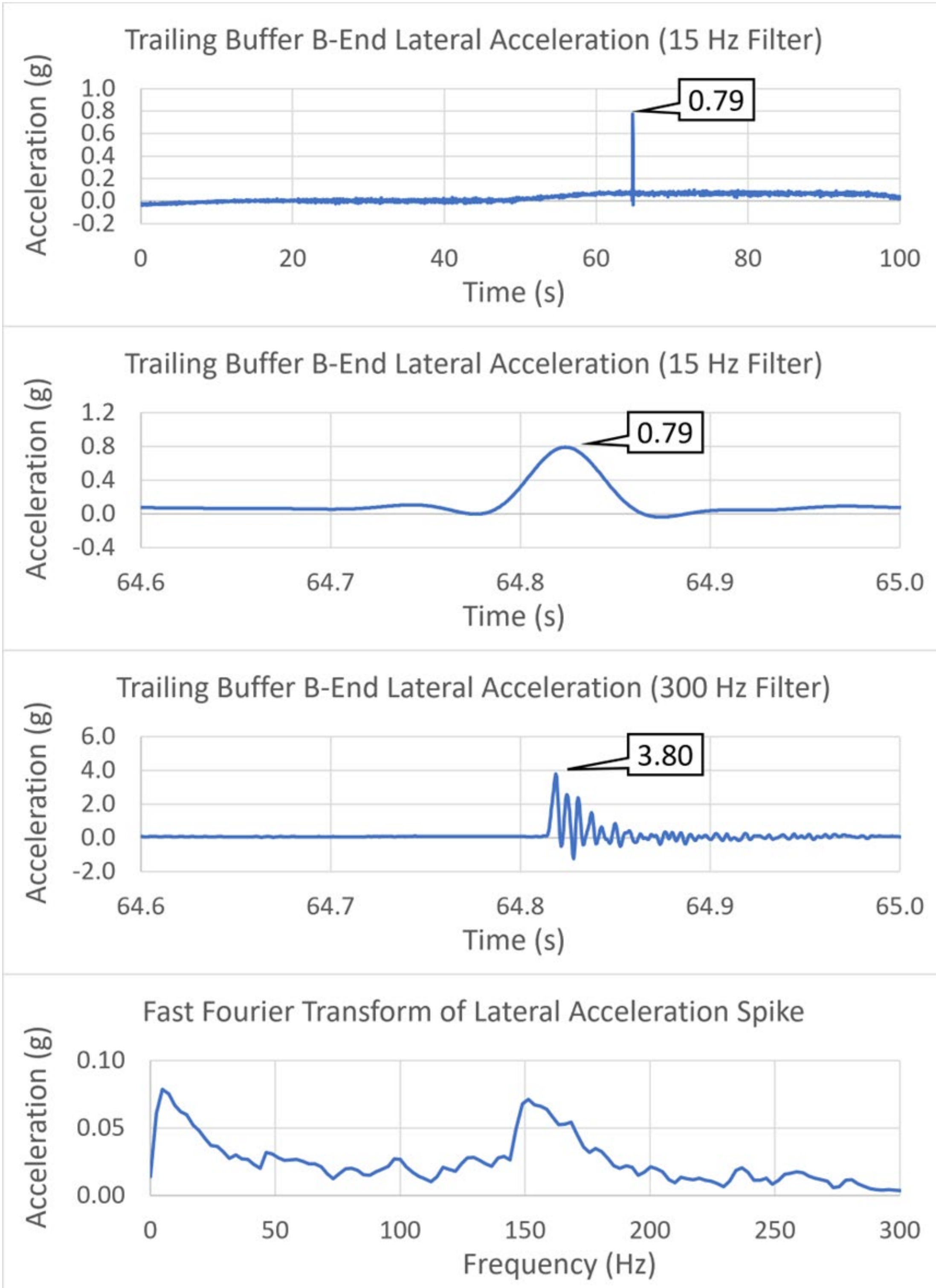

Figure 19. Trailing Buffer car (IDOX 20001) lateral acceleration exception (in buff)

Table 22 summarizes the worst-case values measured on the trailing Buffer car during all draft curving test runs compared to the limiting criteria of S-2043. While testing with the A-end leading CW through the 12-degree curve, the car did not meet the lateral peak-to-peak acceleration or the maximum lateral acceleration criterion during a single test run with an average draft force of 298 kips (11.9 mph). The trailing Buffer car met all other S-2043 criteria for draft curving runs.

The lateral peak-to-peak and maximum lateral acceleration exceptions stemmed from a single spike in the acceleration data within the 12-degree curve. This event is not representative of the trailing Buffer car's gross motion. The single exception is shown in Figure 20, and this exception is of the same nature as the acceleration spikes described in Section 6.3.2 for the leading Buffer car exceptions.

As with the acceleration spikes observed on the leading Buffer car, the exceptions produced by the trailing Buffer car are each considered outliers among the distribution of all maximum accelerations. Out of the 40 total datasets, there were three lateral acceleration outliers and seven vertical acceleration outliers. Two of the lateral acceleration outliers caused exceptions to Standard S-2043 criteria (one in buff curving and one in draft curving) while none of the vertical acceleration outliers caused exceptions. The average maximum lateral and vertical carbody accelerations were 0.23 g and 0.22 g, respectively.

Table 22. Trailing Buffer car draft curving results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.2	0.2	0.2	0.2
Maximum wheel L/V ratio	0.8	0.43	0.46	0.41	0.41
Maximum truck side L/V ratio	0.5	0.41	0.44	0.36	0.37
Minimum vertical wheel load	25 (% of static)	51%	53%	62%	56%
Lateral peak-to-peak acceleration	1.3 (g)	0.21	0.76	0.22	1.89
Maximum lateral acceleration	0.75 (g)	0.17	0.64	0.13	1.77
Lateral acceleration standard deviation	0.13 (g)	0.03	0.04	0.03	0.05
Maximum vertical acceleration	0.90 (g)	-0.24	0.87	0.15	0.85
Maximum vertical suspension deflection	95 (%)	57%	38%	37%	52%

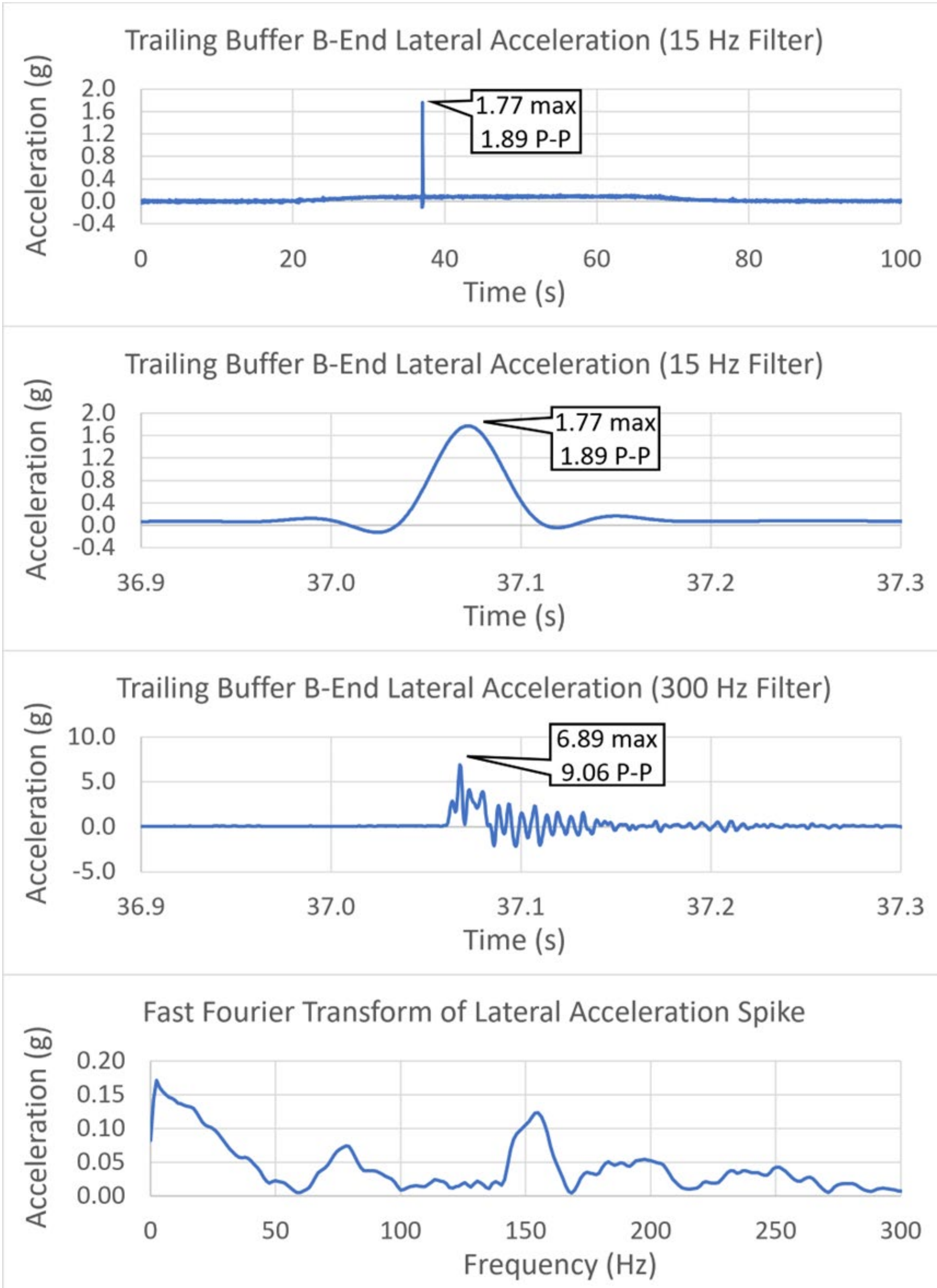

Figure 20. Trailing Buffer car (IDOX 20001) lateral P-P and maximum acceleration exception (in draft)

6.3.4 Rail Escort Vehicle (REV)

Table 23 summarizes the worst-case values measured on the REV during all buff curving test runs compared to the limiting criteria of S-2043. The REV met all S-2043 criteria for buff curving runs.

Table 23. Buff curving results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.2	0.2	0.2	0.1
Maximum wheel L/V ratio	0.8	0.43	0.31	0.31	0.15
Maximum truck side L/V ratio	0.5	0.33	0.29	0.27	0.14
Minimum vertical wheel load	25 (% of static)	77%	61%	66%	83%
Lateral peak-to-peak acceleration	0.60 (g)	0.10	0.29	0.10	0.08
Maximum lateral acceleration	0.35 (g)	0.12	-0.22	-0.10	0.11
Lateral acceleration standard deviation	0.13 (g)	0.03	0.04	0.04	NC
Maximum vertical acceleration	0.60 (g)	0.13	-0.15	0.13	0.14
Maximum vertical suspension deflection	95 (%)	41%	26%	37%	37%

* NC means Not Calculated because the length of this run was less that the 2000-foot distance of the lateral acceleration standard deviation calculation

Table 24 summarizes the worst-case values measured on the REV during all draft curving test runs compared to the limiting criteria of S-2043. The REV met all S-2043 criteria for draft curving runs.

Table 24. Draft Curving Results

Criterion	Limiting Value	B-End CCW	B-End CW	A-End CCW	A-End CW
Roll Angle (degree)	4	0.3	0.1	0.3	0.2
Maximum wheel L/V ratio	0.8	0.40	0.38	0.46	0.44
Maximum truck side L/V ratio	0.5	0.38	0.36	0.44	0.41
Minimum vertical wheel load	25 (% of static)	48%	45%	36%	47%
Lateral peak-to-peak acceleration	0.60 (g)	0.16	0.10	0.13	0.09
Maximum lateral acceleration	0.35 (g)	0.15	-0.13	-0.13	0.14
Lateral acceleration standard deviation	0.13 (g)	0.03	0.04	0.04	0.06
Maximum vertical acceleration	0.60 (g)	0.23	0.24	0.12	0.12
Maximum vertical suspension deflection	95 (%)	41%	44%	49%	37%

7.0 SYSTEM MONITORING TESTS

System monitoring tests were performed in the laboratory and during the on-track testing to demonstrate that the Safety System Monitoring (SSM) equipment performed correctly and met the requirements of Standard S-2043, paragraph 4.5.4. These tests were conducted per the requirements of Standard S-2043, paragraphs 6.2.1 and 6.2.2.

The DOE Atlas and Buffer railcars were equipped with the same SSM equipment used by the NNPP on the M-290 cask cars. The SSM was supplied by 3C Telemetry (3CT) of Centennial, Colorado, who now has either patents or licenses for all the technology used. The SSM equipment on the Atlas and Buffer cars was upgraded from GEN-I to GEN-II during the Atlas test project because the GEN-I equipment depended on the discontinued 2G cellular network and included certain other components that had become obsolete.

A monitoring system consists of a pedestal (Figure 21), a wired sensor (Figure 22), and 8 or 12 wireless axle sensors (Figure 23). The pedestal contains a GPS base unit, a memory model, a battery module, and a solar/antenna cap. The wired sensor measures the longitudinal, lateral, and vertical acceleration and the carbody roll angle. The wireless sensors measure bearing temperature and acceleration (to sense wheel flats). The Atlas railcar is equipped with two systems, one on each end of the car; the Buffer cars and REV are each equipped with one system.

Figure 21. Monitoring system pedestal unit

Figure 22. Monitoring system wired sensor

Figure 23. Monitoring system wireless sensor

The portable display unit (PDU) shows the system status, the measured data, and any alarms noted by the system. If an alarm condition is noted on any of the cars being monitored, the PDU automatically switches to the alarm screen and sounds an audible alarm. The audible alarm continues until the user acknowledges the alarm.

7.1 System Functional Test

Per Standard S-2043 requirements, the system was operated under normal service conditions and during dynamic tests at the controlled test site.

7.1.1 Real-Time Monitoring

The real-time monitoring capability was verified per Standard S-2043, paragraph 4.5.4.2.

Standard S-2043, paragraph 4.5.4.2.1 requires that a train stop alarm be transmitted in the following situations:

- Hunting—Root mean square (RMS) lateral carbody acceleration of 0.26 g sustained for 10 seconds
- Rocking—peak-to-peak roll angles of 5 degrees for three consecutive cycles
- Bearing temperature—indication of impending failure
- Vertical acceleration—peak vertical carbody acceleration of 1.0 g
- Lateral acceleration—peak lateral carbody acceleration of 0.75 g
- Longitudinal acceleration—peak longitudinal carbody acceleration of 1.5 g
- Brakes—indication of a stuck brake (Marked *preferred* in S-2043 edits of 2021-01-06) This is not a monitored condition for the 3CT system

Standard S-2043, paragraph 4.5.4.2.2 requires that a signal requiring a train inspection be transmitted in the following situations:

- Hunting—sustained RMS lateral carbody acceleration of 0.13 g
- Rocking—indication of degraded performance or peak-to-peak roll angles of 4 degrees for three consecutive cycles
- Bearing temperature—indication of degraded performance
- Wheel flat—wheel flat indication
- Brakes—indication of an inoperative brake (Marked *preferred* in S-2043 edits of 2021-01-06). This is not a monitored condition for the 3CT system

The ability of the system to alarm at the levels described in Standard S-2043, paragraphs 4.5.4.2.1 and 4.5.4.2.2 is demonstrated in Section 7.2. The function of the real-time monitoring was observed during controlled site tests, revenue service tests, and the demonstration test run. Real-time monitoring is done with the PDU. The PDU may be placed in the locomotive, but for the revenue service test and the demonstration test run, the test engineer monitored the PDU from the REV car and would have contacted the operations crew via radio if a legitimate train stop or inspect train alarm had occurred. Figure 24 shows the screen of the PDU used to review the data on a four-axle car. Figure 25 shows the screen of the PDU used to review the data on the Atlas railcar. If an alarm condition is noted on any of the cars being monitored, the PDU automatically switches to the alarm screen and sounds an audible alarm. The audible alarm continues until the user acknowledges the alarm.

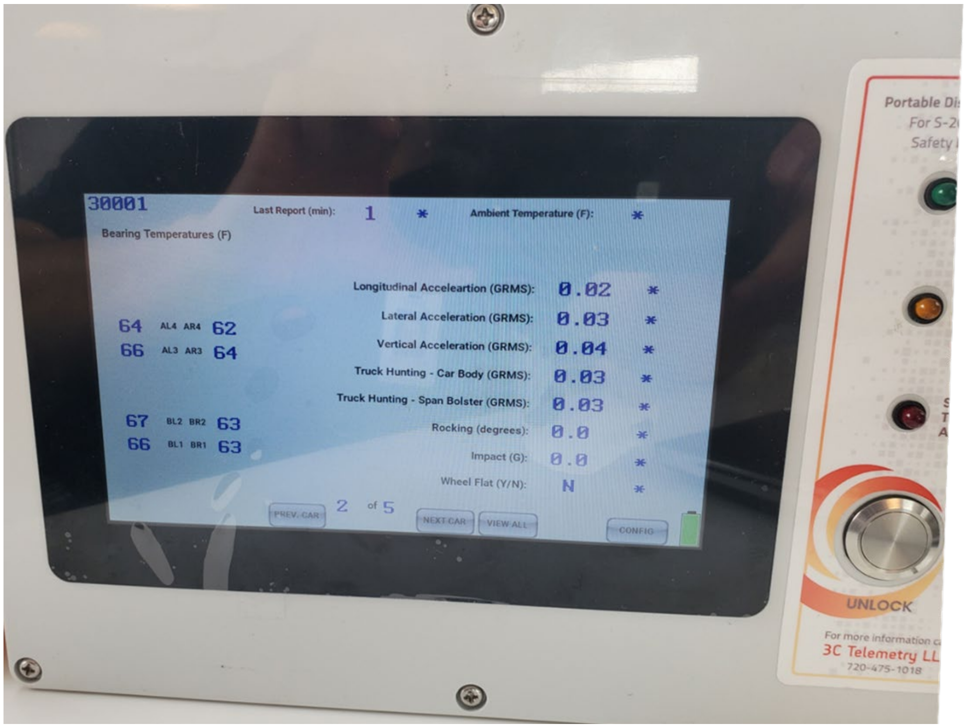

Figure 24. PDU screen monitoring a four-axle railcar

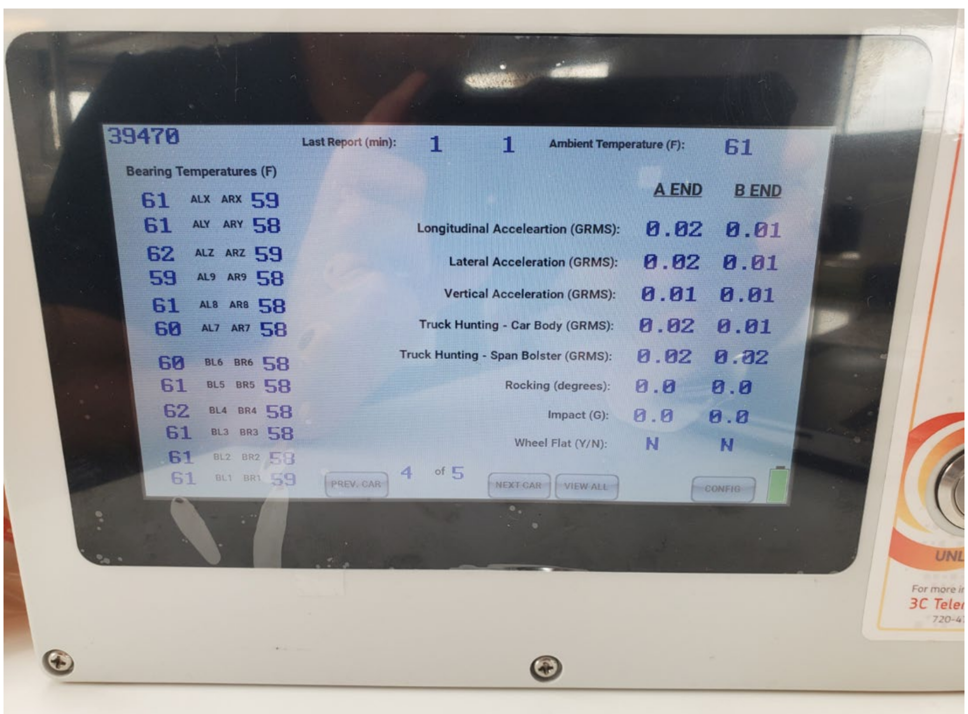

Figure 25. PDU screen monitoring the Atlas railcar

The ability of the monitoring system to communicate with the PDU was demonstrated during both buff and draft curve testing. The high carbody acceleration on the Buffer cars described in Sections 6.3.2 and 6.3.3 set off alarms on the 3CT monitoring system. Although such alarms occurred during the Atlas railcar buff and draft curving tests, they were better documented while performing a separate set of buff and draft curving tests with the DOE's REV and Buffer cars together with a different 12-axle flat car. During these tests, similar brief acceleration events that did not meet S-2043 criteria occurred and also set off alarms on the 3CT monitoring system.

Figure 26 shows an example set of these alarms circled in yellow on the PDU screen. These longitudinal, lateral, and vertical impact alarms occurred on IDOX 20001 (trailing Buffer car) and IDOX 20002 (leading Buffer car) on June 28, 2022, at 18:45 coordinated universal time (UTC). At approximately the same time Mountain, MxV Rail measured high accelerations on the vertical and lateral accelerometers on the A-end of the two Buffer cars (Figure 27).

The acceleration amplitudes reported by the monitoring system (~ 10 g vertical, ~ 25 g lateral) do not match the amplitude of the acceleration measured by MxV Rail (3.78 g and 2.71 g vertical, 1.20 g and 0.82 g lateral). This difference (6–7 g vertical and 24 g lateral) in measured amplitude could be due to the monitoring system's wired sensor being mounted to the underside of the deck, body bolster, and center sill with a special mounting bracket while the MxV Rail accelerometers were rigidly mounted to the top of the flatcar deck. The difference may also be due to the different frequency response characteristics of the two measurement devices. The buff and draft test was the only test that 1) triggered the impact alarms on the 3CT monitoring system and 2) did not meet the Standard S-2043 maximum acceleration criteria during the vertical and lateral acceleration measured by MxV Rail. These results indicate that, although the amplitudes do not match, the alarms from the 3CT system represent high acceleration levels experienced by the carbody.

Figure 26. Alarm transmitted by the 3CT monitoring system

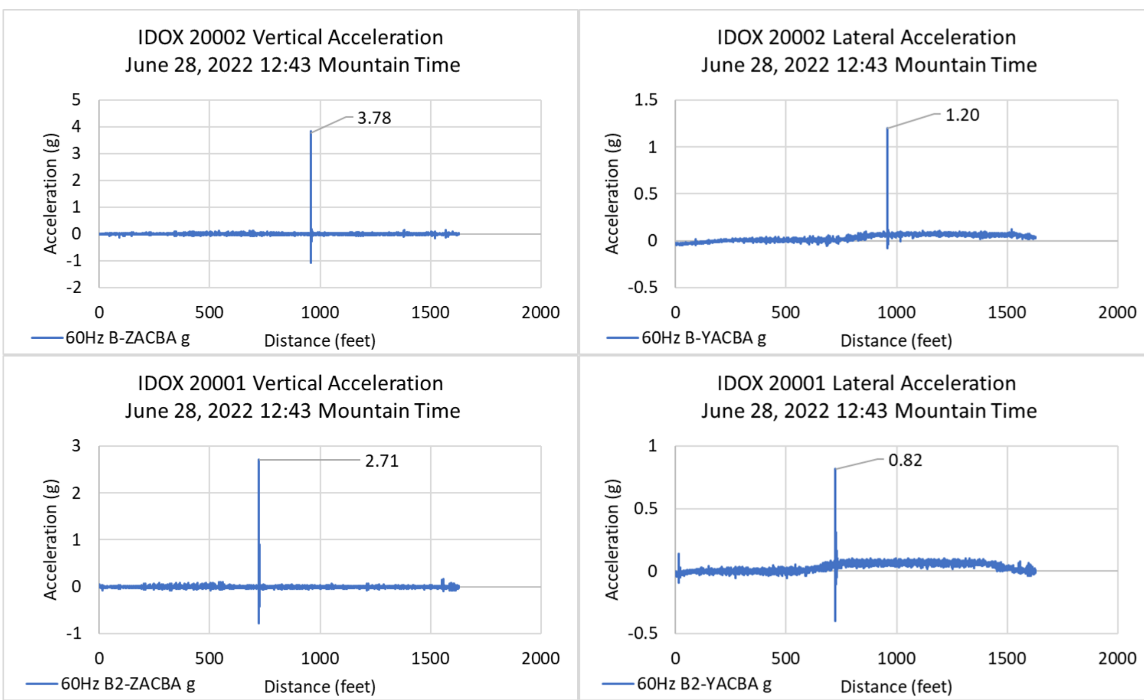

Figure 27. Acceleration measured by MxV Rail on Buffer car IDOX 20001

7.1.2 Remote Monitoring

The remote monitoring capability was verified per Standard S-2043, paragraph 4.5.4.3, which requires that the system report the following every 12 hours:

- Location—location at beginning and end of 12-hour period minimum
- Speed—histogram of train speed
- Ride quality—histogram of carbody acceleration for each axis
- Power supply voltage—histogram of power supply voltage

The remote monitoring of the SSM equipment is done through a website. The 3CT website has the following reports available:

- Alarm Report
- Basic History Report
- Bearing Temperature Report
- Remote Monitoring Report (Figure 28 and Figure 29)
- System Health History Report

Each type of report required the user to input the car number and a date range to query. The bearing temperature report and the remote monitoring report have one version for the Buffer and REV and another version for the Atlas railcar because the systems on the Buffers and REV monitor four axles, while each of the systems on an Atlas monitors six axles. The alarm report lists all alarms that have occurred on that car within the date range, including the date and time of the alarm, the alarm type, the geographical location where the alarm occurred, course, speed, and acceleration amplitude in X, Y, and Z directions, and ambient temperature. Other data outputs depend on alarm type. The basic history, bearing temperature, system health, and remote monitoring reports all report once per hour: at the beginning of a move, hourly during movement, and at the end of a move. These reports also contain daily health checks and daughter card health checks.

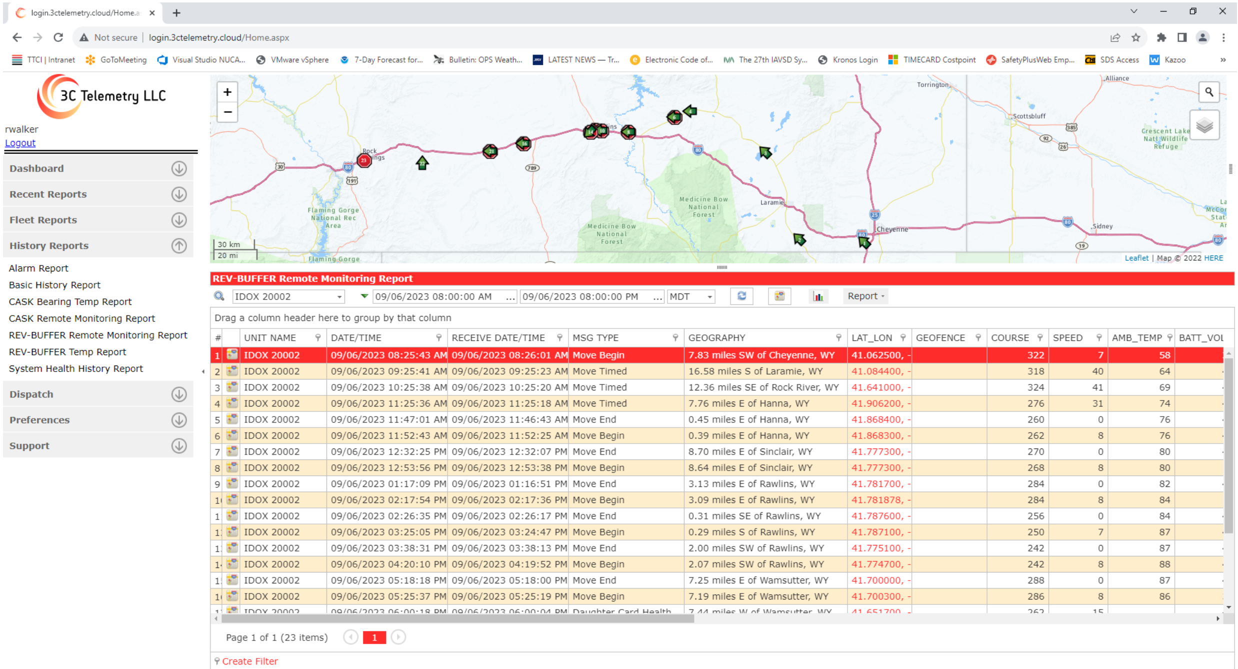

Figure 28. Remote monitoring report for IDOX 20002 from 8:00 AM to 8:00 PM on September 6, 2023, during the demonstration test run

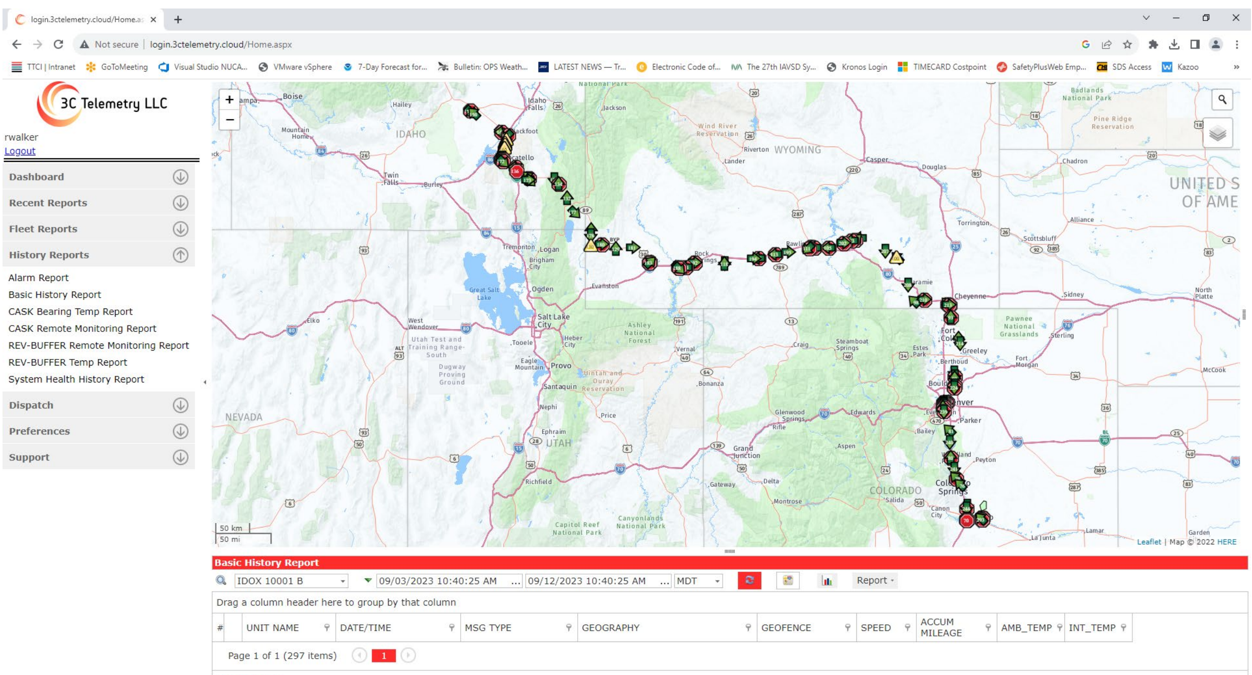

Figure 29. Remote monitoring report for IDOX 10001 (B-end) containing the entire demonstration test run

7.2 Failure Simulations

Failure simulations were conducted on December 14, 2021, and January 20, 2022, at the 3C-Telemetry (3CT) facility in Centennial, Colorado. 3C-Telemetry has built specialized equipment to develop and test the monitoring system components. MxV Rail asked 3CT to provide inputs to the monitoring system while MxV Rail measured the input levels to confirm the system transferred alarms at the appropriate amplitude levels. Per Standard S-2043 requirements, the failure simulation tests were observed by Steve Belport, MxV Rail Principal Investigator II.

7.2.1 Hunting

Standard S-2043 states:

- A signal requiring train stop must be transmitted to the train crew if an RMS lateral carbody acceleration sustained at 0.26 g for 10 seconds is measured.
- A signal requiring train inspection at the next scheduled stop must be transmitted to the train crew if a sustained RMS lateral carbody acceleration of 0.13 g is measured.

To test the ability of the monitoring system to transmit hunting alarms, 3CT installed the wired sensor on the hunting test apparatus (Figure 31). MxV Rail attached a lateral accelerometer to the bracket that held the wired sensor. The wired sensor was cycled laterally at an amplitude of 0.12 g standard deviation for five minutes and no alarm was transmitted. The lateral acceleration amplitude was increased to 0.20 g standard deviation, and after 5 minutes at this level, an inspection alarm was transmitted. The lateral acceleration amplitude was increased to 0.43 g standard deviation, and after 5 minutes at this level, a stop train alarm was transmitted. Figure 31 shows the lateral acceleration measured on the hunting test apparatus during the tests. The testing demonstrated that the system both transmitted the appropriate alarm for the range of amplitude levels and met the requirements for the hunting alarm monitoring system test.

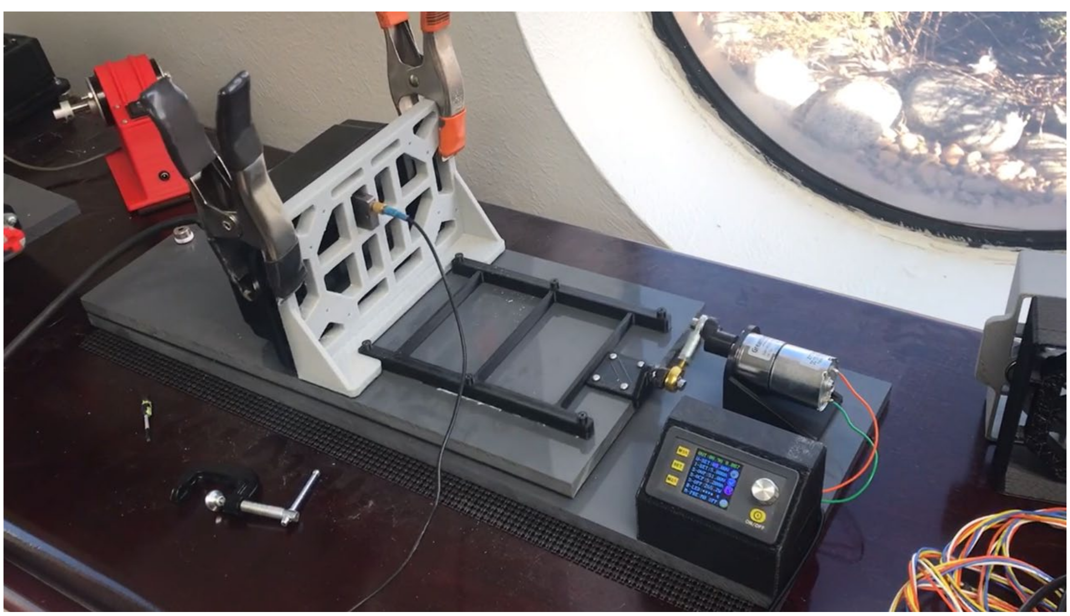

Figure 30. Hunting test apparatus

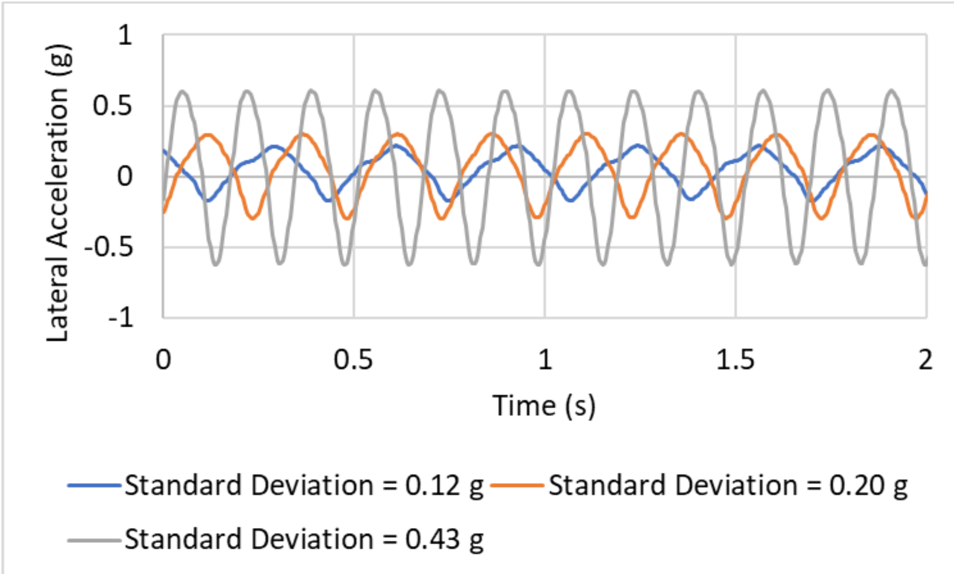

Figure 31. Hunting inputs measured on the hunting test apparatus

7.2.2 Rocking

Standard S-2043 states:

- A signal requiring train inspection at the next scheduled stop must be transmitted to the train crew if three consecutive cycles of 4-degree peak-to-peak roll angles are measured.
- A signal requiring train stop must be transmitted to the train crew if three cycles of 5-degree peak-to-peak roll angles are measured.

To test the ability of the monitoring system to transmit rocking alarms, 3CT installed the wired sensor on the rocking test apparatus (Figure 32). MxV Rail attached a roll rate gyro to the bracket that held the wired sensor. The wired sensor was rocked at an amplitude of 3 degrees peak to peak for more than three cycles, and no alarm occurred. The rocking amplitude was increased to 4.5 degrees, and after three cycles passed, the system triggered an inspect train alarm. The rocking amplitude was increased further to 6 degrees, and after three cycles passed, the system triggered a stop train alarm. Figure 33 shows the roll angle measured on the rocking test apparatus during the tests, demonstrating the system transmitted the appropriate alarm for the range of amplitude levels. The system met the requirements for the carbody rocking alarm monitoring system test.

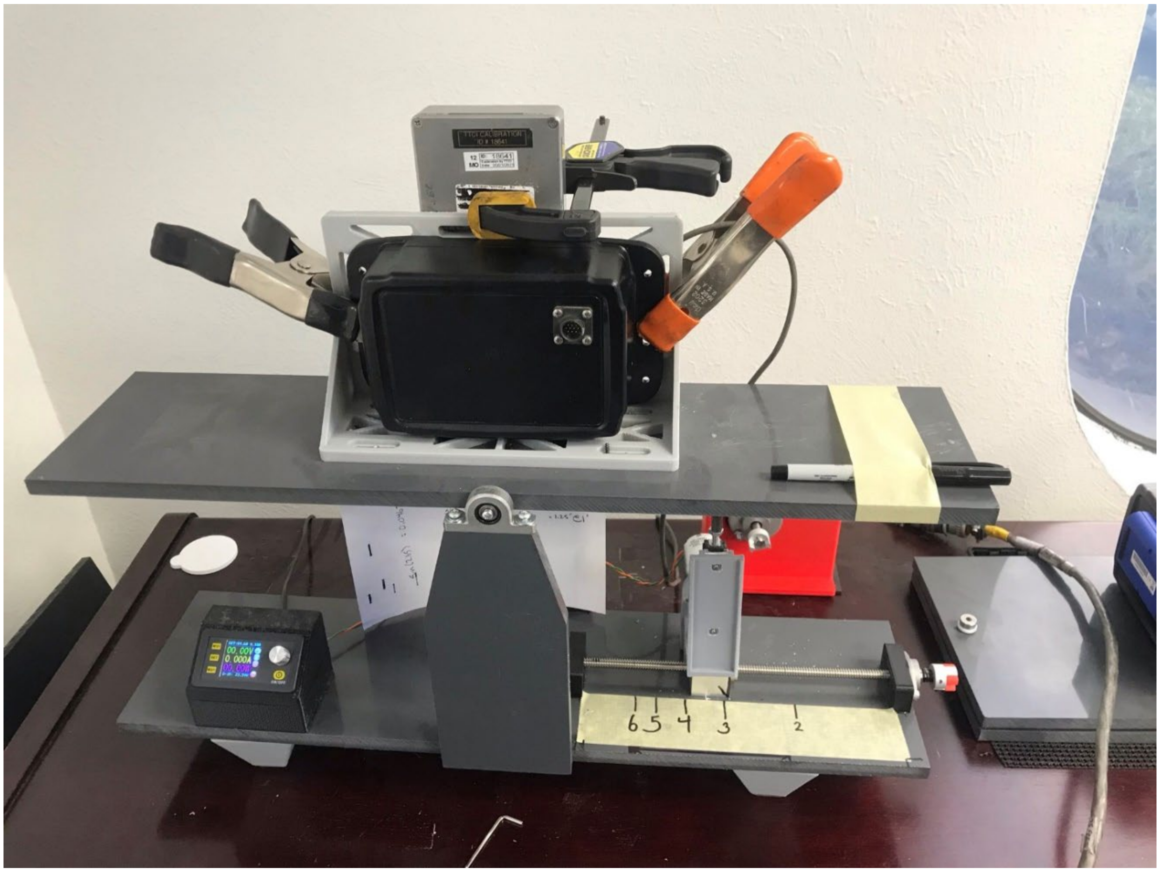

Figure 32. Rocking test apparatus

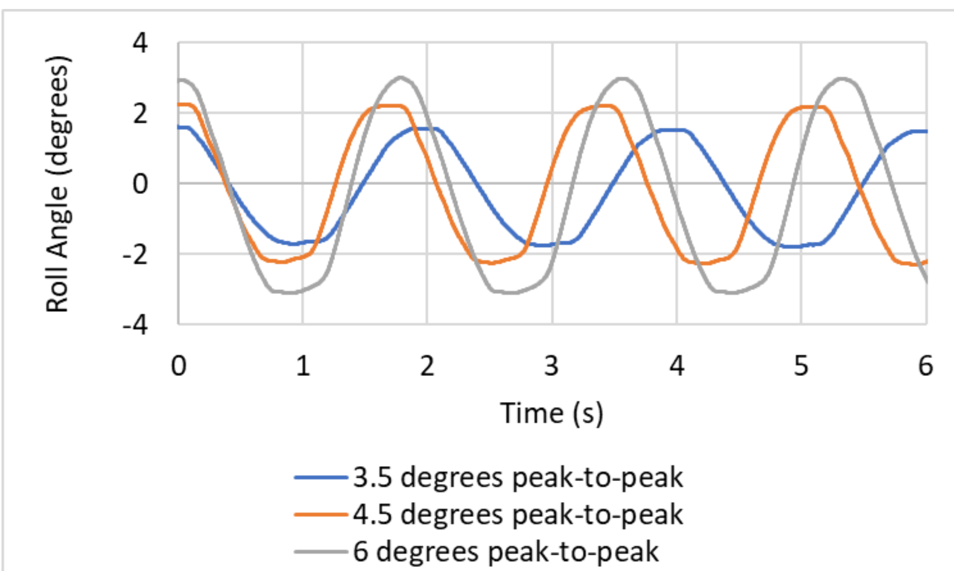

Figure 33. Roll inputs measured on the rocking test apparatus

7.2.3 Bearing Temperature

Standard S-2043 states:

- A signal requiring train stop must be transmitted to the train crew if there is an indication of an impending failure.
- A signal requiring train inspection at the next scheduled stop must be transmitted to the train crew if there is an indication of degraded performance.

3CT has identified the following alarm conditions corresponding to the Standard S-2043 requirements:

- Inspection alarms
  - Absolute temperature of 175° F
  - A temperature of 150° F above ambient
- Train Stop Alarms
  - Absolute temperature of 200° F
  - A temperature of 170° F above ambient
  - A difference between bearings on the same axle of 95° F

To test the ability of the monitoring system to transmit bearing temperature alarms, 3CT built a bearing temperature test apparatus that can be heated with a heat gun (Figure 34). The alarm function was tested by heating the simulated bearing to 178° F, just above the absolute temperature for a train inspection alarm. The temperature was checked with the MxV Rail's infrared thermometer. The system transmitted an inspect train alarm.

While preparing this report it was noted that no record of a test at the train stop bearing temperature level was found. On February 7, 2023, MxV Rail conducted a test of the system using axle sensors removed from Axle 8 of IDOX 10001. When the bearing temperature exceeded 200° F a train stop alarm was transferred to the PDU. It should be noted that the thermocouple used to verify the applied temperature indicated the temperature was about 20–30° F higher than was indicated on the PDU. The system met the requirements for the bearing temperature alarm monitoring system test.

Figure 34. Bearing temperature test apparatus

7.2.4 Vertical Acceleration

Standard S-2043 states:

- A signal requiring train stop must be transmitted to the train crew if a peak vertical carbody acceleration of 1.0 g is measured.

To test the ability of the monitoring system to transmit vertical acceleration alarms, 3CT built an impact test apparatus to test vertical, lateral, and longitudinal impacts. The mounting orientation of the wired sensor on the fixture can be changed to test the different directions. MxV Rail mounted an accelerometer on the test fixture to measure the acceleration input to the wired sensor. The apparatus was used to input accelerations below and above the levels that triggered a train stop alarm (Figure 35).

The frequency content of the acceleration measured by MxV Rail's accelerometer appears to be different from that being measured by the wired sensor of the monitoring system. Furthermore, the discrepancy changes somewhat when the wired sensor is oriented vertically, laterally, and longitudinally. When filtered at 10 Hz, MxV Rail's vertical acceleration measurement matched the appropriate alarm levels. This frequency is lower than that required by Standard S-2043 for filtering carbody acceleration data during single car tests (15 Hz). Ten Hz frequency content is within the range often used for this type of measurement, e.g., it is consistent with the filter frequency (10 Hz) required by the Code of Federal Regulations (49 CFR 213.333 Vehicle/Track Interaction Safety Limits) for filtering carbody acceleration. The monitoring system may be less prone to nuisance alarms due to this lower frequency content. With an allowance for the 10 Hz frequency content monitoring system's vertical acceleration measurement, the system met the requirements for the test of the monitoring system vertical acceleration alarm.

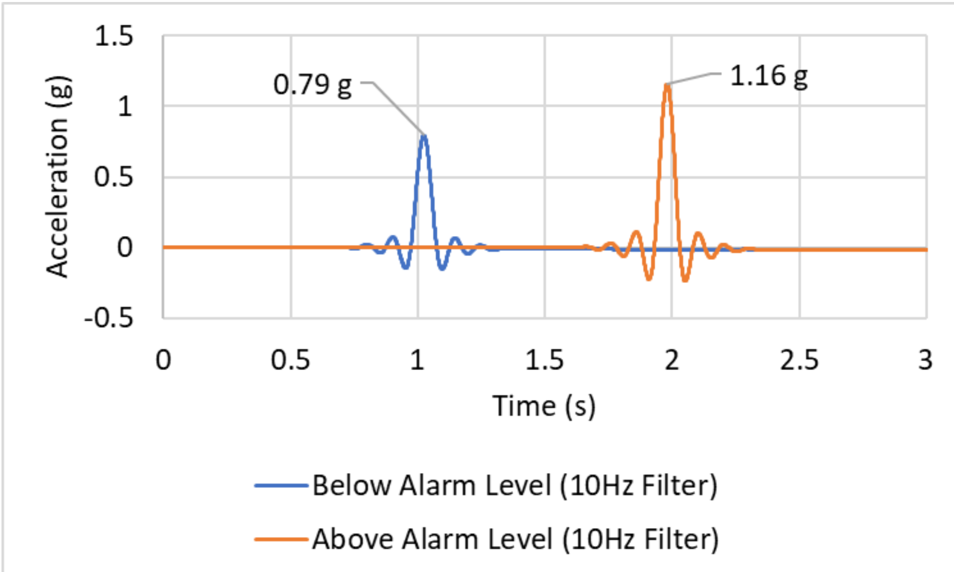

Figure 35. Vertical acceleration inputs

7.2.5 Lateral Acceleration

Standard S-2043 states:

- A signal requiring train stop must be transmitted to the train crew if a peak lateral carbody acceleration of 0.75 g is measured.

To test the ability of the monitoring system to transmit lateral acceleration alarms, 3CT built an impact test apparatus to test vertical, lateral, and longitudinal impacts (Figure 36). The mounting orientation of the wired sensor on the fixture will be changed to test the different directions. MxV Rail mounted an accelerometer on the test fixture to measure the acceleration input to the wired sensor. The apparatus was used to input accelerations both below and above the levels that triggered a train stop alarm (Figure 37).

The frequency content of the acceleration measured by MxV Rail's accelerometer appears to be different from that being measured by the wired sensor of the monitoring system. Furthermore, the discrepancy changes somewhat when the wired sensor is oriented vertically, laterally, and longitudinally. MxV Rail's lateral acceleration measurement matched the appropriate alarm levels when filtered at 9 Hz. This frequency is lower than what is required by Standard S-2043 for filtering carbody acceleration data during single car tests (15 Hz). Nine Hz frequency content is close to the range often used for this type of measurement, e.g., it is close to the filter frequency (10 Hz) required by CFR 213.333 Vehicle/Track Interaction Safety Limits for filtering carbody acceleration. The monitoring system may be less prone to nuisance alarms because of this lower frequency content. With an allowance for the 9 Hz frequency content monitoring system's lateral acceleration measurement, the system met the requirements for the test of the monitoring system vertical acceleration alarm.

Figure 36. Lateral acceleration impact test apparatus

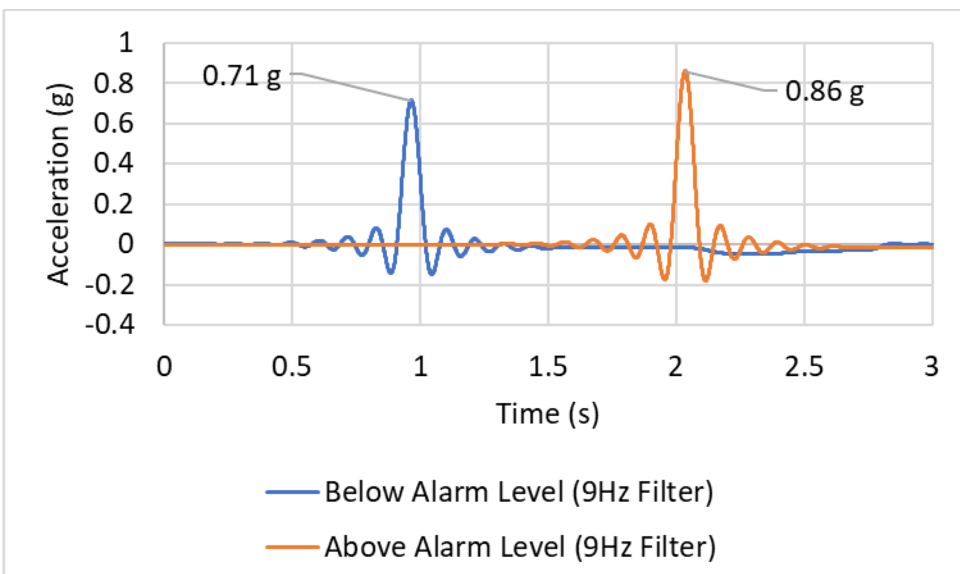

Figure 37. Lateral acceleration inputs

7.2.6 Longitudinal Acceleration

Standard S-2043 states:

- A signal requiring train stop must be transmitted to the train crew if a peak longitudinal carbody acceleration of 1.5 g is measured.

To test the ability of the monitoring system to transmit longitudinal acceleration alarms 3CT built an impact test apparatus to test vertical, lateral, and longitudinal impacts. The mounting orientation of the wired sensor on the fixture is changed to test the different directions. MxV Rail mounted an accelerometer on the test fixture to measure the acceleration input to the wired sensor. The apparatus was used to input accelerations below and above the levels that triggered a train stop alarm (Figure 38).

The frequency content of the acceleration measured by MxV Rail's accelerometer appears to be different from that being measured by the wired sensor of the monitoring system. Furthermore, the discrepancy changes somewhat when the wired sensor is oriented vertically, laterally, and longitudinally. MxV Rail's longitudinal acceleration measurement matched the appropriate alarm levels when filtered at 15 Hz. This frequency matches what is required by Standard S-2043 for filtering carbody acceleration data during single car tests (15 Hz). The system met the requirements for the test of the monitoring system vertical acceleration alarm.

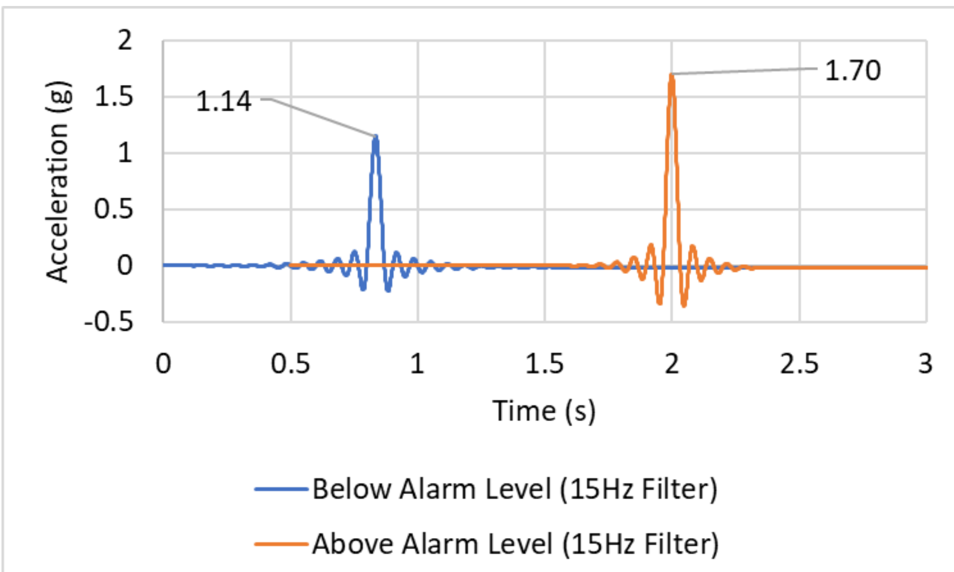

Figure 38. Longitudinal acceleration inputs

7.2.7 Wheel Flat

Standard S-2043 states:

- A signal requiring train inspection at the next scheduled stop must be transmitted to the train crew if there is a wheel flat indication.

Correlating the onboard vehicle measurements with the existence of a high impact wheel is not straightforward. The 3CT alarm was based on a level of peak vertical acceleration measured at the bearing location of more than 3 g sustained for a period of 5 minutes. To take the measurements, 3CT mounted a wireless axle sensor on the wheel flat test apparatus (Figure 39).

MxV Rail attached a vertical accelerometer to the fixture to measure the acceleration input to the wireless axle sensor. Then, 3CT input a low-level acceleration (between 2 g and 3 g) to the wireless axle sensor for more than five minutes, and no alarm was transmitted. After five minutes, 3CT then increased the amplitude of the acceleration input (between 3.5 g and 4.5 g), and no alarm occurred until the higher amplitude acceleration had been applied for more than five minutes. The peak acceleration amplitude was very sensitive to the frequency of the filter applied to the data. The peak acceleration levels quoted were taken when the signal was filtered at 200Hz (Figure 40). Given the acceptance of the assumptions made for sensing wheel flats, the system met the requirements for the test of the monitoring system wheel flat alarm.

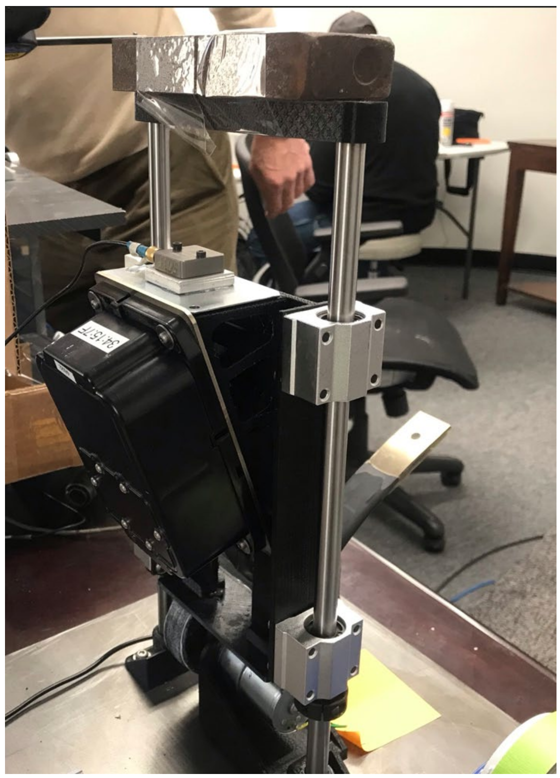

Figure 39. Wheel flat test apparatus

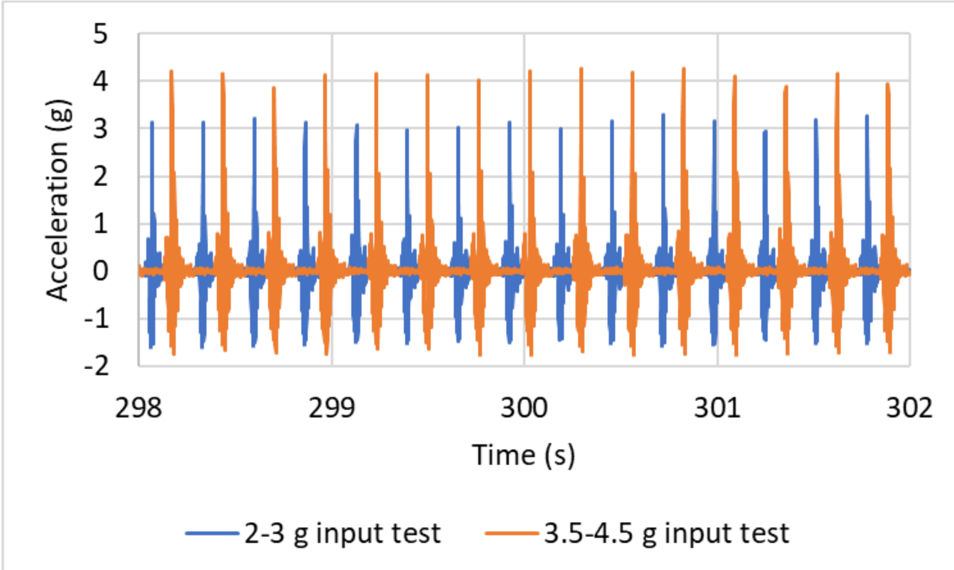

Figure 40. Acceleration measured by MxV Rail on the wheel flat test apparatus for two tests, filtered at 200 Hz

7.2.8 Brakes

Based on the edits to Standard S-2043 dated January 6, 2021, the brake system monitoring is a "preferred" feature of the onboard monitoring system rather than a requirement. Brake system monitoring has not been implemented on the system currently in place on the Atlas, REV, and Buffer cars.

8.0 REVENUE SERVICE TESTS

Revenue service tests were conducted using the complete test train in accordance with the requirements of S-2043, paragraph 6.3. These tests are intended to demonstrate satisfactory performance for an entire representative HLRM running over representative revenue service conditions, including, but not limited to, turnouts, crossovers, and tight curves (S-2043, paragraph 6.3.1), and track maintained to no better than FRA Class 2 standards (S-2043, paragraph 6.3.2). MxV Rail and the DOE selected the minimum test load case for revenue service tests because this test load case was the most challenging for the Atlas railcar during single car testing.

The tests described in Sections 8.1.1, 8.1.2, 8.2.1, 8.2.3, 8.3.1, 8.3.4, and 8.3.5 were performed with AAR-1B narrow flange wheel profiles. The tests described in Sections 8.1.3, 8.2.2, 8.3.2, and 8.3.3 were conducted with AAR-2A narrow flange wheel profiles. The change from AAR-1B narrow flange wheel profiles to AAR-2A narrow flange wheel profiles is described in Section 4.0.

Revenue service tests require the use of instrumented wheel sets (IWS). The IWS were placed in the A-end span bolster of the Atlas, the A-end truck of the trailing Buffer car (IDOX 20001), and the B-end truck of the REV (Figure 41). During tests with the AAR-1B narrow flange profiles, DOE-owned IWS 96 through 101 were used in the Atlas railcar; DOE-owned IWS 102 and 103 were used in the Buffer railcar, and Navy-owned IWS 73 and 74 were used in the REV. The Navy was reluctant to reprofile their IWS when it became necessary to test the DOE train with AAR-2A narrow flange profiles, therefore, two of MxV Rail's IWS that had the AAR-2A profile were used. The DOE owned IWS were all reprofiled (machined) to the AAR-2A narrow flange profile. During tests with the AAR-2A narrow flange profiles, DOE-owned IWS 96 through 101 were used in the Atlas railcar; MxV Rail-owned IWS 59 and 60 were used in the Buffer railcar; and DOE-owned IWS 102 and 103 were used in the REV.

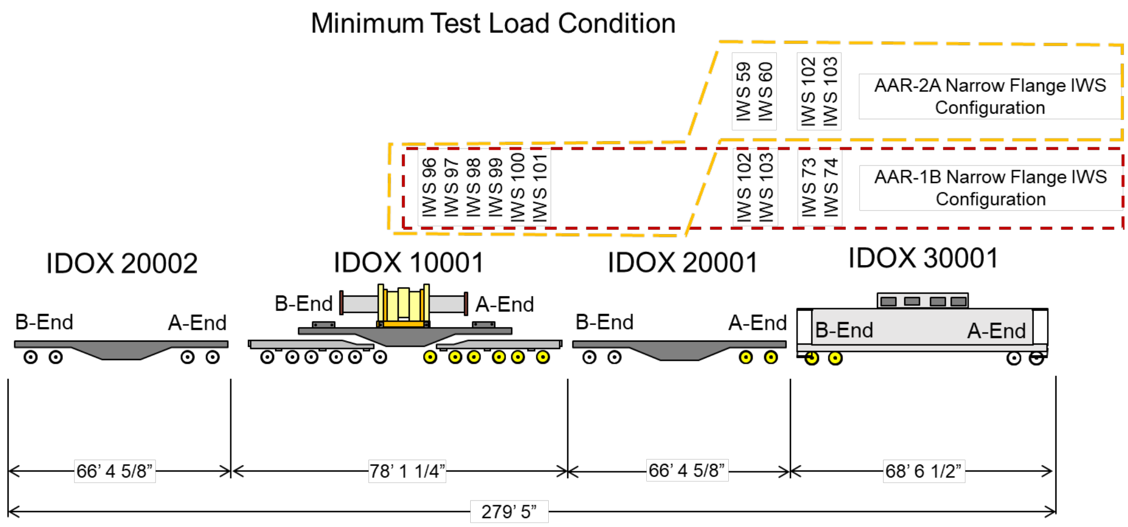

Figure 41. Revenue service test configuration

8.1 Turnouts, Crossovers, and Tight Curves

The tests were conducted in accordance with the requirements of S-2043, paragraph 6.3.1 to demonstrate acceptable performance over the sharpest curves, turnouts, and crossovers that would typically be encountered in revenue service. The tests were performed over 10- and 12-degree curves, a No. 8 turnout, and a No. 8 crossover at the PCD and over a 10-degree curve on BNSF Railway tracks at Alps, New Mexico. Tests were also conducted on the WRM 12-degree curve at the TTC.

8.1.1 Turnouts and Crossovers

The turnout and crossover tests were performed on No. 8 turnouts and a No. 8 crossover at the North Classification Yard at the PCD on September 21 and 22, and October 11, 2022. Per Standard S-2043 requirements, the tests performed on September 21 and 22 were observed by Matt DeGeorge, MxV Rail Senior Engineer II, and the October 11 test was observed by Steve Belport, MxV Rail Principal Investigator II.

Data for the turnout tests were recorded on North Yard tracks 1 and 2 at the PCD (Figure 42). Tests were performed for leading point (eastbound) and trailing point (westbound) moves on tracks 1 and 2. In addition to the turnout and crossover requirements, the test data presented in this section also serve as partial fulfilment of the requirements of Standard S-2043, paragraph 6.3.2, Class 2 Maintained Track. The entire yard track, about one-mile length, was recorded for the turnout test runs. For tracks 1 and 2, this totals about two miles. The tests were conducted with the locomotive coupled to the B-end of IDOX 20002 (see Figure 41 for train configuration) operating eastbound with the locomotive pushing, westbound with the locomotive pulling, eastbound with the locomotive pulling, and westbound with the locomotive pushing. Test speeds were 20 mph (the switch speed limit as required by S-2043) for all the test runs. Table 25 through Table 28 show the worst-case test results for the Atlas, Lead Buffer (IDOX 20002), Trail Buffer (IDOX 20001), and the REV. All four cars met the Standard S-2043 criteria for turnout tests.

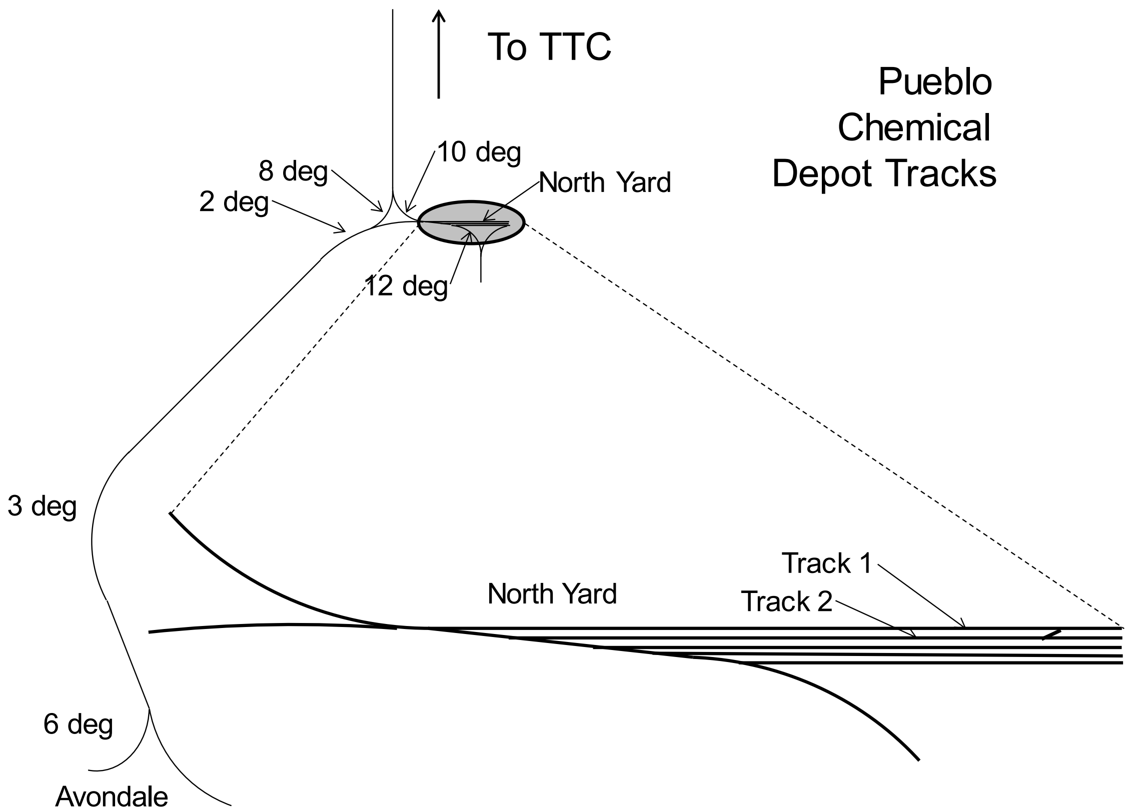

Figure 42. PCD tracks

Table 25. Atlas turnout results

Criterion	Limiting Value	Push East	Push West	Pull East	Pull West
Roll Angle (degree)	4	0.5	0.5	0.7	0.4
Maximum wheel L/V ratio	0.8	0.77	0.67	0.65	0.64
Maximum truck side L/V ratio	0.5	0.37	0.36	0.39	0.44
Minimum vertical wheel load	25 (% of static)	60%	52%	49%	51%
Lateral peak-to-peak acceleration	1.3 (g)	0.24	0.30	0.29	0.27
Maximum lateral acceleration	0.75 (g)	0.16	0.21	0.21	0.20
Lateral acceleration standard deviation	0.13 (g)	0.03	0.03	0.03	0.02
Maximum vertical acceleration	0.90 (g)	0.23	0.30	0.25	0.22
Maximum vertical suspension deflection	95 (%)	22%	22%	24%	20%

Table 26. Lead Buffer (IDOX 20002) turnout results

Criterion	Limiting Value	Push East	Push West	Pull East	Pull West
Roll Angle (degree)	4	0.7	0.7	0.8	0.6
Lateral peak-to-peak acceleration	1.3 (g)	0.34	0.30	0.32	0.30
Maximum lateral acceleration	0.75 (g)	0.18	0.20	0.20	0.13
Lateral acceleration standard deviation	0.13 (g)	0.03	0.03	0.04	0.03
Maximum vertical acceleration	0.90 (g)	0.26	0.23	0.20	0.24
Maximum vertical suspension deflection	95 (%)	32%	45%	43%	37%

Table 27. Trail Buffer (IDOX 20001) turnout results

Criterion	Limiting Value	Push East	Push West	Pull East	Pull West
Roll Angle (degree)	4	0.7	0.9	0.8	0.6
Maximum wheel L/V ratio	0.8	0.58	0.59	0.57	0.57
Maximum truck side L/V ratio	0.5	0.27	0.27	0.33	0.28
Minimum vertical wheel load	25 (% of static)	74%	54%	65%	61%
Lateral peak-to-peak acceleration	1.3 (g)	0.33	0.35	0.33	0.31
Maximum lateral acceleration	0.75 (g)	0.22	0.27	0.21	0.20
Lateral acceleration standard deviation	0.13 (g)	0.03	0.04	0.04	0.03
Maximum vertical acceleration	0.90 (g)	0.26	0.27	0.24	0.24
Maximum vertical suspension deflection	95 (%)	35%	58%	49%	42%

Table 28. REV turnout results

Criterion	Limiting Value	Push East	Push West	Pull East	Pull West
Roll Angle (degree)	4	0.9	1.0	0.9	0.9
Maximum wheel L/V ratio	0.8	0.63	0.69	0.72	0.75
Maximum truck side L/V ratio	0.5	0.30	0.33	0.30	0.33
Minimum vertical wheel load	25 (% of static)	51%	47%	45%	52%
Lateral peak-to-peak acceleration	0.6 (g)	0.37	0.36	0.39	0.34
Maximum lateral acceleration	0.35 (g)	0.22	0.24	0.26	0.20
Lateral acceleration standard deviation	0.13 (g)	0.03	0.04	0.04	0.03
Maximum vertical acceleration	0.60 (g)	0.25	0.42	0.39	0.21
Maximum vertical suspension deflection	95 (%)	30%	41%	42%	28%

The data for the crossover tests were recorded on the crossover between North Yard tracks 1 and 2 at the PCD (Figure 43). The crossover is a No. 8 on 14-foot 2-inch track centers. The tests were performed during the crossing from track 1 to track 2 westbound and from track 2 to track 1 eastbound. The tests were conducted with the locomotive coupled to the B-end of IDOX 20002 (Figure 41) operating eastbound with the locomotive pushing, westbound with the locomotive pulling, eastbound with the locomotive pulling, and westbound with the locomotive pushing. Test speeds were 5-, 10-, 15-, and 19-mph. Table 29 through Table 32 show the worst-case test results for the Atlas, Lead Buffer (IDOX 20002), Trail Buffer (IDOX 20001), and the REV, respectively. Figure 44 through Figure 46 show the maximum 50-millisecond wheel L/V ratio for the Atlas, trail Buffer, and REV plotted against speed. All four cars met Standard S-2043 criteria for crossover tests.

Figure 43. Crossover between north yard tracks 1 and 2

Table 29. Atlas crossover results

Criterion	Limiting Value	Push East	Push West	Pull East	Pull West
Roll Angle (degree)	4	0.3	0.4	0.3	0.3
Maximum wheel L/V ratio	0.8	0.60	0.67	0.58	0.62
Maximum truck side L/V ratio	0.5	0.35	0.41	0.29	0.42
Minimum vertical wheel load	25 (% of static)	50%	59%	51%	58%
Lateral peak-to-peak acceleration	1.3 (g)	0.22	0.23	0.21	0.21
Maximum lateral acceleration	0.75 (g)	0.16	0.16	0.13	0.15
Lateral acceleration standard deviation	0.13 (g)	NC	NC	NC	NC
Maximum vertical acceleration	0.90 (g)	0.38	0.18	0.19	0.58
Maximum vertical suspension deflection	95 (%)	18%	18%	19%	15%

* NC means Not Calculated because the length of this run was less that the 2000-foot distance of the lateral acceleration standard deviation calculation

Table 30. Lead Buffer (IDOX 20002) crossover results

Criterion	Limiting Value	Push East	Push West	Pull East	Pull West
Roll Angle (degree)	4	0.4	0.4	0.4	0.4
Lateral peak-to-peak acceleration	1.3 (g)	0.23	0.23	0.22	0.24
Maximum lateral acceleration	0.75 (g)	0.14	0.10	0.17	0.17
Lateral acceleration standard deviation	0.13 (g)	NC	NC	NC	NC
Maximum vertical acceleration	0.90 (g)	0.17	0.17	0.18	0.17
Maximum vertical suspension deflection	95 (%)	30%	34%	32%	36%

* NC means Not Calculated because the length of this run was less that the 2000-foot distance of the lateral acceleration standard deviation calculation
* This car did not have IWS installed so some parameters (Maximum wheel L/V ratio, Maximum truck side L/V ratio, and Minimum vertical wheel load) were not measured

Table 31. Trail Buffer (IDOX 20001) crossover results

Criterion	Limiting Value	Push East	Push West	Pull East	Pull West
Roll Angle (degree)	4	0.4	0.5	0.5	0.5
Maximum wheel L/V ratio	0.8	0.49	0.56	0.50	0.54
Maximum truck side L/V ratio	0.5	0.24	0.24	0.23	0.27
Minimum vertical wheel load	25 (% of static)	69%	74%	71%	69%
Lateral peak-to-peak acceleration	1.3 (g)	0.23	0.26	0.23	0.24
Maximum lateral acceleration	0.75 (g)	0.16	0.21	0.17	0.19
Lateral acceleration standard deviation	0.13 (g)	NC	NC	NC	NC
Maximum vertical acceleration	0.90 (g)	0.16	0.18	0.18	0.17
Maximum vertical suspension deflection	95 (%)	54%	52%	42%	61%

* NC means Not Calculated because the length of this run was less that the 2000-foot distance of the lateral acceleration standard deviation calculation

Table 32. REV crossover results

Criterion	Limiting Value	Push East	Push West	Pull East	Pull West
Roll Angle (degree)	4	0.6	0.6	0.6	0.7
Maximum wheel L/V ratio	0.8	0.53	0.65	0.65	0.64
Maximum truck side L/V ratio	0.5	0.24	0.33	0.30	0.24
Minimum vertical wheel load	25 (% of static)	54%	57%	63%	55%
Lateral peak-to-peak acceleration	0.6 (g)	0.26	0.26	0.22	0.26
Maximum lateral acceleration	0.35 (g)	0.19	0.22	0.17	0.22
Lateral acceleration standard deviation	0.13 (g)	NC	NC	NC	NC
Maximum vertical acceleration	0.60 (g)	0.36	0.35	0.39	0.36
Maximum vertical suspension deflection	95 (%)	38%	45%	33%	36%

* NC means Not Calculated because the length of this run was less that the 2000-foot distance of the lateral acceleration standard deviation calculation

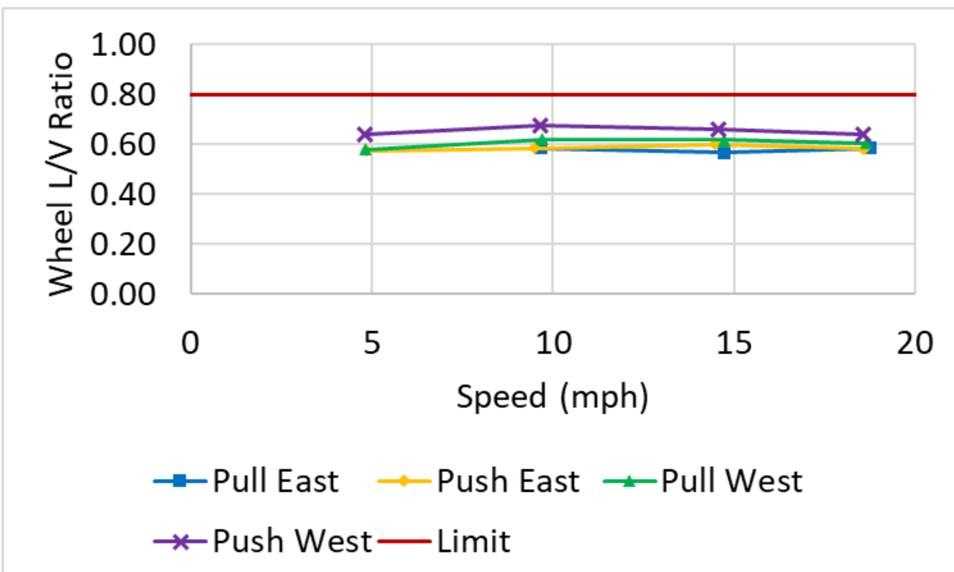

Figure 44. Atlas railcar single wheel L/V ratio results for crossover test

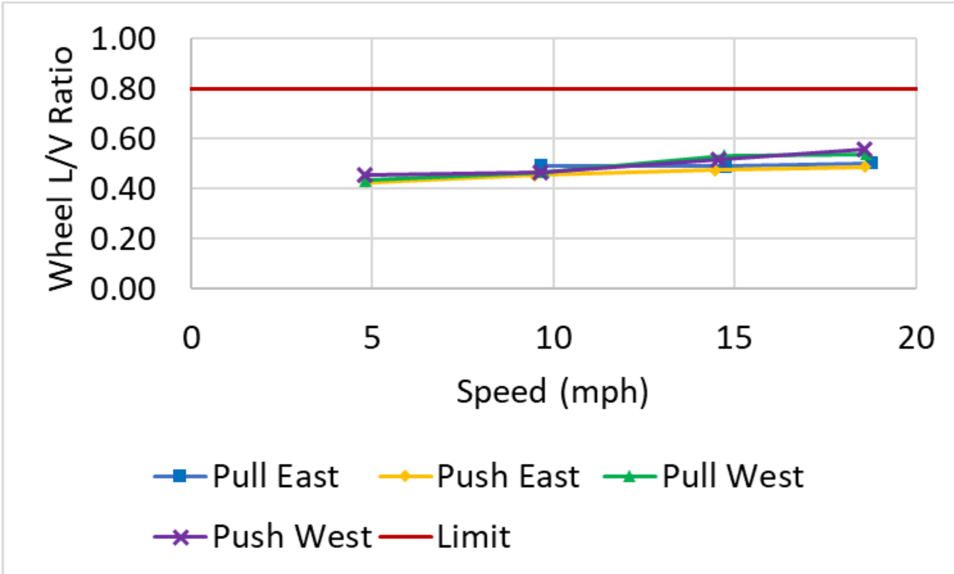

Figure 45. Buffer railcar single wheel L/V ratio results for crossover test

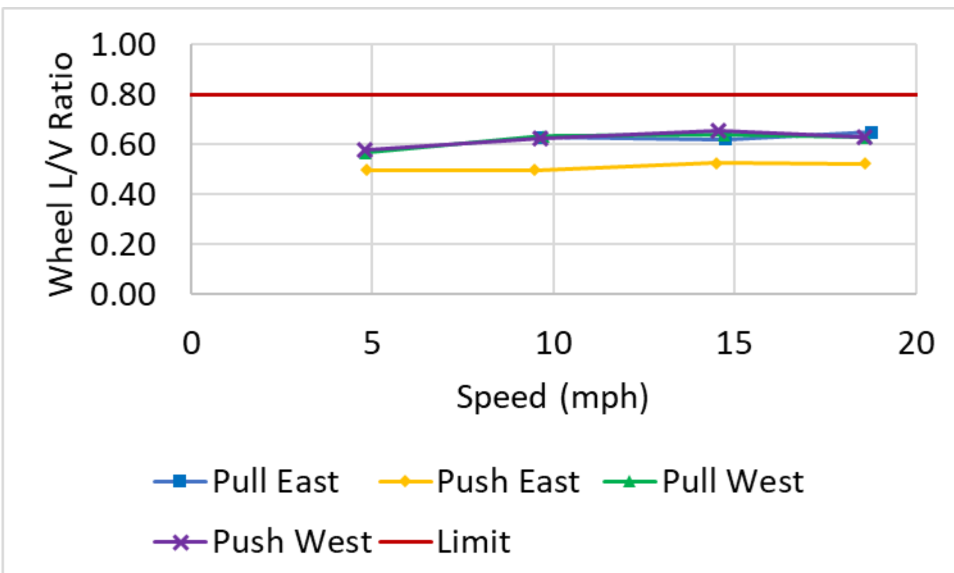

Figure 46. REV single wheel L/V ratio results for crossover test

8.1.2 Tight Curves – 12-degree Curve at the TTC Controlled Test Site

The last published revision of Standard S-2043 (2017) required that the tight curve test (paragraph 6.3.1.2) be performed in a curve with radius no greater than 410 feet (14 degrees). Because of the difficulty identifying a 14-degree curve in revenue service for testing, the EEC Standard S-2043 Task Force edited this requirement in January 2021 to allow testing on a 10-degree curve. At that time an additional requirement to test on a 12-degree curve at the controlled test site was added if the revenue service curve was less than 12 degrees. The controlled site test was performed on the 12-degree curve of the WRM test track at the TTC. On

September 15, 2022, the test was carried out per Standard S-2043 requirements and observed by Matt DeGeorge, MxV Rail Senior Engineer II.

The tests were conducted with the locomotive coupled to the B-end of IDOX 20002 (see Figure 41 for train configuration) operating with the locomotive pulling CW and pushing CCW on the loop. The train was then turned and operated with the locomotive pulling CCW and pushing CW on the loop. Table 33 lists the friction measurements taken during and after testing.

In his review of the Atlas post-test modeling report, Bill Shust, independent reviewer, expressed concern that the Atlas railcar may cause gage spreading while operating at low speeds in tight curves. To address this concern, the EEC directed DOE and MxV Rail to measure gage spreading caused by the car as it passes through curves at walking speed. MxV Rail measured the gage spreading using a fish scale, a device that indicates the maximum displacement of the railhead since the device was zeroed. To show how the displacement is measured, Figure 47 shows the zeroed device (left) and the device after it was manually displaced (right). The displacement indicated in Figure 47 is much greater than any displacement measured during the test.

Figure 47. Fish scale placed on 12-degree curve

The track was continuously welded 136-pound rail attached to concrete ties with elastic fasteners, and the fish scales were placed in the body of the curve. The railhead displacements from the locomotive and the Atlas railcar passing by the fish scales at walking speed are shown in Table 34. The largest displacement from the Atlas railcar was 0.043 inches. For comparison, the largest displacement from the locomotive (four axle, GP40-2 with high-speed trucks) was 0.062 inches.

Table 35 through Table 38 show the worst-case test results for the Atlas rail car, the lead Buffer car, the trailing Buffer car, and the REV, respectively. All four railcars met Standard S-2043 criteria for the tight curve test on the WRM 12-degree curve at the TTC controlled test site.

Table 33. WRM 12-degree curve rail friction measurements

Date	Time	Gage Face Inside Rail	Gage Face Outside Rail	Railhead Inside Rail	Railhead Outside Rail
9-15-22	13:20	0.46	0.47	0.48	0.49
9-15-22	14:30	0.46	0.47	0.49	0.48

Table 34. Rail head deflection measurements

Test Run	Lead Locomotive		Atlas Car	
	Inside Rail (inch)	Outside Rail (inch)	Inside Rail (inch)	Outside Rail (inch)
B-end Lead Pull	0.063	0.063	0.047	0.031
A-end Lead Push	0.063	0.016	0.031	0.015
B-end Lead Pull	0.031	0.031	0.031	0.031
A-end Lead Push	0.063	0.031	0.047	0.031

Table 35. Atlas WRM 12-degree curve results

Criterion	Limiting Value	Push CW	Push CCW	Pull CW	Pull CCW
Roll Angle (degree)	4	0.5	0.5	0.5	0.5
Maximum wheel L/V ratio	0.8	0.53	0.52	0.56	0.48
Maximum truck side L/V ratio	0.5	0.35	0.33	0.34	0.35
Minimum vertical wheel load	25 (% of static)	47%	55%	53%	48%
Lateral peak-to-peak acceleration	1.3 (g)	0.12	0.13	0.11	0.11
Maximum lateral acceleration	0.75 (g)	0.12	0.13	0.11	0.13
Lateral acceleration standard deviation	0.13 (g)	0.04	0.04	0.04	0.04
Maximum vertical acceleration	0.90 (g)	0.14	0.15	0.16	0.15
Maximum vertical suspension deflection	95 (%)	16%	16%	16%	16%

Table 36. Lead Buffer (IDOX 20002) WRM 12-degree curve results

Criterion	Limiting Value	Push CW	Push CCW	Pull CW	Pull CCW
Roll Angle (degree)	4	0.5	0.4	0.5	0.4
Lateral peak-to-peak acceleration	1.3 (g)	0.16	0.15	0.14	0.16
Maximum lateral acceleration	0.75 (g)	0.11	0.15	0.14	0.13
Lateral acceleration standard deviation	0.13 (g)	0.04	0.04	0.04	0.04
Maximum vertical acceleration	0.90 (g)	0.34	0.16	0.19	0.15
Maximum vertical suspension deflection	95 (%)	43%	36%	44%	40%

* This car did not have IWS installed so some parameters (Maximum wheel L/V ratio, Maximum truck side L/V ratio, and Minimum vertical wheel load) were not measured

Table 37. Trail Buffer (IDOX 20001) WRM 12-degree curve results

Criterion	Limiting Value	Push CW	Push CCW	Pull CW	Pull CCW
Roll Angle (degree)	4	0.5	0.5	0.5	0.5
Maximum wheel L/V ratio	0.8	0.42	0.47	0.41	0.46
Maximum truck side L/V ratio	0.5	0.26	0.27	0.25	0.28
Minimum vertical wheel load	25 (% of static)	63%	66%	70%	64%
Lateral peak-to-peak acceleration	1.3 (g)	0.21	0.19	0.16	0.23
Maximum lateral acceleration	0.75 (g)	0.13	0.13	0.13	0.15
Lateral acceleration standard deviation	0.13 (g)	0.04	0.04	0.04	0.04
Maximum vertical acceleration	0.90 (g)	0.17	0.17	0.20	0.16
Maximum vertical suspension deflection	95 (%)	50%	47%	51%	45%

Table 38. REV WRM 12-degree curve results

Criterion	Limiting Value	Push CW	Push CCW	Pull CW	Pull CCW
Roll Angle (degree)	4	0.7	0.6	0.4	0.6
Maximum wheel L/V ratio	0.8	0.40	0.44	0.61	0.50
Maximum truck side L/V ratio	0.5	0.24	0.31	0.30	0.28
Minimum vertical wheel load	25 (% of static)	55%	53%	54%	54%
Lateral peak-to-peak acceleration	0.6 (g)	0.38	0.20	0.17	0.20
Maximum lateral acceleration	0.35 (g)	0.33	0.15	0.14	0.16
Lateral acceleration standard deviation	0.13 (g)	0.04	0.05	0.04	0.04
Maximum vertical acceleration	0.60 (g)	0.41	0.39	0.26	0.22
Maximum vertical suspension deflection	95 (%)	35%	41%	38%	40%

8.1.3 Tight Curves – 10-degree Curve in Revenue Service

MxV Rail selected the 10-degree curve at Alps, New Mexico, on BNSF's Twin Peaks Subdivision for the revenue service 10-degree curve test (Figure 48). This curve was selected to satisfy the requirements of Standard S-2043, paragraph 6.3.1.2. The tests were initially performed in October 2022 with AAR-1B narrow flange wheel profiles. During these tests, MxV Rail measured many instances of single wheel L/V ratios and truck side L/V ratios that did not meet Standard S-2043 criteria. The data presented in this section was measured using AAR-2A narrow flange wheel profiles in June 2023. The change from AAR-1B narrow flange profile to AAR-2A narrow flange profile dramatically improved the performance of the train and is described in Section 4.0. Matthew Wenger, MxV Rail Senior Engineer III, observed the tests per Standard S-2043 requirements. Table 39 shows the friction levels measured during the tests.

Figure 48. Location of the Alps 10-degree curve

Table 39. Alps 10-degree curve rail friction measurements

Date	Time	Gage Face Inside Rail	Gage Face Outside Rail	Railhead Inside Rail	Railhead Outside Rail
2023-06-27	15:00	0.36	0.36	0.44	0.49
2023-06-27	16:30	0.40	0.39	0.44	0.50
2023-06-29	15:15	0.42	0.37	0.39	0.48
2023-06-29	16:40	0.34	0.29	0.50	0.48

The test train was configured as shown in Figure 41. The Atlas railcar had six IWS installed in the E, F, and A-trucks under the A-span bolster. The trailing Buffer car (IDOX 20001) had two IWS installed in the A-truck, and the REV had two IWS installed in the B-truck. The brakes on the A-span bolster of the Atlas railcar, the trailing Buffer car, and the REV were disabled 1) to prevent damage to the IWS and 2) because brakes may interfere with the function of the IWS. A letter (Appendix G) from Michael Lodge (FRA) to Steve Belport (MxV Rail) authorizing the one-time move of the train with disabled brakes required that locomotives be used at each end of the test train and that at least 19 braking cars be added to the train to ensure that at least 85 percent of the axles were braked. Twenty-three braking cars, provided by BNSF, were coupled to the A-end of the REV.

One locomotive was coupled to the leading Buffer car, and a second locomotive was coupled to the last braking car. For tests in the Alps curve the train was operated from one locomotive with the other unit cut out. The locomotive engineer and conductor controlled the train from the operating locomotive while a brakeman (who was also qualified as an engineer) protected shoving movements from the cut out locomotive. The tests were performed with the locomotive coupled to the leading Buffer car pushing and pulling, the crew swapped ends, and the tests were repeated with the locomotive coupled to the last braking car pushing and pulling. Test runs were performed at 10-, 15-, 20-, and 25-mph. Tests were performed with the leading Buffer oriented to the south on June 27, 2023, and the leading Buffer car oriented to the north on June 29, 2023. A total of 32 runs were planned for the test. Table 40 and Table 41 show the worst-case results for the Atlas railcar with the B-end leading and A-end leading, respectively. Table 42 and Table 43 show the worst-case results for the leading Buffer (IDOX 20002) car with the B-end leading and A-end leading, respectively. Table 44 and Table 45 show the worst-case results for the trailing Buffer car (IDOX 20001) with the B-end leading and A-end leading, respectively. Table 46 and Table 47 show the worst-case results for the REV car with the B-end leading and A-end leading, respectively. The following series of figures show the trend in truck side L/V results with B-end leading and A-end leading: Figure 49 and Figure 50 show the Atlas railcar results; Figure 51 and Figure 52 show the trailing Buffer car (IDOX 20001) results; and Figure 53 and Figure 54 show the REV results.

The Atlas railcar did not meet the Standard S-2043 criterion for truck side L/V ratio (max 6-foot value = 0.53, limit = 0.5) during the first 10-mph run with the B-end leading going north in draft. The maximum value occurred on the inside (low) rail at the trailing truck in the exit spiral of the curve. After the remainder of the test series was completed, this run was repeated and on the second run all the criteria were met. Figure 55 shows an overlay of the run that did not meet criteria with the repeat run that did meet criteria. The difference in truck side L/V ratio between the two runs may be due to changes in the wheel-rail friction during the test series. The Atlas railcar met all other criteria on this test run and met all criteria for the other test runs. The Buffer and REV car met criteria for all the runs over the Alps curve. On behalf of the DOE, MxV Rail requests an exception from the AAR EEC to approve the Atlas train because the one exception to the truck-side L/V ratio criterion still meets the Chapter 11 criterion, was not reproduced on a repeat run, and also represents a significant improvement over the performance measured with the AAR-1B profile.

Table 40. Atlas B-end lead Alps 10-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.2	0.2	0.2	0.4
Maximum wheel L/V ratio	0.8	0.76	0.74	0.76	0.71
Maximum truck side L/V ratio	0.5	0.48	0.43	0.53	0.42
Minimum vertical wheel load	25 (% of static)	57%	65%	63%	65%
Lateral peak-to-peak acceleration	1.3 (g)	0.16	0.16	0.29	0.18
Maximum lateral acceleration	0.75 (g)	0.10	0.12	0.19	0.13
Lateral acceleration standard deviation	0.13 (g)	0.04	0.02	0.04	0.02
Maximum vertical acceleration	0.90 (g)	0.09	0.10	0.26	0.12
Maximum vertical suspension deflection	95 (%)	12%	13%	12%	13%

Table 41. Atlas A-end lead Alps 10-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.2	0.2	0.22	0.4
Maximum wheel L/V ratio	0.8	0.77	0.77	0.76	0.74
Maximum truck side L/V ratio	0.5	0.47	0.48	0.47	0.44
Minimum vertical wheel load	25 (% of static)	60%	60%	60%	60%
Lateral peak-to-peak acceleration	1.3 (g)	0.19	0.17	0.20	0.18
Maximum lateral acceleration	0.75 (g)	0.14	0.11	0.14	0.14
Lateral acceleration standard deviation	0.13 (g)	0.04	0.03	0.03	0.02
Maximum vertical acceleration	0.90 (g)	0.14	0.12	0.20	0.17
Maximum vertical suspension deflection	95 (%)	12%	12%	11%	12%

Table 42. Lead Buffer (IDOX 20002) B-end lead Alps 10-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.3	0.3	0.3	0.5
Lateral peak-to-peak acceleration	1.3 (g)	0.21	0.20	0.25	0.20
Maximum lateral acceleration	0.75 (g)	0.10	0.16	0.11	0.14
Lateral acceleration standard deviation	0.13 (g)	0.03	0.04	0.04	0.03
Maximum vertical acceleration	0.90 (g)	0.11	0.10	0.20	0.10
Maximum vertical suspension deflection	95 (%)	34%	42%	32%	40%

*This car did not have IWS installed so some parameters (Maximum wheel L/V ratio, Maximum truck side L/V ratio, and Minimum vertical wheel load) were not measured

Table 43. Lead Buffer (IDOX 20002) A-end lead Alps 10-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.3	0.4	0.3	0.5
Lateral peak-to-peak acceleration	1.3 (g)	0.20	0.19	0.19	0.19
Maximum lateral acceleration	0.75 (g)	0.16	0.12	0.18	0.10
Lateral acceleration standard deviation	0.13 (g)	0.03	0.03	0.04	0.03
Maximum vertical acceleration	0.90 (g)	0.13	0.08	0.13	0.10
Maximum vertical suspension deflection	95 (%)	46%	31%	39%	28%

*This car did not have IWS installed so some parameters (Maximum wheel L/V ratio, Maximum truck side L/V ratio, and Minimum vertical wheel load) were not measured

Table 44. Trail Buffer (IDOX 20001) B-end lead Alps 10-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.3	0.4	0.3	0.5
Maximum wheel L/V ratio	0.8	0.70	0.74	0.73	0.76
Maximum truck side L/V ratio	0.5	0.41	0.48	0.43	0.49
Minimum vertical wheel load	25 (% of static)	81%	83%	82%	81%
Lateral peak-to-peak acceleration	1.3 (g)	0.19	0.19	0.23	0.19
Maximum lateral acceleration	0.75 (g)	0.13	0.14	0.18	0.13
Lateral acceleration standard deviation	0.13 (g)	0.04	0.03	0.04	0.03
Maximum vertical acceleration	0.90 (g)	0.11	0.12	0.24	0.11
Maximum vertical suspension deflection	95 (%)	40%	37%	39%	38%

Table 45. Trail Buffer (IDOX 20001) A-end Lead Alps 10-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.3	0.4	0.3	0.4
Maximum wheel L/V ratio	0.8	0.73	0.75	0.75	0.69
Maximum truck side L/V ratio	0.5	0.45	0.39	0.46	0.37
Minimum vertical wheel load	25 (% of static)	76%	80%	78%	81%
Lateral peak-to-peak acceleration	1.3 (g)	0.21	0.18	0.20	0.18
Maximum lateral acceleration	0.75 (g)	0.15	0.12	0.15	0.11
Lateral acceleration standard deviation	0.13 (g)	0.03	0.03	0.04	0.03
Maximum vertical acceleration	0.90 (g)	0.25	0.08	0.22	0.12
Maximum vertical suspension deflection	95 (%)	46%	33%	46%	30%

Table 46. REV B-end Lead Alps 10-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.40	0.4	0.4	0.7
Maximum wheel L/V ratio	0.8	0.67	0.73	0.76	0.69
Maximum truck side L/V ratio	0.5	0.40	0.44	0.44	0.42
Minimum vertical wheel load	25 (% of static)	71%	71%	71%	71%
Lateral peak-to-peak acceleration	0.6 (g)	0.25	0.21	0.28	0.23
Maximum lateral acceleration	0.35 (g)	0.18	0.16	0.22	0.17
Lateral acceleration standard deviation	0.13 (g)	0.04	0.04	0.04	0.04
Maximum vertical acceleration	0.60 (g)	0.12	0.13	0.17	0.12
Maximum vertical suspension deflection	95 (%)	43%	29%	38%	26%

Table 47. REV A-end Lead Alps 10-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.5	0.3	0.4	0.5
Maximum wheel L/V ratio	0.8	0.58	0.70	0.60	0.69
Maximum truck side L/V ratio	0.5	0.44	0.39	0.45	0.38
Minimum vertical wheel load	25 (% of static)	69%	73%	69%	72%
Lateral peak-to-peak acceleration	0.6 (g)	0.27	0.22	0.29	0.21
Maximum lateral acceleration	0.35 (g)	0.17	0.15	0.20	0.15
Lateral acceleration standard deviation	0.13 (g)	0.04	0.04	0.05	0.03
Maximum vertical acceleration	0.60 (g)	0.16	0.11	0.12	0.12
Maximum vertical suspension deflection	95 (%)	32%	37%	31%	32%

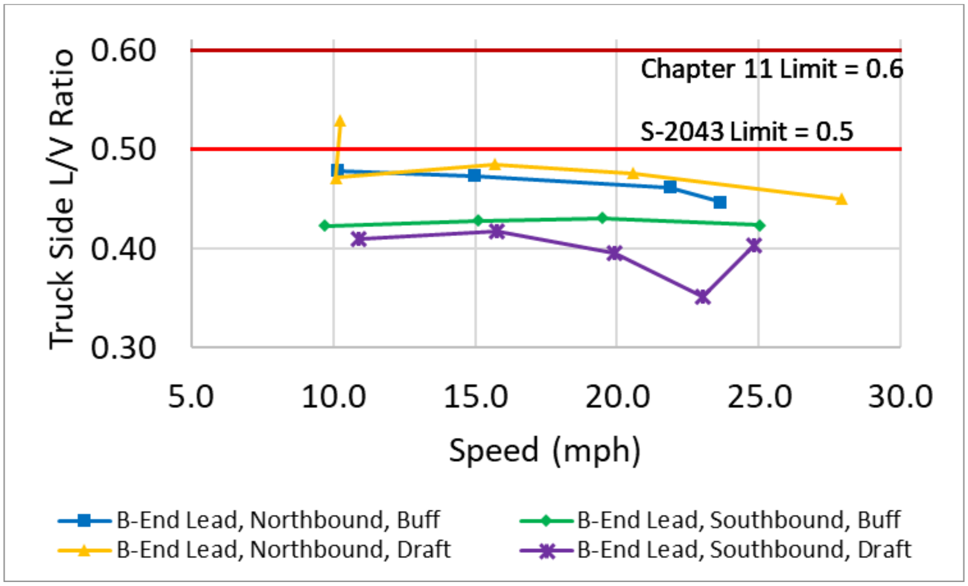

Figure 49. Trend in Atlas railcar truck side L/V ratios, B-end leading runs

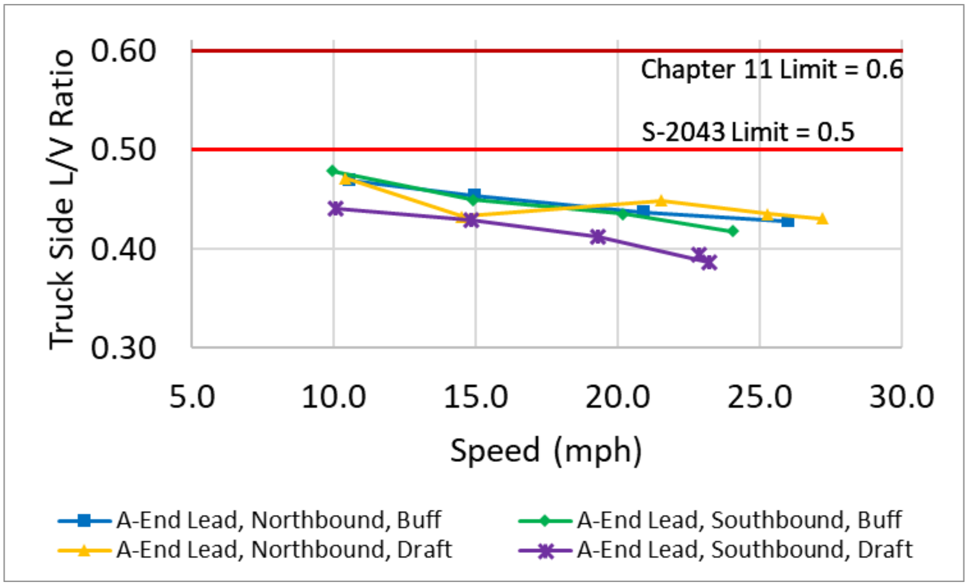

Figure 50. Trend in Atlas railcar truck side L/V ratios, A-end leading runs

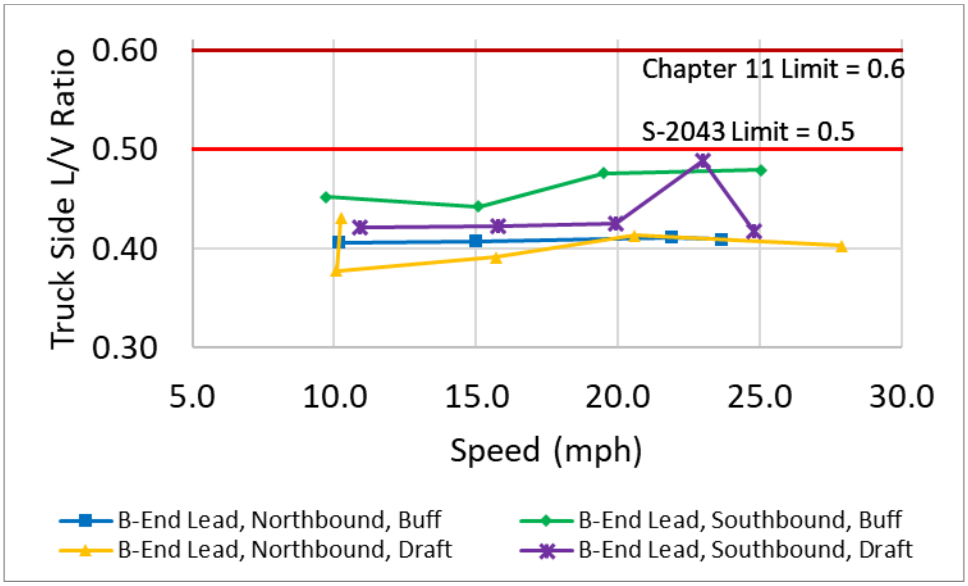

Figure 51. Trend in Buffer car truck side L/V ratios, B-end leading runs

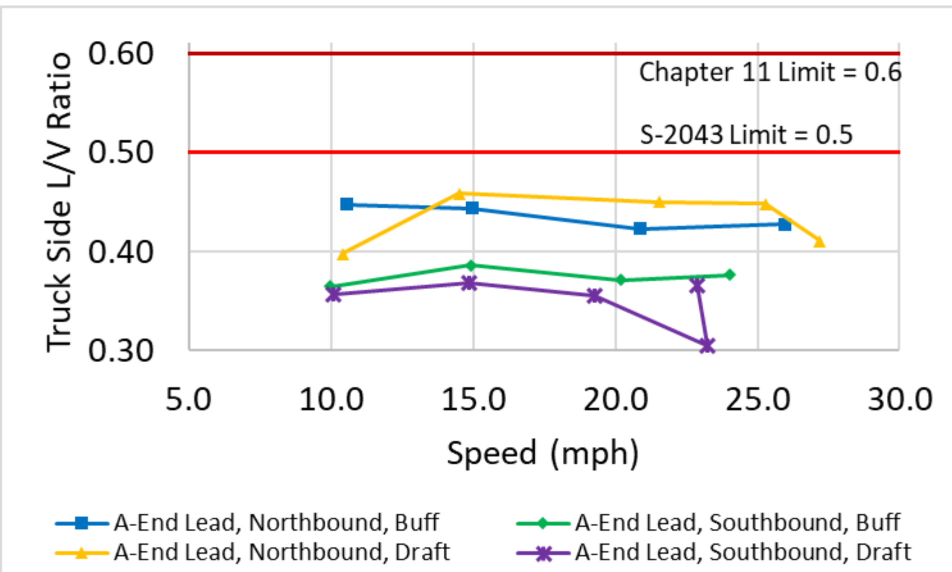

Figure 52. Trend in Buffer car truck side L/V ratios, A-end leading runs

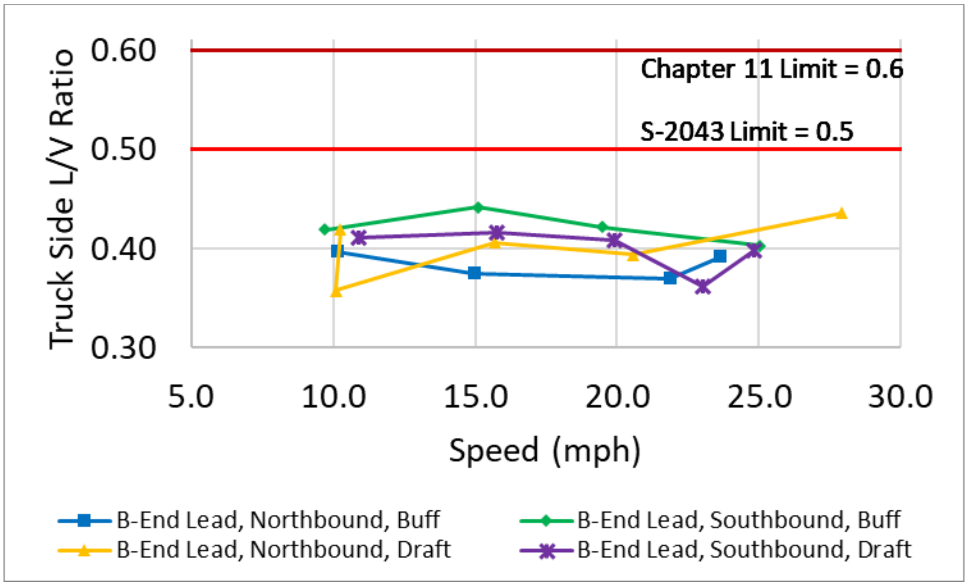

Figure 53. Trend in REV truck side L/V ratios, B-end leading runs

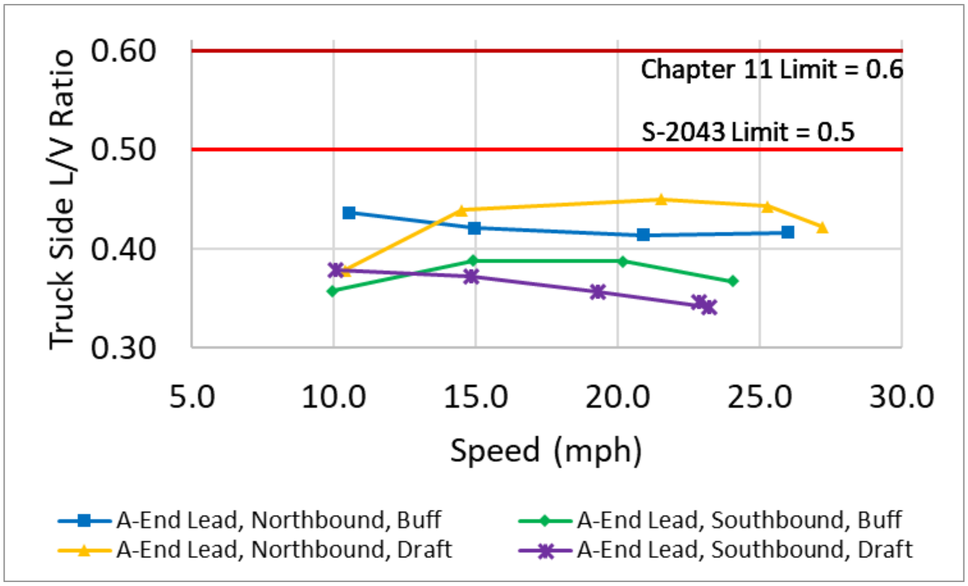

Figure 54. Trend in REV car truck side L/V ratios, A-end leading runs

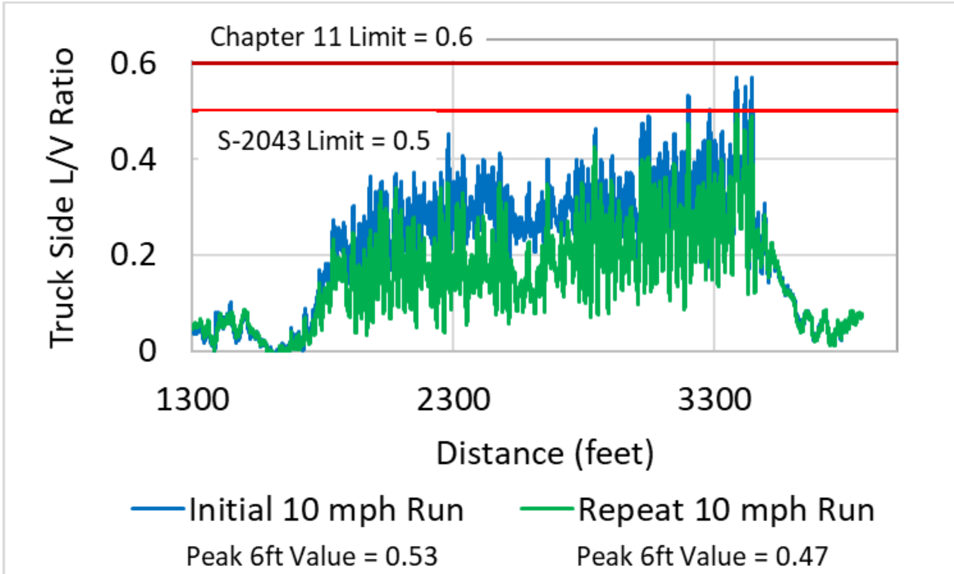

Figure 55. Atlas railcar A-truck left side truck side L/V ratio B-end leading, draft, northbound, 10-mph, showing run with exception and repeat run

8.2 Class 2 Maintained Track

Standard S-2043, paragraph 6.3.2 Class 2 Maintained Track requires:

> "*The multiple-car test train shall be run on lead tracks, branch lines, feeder lines, etc. Tracks should be representative of those expected to be encountered during HLRM service, and should include the following:*
>
> - *A minimum length of 20 route miles to ensure that exposure to a variety of track geometry conditions is obtained. At least 5 miles of the route should be maintained to no better than FRA class 2 (or worse).*
> - *A variety of curves including at least one curve of at least 10°.*
> - *At least one No. 10 turnout (or sharper) on diverging route.*
> - *At least one No. 12 crossover (or sharper) on 15 ft centers (or narrower).*
>
> *A route description, speed profile, measured track geometry, track geometry exception report, or other data to document the track route and condition shall be provided to EEC for review to ensure that the selected track meets the intent of this section. Table 5.1 performance criteria apply. These tests require the use of instrumented wheel sets.*"

Data to fulfill the requirement for "five miles of the route maintained to no better than FRA class 2" are presented in Section 8.2.1. Data to fulfill the requirement for the remainder of the "minimum length of 20 route miles" are presented in Section 8.2.2. Data to fulfill the requirement "A variety of curves including at least one curve of at least 10°" are presented in Section 8.2.3. Data to fulfill the requirement "At least one No. 10 turnout (or sharper) on diverging route" and the requirement "At least one No. 12 crossover (or sharper) on 15 feet centers (or narrower)" overlap with the requirements of Standard S-2043, paragraph 6.3.1.1 and are presented in Section 8.1.1.

8.2.1 Minimum 5 Route Miles Maintained to FRA Class 2

The required five route miles of FRA Class 2 maintained track was recorded on the PCD mainline track between the depot's north and south gates (Figure 56). The tests performed per Standard S-2043 requirements on September 21 and 22 were observed by Matt DeGeorge, MxV Rail Senior Engineer II, and the October 11 test was observed by Steve Belport, MxV Rail Principal Investigator II. Figure 56 shows the five-mile route used for these tests. The test was conducted with the locomotive(s) coupled to the B-end of IDOX 20002 (see Figure 41 for train configuration) operating with the locomotive pulling and pushing as required. Test runs were performed at 20 mph.

Figure 57 shows a plot of the curvature, cross level, and gage for the FRA Class 2 track section. The gage appears to exceed the maximum Class 2 limit at approximately 10,700 feet and gage falls below the minimum limit at several locations along the track. Figure 58 shows a plot of the left and right track profile (vertical position) and track alignment (lateral position). The track alignment appears to fall outside of the class to limits at 10,700 feet. Figure 59 shows a plot of speed, left and right alignment, and gage, zoomed in to the critical areas. The gage appears to be a very short duration spike. The gage drops below 56 inches in several locations is likely due to lips developing on the gage face of tangent rails. The measurements of the alignment deviations may have been affected by the slow speed (approximately 10 mph) of the measurement car. Inertial measurements systems used for track geometry measurements are not always reliable at extremely slow speeds.

Table 48 through Table 51 show the worst-case test results for the Atlas rail car, the lead Buffer car, the trailing Buffer car, and the REV, respectively. All four railcars met Standard S-2043 criteria for the five miles of FRA Class 2 track at the PCD test site.

Figure 56. Location of the five route miles of track maintained to FRA Class 2 levels

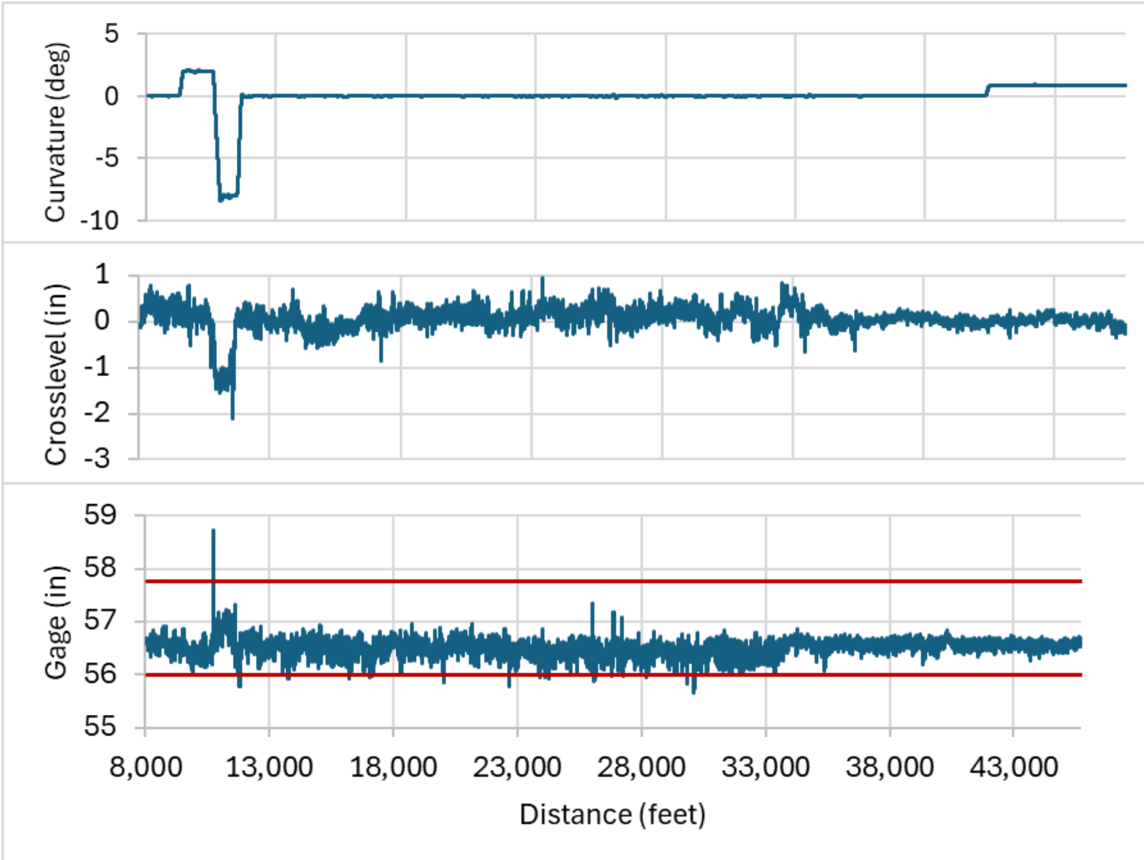

Figure 57. Plot of curvature, cross level, and gage for the FRA class 2 track section. Note: Red lines indicate Class 2 limits.

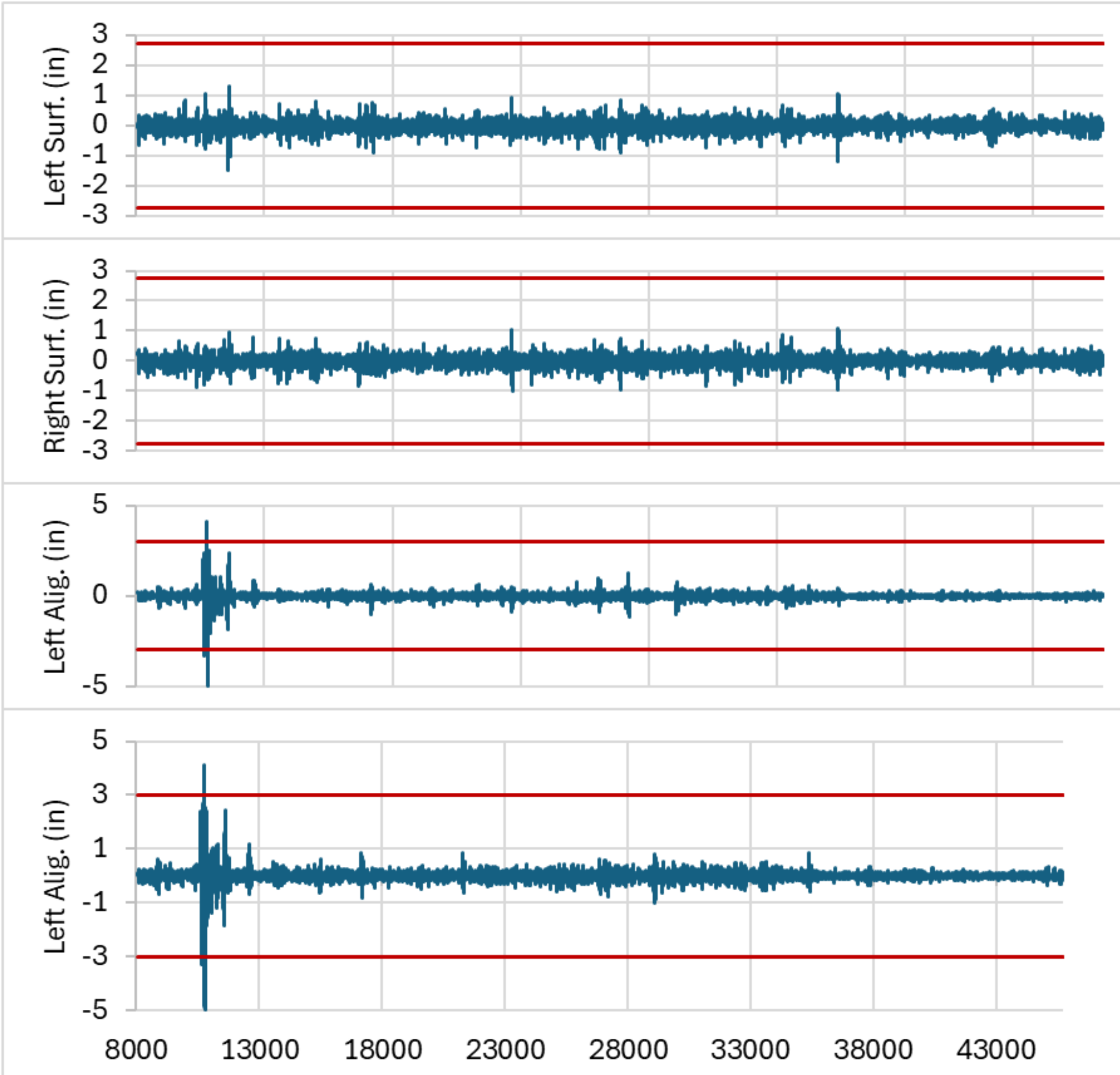

Figure 58. Plot of surface and alignment for the FRA class 2 track section.
Note: Red lines indicate Class 2 limits.

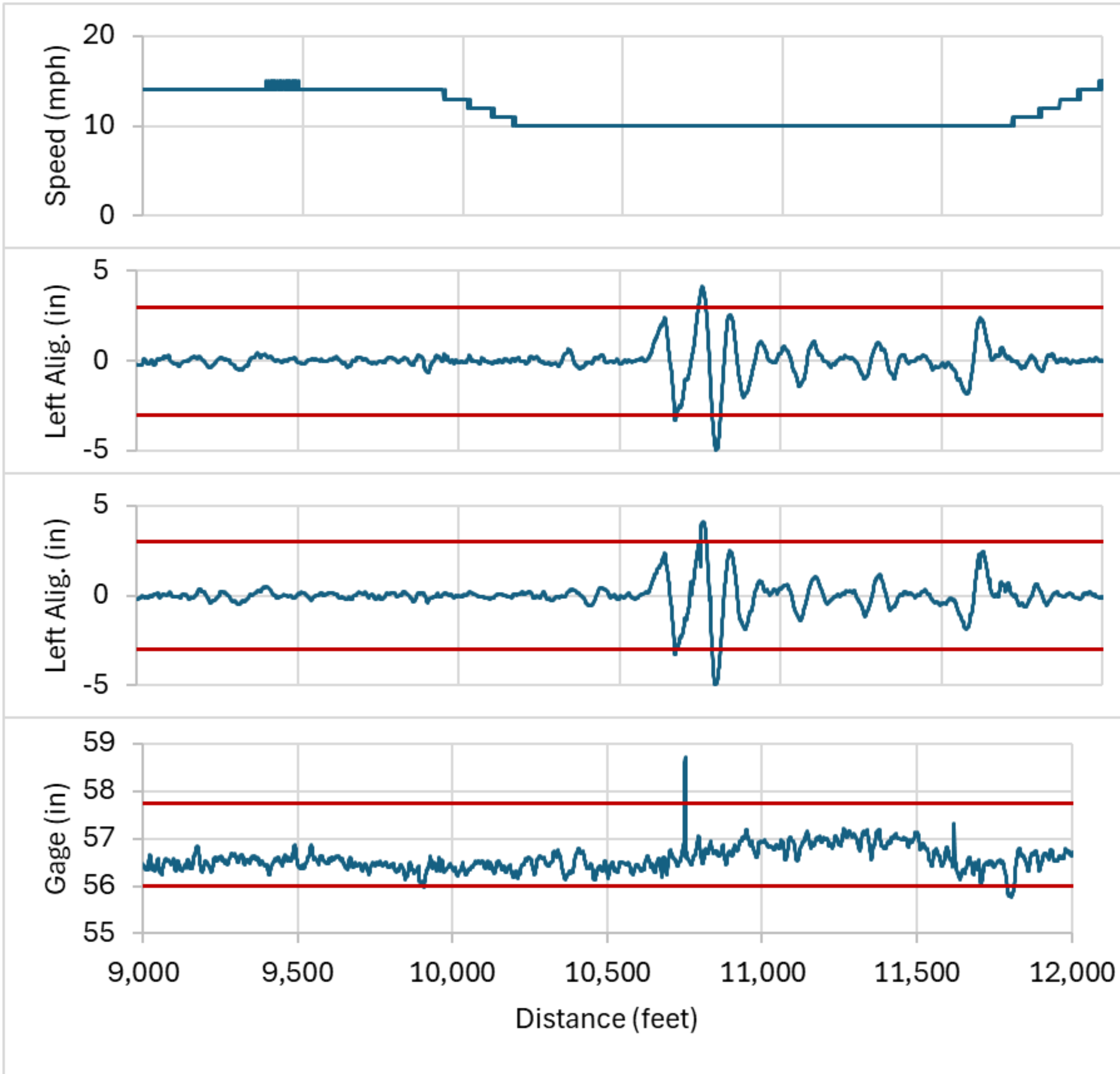

Figure 59. Zoomed in plot of speed, alignment, and gage for the FRA class 2 track section. Note: Red lines indicate Class 2 limits.

Table 48. Atlas Class 2 maintained track results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.4	0.4	0.3	0.4
Maximum wheel L/V ratio	0.8	0.67	0.62	0.54	0.67
Maximum truck side L/V ratio	0.5	0.44	0.38	0.34	0.42
Minimum vertical wheel load	25 (% of static)	54%	60%	59%	56%
Lateral peak-to-peak acceleration	1.3 (g)	0.22	0.21	0.24	0.19
Maximum lateral acceleration	0.75 (g)	0.12	0.11	0.12	0.13
Lateral acceleration standard deviation	0.13 (g)	0.03	0.02	0.02	0.02
Maximum vertical acceleration	0.90 (g)	0.25	0.27	0.29	0.27
Maximum vertical suspension deflection	95 (%)	*NM	21%	18%	17%

*NM indicates this value was not measured for this run. Weeds near the tracks had damaged several stringpots during previous test runs, so the stringpots were removed for this test.

Table 49. Lead Buffer (IDOX 20002) Class 2 maintained track results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.6	0.5	0.6	0.6
Lateral peak-to-peak acceleration	1.3 (g)	0.26	0.23	0.25	0.27
Maximum lateral acceleration	0.75 (g)	0.12	0.15	0.16	0.13
Lateral acceleration standard deviation	0.13 (g)	0.03	0.03	0.03	0.03
Maximum vertical acceleration	0.90 (g)	0.23	0.18	0.19	0.19
Maximum vertical suspension deflection	95 (%)	35%	26%	32%	36%

*This car did not have IWS installed so some parameters (Maximum wheel L/V ratio, Maximum truck side L/V ratio, and Minimum vertical wheel load) were not measured

Table 50. Trail Buffer (IDOX 20001) Class 2 maintained track results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.6	0.6	0.5	0.6
Maximum wheel L/V ratio	0.8	0.55	0.48	0.52	0.50
Maximum truck side L/V ratio	0.5	0.29	0.27	0.26	0.27
Minimum vertical wheel load	25 (% of static)	64%	76%	72%	73%
Lateral peak-to-peak acceleration	1.3 (g)	0.30	0.27	0.24	0.25
Maximum lateral acceleration	0.75 (g)	0.20	0.16	0.17	0.17
Lateral acceleration standard deviation	0.13 (g)	0.03	0.03	0.03	0.03
Maximum vertical acceleration	0.90 (g)	0.25	0.21	0.22	0.22
Maximum vertical suspension deflection	95 (%)	37%	33%	64%	54%

Table 51. REV Class 2 maintained track results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.8	0.7	0.7	0.8
Maximum wheel L/V ratio	0.8	0.69	0.57	0.64	0.57
Maximum truck side L/V ratio	0.5	0.34	0.26	0.30	0.31
Minimum vertical wheel load	25 (% of static)	64%	59%	55%	63%
Lateral peak-to-peak acceleration	0.6 (g)	0.35	0.28	0.36	0.28
Maximum lateral acceleration	0.35 (g)	0.19	0.19	0.20	0.18
Lateral acceleration standard deviation	0.13 (g)	0.03	0.03	0.03	0.03
Maximum vertical acceleration	0.60 (g)	0.21	0.29	0.19	0.23
Maximum vertical suspension deflection	95 (%)	30%	32%	41%	24%

8.2.2 Remaining Minimum 15 Miles - Variety of Track Geometry Conditions

MxV Rail recorded data over 196 route miles (Figure 57) enroute to the Alps test curve during the revenue service test to ensure exposure to a variety of track geometry conditions. The tracks from Avondale to La Junta to Trinidad were largely tangent with only mild curves. Train speed from Avondale to La Junta to Trinidad was 45 mph or less. The track from Trinidad to the siding at Folsom had many curves up to 6.5 degrees and two curves (Alps and Folsom) of 10 degrees. The train speed from Trinidad to Folsom was 35 mph or less. These tests were performed per Standard S-2043 requirements on June 26, 27, and 29, 2023 and were observed by Matthew Wenger, MxV Rail Senior Engineer III. Data for the Alps test curve the presented in Section 8.1.3, and data for the rest of the tracks are presented in this section. The tests described in this section were performed using wheelsets recently reprofiled to the AAR-2A narrow flange profile.

The test train was configured as shown in Figure 41. The Atlas railcar had six IWS installed in the E, F, and A-trucks under the A span bolster. The trailing Buffer car (IDOX 20001) had two IWS installed in the A-truck and the REV had two IWS installed in the B-truck. The brakes on the A-span bolster of the Atlas railcar, the trailing Buffer car, and the REV were disabled to prevent damage to the IWS and because brakes may interfere with the function of the IWS. The FRA letter (Appendix G) from Michael Lodge to Steve Belport authorizing the one-time move of the train with disabled brakes required that locomotives be used at each end of the test train and that at least 19 braking cars be added to the train to ensure that at least 85 percent of the axles were braked. Twenty-three braking cars, provided by BNSF, were coupled to the A-end of the REV. One locomotive was coupled to the leading Buffer car, and a second locomotive was coupled to the last braking car. The two locomotives were operated in distributed power mode for the tests described in this section.

Table 52 through Table 55 show the worst-case test results for the Atlas rail car, the lead Buffer car, the trailing Buffer car, and the REV, respectively. All four railcars met the Standard S-2043 criteria for the revenue service tracks between Avondale and Trinidad. The Atlas railcar showed truck side L/V exceptions in two curves when traveling between Trinidad and the Folsom siding on June 27 with the B-end leading southbound and A-end leading northbound. The Atlas railcar showed truck side L/V exceptions in two curves when traveling between Trinidad and the Folsom siding on June 29 with the A-end leading southbound and B-end leading northbound. The Atlas railcar also showed truck side L/V exceptions in two curves when traveling between Trinidad and the Folsom siding on June 29 with the A-end leading southbound and the B-end leading northbound.

Exceptions were measured on the Atlas railcar in five curves during the following tests:

1. One wheel L/V ratio exception was measured June 27 while traveling north with A-end leading in a six-degree curve. The exception (0.82, Figure 59) was on the high rail at Axle 12.
2. Several truck side L/V ratio exceptions were measured on June 27 while traveling north with B-end leading in a six-degree curve at 35 mph. Eleven exceptions on the low rail side of E truck (worst=0.56); four exceptions on the high rail side of E truck (worst=0.52); 17 exceptions on the low rail side of F truck (worst=0.56); and 13 exceptions on the low rail side of A truck (worst=0.57, Figure 59).
3. Three truck side L/V ratio exceptions were measured on June 27 while traveling North with B-end leading in a four-degree curve at 23 mph. All three exceptions were on the high rail side of A truck (worst=0.56).
4. Two truck side L/V ratio exceptions were measured on June 29 while traveling South with A-end leading in a six-degree curve at 31 mph. Both exceptions were on the high rail side of A truck (worst=0.54).
5. Several truck side L/V ratio exceptions were measured on June 29 while traveling south with A-end leading in a six-degree curve at 33 mph. Sixteen exceptions on the high rail

side of A truck (worst=0.56), and nine exceptions on the low rail side of A truck (worst=0.52).

Exceptions were measured on the REV in three curves during these tests:

1. One truck side L/V ratio exception was measured on June 27 while traveling south with B-end leading in a six-degree curve. The exception (0.51) occurred on the high rail side of the B-truck at 25 mph.
2. Several truck side L/V ratio exceptions were measured on June 27 while traveling south with B-end leading in a six-degree curve at 34 mph. One exception was measured on the low rail side of the B truck (0.55, Figure 60). Seven exceptions were measured on the high rail side of the B truck (worst = 0.54).
3. Three truck side L/V ratio exceptions were measured on June 29 while traveling south with A-end leading in a six-degree curve at 32 mph. All three exceptions were on the low rail side of A truck (worst=0.55).

These exceptions posed little risk of derailment because the track was built with elastic fasteners on concrete ties. In addition, the track was equipped with wayside lubricators, and the railhead had been ground like the rail shown in Figure 7 of Section 4.0.

On behalf of the DOE, MxV Rail requests an exception from the AAR EEC to approve the Atlas train because the exceptions to the truck-side L/V ratio criterion and the one exception to the wheel L/V ratio criterion still meet the Chapter 11 criterion and also represent a significant improvement over the performance measured with the AAR-1B profile.

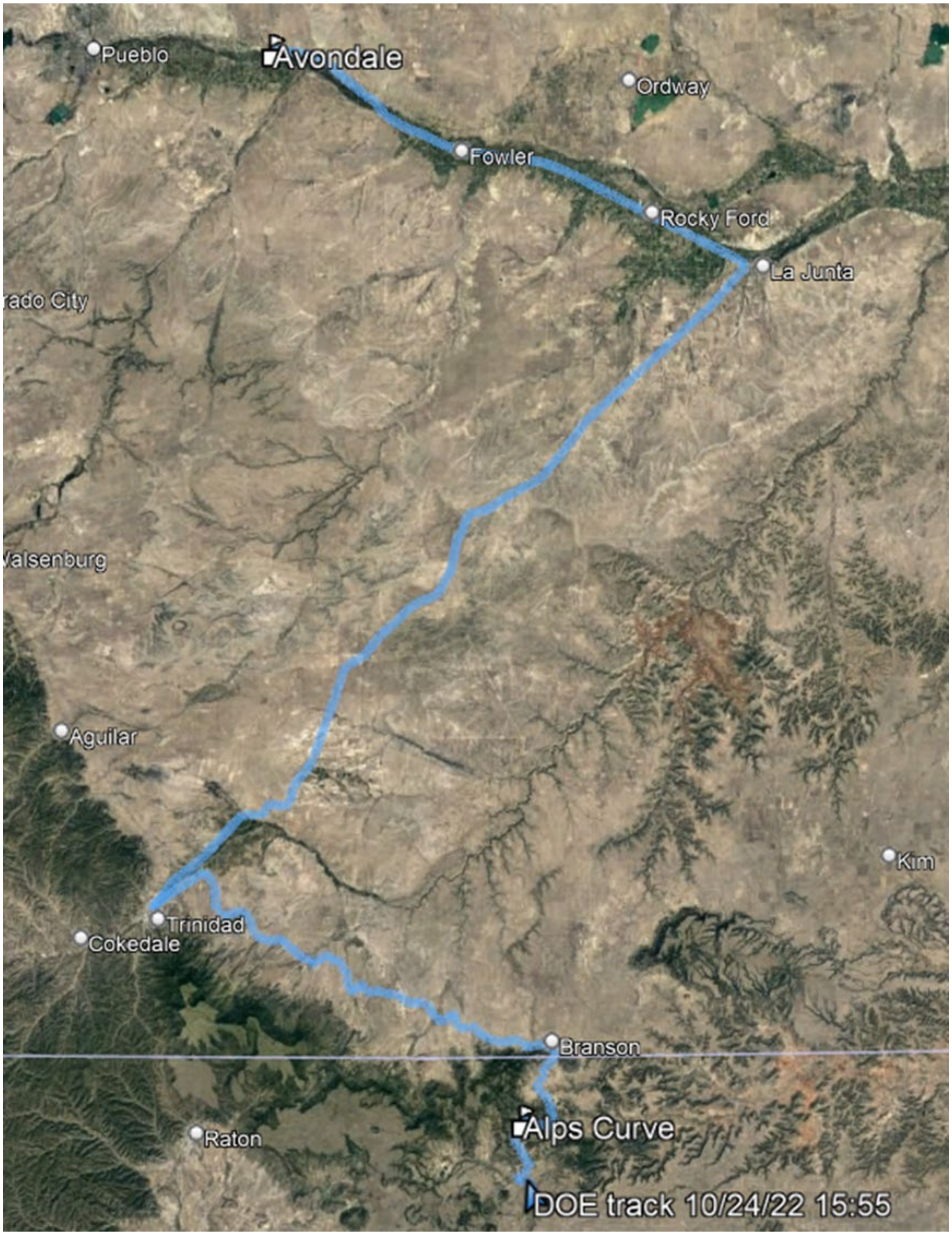

Figure 60. Location of the 196 route miles of track to ensure exposure to a variety of track geometry conditions

Table 52. Atlas revenue service track results

Criterion	Limiting Value	Avondale to Trinidad	Trinidad to Folsom June 27	Trinidad to Folsom June 29
Roll Angle (degree)	4	0.7	0.8	0.7
Maximum wheel L/V ratio	0.8	0.78	0.82	0.78
Maximum truck side L/V ratio	0.5	0.48	0.57	0.56
Minimum vertical wheel load	25 (% of static)	40%	51%	55%
Lateral peak-to-peak acceleration	1.3 (g)	0.22	0.23	0.25
Maximum lateral acceleration	0.75 (g)	0.15	0.16	0.16
Lateral acceleration standard deviation	0.13 (g)	0.03	0.05	0.05
Maximum vertical acceleration	0.90 (g)	0.40	0.25	0.27
Maximum vertical suspension deflection	95 (%)	21%	23%	21%

Table 53. Lead Buffer (IDOX 20002) revenue service track results

Criterion	Limiting Value	Avondale to Trinidad	Trinidad to Folsom June 27	Trinidad to Folsom June 29
Roll Angle (degree)	4	1.2	0.9	0.8
Lateral peak-to-peak acceleration	1.3 (g)	0.35	0.23	0.24
Maximum lateral acceleration	0.75 (g)	0.15	0.18	0.15
Lateral acceleration standard deviation	0.13 (g)	0.04	0.04	0.04
Maximum vertical acceleration	0.90 (g)	0.67	0.22	0.20
Maximum vertical suspension deflection	95 (%)	48%	48%	39%

*This car did not have IWS installed so some parameters (Maximum wheel L/V ratio, Maximum truck side L/V ratio, and Minimum vertical wheel load) were not measured

Table 54. Trail Buffer (IDOX 20001) revenue service track results

Criterion	Limiting Value	Avondale to Trinidad	Trinidad to Folsom June 27	Trinidad to Folsom June 29
Roll Angle (degree)	4	1.2	0.8	0.8
Maximum wheel L/V ratio	0.8	0.72	0.69	0.77
Maximum truck side L/V ratio	0.5	0.35	0.39	0.43
Minimum vertical wheel load	25 (% of static)	62%	70%	67%
Lateral peak-to-peak acceleration	1.3 (g)	0.33	0.21	0.22
Maximum lateral acceleration	0.75 (g)	0.20	0.13	0.15
Lateral acceleration standard deviation	0.13 (g)	0.07	0.04	0.04
Maximum vertical acceleration	0.90 (g)	0.60	0.28	0.33
Maximum vertical suspension deflection	95 (%)	57%	45%	41%

Table 55. REV revenue service track results

Criterion	Limiting Value	Avondale to Trinidad	Trinidad to Folsom June 27	Trinidad to Folsom June 29
Roll Angle (degree)	4	1.2	1.3	1.3
Maximum wheel L/V ratio	0.8	0.77	0.73	0.71
Maximum truck side L/V ratio	0.5	0.41	0.55	0.55
Minimum vertical wheel load	25 (% of static)	54%	59%	53%
Lateral peak-to-peak acceleration	0.6 (g)	0.37	0.26	0.26
Maximum lateral acceleration	0.35 (g)	0.20	0.15	0.19
Lateral acceleration standard deviation	0.13 (g)	0.06	0.04	0.04
Maximum vertical acceleration	0.60 (g)	0.52	0.24	0.27
Maximum vertical suspension deflection	95 (%)	34%	31%	37%

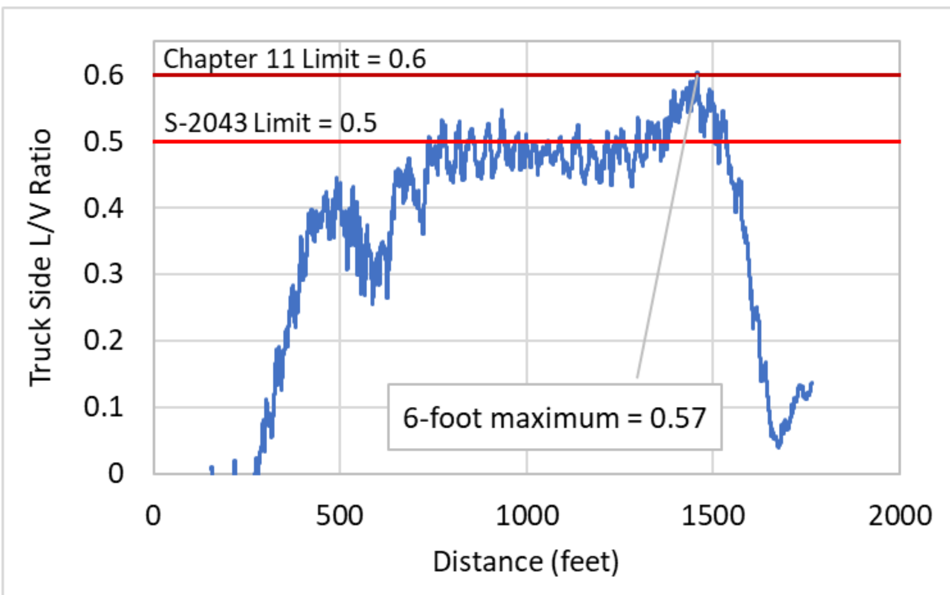

Figure 61. Atlas railcar A-truck left side truck side L/V ratio B-end leading in a six-degree curve while traveling from Trinidad to the Alps Curve

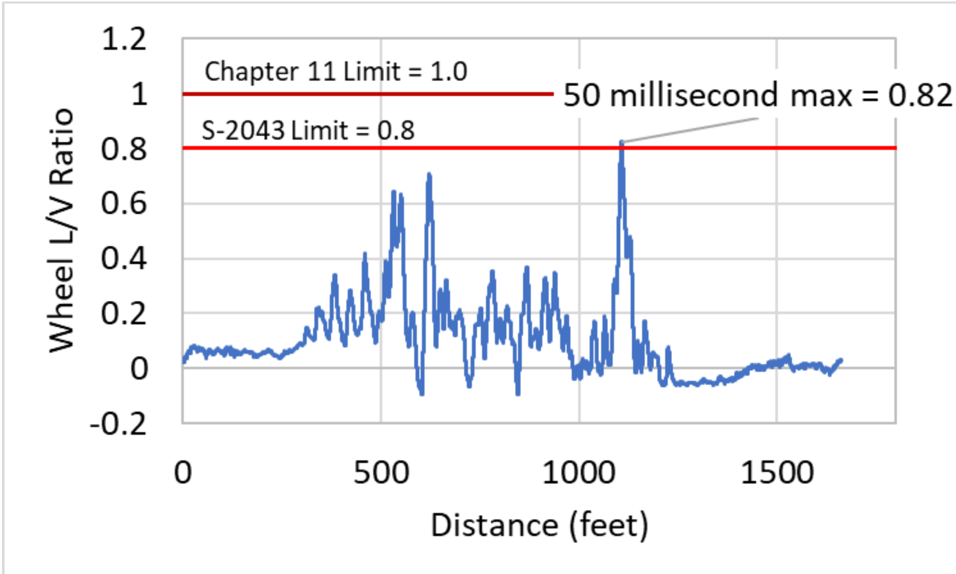

Figure 62. Atlas railcar axle 12 right wheel L/V ratio with A-end leading in a six-degree curve while traveling from the Alps curve to Trinidad

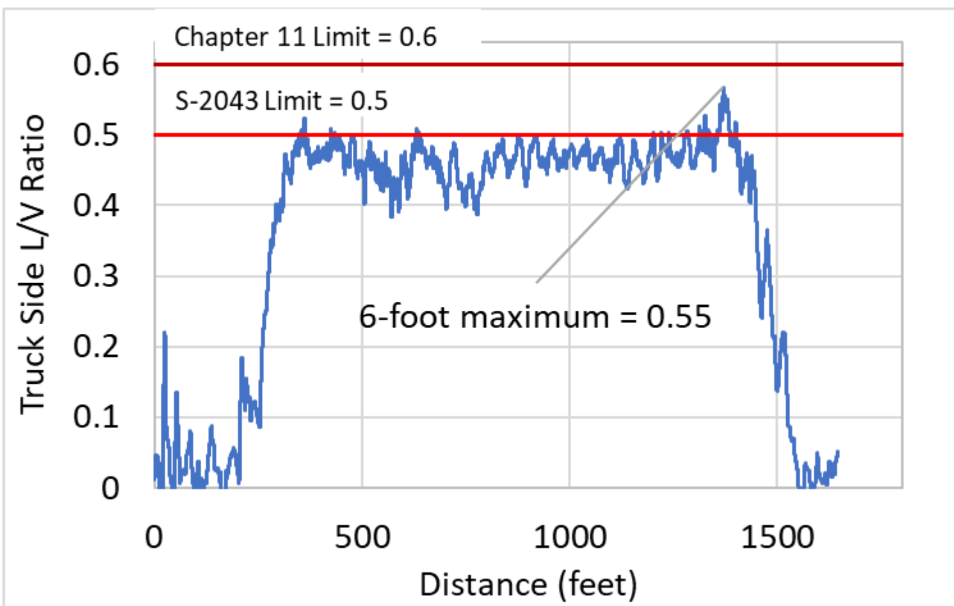

Figure 63. REV B-truck left, truck side L/V ratio B-end leading June 27 in six-degree curve enroute to Alps test curve

8.2.3 Tight Curves – 10- and 12-degree Curves at PCD Controlled Test Site

To fulfill the requirement to test on "A variety of curves including at least one curve of at least 10°," tests were performed at the 10-degree curve on the east leg of the PCD wye and the 12-degree curve southeast of the wye (Figure 42).

In his review of the Atlas post-test modeling report, Bill Shust, expert reviewer, expressed concern that the Atlas railcar may cause gage spreading while operating at low speeds in tight curves. To address this concern, the EEC directed DOE and MxV Rail to measure gage spreading caused by the car as it passes through curves at walking speed. MxV Rail measured the gage spreading using a fish scale, a device that indicates the maximum displacement of the railhead since the device was zeroed. To show how the displacement is measured, Figure 47 shows the zeroed device (left) and the device after it was manually displaced (right). The displacement indicated in Figure 47 is much greater than any displacement measured during the test.

At the PCD, the fish scales were placed in the body of the 10-degree curve, and. measurements were taken on the PCD curve to document gage widening on a different track condition than that of the 12-degree curve on the WRM loop at the TTC. The track on the 10-degree curve at the PCD is 115-pound jointed rail connected to wood ties with cut spikes. The railhead displacements from the locomotive and the Atlas railcar passing by the fish scales at walking speed are shown in Table 57. The largest railhead displacement from the Atlas railcar was 0.094 inches. For comparison, the largest railhead displacement from the locomotive was 0.109 inches.

The PCD tight curve test was done at EEC request to supplement the gage widening measurements and in partial fulfillment of the Standard S-2043, paragraph 6.3.2 Class 2 Maintained Track, representing about 0.5 miles of track. The test was performed on the 10- and 12-degree curves at the PCD. The test was carried out on September 22 and October 11, 2022. Per Standard S-2043 requirements, the test was observed by Matt DeGeorge, MxV Rail Senior Engineer II on September 22 and by Steve Belport, Principal Investigator II on October 11.

The test was conducted with the locomotive(s) coupled to the B-end of IDOX 20002 (see Figure 41 for train configuration) operating with the locomotive pulling and pushing as required. Test runs were performed at 5-, 10-, 15-, and 19-mph. These two curves do not have consistent superelevation throughout their length, so the unbalance corresponding to these speeds was not calculated. The friction measurements taken during and after testing are shown in Table 56.

Table 58 through Table 61 show the worst-case test results for the Atlas rail car, the lead Buffer car, the trailing Buffer car, and the REV, respectively. All four railcars met Standard S-2043 criteria for the tight curve test on the 10- and 12-degree curve at the PCD test site.

Table 56. PCD 10-degree curve rail friction measurements

Date	Time	Gage Face Inside Rail	Gage Face Outside Rail	Railhead Inside Rail	Railhead Outside Rail
2022-10-11	15:30	0.45	0.44	0.47	0.45
2022-10-11	15:30	0.42	0.45	0.44	0.43
2022-10-11	17:00	0.41	0.43	0.43	0.42
2022-10-11	17:00	0.43	0.44	0.42	0.49

Table 57. Rail head deflection measurements

Test Run	Locomotive		Atlas Car	
	Inside Rail (inch)	Outside Rail (inch)	Inside Rail (inch)	Outside Rail (inch)
B-end Lead Pull South Two 4-axle locomotives	0.078	0.063	0.063	0.063
A-end Lead Push North One 6-axle loco. with radial trucks	0.094	0.094	0.078	0.063
B-end Lead Pull South One 6-axle loco. with radial trucks	0.109	0.109	0.078	0.063
A-end Lead Push North One 6-axle loco. with radial trucks	0.094	0.094	0.094	0.063

Table 58. Atlas PCD 10- and 12-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.5	0.6	0.4	0.5
Maximum wheel L/V ratio	0.8	0.69	0.75	0.71	0.69
Maximum truck side L/V ratio	0.5	0.44	0.47	0.43	0.44
Minimum vertical wheel load	25 (% of static)	44%	43%	45%	46%
Lateral peak-to-peak acceleration	1.3 (g)	0.27	0.26	0.25	0.23
Maximum lateral acceleration	0.75 (g)	0.16	0.23	0.18	0.18
Lateral acceleration standard deviation	0.13 (g)	0.04	0.04	0.04	0.03
Maximum vertical acceleration	0.90 (g)	0.24	0.24	0.24	0.22
Maximum vertical suspension deflection	95 (%)	20%	39%	31%	22%

Table 59. Lead Buffer (IDOX 20002) PCD 10- and 12-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.8	0.8	0.8	0.8
Lateral peak-to-peak acceleration	1.3 (g)	0.29	0.29	0.34	0.26
Maximum lateral acceleration	0.75 (g)	0.19	0.16	0.13	0.16
Lateral acceleration standard deviation	0.13 (g)	0.04	0.04	0.04	0.04
Maximum vertical acceleration	0.90 (g)	0.23	0.20	0.27	0.20
Maximum vertical suspension deflection	95 (%)	41%	41%	43%	39%

*This car did not have IWS installed so some parameters (Maximum wheel L/V ratio, Maximum truck side L/V ratio, and Minimum vertical wheel load) were not measured

Table 60. Trail Buffer (IDOX 20001) PCD 10- and 12-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	0.8	0.8	0.7	0.8
Maximum wheel L/V ratio	0.8	0.56	0.58	0.61	0.58
Maximum truck side L/V ratio	0.5	0.29	0.31	0.30	0.29
Minimum vertical wheel load	25 (% of static)	61%	63%	63%	65%
Lateral peak-to-peak acceleration	1.3 (g)	0.33	0.28	0.33	0.24
Maximum lateral acceleration	0.75 (g)	0.20	0.20	0.25	0.17
Lateral acceleration standard deviation	0.13 (g)	0.04	0.04	0.04	0.04
Maximum vertical acceleration	0.90 (g)	0.24	0.26	0.25	0.25
Maximum vertical suspension deflection	95 (%)	42%	46%	48%	38%

Table 61. REV PCD 10- and 12-degree curve results

Criterion	Limiting Value	Push North	Push South	Pull North	Pull South
Roll Angle (degree)	4	1.1	1.0	1.2	0.9
Maximum wheel L/V ratio	0.8	0.72	0.79	0.81	0.75
Maximum truck side L/V ratio	0.5	0.37	0.37	0.49	0.36
Minimum vertical wheel load	25 (% of static)	48%	47%	51%	45%
Lateral peak-to-peak acceleration	0.6 (g)	0.36	0.30	0.39	0.33
Maximum lateral acceleration	0.35 (g)	0.22	0.23	0.25	0.23
Lateral acceleration standard deviation	0.13 (g)	0.05	0.05	0.05	0.04
Maximum vertical acceleration	0.60 (g)	0.23	0.20	0.20	0.26
Maximum vertical suspension deflection	95 (%)	37%	58%	51%	34%

8.3 Ride Quality

Standard S-2043, paragraph 6.3.3 Ride Quality required that tests be performed in revenue service to evaluate personnel ride quality. The track sections used for testing were chosen to represent FRA designations of Class 2 through Class 6. The ride quality tests were performed per ISO Standard 2631-1:1997.[3] Table 62 lists the tracks used and the maximum speed for each track class.

AAR OT-55[4] limits the speed of key trains to 50 mph, but S-2043 requires that testing be conducted at speeds up to the FRA freight speed limit for the class of track. As the maximum safe operating speed of the HLRM cars for single-car testing was only required to be 70 mph, that was the maximum test speed for the multiple-car test train for track Classes 5 and 6. For FRA Classes 2, 3, and 4, the speeds were limited by the prevailing operating rules.

Table 62. Tracks and speeds for ride quality tests

Description	Track	Maximum Speed
FRA Class 2	Mainline from north gate to south gate at PCD	20
FRA Class 3	BNSF Raton Sub from Trinidad to Folsom	35
FRA Class 4	BNSF Pueblo Subdivision from Avondale to La Junta and BNSF Raton Subdivision from La Junta to Trinidad	45
FRA Class 5	Transit Test Track (TTT) at the TTC	70
FRA Class 6	Precision Test Track (PTT) at the TTC	70

Tri-axial accelerometers were used to measure the ride quality at eight locations in the REV. Three accelerometers were mounted rigidly to the floor centered laterally in the main hallway aligned longitudinally over the B- and A-end trucks and in the center of the car. Two accelerometers were mounted on disks at the center of the mattress in the upper and lower berths on the A-end of the car. One accelerometer was mounted on a disk located at the center of the galley seat on the A-end of the car. Two accelerometers were mounted on disks located on the seat pans of the left and right upper observation level (UOL) chairs toward the A-end of the car.

The mounting disks used for cushioned surfaces were 1/4-inch thick aluminum disks of 3-inch diameter drilled and tapped to accept a tri-axial accelerometer in the center. The disks were weighed down with either four sandbags weighing approximately 25-pounds each or a member of the test team sitting on an additional cushion placed over the accelerometer.

Table 63. Ride quality measurement locations

<table>
<tr><th>Description</th><th>General Location</th><th>Attachment Point</th></tr>
<tr><td>A-End Carbody</td><td>Floor over A-End bogie</td><td rowspan="3">Rigidly attached to floor of car interior</td></tr>
<tr><td>B-End Carbody</td><td>Floor over B-End bogie</td></tr>
<tr><td>Center</td><td>Floor center of car</td></tr>
<tr><td>Bed</td><td>Upper bed located at A-End of the car.</td><td rowspan="2">Mounting disk at center of mattress</td></tr>
<tr><td>Bed</td><td>Lower bed located at A-End of the car.</td></tr>
<tr><td>Galley Seat</td><td>Galley seat located in corner of car interior</td><td rowspan="3">Mounting disk on seat pan</td></tr>
<tr><td>UOL Chair 1</td><td>UOL Chair nearest to AR corner of carbody</td></tr>
<tr><td>UOL Chair 2</td><td>UOL Chair nearest to AL corner of carbody</td></tr>
</table>

The accelerometers were sampled at 1250 Hz. The appropriate frequency-weighting curve was applied to each measurement based on location and direction of measurement. The ride quality for each measurement location and direction was analyzed with regard to Health (ISO

2631-1 Annex B), Comfort (ISO 2631-1 Annex C), and Motion Sickness (ISO 2631-1 Annex D). Table 64 describes the passenger comfort level assigned to the weighted vibration magnitudes. The ranges overlap, and it is important to consider that passenger comfort depends greatly on trip duration, passenger activity, and many other factors.

Table 64. ISO 2631 comfort ranges

Less than 0.315 m/s^2	Not uncomfortable
0.315 m/s^2 to 0.63 m/s^2	A little uncomfortable
0.5 m/s^2 to 1 m/s^2	Fairly uncomfortable
0.8 m/s^2 to 1.6 m/s^2	Uncomfortable
1.25 m/s^2 to 2.5 m/s^2	Very uncomfortable
Greater than 2 m/s^2	Extremely uncomfortable

ISO 2631 provides several analysis methods for measured accelerations. The crest factor determines which method is used. The crest factor is the ratio of the instantaneous peak value of the frequency weighted acceleration to its RMS value. If the crest factor is below nine, a basic RMS method is used for the general evaluation of ride quality. If the crest factor is above nine, the running RMS method is used. The running RMS method, referred to as the maximum transient vibration value (MTVV) method, uses the MTVV as the defined vibration magnitude. The MTVV method considers the occasional shock and transient vibration by using a short integration time constant. For each location and run, the RMS or MTVV values (based on each individual crest factor) were combined into one plot to compare against the ISO 2631 comfort values seen in Table 64. The results for each location listed in Table 63 were considered, and plots for all RMS and MTVV results (based on crest factor) are provided in Appendix (H). The current section outlines the worst ride quality results for the center carbody, A-end carbody, and B-end carbody floor locations for each track class tested listed in Table 62, and a plot of the data at the A-end carbody location is shown in Sections 8.3.1 through 8.3.5 for each track class.

8.3.1 Class 2

Test runs consisted of one complete pass over the PCD main line (approximately 5 miles) with a maximum speed of 20 mph. The test was observed by Matt DeGeorge, MxV Rail Senior Engineer II on September 22 and by Steve Belport, Principal Investigator II on October 11, per Standard S-2043 requirements. The worst ride quality results for the center carbody, A-end carbody, and B-end carbody floor locations were recorded as follows:

- Center carbody
  - "Not uncomfortable" for the lateral direction
  - "Not uncomfortable" for the longitudinal direction
  - "Fairly uncomfortable" for the vertical direction

- A-end carbody
  - "Fairly uncomfortable" for the lateral direction
  - "Not uncomfortable" for the longitudinal direction
  - "Very uncomfortable" for the vertical direction
- B-end carbody
  - "Fairly uncomfortable" for the lateral direction
  - "Not uncomfortable" for the longitudinal direction
  - "Very uncomfortable" for the vertical direction

Figure 61 outlines the ride quality results at the A-end carbody floor location for speeds tested on the Class 2 track.

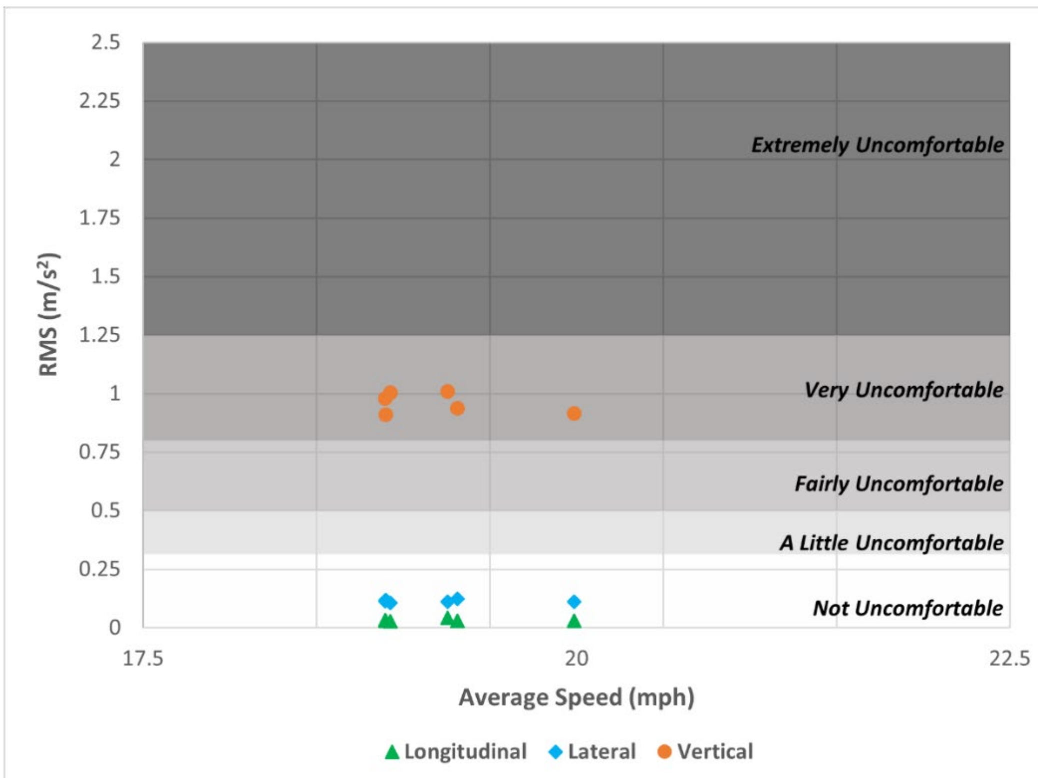

Figure 64. FRA Class 2 track at PCD ride quality results at the A-end carbody location

8.3.2 Class 3

Test runs consisted of a complete pass of the BNSF Raton Subdivision from Trinidad to Folsom with a maximum speed of 35 mph. Per Standard S-2043 requirements, the test was observed by Matthew Wenger, MxV Rail Senior Engineer III on June 27 and 29, 2023. The FRA Class 3 ride quality tests were performed with the AAR-2A narrow flange profile. The worst ride quality results for the center carbody, A-end carbody, and B-end carbody floor locations were recorded as follows:

- Center Carbody
  - "Not uncomfortable" for the lateral direction
  - "Very uncomfortable" for the longitudinal direction
  - "Extremely uncomfortable" for the vertical direction
- A-End Carbody
  - "A little uncomfortable" for the lateral direction
  - "Very uncomfortable" for the longitudinal direction
  - "Extremely uncomfortable" for the vertical direction
- B-End Carbody
  - "A little uncomfortable" for the lateral direction
  - "Very uncomfortable" for the longitudinal direction
  - "Extremely uncomfortable" for the vertical direction

Figure 62 outlines the ride quality results at the A-end carbody floor location for speeds tested on the Class 3 track.

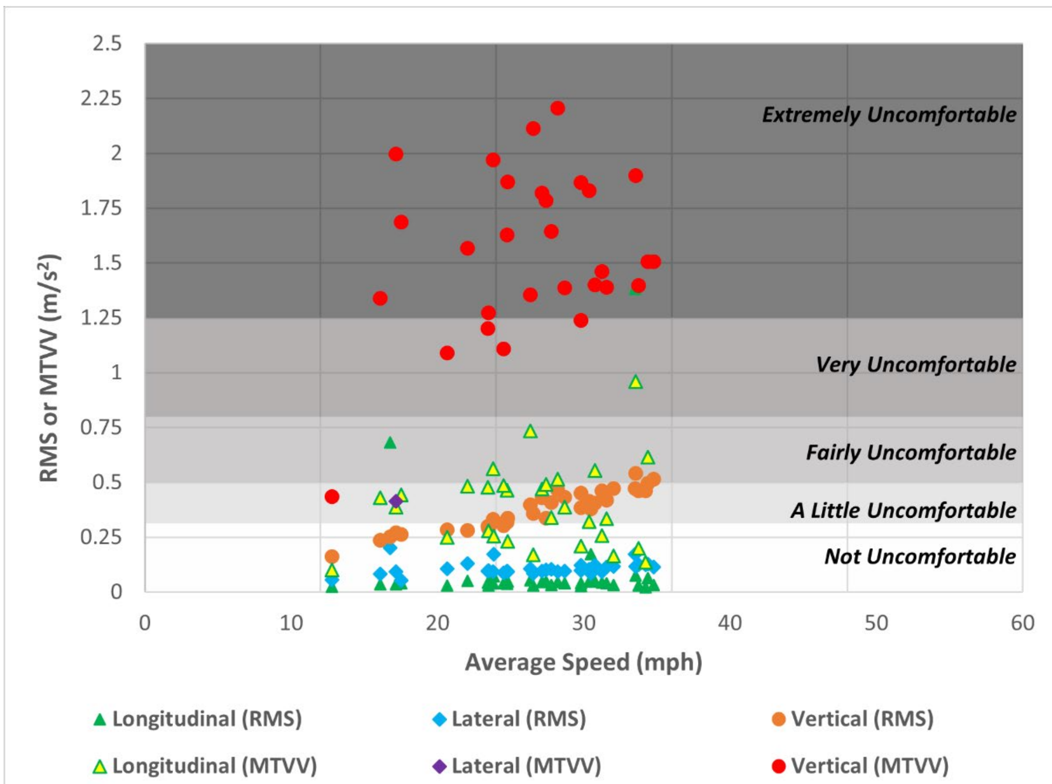

Figure 65. FRA Class 3 Track (BNSF) Ride Quality Results at the A-End Carbody Location

8.3.3 Class 4

Test runs consisted of a complete pass of the BNSF Pueblo Subdivision from Avondale to La Junta and the BNSF Raton Subdivision from La Junta to Trinidad with a maximum speed of

45mph. Per Standard S-2043 requirements, the test was observed by Matthew Wenger, MxV Rail Senior Engineer III on June 26, 2023. The FRA Class 4 ride quality tests were performed with the AAR-2A narrow flange profile. The worst ride quality results for the center carbody, A-end carbody, and B-end carbody floor locations were recorded as follows:

- Center carbody
  - "A little uncomfortable" for the lateral direction
  - "Fairly uncomfortable" for the longitudinal direction
  - "Very uncomfortable" for the vertical direction
- A-end carbody
  - "Fairly uncomfortable" for the lateral direction
  - "Fairly uncomfortable" for the longitudinal direction
  - "Extremely uncomfortable" for the vertical direction
- B-end carbody
  - "Fairly uncomfortable" for the lateral direction
  - "Fairly uncomfortable" for the longitudinal direction
  - "Extremely uncomfortable" for the vertical direction

Figure 63 outlines the ride quality results at the A-end carbody floor location for speeds tested on Class 4 track.

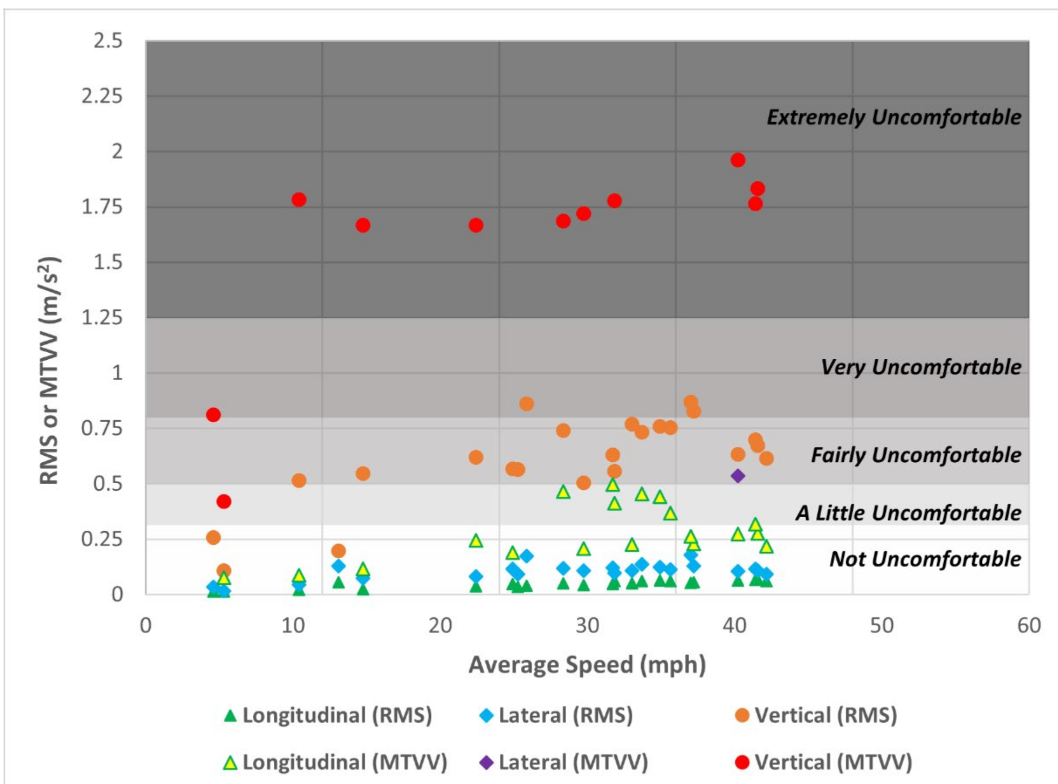

Figure 66. FRA Class 4 track (BNSF) ride quality results at the A-end carbody location

8.3.4 Class 5

Test runs consisted of one complete lap for the TTT (9.1 miles) with a maximum speed of 70 mph. The test was observed by Matt DeGeorge, MxV Rail Senior Engineer III on September 16, 2022, per Standard S-2043 requirements. The worst ride quality results for the center carbody, A-end carbody, and B-end carbody floor locations were recorded as follows:

- Center Carbody
  - "Not uncomfortable" for the lateral direction
  - "Not uncomfortable" for the longitudinal direction
  - "Very uncomfortable" for the vertical direction
- A-End Carbody
  - "Not uncomfortable" for the lateral direction
  - "Not uncomfortable" for the longitudinal direction
  - "Extremely uncomfortable" for the vertical direction
- B-End Carbody
  - "Fairly uncomfortable" for the lateral direction
  - "A little uncomfortable" for the longitudinal direction
  - "Extremely uncomfortable" for the vertical direction

Figure 64 outlines the ride quality results at the A-End Carbody floor location for speeds tested on the Class 5 track.

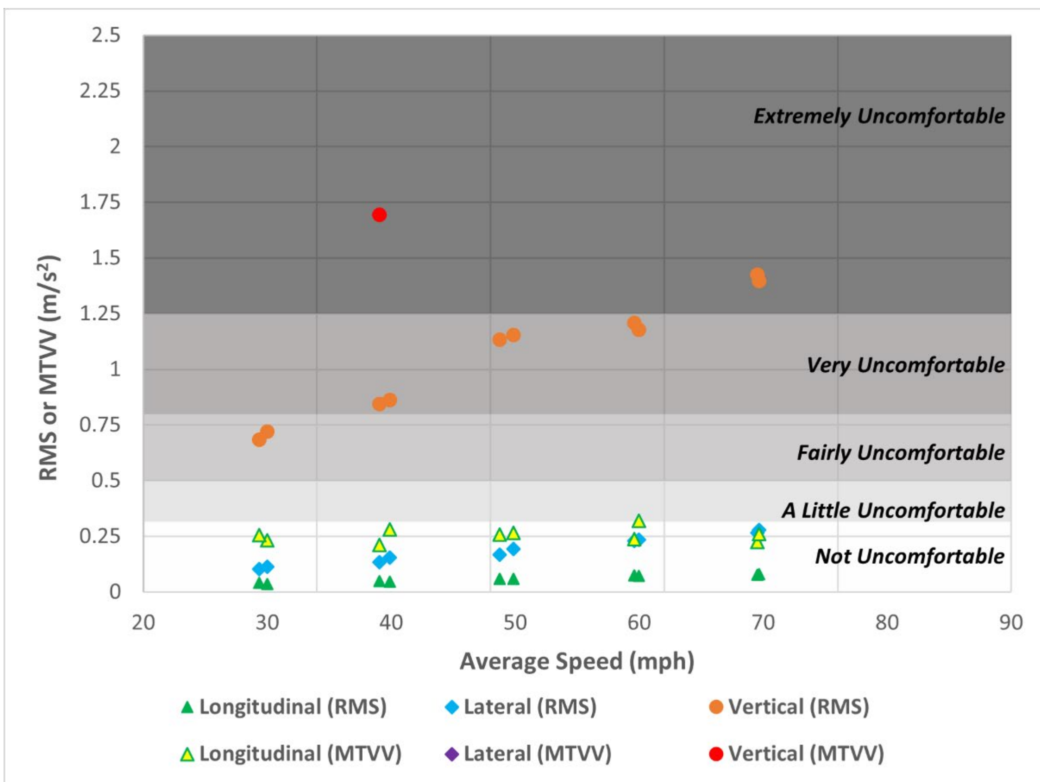

Figure 67. FRA Class 5 Track at TTT Ride Quality Results at the A-End Carbody Location

8.3.5 Class 6

Test runs consisted of one complete pass over the PTT (about 6.5 miles) with a maximum speed of 70 mph. The test was observed by Matt DeGeorge, MxV Rail Senior Engineer III on September 19, 2022, per Standard S-2043 requirements. The worst ride quality results for the center carbody, A-end carbody, and B-end carbody floor locations were recorded as follows:

- Center Carbody
  - "Not uncomfortable" for the lateral direction
  - "Not uncomfortable" for the longitudinal direction
  - "Very uncomfortable" for the vertical direction
- A-End Carbody
  - "Not uncomfortable" for the lateral direction
  - "Not uncomfortable" for the longitudinal direction
  - "Extremely uncomfortable" for the vertical direction
- B-End Carbody
  - "Not uncomfortable" for the lateral direction
  - "Not uncomfortable" for the longitudinal direction
  - "Extremely uncomfortable" for the vertical direction

Figure 65 outlines the ride quality results at the A-end carbody floor location for speeds tested on the Class 6 track.

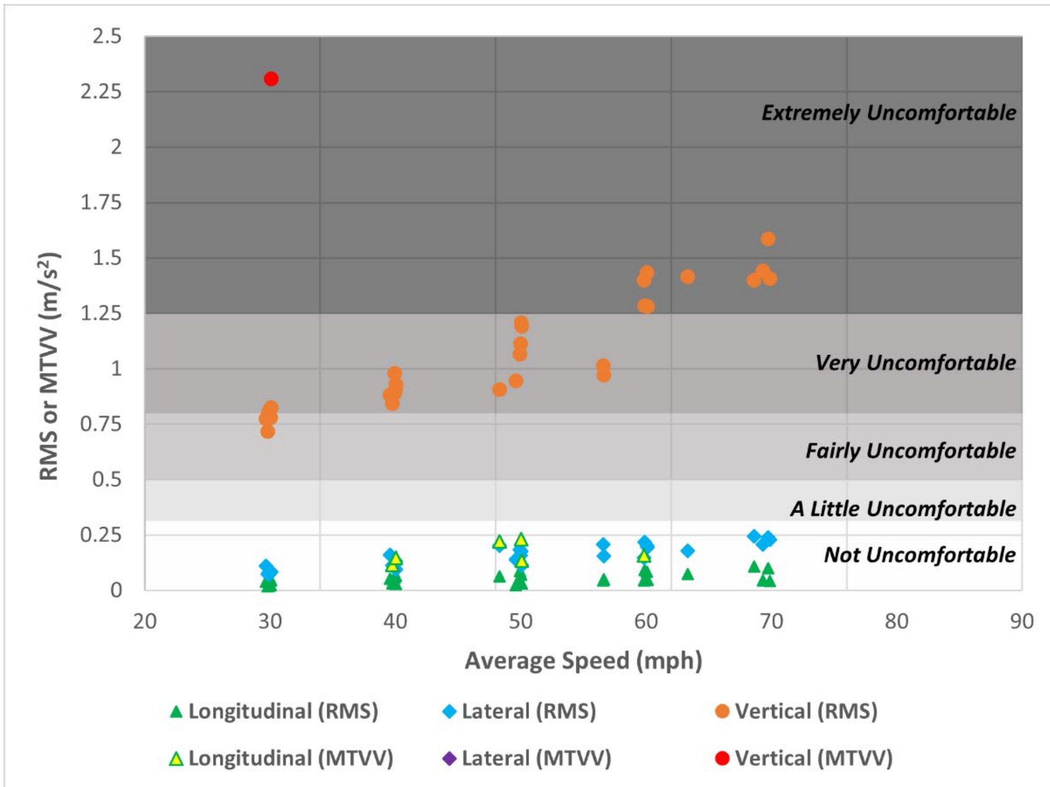

Figure 68. FRA Class 6 Track at PTT Ride Quality Results at the A-End Carbody Location

Standard S-2043, paragraph 6.3.3 requires ride quality tests per ISO Standard 2631 but does not specify any criteria. While ISO Standard 2631 also does not specify any criterion, it does offer guidance on the effects of vibration on perception and comfort. When applied to the REV ride quality data this guidance indicates that 1) longitudinal acceleration ranged from "not uncomfortable" to fairly "uncomfortable," 2) lateral acceleration ranged from "not uncomfortable" to "fairly uncomfortable," and 3) vertical acceleration ranged from "very uncomfortable" to "extremely uncomfortable."

8.4 Demonstration Test Run

Standard S-2043, paragraph 6.3.4 states:

> *"A demonstration run must be performed over an actual service route at the applicant's expense. With the exception of normal system monitoring equipment, no instrumentation is required. An operator's log must be kept throughout the trip to document train operation and any problems that occur. The log, combined with a route map and photo documentation, must be submitted as part of the test report."*

The demonstration test run (DTR) was administered by MxV Rail directly with Union Pacific (UP) Railroad on a route between MxV Rail's test facility near Avondale, CO, and a junction that serves the DOE's Idaho National Laboratory (INL) near Scoville, ID. This route is representative of the types of tracks that a future service route may encounter. This route was chosen because there are currently no "actual service routes" that have been identified at the time of testing. The route was reviewed and approved by the EEC on October 20, 2022. The test took place between September 5 and September 9, 2023. The DTR was completed successfully without performance issues on any of the four cars under test.

Two DOE personnel and two MxV Rail personnel, one of whom served as an official AAR observer, traveled aboard the REV car for the duration of the DTR. Additionally, one MxV Rail employee followed the train by highway for photo documentation of the test. The test team's credentials are summarized in Table 65.

Table 65. Test team for DTR

DTR Participant	Affiliation	Title/DTR Role
Patrick Schwab	DOE	Atlas Project Manager/REV Passenger
Michael Schultze	ORNL	R&D Staff, Transportation Security Specialist/ REV Passenger
Matthew Wenger	MxV Rail	Senior Engineer III/REV Passenger/AAR Observer
Justin Penrod	MxV Rail	Lead Test Controller/REV Passenger
Brandon-Dean Morris	MxV Rail	Senior Engineer III/UAV Photographer

Figure 66 and Figure 67 depict the test train's outbound and return routes, respectively, which totaled 1,471 miles round-trip. The location markers in the route maps were recorded during train starts and periodically while moving by the REV car's TRANSCOM tracking system, and therefore, marker spacing may be interpreted as indicative of the trains average speed (i.e., close marker spacing is indicative of numerous stops and/or low train speed). Additionally, the location markers are color-coded so each day of the DTR has a unique marker color.

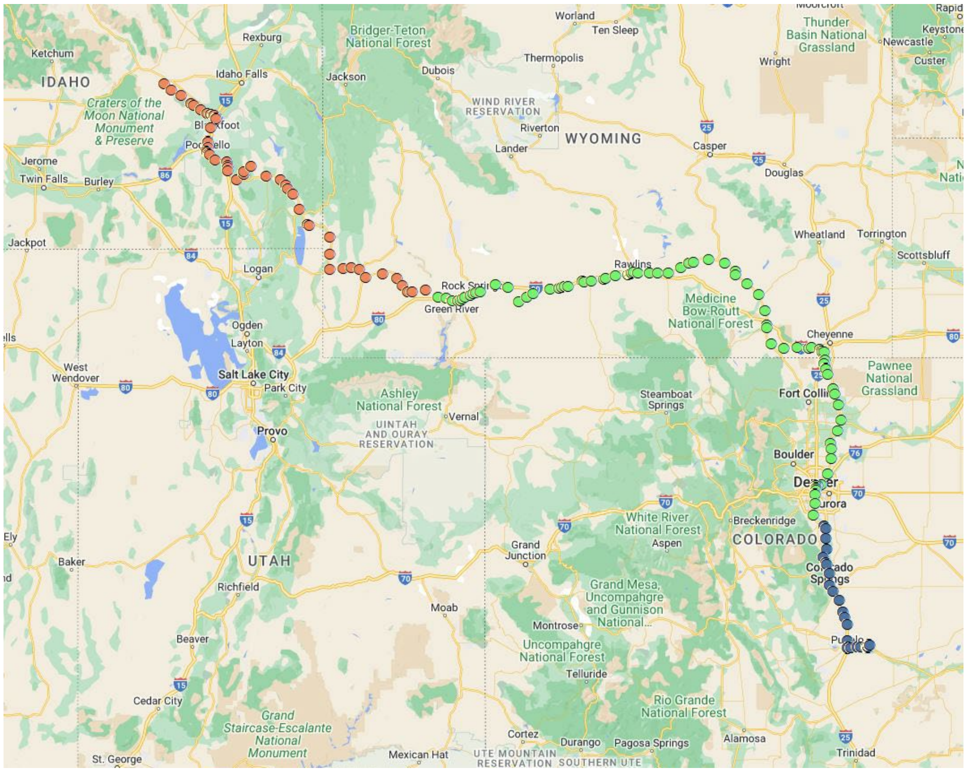

Figure 69. Outbound route of DTR as recorded by TRANSCOM system

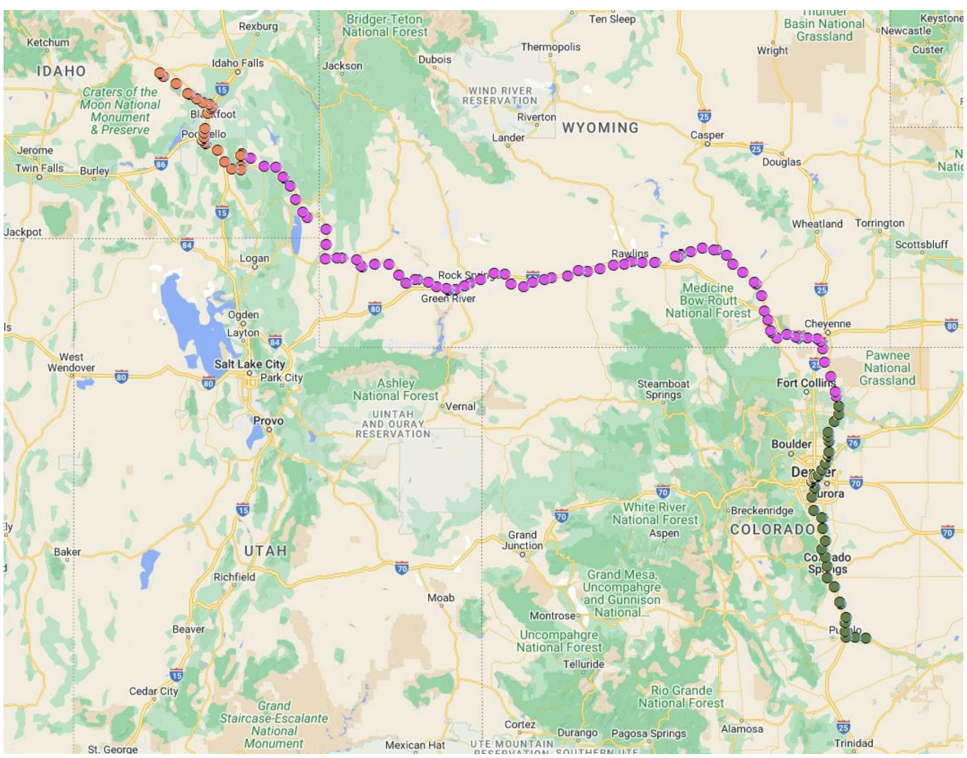

Figure 70. Return route of DTR as recorded by TRANSCOM system

The test consist was made up of two UP locomotives coupled back-to-back, followed by the HLRM train, with the B-end of each car leading as shown in Figure 68. The Atlas railcar was configured in its maximum test load condition during the demonstration test.

Figure 71. Train configuration for DTR (maximum test load condition)

Table 66 serves as the operator's log and contains location and cumulative mileage information taken by the Atlas railcar's SSM system for the duration of the round-trip demonstration run. The log entries include every instance when the train was stopped for a locomotive crew change and the subsequent start time of the trip's next segment. In addition to the crew changes, there were numerous additional stops throughout the trip due to other rail traffic that are not included in the table. Differences in the location of stops and subsequent starts shown in the table are likely due to system thresholds that are used to determine if the train has started or stopped moving. The largest difference between a stop and subsequent start, 0.44 miles on September 6, 2023, at 5:15 PM, was thought to be because the train moved very slowly through the wye track at Scoville, ID.

An unforeseen stop occurred on the return trip in Denver, CO, when a new locomotive crew neglected to release the hand brake on the Atlas railcar's A-end. The crew began traveling south from downtown Denver's North Yard slowly and intermittently. In the span of 38 minutes, the train moved in a start-and-stop manner (total time in motion of 29 minutes) and covered seven miles of track when Justin Penrod, MxV Rail's Lead Test Controller, noticed the scent of hot brake pads inside the REV and immediately alerted the locomotive via radio. The crew stopped and quickly realized they had not noticed the hand brake on the Atlas railcar's A-end and subsequently released it. No discoloration of wheel treads was observed and the DTR resumed shortly thereafter.

Table 66. Operator's log for DTR

DATE	TIME	ACTION	LOCATION	NOTES	MILEAGE
09/05/2023	16:33	Start	6.30 miles W of Boone, CO	**Began DTR in Avondale, CO** Pueblo Subdivision	0
09/05/2023	17:22	Stop	0.28 miles NW of Pueblo, CO	UP Crew Change	14
09/05/2023	20:11	Start	0.60 miles N of Pueblo, CO	Pikes Peak Subdivision	14
09/06/2023	00:46	Stop	1.43 miles W of Denver, CO	UP Crew Change	119
09/06/2023	01:55	Start	1.42 miles W of Denver, CO	Greeley Subdivision	119

DATE	TIME	ACTION	LOCATION	NOTES	MILEAGE
09/06/2023	07:28	Stop	7.84 miles SW of Cheyenne, WY	UP Crew Change	215
09/06/2023	08:25	Start	7.83 miles SW of Cheyenne, WY	Laramie Subdivision	215
09/06/2023	14:26	Stop	0.31 miles SE of Rawlins, WY	UP Crew Change	367
09/06/2023	15:25	Start	0.29 miles SE of Rawlins, WY	Rawlins Subdivision	367
09/06/2023	23:30	Stop	0.25 miles SE of Green River, WY	UP Crew Change	485
09/06/2023	23:41	Start	0.21 miles S of Green River, WY	Evanston Subdivision	485
09/07/2023	07:47	Stop	1.42 miles SE of Inkom, ID	UP Crew Change	660
09/07/2023	09:17	Start	1.36 miles SE of Inkom, ID	Pocatello Subdivision	660
09/07/2023	10:59		2.67 miles N of Chubbuck, ID	Entered Fort Hall Indian Reservation; Montana Subdivision	681
09/07/2023	11:31		0.68 miles SW of Blackfoot, ID	Exited Fort Hall Indian Reservation; Montana Subdivision	697
09/07/2023	13:34	Stop	9.70 miles W of Atomic City, ID	**Arrived in Scoville, ID** UP Crew Change; Scoville Subdivision	735
09/07/2023	17:15	Start	9.26 miles W of Atomic City, ID	Departed Scoville, ID	735
09/07/2023	18:53		0.68 miles SW of Blackfoot, ID	Entered Fort Hall Indian Reservation; Montana Subdivision	776
09/07/2023	19:25		2.67 miles N of Chubbuck, ID	Exited Fort Hall Indian Reservation; Montana Subdivision	792
09/07/2023	20:48	Stop	0.79 miles S of Pocatello, ID	UP Crew Change	798
09/07/2023	22:03	Start	0.86 miles S of Pocatello, ID	Pocatello Subdivision	798
09/08/2023	09:05	Stop	0.45 miles N of Rock Springs, WY	UP Crew Change	1,007
09/08/2023	11:24	Start	0.45 miles N of Rock Springs, WY	Rawlins Subdivision	1,007
09/08/2023	21:28	Stop	7.59 miles SW of Cheyenne, WY	UP Crew Change	1,256
09/08/2023	22:53	Start	7.57 miles SW of Cheyenne, WY	Greeley Subdivision	1,256
09/09/2023	07:21	Stop	3.12 miles E of Lakeside, CO	UP Crew Change	1,350
09/09/2023	09:30	Start	2.68 miles N of Denver, CO	Pikes Peak Subdivision	1,350
09/09/2023	10:05	Stop	2.67 miles N of Englewood, CO	Stopped to release Atlas A-End hand brake	1,357
09/09/2023	10:12	Start	2.63 miles N of Englewood, CO	Pikes Peak Subdivision	1,357
09/09/2023	14:21	Stop	1.12 miles N of Pueblo, CO	UP Crew Change	1,457
09/09/2023	14:56	Start	1.07 miles NE of Pueblo, CO	Pueblo Subdivision	1,457

DATE	TIME	ACTION	LOCATION	NOTES	MILEAGE
09/09/2023	15:27	Stop	5.30 miles W of Boone, CO	**Arrived in Avondale, CO** DTR Complete	1,471

The train's SSM system generated a total of 20 alarms during the DTR as summarized in

Table 67. Seventeen of the 20 alarms occurred in the 20-mile span between Chubbuck, ID, and Blackfoot, ID, in the Montana Subdivision where jointed rail is used in place of continuously welded rail. The harsh jointed rail in this section caused 14 wheel flat alarms that were considered to be erroneous given the smooth, quiet performance of the wheels observed before and after this short portion of track. Additionally, three truck hunting alarms occurred in short succession on the Atlas railcar in the same section of jointed rail. The test team did not observe any signs of truck hunting on the Atlas railcar and decided to continue the DTR without stopping.

Outside of the jointed rail in the Montana Subdivision, the SSM generated two rocking alarms on the Atlas railcar and one wheel flat alarm on the REV. In each instance, the test team did not observe any dangerous conditions or cause for stopping the train.

Table 67. SSM alarm log for the DTR

DATE	TIME	CAR NUMBER	ALARM TYPE	LOCATION	SPEED (mph)
09/06/2023	10:29:22	IDOX 10001 B	Rocking Alarm	10.01 miles SE of Rock River, WY	44
09/07/2023	02:14:41	IDOX 10001 B	Rocking Alarm	14.66 miles NE of Randolph, UT	42
09/07/2023	11:03:17	IDOX 10001 A	Wheel Flat Alarm	4.66 miles N of Chubbuck, ID	36
09/07/2023	11:05:28	IDOX 10001 A	Wheel Flat Alarm	6.01 miles N of Chubbuck, ID	40
09/07/2023	11:15:49	IDOX 10001 B	Wheel Flat Alarm	7.70 miles SW of Blackfoot, ID	36
09/07/2023	11:23:09	IDOX 20002	Wheel Flat Alarm	3.37 miles SW of Blackfoot, ID	36
09/07/2023	11:23:30	IDOX 20002	Wheel Flat Alarm	3.16 miles SW of Blackfoot, ID	36
09/07/2023	13:26:34	IDOX 30001	Wheel Flat Alarm	8.66 miles W of Atomic City, ID	36
09/07/2023	19:03:23	IDOX 20002	Wheel Flat Alarm	3.76 miles SW of Blackfoot, ID	38
09/07/2023	19:03:27	IDOX 10001 A	Wheel Flat Alarm	3.77 miles SW of Blackfoot, ID	38
09/07/2023	19:05:02	IDOX 10001 B	Wheel Flat Alarm	4.82 miles SW of Blackfoot, ID	39
09/07/2023	19:11:12	IDOX 10001 A	Wheel Flat Alarm	8.62 miles SW of Blackfoot, ID	39

DATE	TIME	CAR NUMBER	ALARM TYPE	LOCATION	SPEED (mph)
09/07/2023	19:12:12	IDOX 10001 B	Wheel Flat Alarm	9.26 miles SW of Blackfoot, ID	39
09/07/2023	19:13:39	IDOX 10001 A	Wheel Flat Alarm	9.60 miles N of Chubbuck, ID	38
09/07/2023	19:16:33	IDOX 10001 B	Truck Hunting Alarm	7.77 miles N of Chubbuck, ID	37
09/07/2023	19:16:37	IDOX 10001 B	Truck Hunting Alarm	7.73 miles N of Chubbuck, ID	38
09/07/2023	19:16:44	IDOX 10001 A	Truck Hunting Alarm	7.66 miles N of Chubbuck, ID	38
09/07/2023	19:17:03	IDOX 10001 B	Wheel Flat Alarm	7.46 miles N of Chubbuck, ID	38
09/07/2023	19:27:35	IDOX 10001 A	Wheel Flat Alarm	1.98 miles N of Chubbuck, ID	23
09/07/2023	19:28:02	IDOX 10001 A	Wheel Flat Alarm	1.81 miles N of Chubbuck, ID	21

Figure 69 through Figure 73 show bearing temperatures for each car as recorded by the SSM system throughout the DTR. Bearing temperature data was logged on the 3CT website for each start and stop event and every hour after the latest start or stop. Throughout the DTR, the bearing temperatures typically stayed within approximately 30° F of the ambient temperature. The maximum measured difference between the bearing and ambient temperatures was 48° F, and this difference occurred on the Atlas railcar when the train came to a stop after a downhill grade approaching Inkom, ID, and while the ambient temperature was dropping quickly in the early morning hours of September 7, 2023.

For Buffer car IDOX 20001, the SSM system did not store temperature data during starts and stops, but rather only once every hour. Therefore, Figure 71 shows fewer data points than the temperature plots from the other cars in the train. Because the system maintained communication with the PDU during this time, it was still in compliance with Standard S-2043. After the system was reset during a crew change, the SSM began logging temperature data for IDOX 20001 on the 3CT website correctly at approximately 11:00 AM on September 8, 2023.

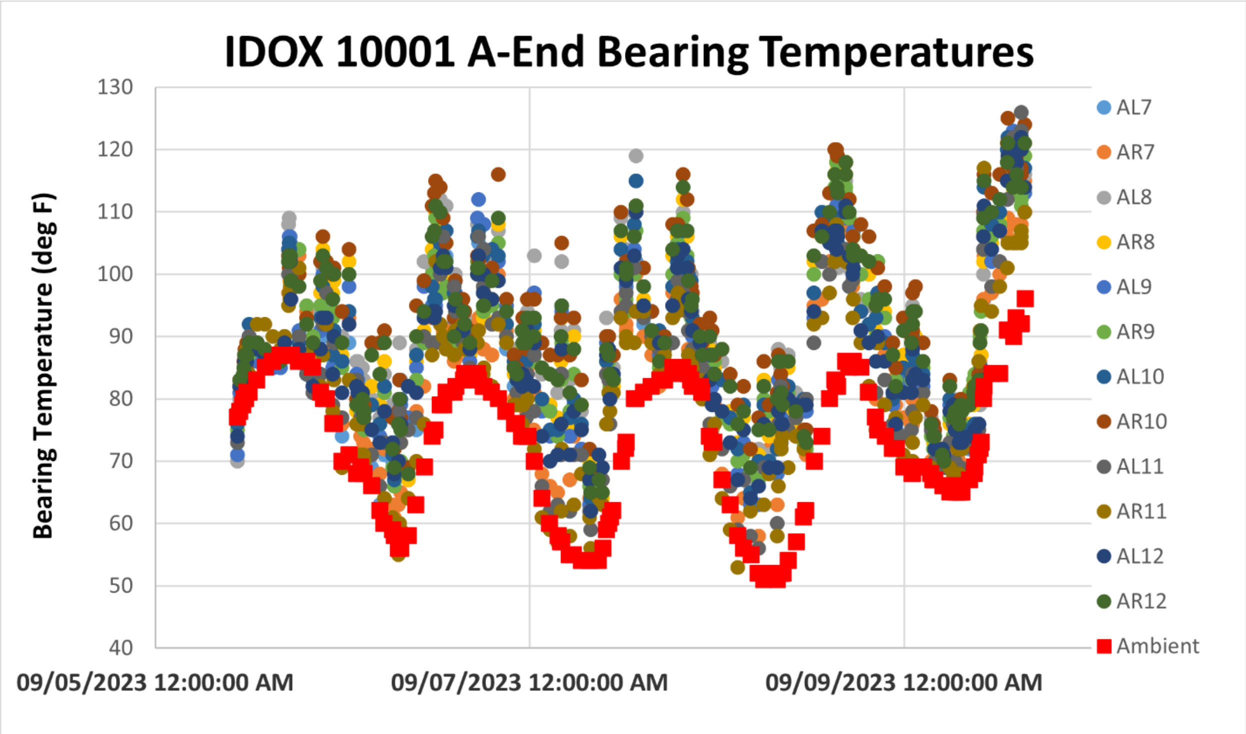

Figure 72. Atlas A-end DTR bearing temperatures

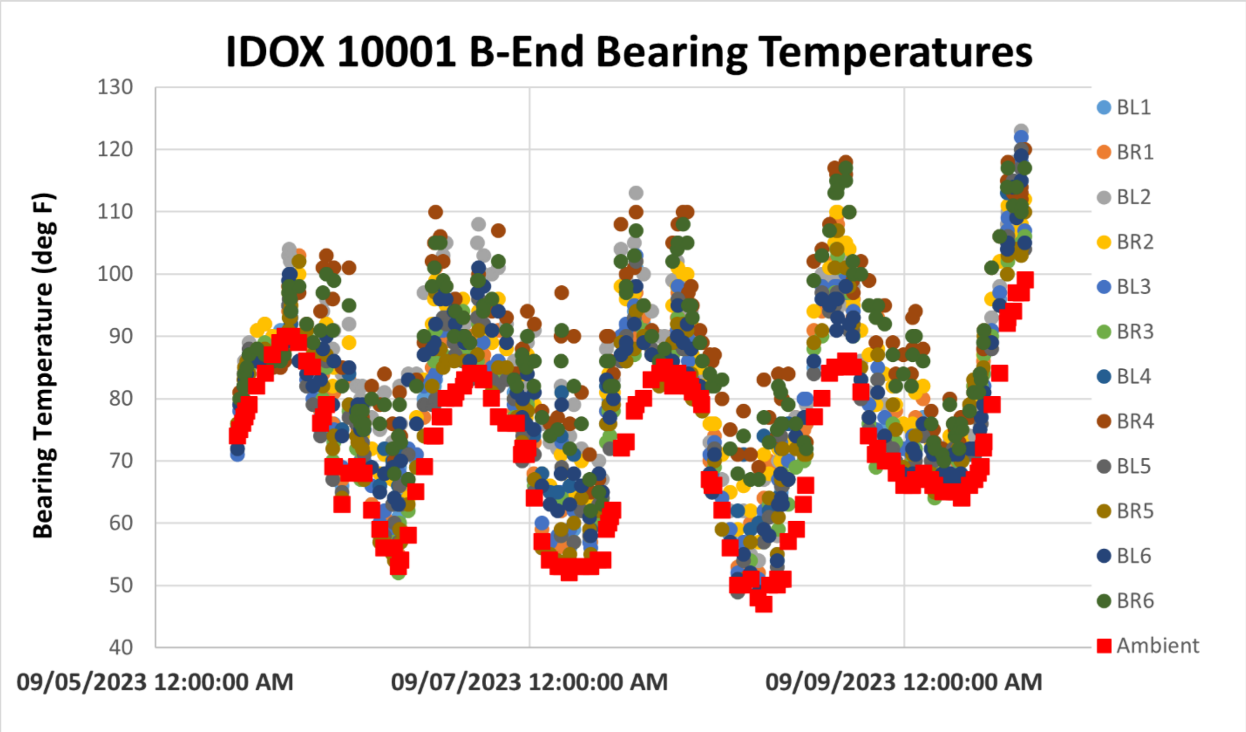

Figure 73. Atlas B-end DTR bearing temperatures

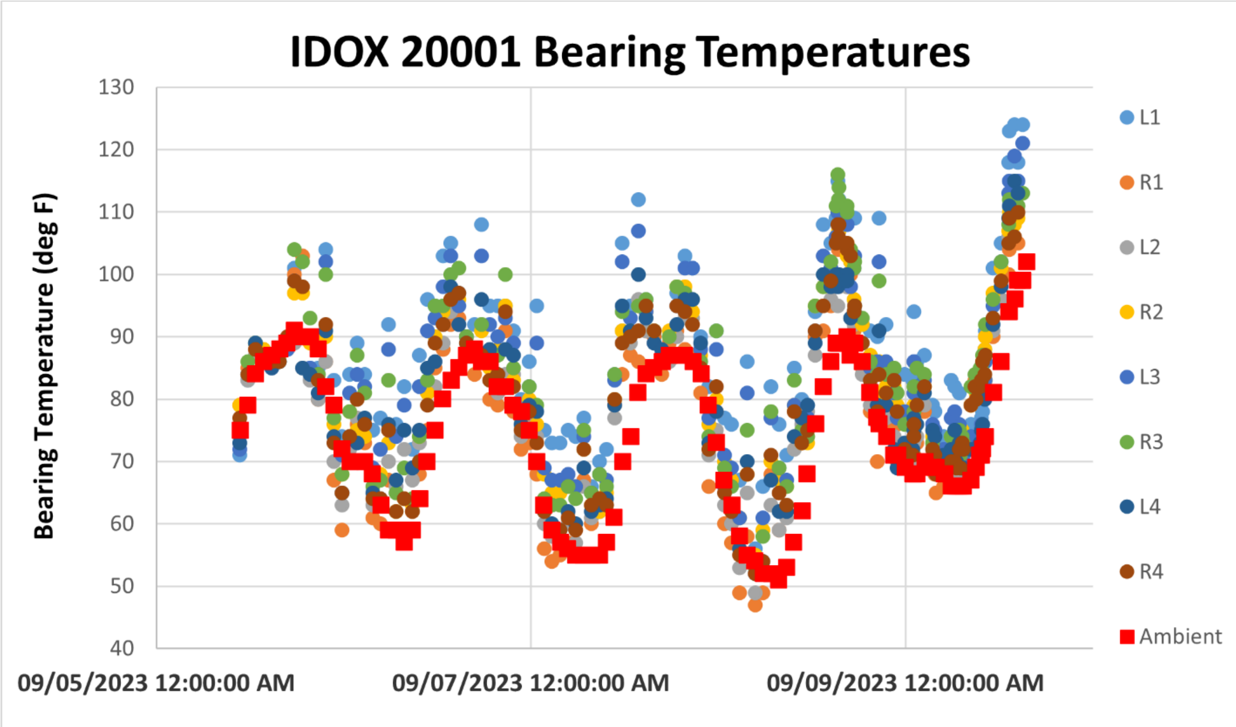

Figure 74. IDOX 20001 DTR bearing temperatures

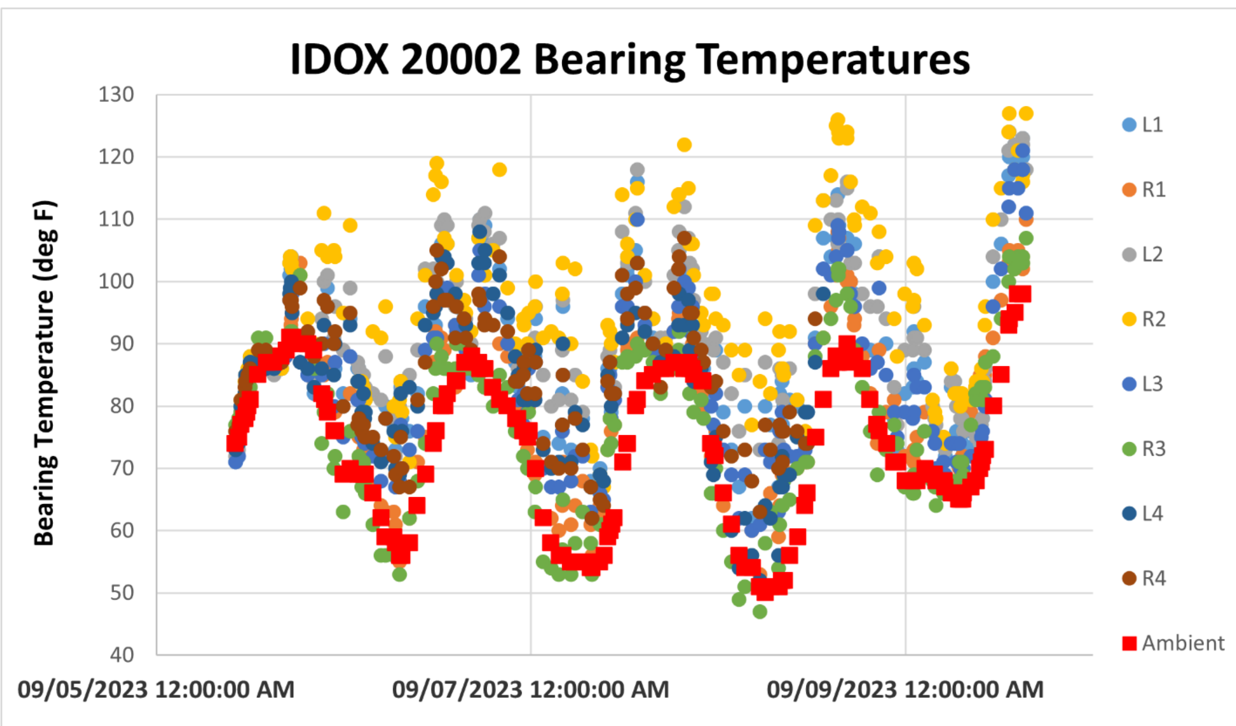

Figure 75. IDOX 20002 DTR bearing temperatures

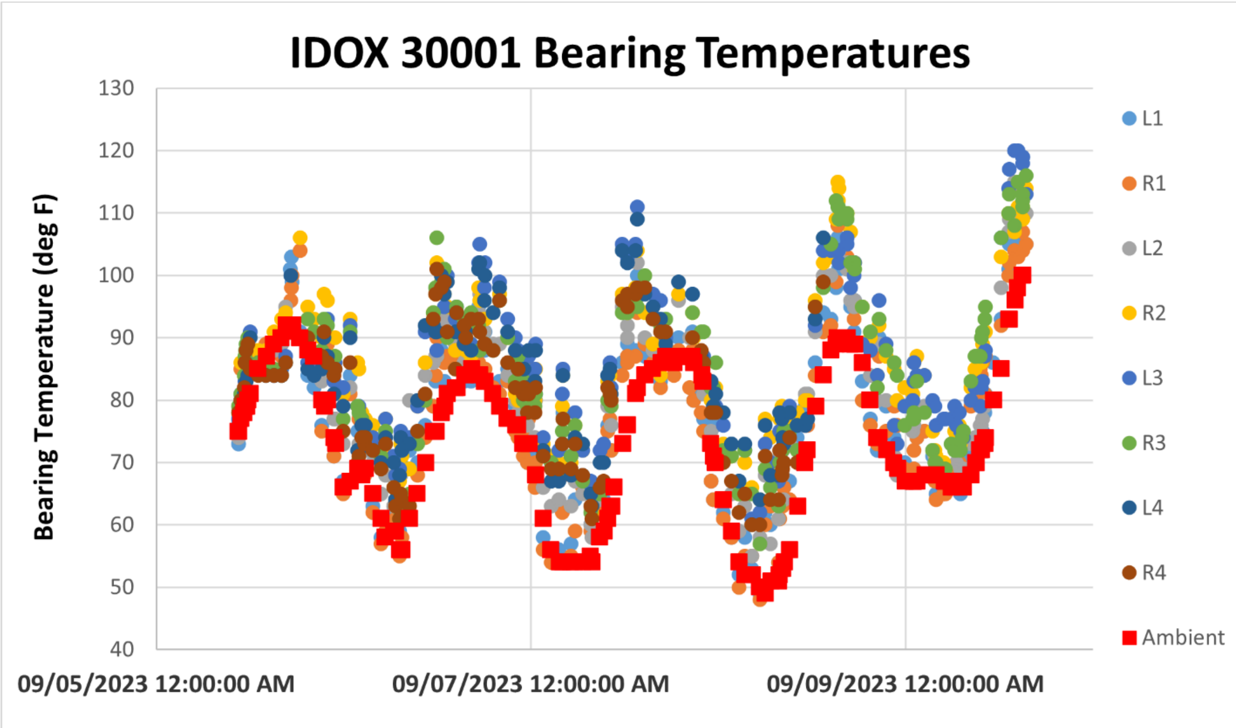

Figure 76. IDOX 30001 DTR bearing temperatures

Prior to the DTR, UP mechanical personnel performed an initial terminal inspection on August 29, 2023, during which no issues were noted with the four test cars. Following the DTR, MxV Rail personnel inspected the cars per the mechanical inspection checklist found in the DTR test plan (TP-23-002, located in Appendix F) and again found no deficiencies among the four cars.

Using aerial drone photography, MxV Rail documented the DTR at numerous locations along the test's route. Brandon Morris, General Manager–SERTC Outreach & Education, followed the train by highway and gained permission from UP to access railroad rights-of-way by car, foot, and drone in order to photograph and film the train. Additionally, Brandon Morris gained permission from DOE and INL to access the junction at Scoville, ID, for the purposes of photographic documentation. Caution was taken to avoid drone use near restricted airspaces along the route (e.g., near the United States Air Force Academy). Photo documentation of the DTR in chronological order may be found in Figure 74 through Figure 86.

Figure 77. DTR train leaving Avondale, CO, with Pikes Peak in background

Figure 78. DTR train near Cheyenne, WY (northbound)

Figure 79. DTR train near Hanna, WY (westbound)

Figure 80. DTR train near Rock Springs, WY (westbound)

Figure 81. DTR train near Inkom, ID (westbound)

Figure 82. DTR train in Scoville, ID, with INL facilities in background

Figure 83. DTR team in Scoville, ID

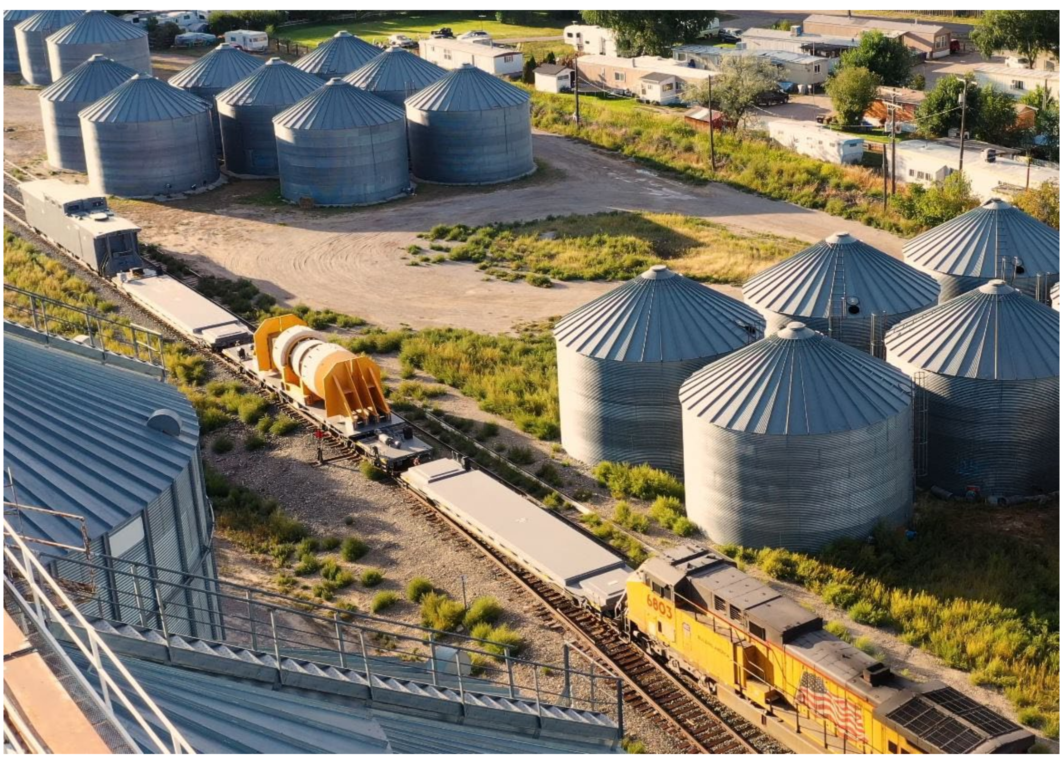

Figure 84. DTR train in Moreland, ID (eastbound)

Figure 85. DTR train near Rock Springs, WY (eastbound)

Figure 86. DTR train exiting the Great Divide Basin near Rawlins, WY (eastbound)


Figure 87. DTR train crossing the North Platte River at Fort Steele Historical Site, WY (eastbound)


Figure 88. DTR train passing United States Air Force Academy and Pikes Peak near Colorado Springs, CO (southbound)

Figure 89. DTR train crossing Fountain Creek in final approach to Avondale, CO (eastbound)

9.0 CONCLUSIONS

Table 68 shows a summary of the multiple car test results.

Table 68. Summary of test results

S-2043 Section	Critical Data (S-2043 Criteria and Loading Condition	Met/Did not Meet
6.1 Dynamic Tests at the Controlled Test Site		
6.1.1.1 Stop Distance (Maximum Test Load)	The jerk rate did not match to within 0.5 mph/sec^2 from car to car during three of the 12 emergency and two of the 14 full-service application stop distance test runs.	Not Met
6.1.1.1 Stop Distance (Minimum Test Load)	The Atlas railcar did not meet the wheel slip criteria (63.4%, limit = 15%) during one (wet) of the 18 (wet and dry) full-service braking run at 50 mph. The jerk rate did not match to within 0.5 mph/sec^2 from car to car during two (one wet, one dry) of the 16 emergency application stop distance test runs.	Not Met
6.1.1.2 Braking in Curves		Met
6.1.2 Hand Brake	No established criteria	NA
6.1.3 Buff and Draft Curving	Buffer car 20001 Maximum vertical acceleration = 0.94 g (0.9 g) Buffer car 20002 Maximum lateral acceleration = 1.77 g (0.75 g) Buffer car 20002 Maximum lateral peak to peak acceleration = 1.89 g (1.3 g)	Not Met
6.2 System Monitoring Tests		
6.2.1 System Functional Tests		Met
6.2.2 Failure Simulations		Met
6.3 Revenue Service Tests		
6.3.1 Turnouts, Crossovers		Met
6.3.1 Tight Curves: 12-degree curve at the TTC		Met
6.3.1 Tight Curves: 10-degree curve at Alps, New Mexico	Atlas railcar maximum truck side L/V ratio = 0.53 (0.5)	Not Met
6.3.2 Class 2 Maintained Track (5 miles no better than FRA class 2)		Met
6.3.2 Class 2 Maintained Track (additional revenue service track)	Atlas railcar maximum truck side L/V ratio = 0.57 (0.5) Atlas railcar maximum wheel L/V ratio = 0.82 (0.8) REV maximum truck side L/V ratio = 0.55 (0.5)	Mot Met
6.3.3 Ride Quality	No established criteria	NA
6.3.4 Demonstration run		Met

During stop distance testing with maximum test load, the car-to-car variation of jerk rate did not match to within 0.5 mph/sec^2 from car to car during three of the 12 emergency stop distance runs and two of the 14 full-service application stop distance test runs. On behalf of the DOE, MxV Rail requests an exception from the AAR EEC to approve the Atlas train because it is unclear how the exception to the jerk rate car-to-car match criteria will affect train operations or safety.

The Atlas railcar did not meet the wheel slip criteria (63.4 percent, limit = 15 percent) during a full-service braking run on wet rail at 50 mph with a minimum test load. The jerk rate from car to car did not match to within 0.5 mph/sec^2 during two of the 16 emergency application stop distance test runs. On behalf of the DOE, MxV Rail requests an exception from the AAR EEC to approve the Atlas train because the wheel slip occurred on only one of the six minimum test load, emergency application, wet rail runs. In addition, MxV Rail requests an exception from the AAR EEC to approve the Atlas train because it is unclear how the exception to the jerk rate car-to-car match criteria will affect train operations or safety.

During buff and draft curve testing, the Buffer cars did not meet maximum vertical, maximum lateral, and maximum lateral peak-to-peak acceleration criteria for three runs. The exceptions were the result of extremely short duration acceleration events that were not representative of the gross motion of the railcars.

The Atlas railcar did not meet the maximum truck side L/V ratio criterion (0.53, limit = 0.5) during the 10-degree curve in the revenue service test. The exception occurred during a 10-mph northbound draft run with the B-end leading. After the completion of the test series, the test crew repeated the 10-mph run, and the maximum truck side L/V ratio met criterion on the second run.

During revenue service testing between Trinidad and the siding at Folsom, NM, the Atlas railcar did not meet criteria in five curves, not including the 10-degree test curve. There was one single wheel L/V ratio exception (0.82, limit = 0.8) in a six-degree curve. The remaining exceptions were truck side L/V ratio exceptions (worst=0.57, limit=0.5). Three of the curves with truck side L/V ratio exceptions were six degrees, and one was a four-degree curve. The number of truck side L/V ratio exceptions in each curve ranged from two to 45. Although the Atlas truck side L/V ratio did not meet the S-2043 criterion in these five curves, the performance with AAR-2A narrow flange profiles met the Chapter 11 criterion and showed a considerable improvement over the performance with AAR-1B narrow flange profiles.

During revenue service testing between Trinidad and the siding at Folsom, NM, the REV did not meet truck side L/V ratio criteria in three (3) six-degree curves (worst=0.55, limit=0.5). The number of truck side L/V ratio exceptions in each curve ranged from one to eight. Although the REV truck side L/V ratio did not meet the S-2043 criterion in several locations, the performance with AAR-2A narrow flange profiles met the Chapter 11 criterion and demonstrated a considerable improvement over the performance with AAR-1B narrow flange profiles.

While the truck side L/V ratios measured on the Atlas and REV did not meet the Standard S-2043 criterion on some curves, these ratios did meet the Chapter 11 criterion in every case. The performance with AAR-2A narrow flange wheel profiles showed a dramatic improvement over the performance with AAR-1B narrow flange wheel profiles. Therefore, on behalf of the DOE, MxV Rail is requesting exceptions from the AAR EEC to approve the Atlas train.

All tests except the second revenue service test and the demonstration test run were performed with AAR-1B narrow flange wheel profiles. After the first revenue service test in October 2022, the wheel tread profiles on the train were changed from AAR-1B narrow flange profiles to AAR-2A narrow flange profiles to improve curving performance. The revenue service 10-degree curve test was repeated with AAR-2A narrow flange profiles in June 2023, and this test showed improved performance. The DTR was completed in September 2023, with AAR-2A narrow flange profiles.

References

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2. Cummings, S, H. Wu, and S. Trevithick. (2016) "Large-Scale SRI-1A Wheel Profile Service Tests." *Technology Digest* TD-16-005. TTCI/AAR, Pueblo, CO.
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4. AAR MSRP, Section C- II, Car Construction Fundamentals and Details, Design, Fabrication, and Construction of Freight Cars, Chapter 11, Service-Worthiness Tests and Analyses for New Freight Cars, Implemented 09/2017, AAR, Washington, D.C.
5. ISO 2631-1:1997/Amd 1:2010, Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration.
6. Association of American Railroads, Circular OT-55: Recommended Railroad Operating Practices for Transportation of Hazardous Materials, Effective May 1, 2019.

Appendix A - Test Plan TP-20-001 rev 2 Dynamic Tests at the Controlled Test Site

TEST IMPLEMENTATION PLAN
MULTIPLE CAR TEST OF THE ATLAS HLRM TRAIN
IN ACCORDANCE WITH
ASSOCIATION OF AMERICAN RAILROADS STANDARD S-2043
PARAGRAPH 6.1 -- TESTS AT CONTROLLED TEST SITE

For the U.S. Department of Energy (DOE)

TEST PLAN TP-20-001 REV 2

Prepared by
Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads
Pueblo, Colorado USA
MAY 27, 2021

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1.0 INTRODUCTION

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete multiple car testing of the U.S. Department of Energy (DOE) Atlas High Level Radioactive Material (HLRM) train as required by the Association of American Railroads (AAR) S-2043 standard titled "Performance Specification for Trains used to Carry High-Level Radioactive Material," Paragraph 6.1 – Dynamic Tests at the Controlled Test Site[1]. Tests include:

- Stop Distance Tests
- Braking in Curves
- Hand Brake Tests
- Buff and Draft Curving

The Buff and Draft Curving test will be repeated for the Navy M-290 12-axle railcar using the test consist and wayside instrumentation already assembled. This work will be conducted under contract to DOE. A separate test plan will be provided.

The Atlas HLRM train to be tested consists of a cask car (the Atlas car), a rail escort vehicle (REV), and two buffer cars as shown in Figure 1 and Table 1. It is anticipated that the REV will be used as the instrumentation coach. Other tests will require additional locomotives and hopper cars in the train.

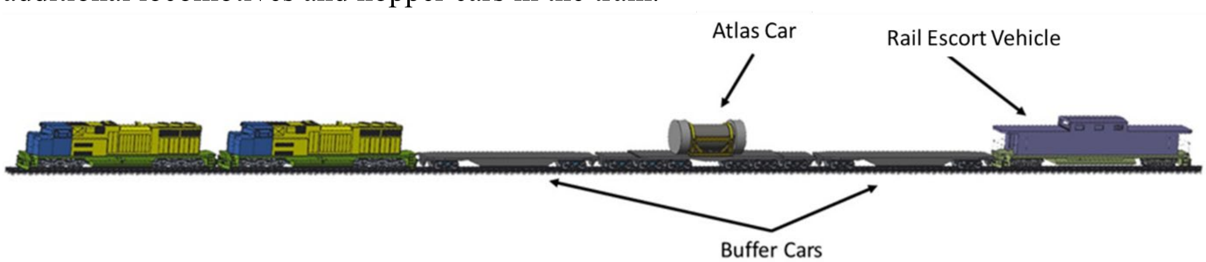

Figure 1. Atlas HLRM Train

Table 1. Atlas HLRM train details

Item	Type	Car Number	Approximate Gross Weight	Remarks
1	Locomotive	TBD	---	
2	Buffer Car	IDOX 20001 or IDOX 20002	263,000 lbs.	
3	Atlas Car (Min test load)	IDOX 10001	425,100 lbs.	Minimum test load condition
	Atlas Car (Max test load)	IDOX 10001	714,200 lbs.	Maximum test load condition
4	Buffer Car	IDOX 20001 or IDOX 20002	263,000 lbs.	
5	REV	IDOX 30001	181,400 lbs.	
Note: Order of IDOX 20001 and IDOX 20002 to be recorded				

2.0 SAFETY

Work is to be conducted in accordance with the most current versions of TTCI's Safety Rulebook[2] and Operating Rulebook[3] which are maintained on TTCI's intranet site.

2.1 Test Loads

Test loads were designed and fabricated by Orano Federal Services to simulate the weight and center of gravity (CG) of the lightest and heaviest packages that the DOE Atlas railcar is designed to transport. The minimum condition test load assembly is designed to simulate the lightest package (MP197) and its cradle, and the maximum condition test load assembly is designed to simulate the heaviest package (HI-STAR 190XL) and its cradle and end stops.

The test loads incorporate a common central beam assembly with various weight assemblies, cradles and end stops that can be configured for either the minimum or maximum condition test load (Figures 2 - 4). A detailed description of the test loads and loading, unloading and assembly instructions can be found in the project document DW-19-013rev1 "Assembly Instructions for the DOE Atlas Railcar Test Loads"[4].

The test load assemblies are marked with 'H↔L' symbols to designate the 'Heavy' and 'Light' ends of each complete test load assembly. These directional symbols must be used during testing to establish the desired orientation on the DOE Atlas railcar. Orientation must be recorded for all tests.

Figure 2. Central Beam Assembly being Mounted on Minimum Test Load Cradle

Figure 3. Minimum Test Load Assembly mounted on Atlas railcar

Figure 4. Maximum Test Load Assembly with End Stops Mounted on Atlas Railcar

2.2 Test Tracks

The Stop Distance and Handbrake tests will be conducted between T30.0 and T33.9 on the Transit Test Track (TTT). This is a level tangent section (Figure 5). The Braking in Curves and Buff and Draft Curve tests will be conducted on the $7^{1}/_{2}$- and 12-degree curves, respectively, on the Wheel / Rail Mechanisms Loop (WRM) (Figure 6).

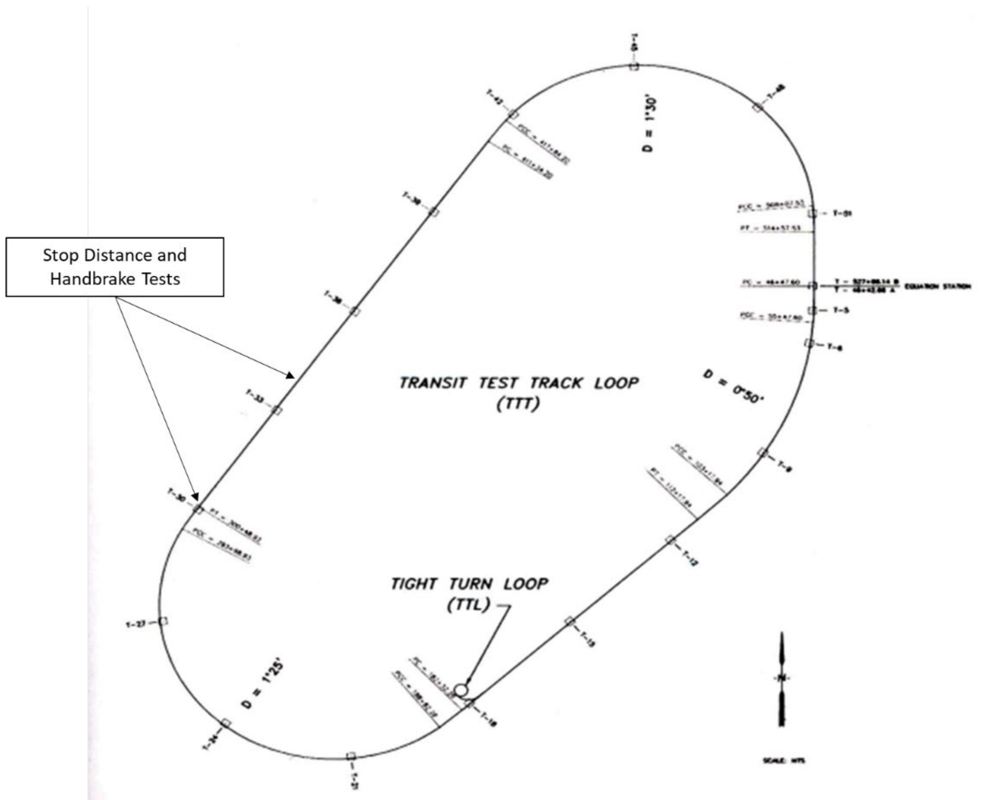

Figure 5. Stop Distance and Hand Brake Test Zone on TTT

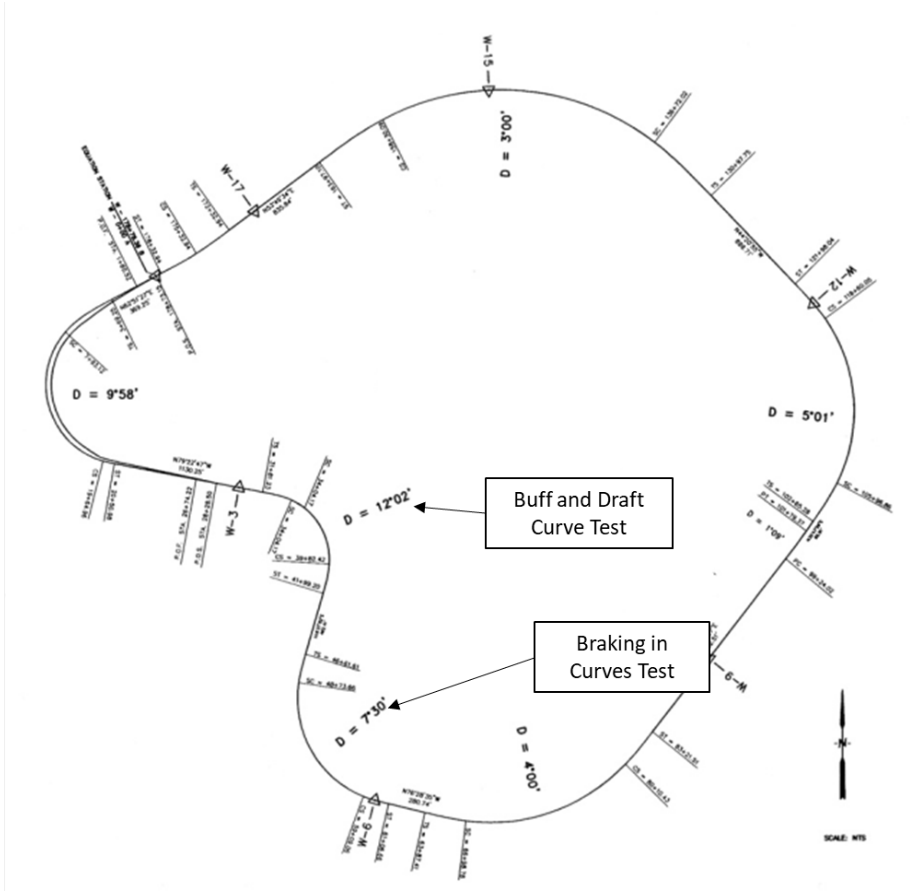

Figure 6. Braking in Curves and Buff and Draft Curve Test Locations on the WRM

3.0 BASIC S-2043 INSTRUMENTATION

Comparison of test consist performance to the dynamic performance criteria in Table 5.1 of S-2043 is required for the Braking and Buff and Draft Curving tests. Table 2 and Figure 7 show the applicable dynamic performance criteria. Tables 3-6 list the on-board channels required for the comparisons for the Atlas car (IDOX 10001), the lead buffer car (IDOX 20001 or IDOX 20002), and the escort car (IDOX 30001). The tests at TTC will use wayside rail force measurements for comparison to wheel force criteria rather than instrumented wheel sets. This will require a load station on the 7 ½-degree curve and a load station on the 12-degree curve on the WRM as described in Paragraphs 4.2 and 5.1. The load station on the $7^1/_2$-degree curve will require angle of attack measurements.

For the Atlas car, on-board data channels will include:

- 2 each – Roll Gyroscopes
- 2 each – Vertical Accelerometers
- 6 each – Lateral Accelerometers

- 12 each – > 5 in. String Potentiometers
- 1 each – Speed Tachometer, may be located anywhere on the train, but location must be recorded. (additional tachometers are required for Stop Distance Tests)
- 1 each – Automatic Location Device may be located anywhere on the train, but location must be recorded.

For the lead buffer car and the escort car, data channels will include:

- 2 each – Roll Gyroscopes
- 2 each – Vertical Accelerometers
- 2 each – Lateral Accelerometers
- 4 each – >5 in. String Potentiometers

Car body lateral acceleration will be taken over truck or span bolster centers. Car body roll angle measurements, and spring group vertical displacement will be taken on each end of each instrumented vehicle.

3.1.1 Data Acquisition

Data will be filtered at a rate ≥ 15 Hz and ≤ (sample rate/2). The minimum sample rate is 300 Hz. Data will be post filtered as required (15 Hz) and analyzed in near-real time using the performance criteria for dynamic testing provided in Table 2.

3.1.2 Instrumentation Functional Checks

Functional checks of the instrumentation must be made to verify that all the measurements are working correctly. These functional checks are not a calibration function but are done to verify the setup. Guidance for performance of functional checks is provided in the Appendix.

Table 2. S-2043 Dynamic Limiting Criteria

Criterion	Limiting Value	Notes
Maximum car body roll angle (degree)	4	Peak-to-peak.
Maximum wheel L/V	0.8	Not to exceed indicated value for a period greater than 50 msec. and for a distance greater than 3 ft. per instance*.
95th percentile single wheel L/V (constant curving tests only)	0.6	Not to exceed indicated value. Applies only for constant curving tests.
Maximum truck side L/V	0.5	Not to exceed indicated value for a duration equivalent to 6 ft. of track per instance.
Minimum vertical wheel load (%)	25	Not to fall below indicated value for a period greater than 50 msec. and for a distance greater than 3 ft. per instance*.
Peak-to-peak car body lateral acceleration (G)	1.3 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum car body lateral acceleration (G)	0.75 0.35	For non-passenger-carrying railcars For passenger-carrying railcars
Car body lateral acceleration standard deviation (G)	0.13	Calculated over a 2000-ft sliding window every 10 ft. over a tangent track section that is a minimum of 4000 ft. long.
Maximum car body vertical acceleration (G)	0.90 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum vertical suspension deflection (%)	95	Suspension bottoming not allowed. Maximum compressive spring travel shall not exceed 95% of the spring travel from the empty car height of the outer load coils to solid spring height.
Maximum vertical dynamic augment acceleration (g)	0.9	Suspension bottoming not allowed. Vertical dynamic augment accelerations of a loaded car shall not exceed 0.9 G.

*Figure 7 illustrates the application of 50 millisecond and 3 ft. distance limits for maximum wheel L/V ratio and minimum vertical wheel load.

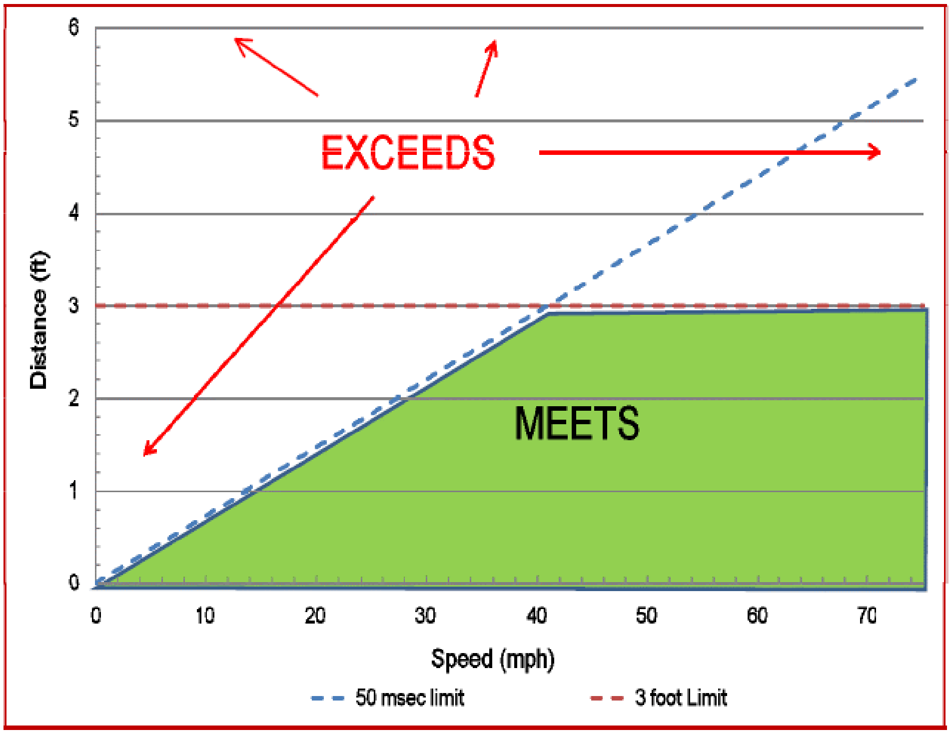

Figure 7. Time and Distance to Climb Limits

Table 3. Basic S-2043 onboard measurement list for Atlas car (IDOX 10001) (1 of 2)

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	Speed	Speed	0-80mph	0-1Hz	≥300Hz	better than 1%
2	ALD	Automatic Location Device	0-5V	≥15Hz	≥300Hz	better than 2%
3	ZACBB	Lead carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
4	ZACBA	Trail carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
5	YACBB	Lead carbody* lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
6	YACBA	Trail carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
7	YASBA1	Lead span bolster lead lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
8	YASBA2	Lead span bolster trail lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
9	YASBB1	Trail span bolster lead lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
10	YASBB2	Trail span bolster trail lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
11	ZDSNBL	Vertical Displacement B truck Left Side >5 inch	>5 inch	≥15Hz	≥300Hz	better than 1%

*Carbody accelerometers to be placed as closely as possible to the span bolster centers.

Table 3. Basic S-2043 onboard measurement list for Atlas car (IDOX 10001) (2 of 2)

NO.	Channel Name	Measurement Description	Expecte d Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
12	ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
13	ZDSNCL	Vertical Displacement C truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
14	ZDSNCR	Vertical Displacement C truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
15	ZDSNDL	Vertical Displacement D truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
16	ZDSNDR	Vertical Displacement D truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
17	ZDSNEL	Vertical Displacement E truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
18	ZDSNER	Vertical Displacement E truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
19	ZDSNFL	Vertical Displacement F truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
20	ZDSNFR	Vertical Displacement F truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
21	ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
22	ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
23	RDCBB	Carbody roll rotation, B-end	±4deg	≥15Hz	≥300Hz	better than 1%
24	RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	better than 1%
25	GPS	GPS	n/a	≥1Hz	≥1Hz	better than 1%

*Carbody accelerometers to be placed as closely as possible to the span bolster centers.

Table 4. Basic S-2043 onboard measurement list for lead buffer car (IDOX 20002)

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	BL-ZACBB	Lead carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
2	BL-ZACBA	Trail carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
3	BL-YACBB	Lead carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
4	BL-YACBA	Trail carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
5	BL-ZDSNBL	Vertical Displacement B truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
6	BL-ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
7	BL-ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
8	BL-ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
9	BL-RDCBB	Carbody roll rotation, B-end	±4deg	≥15Hz	≥300Hz	better than 1%
10	BL-RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	better than 1%

*Carbody accelerometers to be placed as closely as possible to the truck centers

Table 5. Basic S-2043 onboard measurement list for Trailing buffer car (IDOX 20001)

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	BT-ZACBB	Lead carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
2	BT-ZACBA	Trail carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
3	BT-YACBB	Lead carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
4	BT-YACBA	Trail carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
5	BT-ZDSNBL	Vertical Displacement B truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
6	BT-ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
7	BT-ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
8	BT-ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
9	BT-RDCBB	Carbody roll rotation, B-end	±4deg	≥15Hz	≥300Hz	better than 1%
10	BT-RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	better than 1%

*Carbody accelerometers to be placed as closely as possible to the truck centers

Table 6. Basic S-2043 onboard measurement list for REV

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	E-ZACBB	Lead carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
2	E-ZACBA	Trail carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
3	E-YACBB	Lead carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
4	E-YACBA	Trail carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
5	E-ZDSNBL	Vertical Displacement B truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
6	E-ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
7	E-ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
8	E-ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
9	E-RDCBB	Carbody roll rotation, E-end	±4deg	≥15Hz	≥300Hz	better than 1%
10	E-RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	better than 1%

*Carbody accelerometers to be placed as closely as possible to the truck centers

4.0 BRAKING TESTS

The following sections describe the Braking Tests including:

- Stop Distance Tests
- Braking in Curves
- Hand Brake Tests

4.1 Stop Distance Tests

Stop distance tests will be run to verify adequate functioning of the brake system and to quantify stop distances. Stop distance tests will be conducted for the Minimum Test Load and Maximum Test Load conditions, on the TTT between locations T30.0 and T33.9. Per EEC guidance (Nov 2018 EEC meeting minutes), the minimum test load condition is being tested instead of the empty (no cask) condition listed in Table 6.1 of S-2043. Note this section of track is level tangent. Figure 8 shows the test train setup for the stop distance tests. The measurements required include axle speed, wheel tread temperature, brake cylinder pressure, and train line pressure. Instrumented wheel sets (IWS) are not used.

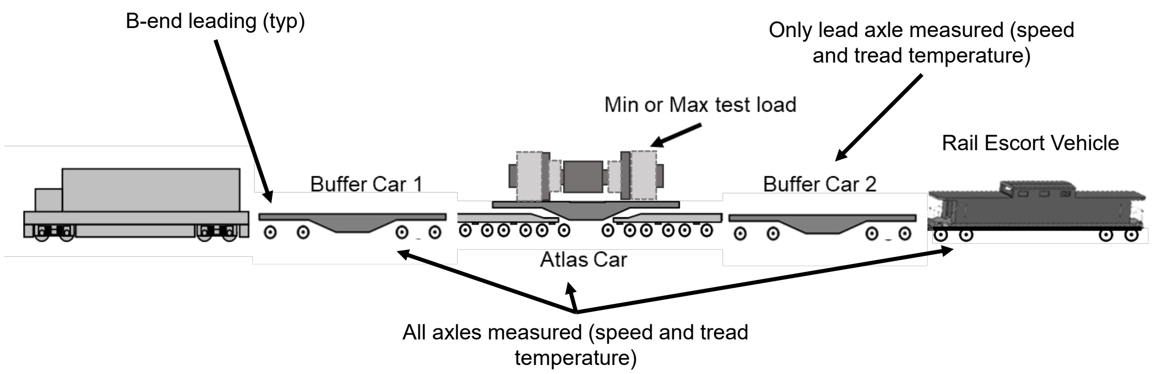

Figure 8. Test Consist for Braking Tests

4.1.1 Test Criteria

- S-2043 Dynamic Limiting Criteria from Table 2 apply, although no wheel-rail forces will be measured. (No IWS)
- For train speeds above 10 mph the measured axle speed shall not differ from train speed by more than 15 percent for longer than 50 msec.
- While not an S-2043 criteria, wheel temperatures should not exceed 700 ºF during testing. Wheels should be allowed to cool to less than 550 ºF between runs.[5]

4.1.2 Measurements

S-2043 requires that train line pressure, brake cylinder pressure, wheel tread temperature, and axle speed must be recorded. These channels are required to monitor wheel temperature and axle speed to verify the wheels are not damaged during testing and that no wheel slides occur.

For this test, all of the axles in the lead buffer car, the Atlas car and the REV, along with the lead axle of the trail buffer car will be measured for axle speed and temperatures as noted above (Figure 8). Tables 7-10 provide measurement details.

Pressure and temperature data should be filtered at a minimum of 10 Hz and sampled at a minimum of 100 Hz. Higher filter and sample rates are OK. Speed tachometer signals should not be filtered and should be sampled at a minimum of 6000 samples per second. If speed tachometer data and pressure/temperature data are recorded on separate systems the ALD signal should be recorded on both systems to allow alignment of the data if required.

Table 7. Data channels for braking tests – lead buffer car (IDOX 20002)

Num.	Channel Name	Description	Range
1	BL-PTRNLINE	Trainline pressure	0-120 psi
2	BL-PBCYL	Brake cylinder pressure, Buffer Car 1	0-120 psi
3	BL-TA01L	Wheel Temperature, Axle 1, Left wheel. IR sensor reading the rim very near the tread. Buffer Car 1	0-1000 °F
4	BL-TA01R	Wheel Temperature, Axle 1, Right wheel. IR sensor reading the rim very near the tread. Buffer Car 1	0-1000 °F
5	BL-SA01	Speed Tachometer, Axle 1. Buffer Car 1	0-80 mph
6-8	Follow convention	Speed Tachometer for Axles 2-4	0-80 mph

Table 8. Data channels for braking tests – Atlas Car

Num.	Channel Name	Description	Range
1	ATL-PBCYLB	Brake cylinder pressure, B-End, Atlas Car	0-120 psi
2	ATL-PBCYLA	Brake cylinder pressure, A-End, Atlas Car	0-120 psi
3	ATL-TA01L	Wheel Temperature, Axle 1, Left wheel. IR sensor reading the rim very near the tread. Atlas Car	0-1000 °F
4	ATL-TA01R	Wheel Temperature, Axle 1, Right wheel. IR sensor reading the rim very near the tread. Atlas Car	0-1000 °F
5	ATL-TA07L	Wheel Temperature, Axle 7, Left wheel. IR sensor reading the rim very near the tread. Atlas Car	0-1000 °F
6	ATL-TA07R	Wheel Temperature, Axle 7, Right wheel. IR sensor reading the rim very near the tread. Atlas Car	0-1000 °F
8	ATL-SA01	Speed Tachometer, Axle 1. Atlas Car	0-80 mph
9-19	Follow convention	Speed Tachometer for Axles 2-12	0-80 mph

Table 9. Data channels for braking tests – trail buffer car (IDOX 20001)

Num.	Channel Name	Description	Range
1	BT-PBCYL	Brake cylinder pressure, Buffer Car 2	0-120 psi
2	BT-TA01L	Wheel Temperature, Axle 1, Left wheel. IR sensor reading the rim very near the tread. Buffer Car 2	0-1000 °F
3	BT-TA01R	Wheel Temperature, Axle 1, Right wheel. IR sensor reading the rim very near the tread. Buffer Car 2	0-1000 °F
4	BT-SA01	Speed Tachometer, Axle 1. Buffer Car 2	0-80 mph

Table 10. Data channels for braking tests – REV

Num.	Channel Name	Description	Range
1	E-PBCYL	Brake cylinder pressure, REV	0-120 psi
2	E-TA01L	Wheel Temperature, Axle 1, Left wheel. IR sensor reading the rim very near the tread. REV	0-1000 °F
3	E-TA01R	Wheel Temperature, Axle 1, Right wheel. IR sensor reading the rim very near the tread. REV	0-1000 °F
10	E-SA01	Speed Tachometer, Axle 1. REV	0-80 mph
11-13	Follow convention	Speed Tachometer, Axle s 2-4. REV	0-80 mph

4.1.3 Water Application Systems

Water systems will be installed on both buffer cars, the Atlas car, and the REV. The water systems will be used for wet braking runs. Each water system will consist of a reservoir of at least 100-gallon capacity, a total rated pump capacity of at least 10-gallons per minute (probably 1 or 2 pumps), and hose/tubing to spray water on the rail in front of the leading wheels of each span bolster on the car (4 nozzles per car).

4.1.4 Test Conduct

Table 11 shows the run matrix for the minimum and maximum loaded stop distance tests. It is likely that on the 70-mph run the braking distance will exceed the zone of level track. Each run will be repeated in the opposite direction to account for grade.

Table 11. Run Matrix for Stop Distance Tests -- all tests shall be conducted in both minimum and maximum test load conditions and in both directions

Run	Brake Application	Initial Speed	Dry/Wet	Direction
1	Full Service	30	Dry	CW
2	Full Service	50	Dry	CW
3	Full Service	70	Dry	CW
4	Full Service	30	Wet	CW
5	Full Service	50	Wet	CW
6	Full Service	70	Wet	CW
7	Emergency	30	Dry	CW
8	Emergency	50	Dry	CW
9	Emergency	70	Dry	CW
10	Emergency	30	Wet	CW
11	Emergency	50	Wet	CW
12	Emergency	70	Wet	CW
13	Full Service	30	Dry	CCW
14	Full Service	50	Dry	CCW
15	Full Service	70	Dry	CCW
16	Full Service	30	Wet	CCW
17	Full Service	50	Wet	CCW
18	Full Service	70	Wet	CCW
19	Emergency	30	Dry	CCW
20	Emergency	50	Dry	CCW
21	Emergency	70	Dry	CCW
22	Emergency	30	Wet	CCW
23	Emergency	50	Wet	CCW
24	Emergency	70	Wet	CCW

4.2 Braking in Curves

The braking in curves test is performed to verify that the braking system does not adversely affect curving performance. This test will be performed on the 7½-degree curve on the WRM. The test consist is shown in Figure 8. The consist will be loaded in the minimum test load condition, which produced the highest L/V ratios in the single-car constant curving test. These tests will be performed on dry rail and will not be repeated using the water spray system. Tests will be performed in both CW and CCW directions with both A-End and B-end of the Atlas car leading. To facilitate testing in both directions, the entire train will be turned.

4.2.1 Test Criteria

S-2043 Dynamic Limiting Criteria from Table 2 apply. Because wayside forces will be measured, rather than instrumented wheel sets, peak values rather than 50 msec values will be used.

Axle angle of attack values shall be reported to verify squaring of the truck. Axle angle of attack in milliradians may not exceed the curvature of the track in degrees plus 5 milliradians.

4.2.2 Instrumentation

The braking in curves test will be conducted using the same on-board instrumentation as the stop distance testing. Additional instrumentation on the track is required to measure the wheel-rail forces and the axle angle of attack. Wheel-rail forces will be measured in the center of the curve. The axle angle of attack will be measured at about the same location. An ALD marker will be placed near the track instrumentation for alignment of the data if required. Table 12 summarizes the wayside measurements.

Table 12. Wayside Measurements-Instrumented Coupler

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	IC	Instrumented Coupler	0-300 kips	30 Hz	256 Hz	+/- 10%
2	ZLR	Vertical force strain bridge LH rail	0-80 kips	200 Hz	1000 Hz	+/- 10%
3	ZRR	Vertical force strain bridge circuit RH rail	0-80 kips	200 Hz	1000 Hz	+/- 10%
4	YLR	Lateral force strain bridge LH rail	0-40 kips	200 Hz	1000 Hz	+/- 15%
5	YRR	Lateral force strain bridge circuit RH rail	0-40 kips	200 Hz	1000 Hz	+/- 15%
6	AOA	Angle of Attack	0-20 mrad	200 Hz	1000 Hz	1 mrad

4.2.3 Test Conduct

The test runs will follow the procedure listed below.

1. Approach the 7½-degree curve on the WRM loop at 32mph. (32 mph is the maximum allowable speed on this portion of the WRM loop, per FRA track safety standards for the degree of curvature and superelevation on the section containing the 7.5, 10, and 12-degree curves. The 32 mph maximum speed for this portion of the WRM loop is also listed in Section 7.9 of TTCI's Operating Rule Book.)

Apply the brakes 100-feet before the entry spiral. Record data as the train comes to a stop. Make note of the speed(s) where the test cars cross the wayside instrumentation.

2. Move the brake application point some distance into the curve, toward the location of the wayside instrumentation and make the run again.

3. By adjusting the brake application location, data will be obtained from the wayside gauges at a range of speeds. The start point shall be adjusted until data points are recorded with the test cars crossing the wayside instrumentation at 12 ±1 mph (almost 2.3 inches underbalance), 24 ±1 mph (balance), and 32 ±1 mph (almost 2.2 inches overbalance). The lowest speeds will be the most difficult because the speed of the train will change significantly over the train's length. All the runs where the train crosses the instrumented location shall be recorded.

4. After each test run the onboard and wayside data will be checked to verify that wheel-rail forces are within acceptable limits as shown in Table 2. Wheel forces will be checked for all cars in the test train. Note wheel-rail forces listed in Table 2 include maximum wheel L/V, maximum truck side L/V, and minimum vertical wheel load.

4.3 Hand Brake Tests

The handbrake test is conducted to verify handbrake performance to hold train on a grade. Figure 9 shows the train to be used for hand brake tests. A hopper car will be placed between the locomotive and the test train so the instrumented coupler can be installed. The Atlas car will be loaded to the Maximum Test Load condition.

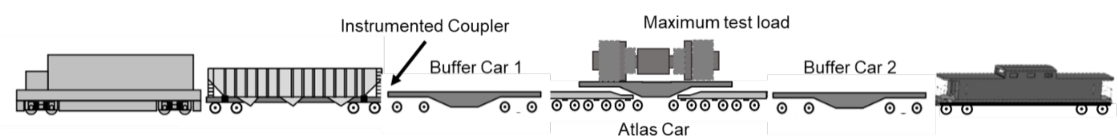

Figure 9. Train to be used for Hand Brake Tests

4.3.1 Instrumentation

An instrumented coupler will be installed in the hopper car on the end facing the loaded test train. The instrumented coupler will be used to measure the force required to move the train. Coupler force and speed are the only required measurements for this test.

4.3.2 Test Conduct

The test will be performed by placing the train on the TTT between locations T30.0 and T33.9, a level tangent track. The train will be stretched to remove free slack between the cars. For each run, handbrakes will be applied as shown in Table 13, and the train will be pulled with the locomotive until the train moves steadily. The force required to move the train will be recorded. The grade-holding capability shall be calculated for each hand brake configuration.

Table 13. Handbrake Test Run Matrix

Run	Buffer Car 1	Atlas Car A-end	Atlas Car B-end	Buffer Car 2	REV
1	Released	Released	Released	Released	Released
2	Set	Set	Set	Set	Set
3	Set	Set	Set	Set	Released
4	Set	Set	Set	Released	Released
5	Set	Set	Released	Released	Released
6	Set	Released	Released	Released	Released
7	Released	Set	Set	Released	Released

5.0 BUFF AND DRAFT CURVING

The buff and draft tests will be performed with the Atlas car loaded to the Minimum Test Load condition. Figure 10 shows the test train to be used for buff-draft testing. This train will be coupled between 3 6-axle locomotives and a hopper with an instrumented coupler on one end and about 33 hopper cars and/or locomotives in dynamic braking on the other end. The number of hopper cars and brake effort on the cars will be varied to obtain the required force as shown in Table 14.

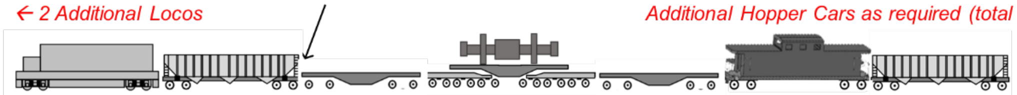

Figure 10. Buff-draft test train

5.1 Additional Criterion for Buff and Draft Curving

- S-2043 Dynamic Limiting Criteria from Table 2 apply. Because wayside forces will be measured, rather than instrumented wheel sets, peak values rather than 50 msec values will be used.

- While not an S-2043 requirement, for the buff-draft test only, net axle lateral L/V ratio will be examined to determine the likelihood of track panel shift. The criterion given in the US Code of Federal Regulations (CFR) 49 CFR Part 213.333 table of Vehicle/Track Interaction Safety Limits will be used for comparison to this measurement. Figure 11 shows a description of the Net Axle Lateral L/V Ratio from the CFR. Because the criterion is dependent on axle load, its value must be calculated for each car in the train. Table 14 lists the axle weight and the corresponding Net Axle Lateral L/V Ratio criterion for each car type used in the test train. If this value is exceeded, testing must be suspended pending a determination of cause.

Net Axle Lateral L/V Ratio	$\leq 0.4 + \frac{5.0}{Va}$	5 ft	The net axle lateral force, in kips, exerted by any axle on the track shall not exceed a total of 5 kips plus 40 percent of the static vertical load that the axle exerts on the track for 5 or more continuous feet. Va = static vertical axle load (kips)

Figure 11. Net Axle Lateral L/V ratio from 49 CFR 213.333

Table 14. Net axle Lateral L/V ratio criteria for the cars in the train

Car	Axle Weight (kips)	Criteria for Net Axle Lateral L/V Ratio
Buffer Car 1	66	≤ 0.48
Atlas Car	34	≤ 0.54
Buffer Car 2	66	≤ 0.48
REV	45	≤ 0.51
Locomotive*	72	≤ 0.47

*Estimated values -- may be revised when scale weight is available

5.1.1 Instrumentation

Measurements onboard the train will include measurements listed in Tables 3-6 and the instrumented coupler. Wayside measurements will include lateral and vertical forces in the body of the 12-degree curve on the WRM. See Table 12 for details (angle of attack is not required for Buff and Draft Curving).

Per request of the AAR Equipment Engineering Committee, additional monitoring will be performed in the south spiral of the 12-degree curve. Fish scales will be mounted on ties to measure rail head lateral deflection (both rails) in the south spiral of the WRM 12-degree curve. Exact location is to be determined by Russell Walker, probably about 10 to 20 feet into the spiral from the curve.

After each test run the onboard and wayside data will be checked to verify that wheel-rail forces are within acceptable limits. Wheel forces will be checked for all cars in the test train.

5.2 Buff and Draft Curving Test Conduct

Table 15. lists the test runs for each car orientation-track direction condition. The test sequence shown below will be performed in each of the following conditions:

- CW with Atlas Car B-end leading
- CCW with Atlas Car B-end leading
- CW with Atlas Car A-End leading
- CCW with Atlas Car A-end leading

Prior to each sequence of buff-draft runs, a walking speed run (Runs EEC-1, -2, -3, and -4) will be performed to check for equipment clearances as well as track gage spreading and rail roll. Person(s) on the ground will be required for the visual observations of clearances and gage spreading. Fish scale readings of maximum lateral rail head displacement will be collected for each rail for both locomotives and the Atlas Car. Each run will be stopped so that the fish scales can be re-zeroed between the locomotives and the Atlas Car. Atlas Car readings will be compared to the readings from the locomotives after each run.

Buff runs will be performed with the train moving in one direction through the curve, and draft runs will be performed with the train moving in the other direction through the curve. Speeds will be the maximum of 15 mph or the limiting speeds of the locomotives for the tractive effort required.

Table 15. Buff-Draft Curving Test Runs Required for Both Directions of Travel with Both Ends of the Atlas Car Leading (Total of 40 runs)

Run	Force	Buff/Draft	Direction	Atlas Car Leading End
EEC-1	nominal	Walking speed	CW	A
1	50-kip	Buff	CW	A
2	50-kip	Draft	CW	A
3	100-kip	Buff	CW	A
4	100-kip	Draft	CW	A
5	150-kip	Buff	CW	A
6	150-kip	Draft	CW	A
7	200-kip	Buff	CW	A
8	200-kip	Draft	CW	A
9	250-kip	Buff	CW	A
10	250-kip	Draft	CW	A

Run	Force	Buff/Draft	Direction	Atlas Car Leading End
EEC-2	nominal	Walking speed	CCW	A
11	50-kip	Buff	CCW	A
12	50-kip	Draft	CCW	A
13	100-kip	Buff	CCW	A
14	100-kip	Draft	CCW	A
15	150-kip	Buff	CCW	A
16	150-kip	Draft	CCW	A
17	200-kip	Buff	CCW	A
18	200-kip	Draft	CCW	A
19	250-kip	Buff	CCW	A
20	250-kip	Draft	CCW	A
EEC-3	nominal	Walking speed	CW	B
21	50-kip	Buff	CW	B
22	50-kip	Draft	CW	B
23	100-kip	Buff	CW	B
24	100-kip	Draft	CW	B
25	150-kip	Buff	CW	B
26	150-kip	Draft	CW	B
27	200-kip	Buff	CW	B
28	200-kip	Draft	CW	B
29	250-kip	Buff	CW	B
30	250-kip	Draft	CW	B
EEC-4	nominal	Walking speed	CCW	B
31	50-kip	Buff	CCW	B
32	50-kip	Draft	CCW	B
33	100-kip	Buff	CCW	B
34	100-kip	Draft	CCW	B
35	150-kip	Buff	CCW	B
36	150-kip	Draft	CCW	B
37	200-kip	Buff	CCW	B
38	200-kip	Draft	CCW	B
39	250-kip	Buff	CCW	B

Run	Force	Buff/Draft	Direction	Atlas Car Leading End
40	250-kip	Draft	CCW	B

6.0 SYSTEM MONITORING TESTS

S-2043 requires that an automatic system be in place to provide real time monitoring of a railcar's performance when it is moving in a HLRM train and to provide remote monitoring during all other moves. TTCI contracted with 3C Telemetry LLC of Denver, CO to build and install the upgraded monitoring system. The monitoring system on the 2 Buffer cars, 1 Atlas Car and 1 REV car will be tested for the system functional test.

6.1 System Functional Test (SSM)

The SSM system functional tests will be performed at the same time as loaded train stop distance tests. The real time monitoring system will be observed during testing and notes can be made regarding the various train condition.

Following a series of braking test runs 60-minutes of data will be downloaded from each of the four cars monitoring systems. The data from this download will be compared to onboard test measurements made as part of the braking tests to verify system functionality. Note TTCI is assuming the SSM system alarm module(s) will be in the REV. TTCI does not expect that any of the loaded train stop distance tests will cause alarms, but the testing will allow verification that the system correctly measures the following parameters:

- Location – Monitoring system GPS can be compared to the GPS of the onboard data system being used for braking tests.
- Speed – Monitoring system speed can be compared to the speed measured on the onboard data system being used for braking tests.
- Truck Hunting – The lateral acceleration measured by the remote monitoring system will be compared to the lateral acceleration measurements made as part of the standard S-2043 instrumentation package.
- Rocking – The roll angle measured by the remote monitoring system will be compared to the roll angle measurements made as part of the standard S-2043 instrumentation package.
- Wheel Flats – Vertical acceleration data from bearing adapter accelerometers will be examined. The effect of speed and track condition, specifically rail joints, on the data will be noted.
- Bearing Condition – Although the bearing temperature should not reach alarm levels, the heat from the wheels during braking and the 70-mph test speeds should cause noticeable increases in bearing temperature.

- Ride Quality – The RMS car body acceleration will be compared to the vertical and lateral acceleration measurements made as part of the standard S-2043 instrumentation package.
- Vertical acceleration – The vertical acceleration measured by the remote monitoring system will be compared to the vertical acceleration measurements made as part of the standard S-2043 instrumentation package.
- Lateral acceleration – The lateral acceleration measured by the remote monitoring system will be compared to the lateral acceleration measurements made as part of the standard S-2043 instrumentation package.
- Longitudinal acceleration – The longitudinal acceleration measured by the monitoring system will be compared to the speed profile to verify that average and peak accelerations make sense considering the acceleration and braking profile during the braking tests.

Note braking performance is not included in the performance to be monitored as the SSM does not monitor braking performance and is not a required in the S-2043 specification (listed as preferred).

6.2 SSM Failure Simulations

Failure simulation tests showing compliance with S-2043 6.2.2 will be performed on a buffer car. More details on the test is provided in TP-21-002 -- SSM Testing on VTU.

7.0 REFERENCES

1. AAR Manual of Standards and Recommended Practices, Car Construction Fundamentals and Details, Performance Specification for Trains Used to Carry High-Level Radioactive Material, Standard S-2043, Effective: 2003; Last Revised: 2017, Association of American Railroads, Washington, DC.

2. Safety Rule Book, TTCI, January 2018 or Latest Revision.

3. Operating Rule Book, TTCI, January 2018 or Latest Revision.

4. Assembly Instructions for the DOE Atlas Railcar Test Loads, Orano Federal Services Document EIR-3022576-001, TTCI Document DW-19-013rev1. On file on TTCI’s network; Q:\Business Services\Tech Docs\DOE Controlled Document Folder\DW - Drawings and Specifications

5. Stone, D., Cummings, S, “Effect of Residual Stress, Temperature, and Adhesion on Wheel Surface Fatigue Cracking,” Proceedings of RTDF2008, 2008 ASME Rail Transportation Division Fall Technical Conference, September 24-25, 2008 Chicago, Illinois, USA

6. Code of Federal Regulations, Title 49, Part 213, Track Safety Standards, 10-1-11 Edition.

APPENDIX – GUIDANCE FOR PERFORMING INSTRUMENTATION FUNCTIONAL TESTS

Functional Checks

Functional checks of the instrumentation should be made to verify that all the measurements are working correctly. These functional checks are not a calibration function but are done to verify the setup.

Common setup errors are faulty transducers, cabling errors, improper gain settings, etc. Perform functional checks to verify that the cables go where they are supposed to and measure about the right value. If a functional check of a transducer shows more than 10% error, look closely at the setup to make sure there are no mistakes.

- Record the functional checks in a data file so you can refer to them later if necessary.
- Perform the functional checks in a specific order and verify that the order matches what you observe in the data file.
- Pay attention to the sign of the output.

The following are typical functional checks for some transducers.

- Roll the accelerometers 90 degrees for a 1g input.
- Pull string pots and verify that extension is positive and that they read 1-inch when pulled one inch.
- Use a block of known size to check LVDTs and bending beams.
- Check speed measurements against GPS speed
- Verify load cells with an R-cal resistor and a breakout box.
- If possible, apply a known force to a loadcell. For example, use the car weight and the track grade from your Operating Rule Book to estimate the average expected force on the appropriate channel for a particular piece of track during resistance testing.

IWS are a special case. The following are suggested for functional tests of IWS. As IWS technology changes the steps might change.

- Verify the cable is connected where you think it is by disconnecting the cable at the wheelset and verifying that the “Disconnected” light comes on at the decoder box where you expect it to.
- Jack all IWS and zero all torque channels through software

- Push the Rcal button on the Decoder box and verify that you see the step change in the correct IWS channels.
- Record sync frequency from decoder boxes and record in the measurement information file (MIF)
- Record data on a portion of tangent track.
  - Vertical loads should match the scale weight to within 5%
  - Lateral loads should be small, resulting in L/V ratios of about 0.05. This may vary depending on truck design and condition.
  - Contact position output should be around zero. This may vary depending on truck design and condition.
  - If the wheelset is equipped with a torque bridge its average should be around zero. This may vary depending on truck design and condition.
- If a truck is fully instrumented with IWS, you can compare the net lateral load to a calculated value for a curve.

Appendix B - Test Plan TP-21-002 rev 2 Test Plan System Safety Monitoring Tests

DRAFT TEST IMPLEMENTATION PLAN

SYSTEM SAFETY MONITORING TESTS
AS PART OF MULTIPLE CAR TEST OF THE
ATLAS RAILCAR CONSIST
IN ACCORDANCE WITH
ASSOCIATION OF AMERICAN RAILROADS STANDARD S-2043,
PARAGRAPH 6.2

For the U.S. Department of Energy (DOE)

Prepared by
Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads
Pueblo, Colorado USA
December, 2021

EXECUTIVE SUMMARY

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete System Safety Monitoring (SSM) Failure Simulation testing of the U.S. Department of Energy (DOE) Atlas High Level Radioactive Material (HLRM) train. Testing of the SSM is required by the Association of American Railroads (AAR) S-2043 standard titled "Performance Specification for Trains used to Carry High-level Radioactive Material."[1] The testing is being carried out to validate performance of the SSM relative to failure simulations. Testing pertains specifically to Section 6.2.2 – Failure Simulations.

This test plan specifies completion of testing on 4-axle car monitoring system and assumes that results will be applicable to all cars in the consist including the Atlas car, rail escort vehicle, and the associated buffer cars, which contain functionally identical SSM systems.

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Purpose

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete failure simulation testing of the System Safety Monitor (SSM) on U.S. Department of Energy (DOE) Atlas High Level Radioactive Material (HLRM) train as required by the Association of American Railroads (AAR) Manual of Standards and Recommended Practices (MSRP) standard S-2043 titled "Performance Specification for Trains used to Carry High-level Radioactive Material."[1] The train is being developed by DOE under the Atlas Railcar Design Project, which is intended to address the future need for large-scale transport of HLRM, including spent nuclear fuel. This testing is required as part of the multiple car tests required by S-2043.

The Atlas HLRM train to be tested consists of a cask car (the Atlas car), a rail escort vehicle (REV), and two buffer cars as shown in Figure 1 and Table 1.

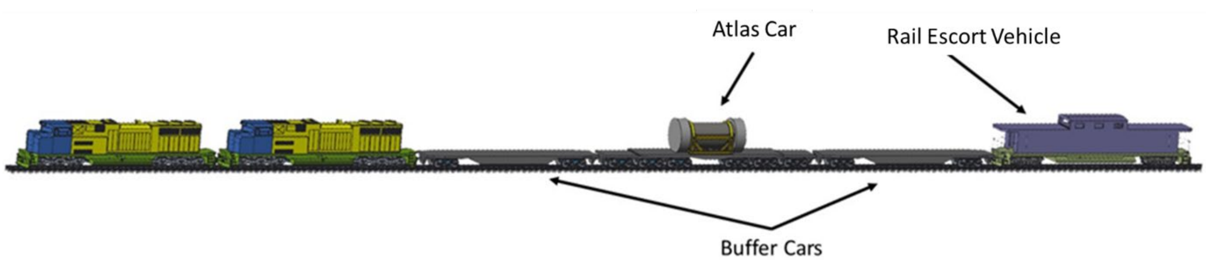

Figure 1. Atlas HLRM Train

Table 1. Atlas HLRM train details

Item	Type	Car Number	Remarks
1	Locomotive	TBD	Does not have SSM equipment
2	Buffer Car	IDOX 20001	4 axles
3	Atlas Car	IDOX 10001	12 axles
4	Buffer Car	IDOX 20002	4 axles
5	REV	TBD	4 axles

S-2043 Section 6.2 requires verification testing of the SSM as part of multiple car tests. This document describes testing to meet the requirements of Standard S-2043 Section 6.2.2 - Failure Simulations. The System Functional Test required by Section 6.2.1 is described in TP-20-001[2].

1.2 Test Description

The majority of testing will take place at 3C Telemetry's laboratory in Centennial, Colorado. 3C has equipment specifically designed to produce the inputs for system monitoring failure simulation tests. Transportation Technology Center, Inc (TTCI) will observe testing and make independent measurements of the inputs used to verify they are at the correct levels.

Some test inputs will be repeated on the using the Vibration Test Unit (VTU) at the Federal Railroad Administrations Transportation Technology Center (TTC) in Pueblo Colorado to demonstrate that the system operates correctly on the full scale vehicle. Using precisely controlled inputs from the VTU, it will be possible to verify alert and alarm levels in-situ for the severak of monitored conditions.

It is not possible to test a 12-axle car on the VTU, so one of the buffer cars (IDOX 20002) will be selected to perform the testing. This test plan assumes that results will be applicable to all cars in the consist including the Atlas car, the REV, and the associated buffer car, which contain functionally identical SSM equipment.

2.0 SAFETY SYSTEM MONITORING DESCRIPTION

The SSM[*] consists of wired and wireless sensors, a GPS unit, a memory module, and associated enclosures. Wireless sensors (bearing temperature and wheel flat accelerometers) are mounted near the end of each axle while wired sensors (body accelerometers and roll gyro) are located on the car body.

Control electronics, including the hardened memory module, are housed in pedestals at the ends of the car. The pedestal cap has solar panels for charging the internal battery. The Atlas car has identical pedestals at each end of the car. The buffer cars and REV have a single pedestal.

The SSM includes a stand-alone Portable Display Unit (PDU.) The PDU, which is designed to be located in the locomotive or escort railcar, will be used during the testing to receive and display SSM system response.

A full description of the SSM is provided in "DW-20-004 S-2043 System Safety Monitoring Design Specification".[3]

3.0 SAFETY

Work is to be conducted in accordance with the most current versions of TTCI's Safety Rulebook[4] and Operating Rulebook[5], which are maintained on TTCI's intranet site.

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[*] The SSM provided with the Atlas car and buffer cars (GEN-I) has recently been upgraded. The upgraded system (GEN-II) is supported by 3C Telemetry, LLC of Centennial Colorado. The GEN-II system has been installed on the REV during manufacture.

4.0 LABORATORY TESTS

Laboratory tests will be performed to check the alarm conditions listed in Standard S-2043 paragraph 4.5.4.2, except for stuck brake and inoperative brake alarms. These tests will be performed at 3C Telemetry's facility using their test equipment and one of DOE's monitoring systems.

TTCI will measure acceleration, roll displacement, and temperature to confirm the inputs are at the correct levels. The PDU will be monitored to verify that alarms are triggered. Table 2 lists the TTCI measurements for the laboratory tests.

Table 2. TTCI Data Channels to Monitor and Record Inputs in Laboratory

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	GREF	Roll Gyro	0-90°	0-1Hz	≥3000Hz	better than 2%
2	AREF	Accelerometer	5g	1300 Hz	≥3000Hz	better than 2%
3	TEMP	IR thermometer or equivalent	-40° F to 250° F	May be measured and recorded manually		better than 2%

4.1 Carbody Rocking Tests

The carbody rocking detector is intended to monitor carbody rocking motion that indicates poor dynamic performance. The requirement for roll angle as specified in S-2043 is as follows:

- Train Inspection Alarm –indication of degraded performance or peak – to – peak roll angles of 4° for 3 cycles
- Train Stop Alarm – indication of peak – to – peak roll angles of 5° for 3 cycles

The following steps will be performed for the carbody rocking test.

- Input peak to peak rocking of approximately 3 degrees for more than 3 cycles. No alarms should trigger.
- Input peak to peak rocking angles over 4 degrees but below 5 degrees for more than 3 cycles. An "inspect train" alarm should trigger.
- Input peak to peak rocking angles over 5 degrees for more than 3 cycles. A "stop train" alarm should trigger.
- Input peak to peak rocking angles over 5 degrees for one cycle and two cycles. No alarms should trigger.

4.2 Hunting Tests

Truck hunting is a result of lateral instability of the rail car. The requirement for identifying hunting as specified in S-2043 is as follows:

- Train Inspection Alarm – sustained RMS lateral car body acceleration of 0.13 g
- Train Stop Alarm – RMS lateral car body acceleration of 0.26 g sustained for 10 seconds

The following steps will be performed to test the hunting inspection alarm and the hunting train stop alarm

- Orient the TTCI accelerometer in the lateral direction and zero the instrumentation
- Input a sustained root mean square (RMS) lateral acceleration of about 0.1 g for at least five minutes. No alarm should trigger
- Input an RMS lateral acceleration of about 0.16 g for at least five minutes. An inspect train alarm should trigger
- Input an RMS lateral acceleration of about 0.3 g for at least five minutes. A stop train alarm should trigger

4.3 Vertical Impact Test

The Standard S-2043 requirement for triggering the vertical acceleration alarm is peak vertical car body acceleration of 1.0 g.

The following steps will be performed for the vertical impact test.

- Orient the TTCI accelerometer in the vertical direction and zero the instrumentation
- Input an acceleration of about 0.9 g. No alarm should trigger.
- Input an acceleration of about 1.1 g. A stop train alarm should trigger.

4.4 Lateral Impact Test

The Standard S-2043 requirement for triggering the lateral acceleration alarm is peak lateral car body acceleration of 0.75 g.

The following steps will be performed for the lateral impact test.

- Orient the TTCI accelerometer in the lateral direction and zero the instrumentation
- Input an acceleration of about 0.65 g. No alarm should trigger.
- Input an acceleration of about 0.85 g. A stop train alarm should trigger.

4.5 Longitudinal Impact Test

The Standard S-2043 requirement for triggering the longitudinal acceleration alarm is peak longitudinal car body acceleration of 1.5 g.

The following steps will be performed for the longitudinal impact test.

- Orient the TTCI accelerometer in the longitudinal direction and zero the instrumentation
- Input an acceleration of about 1.4 g. No alarm should trigger.
- Input an acceleration of about 1.6 g. A stop train alarm should trigger.

4.6 Wheel Flat Tests

The wheel flat detector is intended to identify vertical wheel impacts caused by flat spots on the wheels. The detection is based on vertical accelerations measured by accelerometers at the bearing adapters.

Train Inspection Alarm – Wheel flat indication: 3C Telemetry has defined their wheel flat indication as 3.0 g vertical acceleration measured at the end of the side frame.

The following steps will be performed for the wheel flat test.

- Orient the TTCI accelerometer in the vertical direction and zero the instrumentation
- Input an acceleration of about 2 g for more than 5 minutes. No alarm should trigger.
- Input an acceleration greater than 3 g for two minutes. No alarm should trigger.
- Input an acceleration greater than 3 g for more than five minutes. An inspect train alarm should trigger.

4.7 Bearing Temperature Test

The requirement for bearing temperature alarms are specified in S-2043 as follows:

- Train Inspection Alarm – indication of degraded performance

- Train Stop Alarm – indication of impending failure

  3C Telemetry has identified the following alarm conditions

  - Inspection alarms
    - Absolute temperature of 175° F
    - A temperature of 150° F above ambient
  - Train Stop Alarms
    - Absolute temperature of 200° F
    - A temperature of 170° F above ambient
    - A difference between bearings on the same axle of 95° F

  The following steps will be followed for the bearing temperature test.

- Absolute Temperature Failure Mode
  - Increase bearing sensor temperature to about 165° F. Confirm all temperatures with TTCI's infrared (IR) thermometer. No alarm should trigger.
  - Increase bearing sensor temperature above 175° F. Confirm all temperatures with TTCI's infrared (IR) thermometer. An inspect train alarm should trigger.
  - Increase bearing sensor temperature above 200° F. Confirm all temperatures with TTCI's infrared (IR) thermometer. A stop train alarm should trigger.
- Above Ambient Temperature Failure Mode
  - Hold ambient temperature sensor at low temperature (<0° F). Increase bearing sensor temperature to more than 150° F above ambient. An inspect train alarm should trigger.
  - Hold ambient temperature sensor at low temperature (<0° F). Increase bearing sensor temperature to more than 170° F above ambient. A stop train alarm should trigger.
- Mated Bearing Pair Failure Simulation

- Using two bearing temperature sensors assigned to the same axle, cool one to 32° F or less while warming the other to greater than 127° F or more. A stop train alarm should trigger.

5.0 VTU TESTS

This section describes the SSM failure simulation tests which are also to be completed on the VTU. Tests on the VTU will be done to verify that the system works as expected when installed on the car.

5.1 Test inputs

Validation of the SSM requires controlled inputs. TTCI will use the VTU as a means to input controlled loads and motions into the test car. A series of control scripts will be written to create the inputs defined in Table 3. These values are all well within the capabilities of the hydraulic actuators on the VTU.

Table 3. VTU Maximum Controlled Inputs

Validation Test	Input Description
Body Rocking	Semi-static vehicle roll angle +/- 5º
Truck Hunting	0.26 g lateral inputs for 10 seconds
Vertical Impacts	Vertical 1.0 g peak impulse on all actuators

5.2 Input Signal Monitoring

TTCI will install instruments on the test car to confirm all test input loads. These instruments will be installed on or near the corresponding SSM sensors that they are meant to monitor. Data from these instruments will be monitored in real time and recorded to verify range and accuracy of the applied inputs. Table 2 describes the data channels that TTCI will install.

Table 3. TTCI Data Channels to Monitor and Record VTU Inputs

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	Body_Roll	Roll Gyroscope	0-90º	0-1Hz	≥300Hz	better than 1%
2	Body_Vert_Accel	Accelerometer	5g	1300 Hz	≥3000Hz	better than 2%
3	Body_Lat_Accel	Accelerometer	5g	1300 Hz	≥3000Hz	better than 2%
4	Body_Long_Accel	Accelerometer	5g	1300 Hz	≥3000Hz	better than 2%
5	Side_Frame_Vert_Accel	Accelerometer	5g	1300 Hz	≥3000Hz	better than 2%

5.3 Functional Checks

Functional checks of the instrumentation should be made to verify that all the measurements are working correctly. These functional checks are not a calibration function, but are done to verify the setup. Guidance for performance of functional checks is provided in the Appendix.

5.4 Body Rocking

This test will be performed on the VTU. The vertical actuators on each side will be slowly (approximately 0.1 to 0.2 Hz) stroked in alternate directions to achieve the desired body rocking angle for 3 cycles. The actual roll angle will be monitored and recorded by the TTCI roll gyroscope to assure input levels. The PDU will be monitored for the expected outcomes.

5.5 Truck Hunting

This test will be performed on the VTU. The lateral actuators will be programmed to simulate a sustained hunting motion at 1Hz to 3Hz. Input motions will be monitored and recorded by accelerometers installed on the body structure. The PDU will be monitored for the expected outcomes.

5.6 Vertical Impact Acceleration

This test will be performed on the VTU. The vertical actuators will be actuated simultaneously to produce the desired vertical acceleration. Input levels will be monitored and recorded by the body vertical accelerometer mounted near the SSM wired sensor. The PDU will be monitored for the expected outcome.

5.7 Test Thresholds

The following table summarizes the test thresholds as specified in paragraphs 4.5.4.2.2.1 and 4.5.4.2.2.2.

Table 4. Test Thresholds (per Paragraph 4.5.4.2)

Test	Alert Level	Alarm Level
Body rocking	4° for 3 Cycles	5° for 3 cycles
Truck Hunting	0.13 G for 10 seconds	0.26 G for 10 seconds
Vertical Impact Accel		1.0 G Vertical Peak acceleration

REFERENCES

1. AAR Manual of Standards and Recommended Practices, Car Construction Fundamentals and Details, Performance Specification for Trains Used to Carry High-Level Radioactive Material, Standard S-2043, Effective: 2003; Last Revised: 2017, Association of American Railroads, Washington, DC

2. TTCI Document #TP-20-001 or latest revision: Test Implementation Plan Multiple Car Test of The Atlas HLRM Train in accordance with Association of American Railroads Standard S-2043 Paragraph 6.1 -- Tests at Controlled Test Site Filed on TTCI's network< Q:\Business Services\Tech Docs\DOE Controlled Document Folder\TP-Test Plans_Work Instructions>

3. Tautz, S., David Dunrud and Ryan Minning, August 2020. TTCI Document #DW-20-004: Transportation Technology Center, Inc. S-2043 System Safety Monitoring Design Specification, Centennial Co. Filed on TTCI's network< Q:\Business Services\Tech Docs\DOE Controlled Document Folder\DW - Drawings and Specifications>

4. Safety Rule Book, TTCI Intranet, January 2018 or Latest Revision

5. Operating Rule Book, TTCI Intranet, January 2018 or Latest Revision

APPENDIX – GUIDANCE FOR PERFORMING INSTRUMENTATION FUNCTIONAL TESTS

Functional checks of the instrumentation should be made to verify that all the measurements are working correctly. These functional checks are not a calibration but are done to verify the setup. Common setup errors include but are not limited to faulty transducers, cabling errors, and improper gain settings. Functional checks should be performed to verify that the cables are routed correctly and measure the right value. If a functional check of a transducer shows more than 10% error, look closely at the setup to make sure there are no mistakes.

- Record the functional checks in a data file so you can refer to them later if necessary.
- Perform the functional checks in a specific order and verify that the order matches what you observe in the data file.
- Pay attention to the sign of the output.

  The following are typical functional checks for some transducers:

- Roll the accelerometers 90 degrees for a 1g input.
- Pull string pots and verify that extension is positive and that they read 1-inch when pulled one inch.
- Use a block of known size to check LVDTs and bending beams.
- Check speed measurements against GPS speed
- Verify load cells with an R-cal resistor and a breakout box.
- If possible, apply a known force to a load cell. For example, use the car weight and the track grade from your Operating Rule Book to estimate the average expected force on the appropriate channel for a particular section of track during resistance testing.
- Use a tilt table to rotate a gyro through a known angle. Integrate the resulting signal for a rate gyro.
- Check temperature measurements against ambient air temperature and/or icewater.

Instrumented wheel sets are a special case. The following are suggested for functional tests of IWS. As IWS technology changes the steps might change.

- Verify the cable is connected where you think it is by disconnecting the cable at the wheelset and verifying that the "Disconnected" light comes on at the decoder box where you expect it to.

- Push the R-cal button on the decoder box and verify that you see the step change in the correct IWS channels.

- Record data on a portion of tangent track.

    - Vertical loads should match the scale weight to within 5%

    - Lateral loads should be small, resulting in L/V ratios of about 0.05. This may vary depending on truck design and condition.

    - Contact position output should be around zero. This may vary depending on truck design and condition.

    - If the wheelset is equipped with a torque bridge its average should be around zero. This may vary depending on truck design and condition.

- If a truck is fully instrumented with IWS, you can compare the net lateral load to a calculated value for a curve.

Appendix C - Test Plan TP-21-003 rev 4 Test Implementation Plan Revenue Service At Pueblo Chemical Depot

TEST IMPLEMENTATION PLAN

MULTIPLE CAR TEST OF THE

ATLAS HLRM TRAIN

IN ACCORDANCE WITH

ASSOCIATION OF AMERICAN RAILROADS STANDARD S-2043

(REVENUE SERVICE AT PUEBLO CHEMICAL DEPOT)

FOR THE U.S. DEPARTMENT OF ENERGY (DOE)

TEST PLAN TP-21-003 REV 4

Prepared by
Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads
Pueblo, Colorado USA
July 12, 2022

EXECUTIVE SUMMARY

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete multiple car testing of the U.S. Department of Energy (DOE) High-Level Radioactive Material (HLRM) train as required by the Association of American Railroads (AAR) Standard S-2043 entitled "Performance Specification for Trains used to Carry High-Level Radioactive Material," Section 6.3 – Revenue Service Tests. This test plan addresses all requirements of S-2043 Paragraphs 6.3.1 (excluding 6.3.1.2), 6.3.2, and the Class 2 track portion of 6.3.3. Separate test plans will be provided for 6.3.1.2 and the higher track classes of 6.3.3.

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1.0 INTRODUCTION

1.1 Purpose

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete multiple car testing of the U.S. Department of Energy (DOE) Atlas HLRM train as required by the Association of American Railroads (AAR) Standard S-2043 entitled "Performance Specification for Trains used to Carry High-Level Radioactive Material" [1]. The train is being developed by DOE under the Atlas Railcar Design Project, which is intended to address the future need for large-scale transport of HLRM, including spent nuclear fuel.

This document describes testing to meet the requirements of Standard S-2043 Section 6.3 – Revenue Service Tests, specifically:

- Requirements of Paragraph 6.3.1 – Turnouts, Crossovers, and Tight Curves (excluding 6.3.1.2)
- Paragraph 6.3.2 – Class 2 Maintained Track
- The Class 2 track portion of Paragraph 6.3.3 – Ride Quality.

Separate test plans cover the following:

- Paragraph 6.1 – Dynamic Tests at the Controlled Test Site (TP-20-001)
- Paragraph 6.2 –System Monitoring Tests (TP-21-002)
- Paragraph 6.3.1.2 (the tight turn portion of Paragraphs 6.3.1 -- Turnouts, Crossovers, and Tight Curves) and the higher track classes of Paragraph 6.3.3 – Ride Quality (TP-21-004 and TP-21-005).

1.2 Train Description

The Atlas HLRM train to be tested consists of a cask car (the Atlas car), a rail escort vehicle (REV), and two buffer cars as shown in Figure 1. Table 1 provides additional details of the rail vehicles to be tested. The REV will be used as the instrumentation car. In addition, for testing purposes, it is anticipated that additional locomotives will be added to the other end of the train for braking purposes while testing with instrumented wheel sets installed. For some of the test sequences, locomotives might be placed at both ends of the train for expediency in conducting all the test runs. If necessary, additional braking cars might also be added to the train.

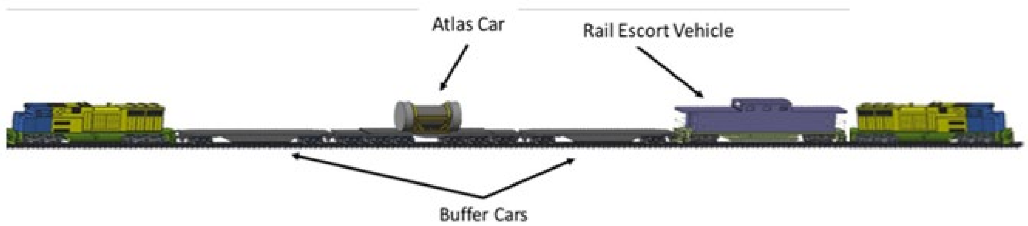

Figure 1. HLRM Train

Two test loads were designed and built to meet both the expected minimum condition and expected maximum condition payloads:

- Minimum condition test load, which simulates an empty MP-197 Cask (199,000 pounds including cradle)

- Maximum condition test load, which simulates loaded HI-STAR 190XL Cask (487,000 pounds including cradle and end stops)

The tests described in this document will be conducted with the Atlas car loaded to the maximum test load condition.

Table 1. Test Train Details

Item	Type	Car Number	Gross Weight	Remarks
1	Locomotive	TBD	TBD	Provided by TTCI
2	Buffer Car	IDOX 20002	263,000 lbs.	
3	Atlas Cask Car	IDOX 10001	421,050 lbs.	(Minimum Test Load condition)
4	Buffer Car	IDOX 20001	263,000 lbs.	
5	REV	IDOX 30001	181,400 lbs.	See Note (1)

Notes:

(1) TTCI might use locomotives at both ends of the train to expedite testing in both directions.

The requirements for multiple car revenue service tests are described in Section 6.3 of the AAR Standard S-2043. This standard requires that all multiple car tests and subsequent data analysis be witnessed by a qualified AAR observer. Transportation Technology Center, Inc. (TTCI) will provide the qualified AAR observer to meet this requirement of the specification.

1.3 Test Tracks

The tests described herein are to be conducted on tracks and turnouts/crossovers available at the Pueblo Chemical Depot (PCD). The PCD is located just south of Transportation Technology Center (TTC). The PCD track connects the TTC trackage with the BNSF Railway (BNSF) and Union Pacific Railroad (UP) at Avondale, Colorado. It is about 9 miles from the DOT Road crossing to the north wye switch at Avondale. Most of the testing would be performed in the 5.4 mile segment between the north and south gates of the PCD, plus the yard area.

The PCD contains several miles of railroad track maintained to FRA Class 2 along with tight curves, turnouts and crossovers that will be used for this testing. Figure 2 shows a sketch of the tracks at the PCD.

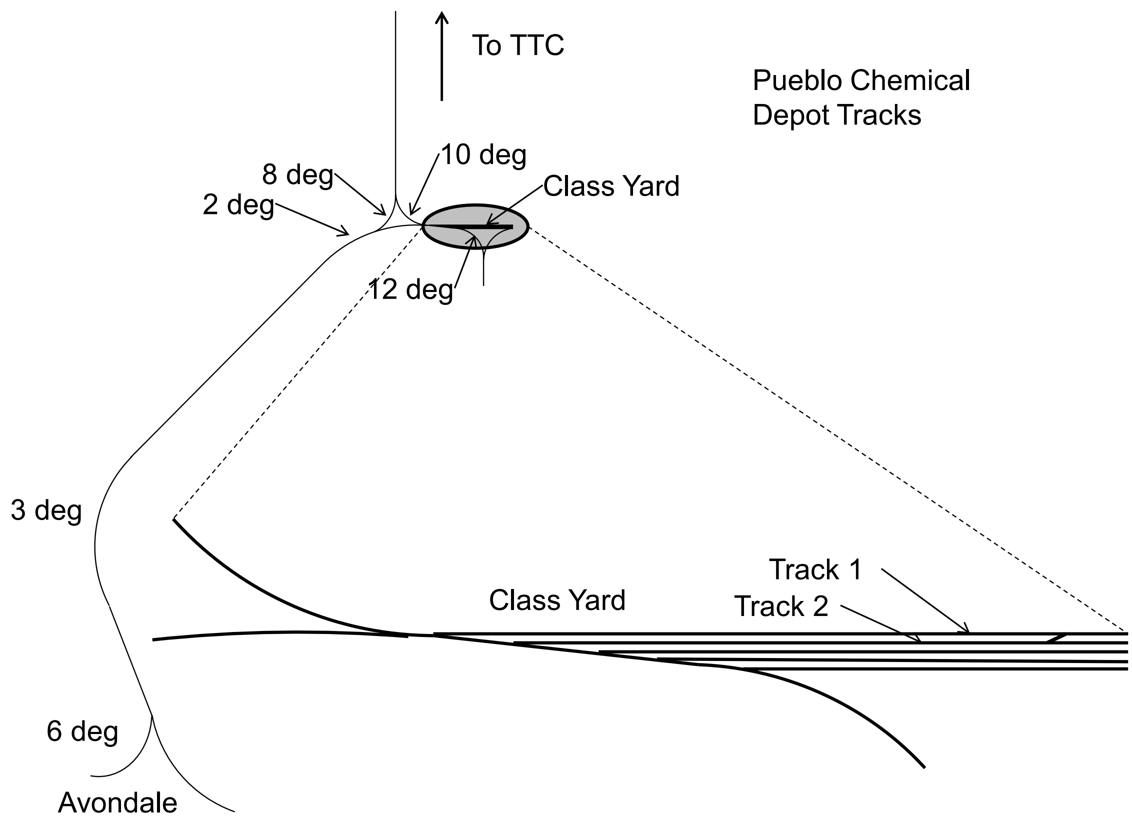

Figure 2. Sketch showing some of the tracks at the Pueblo Chemical Depot

Section 6.3.1.1 of S-2043 requires that the train be operated over number 10 or sharper turnouts and through a number 10 or sharper crossover on 15 feet or narrower track centers. Section 6.3.2 requires that the train be operated over number 10 or sharper turnouts and through a number 12 or sharper crossover on 15 feet or narrower track centers on FRA Class 2 maintained track. The turnouts at the PCD class yard will be used to fulfil these requirements. All turnouts in the class yard are number 8. There is a crossover between class yard tracks 1 and 2 that uses number 8 turnouts on 14-foot 2-inch track centers. Table 2 provides a summary of all tracks proposed for completion of S-2043 Section 6.3 -- Revenue Service Testing. The PCD tracks applicable to this document are shown in bold type.

Table 2. Tracks Proposed for Section 6.3 Revenue Service Tests

S-2043 Paragraph	Requirement	Test Location*
6.3.1	Turnouts, Crossovers, and Tight Curves	
6.3.1.1	**No. 10 (or sharper) turnout**	**PCD No. 8 turnouts**
	No. 10 (or sharper) crossover	**PCD No. 8 crossover on 14'2" track centers**
6.3.1.2	10-degree curve	BNSF Twin Peaks Subdivision
	12-degree curve – controlled test site	TTC WRM loop
6.3.2	Class 2 Maintained Track	
	Minimum length of 20 route miles	Enroute to BNSF 10-degree curve
	5 miles of FRA class 2	**PCD**
	10-degree curve	**PCD 10- and 12-degree curves**
	No. 10 (or sharper) turnout	**PCD No. 8 turnouts**
	No. 12 (or sharper) crossover	**PCD No. 8 crossover on 14' 2" track centers**
6.3.3	Ride Quality -- Class 2 through Class 6	
	Class 2 (25 mph)	**PCD**
	Class 3 (40 mph)	Enroute to BNSF 10-degree curve
	Class 4 (60 mph)	Enroute to BNSF 10-degree curve
	Class 5 (80 mph)	TTC TTT up to 75 mph
	Class 6 (110 mph)	TTC RTT up to 75 mph

*Test locations:
PCD – Pueblo Chemical Depot, track jointly operated by South Plains Railroad
BNSF – BNSF Railway

Speed restrictions per FRA Track Safety Standards and/or TTCI operating rules apply as follows:

- PCD No. 8 turnouts and crossover 19 mph
- PCD 12-degree curve 19 mph
- PCD main track 20 mph.

Note that all tests will be performed on track that is not lubricated. Tribometer readings of rail friction coefficients, while not required by S-2043, will be taken to document the test conditions. The data might be needed for modelling simulations.

2.0 SAFETY

Work is to be conducted in accordance with the most current versions of TTCI's Safety Rulebook[2] and Operating Rulebook[3], which are maintained on TTCI's intranet site.

For testing on PCD tracks, speeds will not exceed the speed limit for FRA Class 2 track, per the Track Safety Standards[4].

3.0 DYNAMIC TESTS

Table 3 summarizes limiting criteria for the dynamic tests in required under S-2043 Paragraphs 6.3.1 and 6.3.2. Figure 3 illustrates the application of 50-millisecond and 3-foot distance limits for L/V ratio and minimum vertical wheel load.

Table 3. Dynamic Limiting Criteria

Criterion	Limiting Value	Notes
Maximum car body roll angle (degree)	4	Peak-to-peak.
Maximum wheel L/V	0.8	Not to exceed indicated value for a period greater than 50 msec. and for a distance greater than 3 ft. per instance*.
95th percentile single wheel L/V (constant curving tests only)	0.6	Not to exceed indicated value. Applies only for constant curving tests.
Maximum truck side L/V	0.5	Not to exceed indicated value for a duration equivalent to 6 ft. of track per instance.
Minimum vertical wheel load (%)	25	Not to fall below indicated value for a period greater than 50 msec. and for a distance greater than 3 ft. per instance*.
Peak-to-peak car body lateral acceleration (G)	1.3 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum car body lateral acceleration (G)	0.75 0.35	For non-passenger-carrying railcars For passenger-carrying railcars
Car body lateral acceleration standard deviation (G)	0.13	Calculated over a 2000-ft sliding window every 10 ft. over a tangent track section that is a minimum of 4000 ft. long.
Maximum car body vertical acceleration (G)	0.90 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum vertical suspension deflection (%)	95	Suspension bottoming not allowed. Maximum compressive spring travel shall not exceed 95% of the spring travel from the empty car height of the outer load coils to solid spring height.
Maximum vertical dynamic augment acceleration (g)	0.9	Suspension bottoming not allowed. Vertical dynamic augment accelerations of a loaded car shall not exceed 0.9 G.

*Figure 3 illustrates the application of 50-millisecond and 3-foot distance limits for L/V ratio and minimum vertical wheel load.

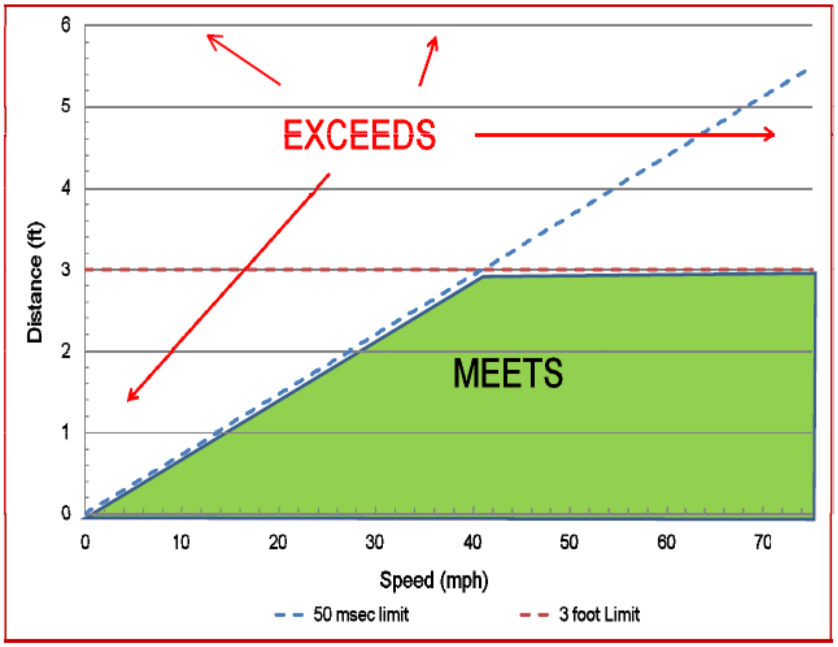

Figure 3. Time and Distance to Climb Limits

3.1 Instrumentation

The instrumentation and data collection package for these tests will be provided by TTCI and will include all the necessary transducers for comparison with S-2043 performance measures. Measurements for dynamic tests are listed in Table 4 through Table 6.

To provide precise measurements of wheel/rail forces, instrumented wheel sets[1] (IWS) will be installed in both axles of the various trucks, as noted below. The train will be tested traveling in both directions, so the IWS will be in both the leading and trailing positions during the test.

Carbody lateral acceleration, carbody roll angle measurements, and spring group vertical displacement will be taken on one end of each type of vehicle in the Atlas HLRM trains.

For the Atlas car, on-board data channels will include:

2 each – Roll Gyroscopes

2 each – Vertical Accelerometers

6 each – Lateral Accelerometers

[1] Instrumented wheelsets must meet requirements of M-1001, Appendix C

12 each – > 5 in. String Potentiometers

1 each – Speed Tachometer, may be located anywhere on the train, but location must be recorded. (additional tachometers are required for Stop Distance Tests)

For the lead buffer car and the REV, data channels will include:

2 each – Roll Gyroscopes

2 each – Vertical Accelerometers

2 each – Lateral Accelerometers

4 each – >5 in. String Potentiometers

A single Automatic Location Device may be located anywhere on the train, but the location must be recorded.

Carbody lateral acceleration will be taken over truck or span bolster centers. Carbody roll angle measurements, and spring group vertical displacement will be taken on each end of each instrumented vehicle.

A total of 10 IWS will be used. For these tests, IWS will be placed in both axles of the trucks in the following locations in the Atlas HLRM train (Figure 4):

IWS locations (reference Figure 4):

- 6 – Trailing end of Atlas car
- 2 – Trailing end of trailing buffer car (next to REV)
- 2 – Leading end of REV.

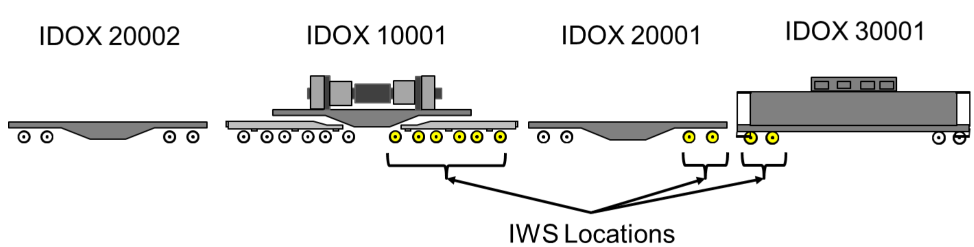

Figure 4. IWS Locations

Table 4. Measurement List for Atlas Car (IDOX 10001) (1 of 2)

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	Speed	Speed	0-80mph	0-1Hz	≥300Hz	better than 1%
2	ALD	Automatic Location Device	0-5V	≥15Hz	≥300Hz	better than 2%
3	VLX VRX LVLX LVRX TSLVLY TSLVRY X=Axle Num. Y=Truck Num.	IWS in Axle 7		≥15Hz	≥300Hz	better than 5%
4		IWS in Axle 8		≥15Hz	≥300Hz	better than 5%
5		IWS in Axle 9		≥15Hz	≥300Hz	better than 5%
6		IWS in Axle 10		≥15Hz	≥300Hz	better than 5%
7		IWS in Axle 11		≥15Hz	≥300Hz	better than 5%
8		IWS in Axle 12		≥15Hz	≥300Hz	better than 5%
9	ZACBB	B-End carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
10	ZACBA	A-End carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
11	YACBB	B-End carbody* lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
12	YACBA	A-End carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
13	YASBA1	A-End span bolster lead lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
14	YASBA2	A-End span bolster trail lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
15	YASBB1	B-End span bolster lead lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
16	YASBB2	B-End span bolster trail lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
17	ZDSNBL	Vertical Displacement B truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%

*Car body accelerometers to be placed as closely as possible to the span bolster centers.

Table 4. Measurement List for Atlas Car (IDOX 10001) (2 of 2)

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
18	ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
19	ZDSNCL	Vertical Displacement C truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
20	ZDSNCR	Vertical Displacement C truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
21	ZDSNDL	Vertical Displacement D truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
22	ZDSNDR	Vertical Displacement D truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
23	ZDSNEL	Vertical Displacement E truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
24	ZDSNER	Vertical Displacement E truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
25	ZDSNFL	Vertical Displacement F truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
26	ZDSNFR	Vertical Displacement F truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
27	ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
28	ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
29	RDCBB	Carbody roll rotation, B-end	±4deg	≥15Hz	≥300Hz	better than 1%
30	RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	better than 1%
31	GPS	GPS	n/a	≥1Hz	≥1Hz	better than 1%

Table 5. Measurement List for Buffer Cars (IDOX 20001 and 20002)

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	VLX VRX LVLX LVRX TSLVLY TSLVRY X=Axle Num. Y=Truck Num.	IWS in Axle 3		≥15Hz	≥300Hz	better than 5%
2		IWS in Axle 4		≥15Hz	≥300Hz	better than 5%
3	B(L)(T)-ZACBB	B-End carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
4	B(L)(T)-ZACBA	A-End carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
5	B(L)(T)-YACBB	B-End carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
6	B(L)(T)-YACBA	A-End carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
7	B(L)(T)-ZDSNBL	Vertical Displacement B truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
8	B(L)(T)-ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
9	B(L)(T)-ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
10	B(L)(T)-ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
11	B(L)(T)-RDCBB	Carbody roll rotation, B-end	±4deg	≥15Hz	≥300Hz	better than 1%
12	B(L)(T)-RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	better than 1%

*Channel names BL (Buffer Car Leading IDOX 20002) and BT (Buffer Car Trailing IDOX 20001)

*Car body accelerometers to be placed as closely as possible to the truck centers

Table 6. Measurement List for REV

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	VLX VRX LVLX LVRX TSLVLY TSLVRY X=Axle Num. Y=Truck Num.	IWS in Axle 1		≥15Hz	≥300Hz	better than 5%
2		IWS in Axle 2		≥15Hz	≥300Hz	better than 5%
3	E-ZACBB	B-End carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
4	E-ZACBA	A-End carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
5	E-YACBB	B-End carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
6	E-YACBA	A-End carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
7	E-ZDSNBL	Vertical Displacement B truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
8	E-ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
9	E-ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
10	E-ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
11	E-RDCBB	Carbody roll rotation, B-end	±4deg	≥15Hz	≥300Hz	better than 1%
12	E-RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	better than 1%

*Car body accelerometers to be placed as closely as possible to the truck centers

Note that additional instrumentation and channels that are required to complete the requirements for ride quality testing are included in Section 4.0.

Per request of the AAR Equipment Engineering Committee, additional monitoring will be performed near one end of the 10-degree curve. Fish scales will be mounted on ties to measure rail head lateral deflection (both rails) near one end of the 10-degree curve. Exact location is to be determined by Russell Walker and Duane Otter.

3.1.1 Data Acquisition

Data will be filtered at a rate greater than or equal to 15 Hz and less than or equal to sample rate divided by 2. The minimum sample rate is 300 Hz. Data will be post filtered as required (15 Hz) and analyzed in near-real time using the performance criteria for dynamic testing provided in Table 3.

3.1.2 Instrumentation Functional Checks

Functional checks of the instrumentation must be made to verify that all the measurements are working correctly. These functional checks are not a calibration function but are done to verify the setup. Guidance for performance of functional checks is provided in the Appendix.

3.2 Test Runs

Table 7 provides a list of test runs to be conducted on the various tracks at PCD along with the applicable paragraph in S-2043.

Prior to each sequence of runs, a walking speed run will be performed to check for equipment clearances as well as track gage spreading and rail roll. Person(s) on the ground will be required for the visual observations of clearances and gage spreading. Fish scale readings of maximum lateral rail head displacement will be collected for each rail for both locomotives and the Atlas Car. Each run will be stopped so that the fish scales can be re-zeroed between the locomotives and the Atlas Car. Atlas Car readings will be compared to the readings from the locomotives after each run. Wheel/rail forces from the IWS will be observed in both the entry and exit zones of the curve for these runs.

Table 7. List of runs at PCD (1 of 4)

Run	Car End Leading	Loco Push/ Pull	Description	Speed (mph)	Require-ment
1	B	Pull	North gate PCD to South Gate PCD	20	6.3.3
2	A	Push	South gate PCD to North Gate PCD	20	6.3.3
3			Slow speed runs on class yard track 1 and 2 including turnout and crossover to allow visual inspection for binding and interference. Also observe track for rail roll and track gage spreading. Take fish scale measurements under locomotives and Atlas Car.	Walking Speed	6.3.1.4
4	B	Pull	West-East Class Yard Track 1 Including turnout at beginning	20	6.3.1.1 & 6.3.2
5	A	Push	East-West Class Yard Track 1 Including turnout at end	20	6.3.1.1 & 6.3.2
6	B	Pull	West-East Class Yard Track 2 Including turnout at beginning	19	6.3.1.1 & 6.3.2
7	A	Push	East-West Class Yard Track 2 Including turnout at end	19	6.3.1.1 & 6.3.2
8	B	Pull	Crossover, West-East, Class Yard Track 2 to 1	5	6.3.1.1 & 6.3.2
9	A	Push	Crossover, East-West, Class Yard Track 1 to 2	5	6.3.1.1 & 6.3.2
10	B	Pull	Crossover, West-East, Class Yard Track 2 to 1	10	6.3.1.1 & 6.3.2
11	A	Push	Crossover, East-West, Class Yard Track 1 to 2	10	6.3.1.1 & 6.3.2
12	B	Pull	Crossover, West-East, Class Yard Track 2 to 1	15	6.3.1.1 & 6.3.2
13	A	Push	Crossover, East-West, Class Yard Track 1 to 2	15	6.3.1.1 & 6.3.2

14	B	Pull	Crossover, West-East, Class Yard Track 2 to 1	19	6.3.1.1 & 6.3.2
15	A	Push	Crossover, East-West, Class Yard Track 1 to 2	19	6.3.1.1 & 6.3.2

Table 7. List of runs at PCD (2 of 4)

Run	Car End Leading	Loco Push/ Pull	Description	Speed	Require-ment
16			Slow speed runs on the 10- and 12-degree curves to allow visual inspection for binding and interference. Also observe track for rail roll and track gage spreading. Take fish scale measurements under locomotives and Atlas Car.	Walking Speed	6.3.1.4
17	B	Pull	10-degree curve and 12-degree curve	5	6.3.2
18	A	Push	12-degree curve and 10-degree curve	5	6.3.2
19	B	Pull	10-degree curve and 12-degree curve	10	6.3.2
20	A	Push	12-degree curve and 10-degree curve	10	6.3.2
21	B	Pull	10-degree curve and 12-degree curve	15	6.3.2
22	A	Push	12-degree curve and 10-degree curve	15	6.3.2
23	B	Pull	10-degree curve and 12-degree curve	19	6.3.2
24	A	Push	12-degree curve and 10-degree curve	19	6.3.2

Between runs 18 and 19, friction coefficients will be measured near the middle of both the 10- and 12-degree curves. A tribometer will be used to measure gage face and top-of-rail friction on both the inside and outside rails of each curve. Tribometer readings of rail friction coefficients, while not required by S-2043, will be taken to document the test conditions.

Table 7. List of runs at PCD (3 of 4)

Run	Car End Leading	Loco Push/ Pull	Description	Speed	Require-ment
			Turn on Wye		
25			Slow speed runs on the 10- and 12-degree curves to allow visual inspection for binding and interference. Also observe track for rail roll and track gage spreading. Take fish scale measurements under locomotives and Atlas Car.	Walking Speed	6.3.1.4
26	B	Pull	12-degree curve and 10-degree curve	5	6.3.2
27	A	Push	10-degree curve and 12-degree curve	5	6.3.2
28	B	Pull	12-degree curve and 10-degree curve	10	6.3.2
29	A	Push	10-degree curve and 12-degree curve	10	6.3.2
30	B	Pull	12-degree curve and 10-degree curve	15	6.3.2
31	A	Push	10-degree curve and 12-degree curve	15	6.3.2
32	B	Pull	12-degree curve and 10-degree curve	19	6.3.2
33	A	Push	10-degree curve and 12-degree curve	19	6.3.2

Between runs 27 and 28, friction coefficients will be measured near the middle of both the 10- and 12-degree curves. A tribometer will be used to measure gage face and top-of-rail friction on both the inside and outside rails of each curve. Tribometer readings of rail friction coefficients, while not required by S-2043, will be taken to document the test conditions.

Table 7. List of runs at PCD (4 of 4)

Run	Car End Leading	Loco Push/ Pull	Description	Speed (mph)	Requirem ent
34	A	Push	North gate PCD to South Gate PCD	20	6.3.3
35	B	Pull	South gate PCD to North Gate PCD	20	6.3.3
36			Slow speed runs on class yard track 1 and 2 including turnout and crossover to allow visual inspection for binding and interference. Also observe track for rail roll and track gage spreading. Take fish scale measurements under locomotives and Atlas Car.	Walking Speed	6.3.1.4
37	A	Push	West-East Class Yard Track 1 Including turnout at beginning	20	6.3.1.1 & 6.3.2
38	B	Pull	East-West Class Yard Track 1 Including turnout at end	20	6.3.1.1 & 6.3.2
39	A	Push	West-East Class Yard Track 2 Including turnout at beginning	20	6.3.1.1 & 6.3.2
40	B	Pull	East-West Class Yard Track 2 Including turnout at end	20	6.3.1.1 & 6.3.2
41	A	Push	Crossover, West-East, Class Yard Track 2 to 1	5	6.3.1.1 & 6.3.2
42	B	Pull	Crossover, East-West, Class Yard Track 1 to 2	5	6.3.1.1 & 6.3.2
43	A	Push	Crossover, West-East, Class Yard Track 2 to 1	10	6.3.1.1 & 6.3.2
44	B	Pull	Crossover, East-West, Class Yard Track 1 to 2	10	6.3.1.1 & 6.3.2
45	A	Push	Crossover, West-East, Class Yard Track 2 to 1	15	6.3.1.1 & 6.3.2
46	B	Pull	Crossover, East-West, Class Yard Track 1 to 2	15	6.3.1.1 & 6.3.2
47	A	Push	Crossover, West-East, Class Yard Track 2 to 1	19	6.3.1.1 & 6.3.2
48	B	Pull	Crossover, East-West, Class Yard Track 1 to 2	19	6.3.1.1 & 6.3.2

4.0 RIDE QUALITY TESTS

The REV will be evaluated for ride quality performance according to paragraph 6.3.3 of S-2043 and ISO 2631-1:1997/AMD 1:2010 standards[5]. S-2043 states that track sections should be chosen to represent FRA Class 2 – Class 6 track. The track at PCD will be used for the FRA Class 2 requirement.

4.1 Ride Quality Instrumentation

Vibrations will be measured at the locations summarized in Table 8 using tri-axial accelerometers at each location. Accelerometers will be rigidly attached to the car floor. Mounting discs will be used for the 4 measurement locations that include cushioning. A disc similar to that shown in ISO 10326[6], but modified to be used with TTCI instrumentation will be used to mount the accelerometers. Weight will be placed on the disks to simulate a person. All accelerometer measurements will be taken at a sample rate of 800 Hz.

Table 8. Ride Quality Measurement Locations

Description	General Location	Attachment Point
Lead	Floor over lead bogie	Rigidly attached to floor of car interior
Trail	Floor over trail bogie	
Center	Floor center of car	
Galley Seat	Galley seat located in corner of car interior	Rigidly attached to seat pan of metal seat frame
Bed	Upper and lower beds located at B-End of the car.	Rigidly attached to metal frame under center of mattress*
UOL Chair 1	UOL Chair nearest to AR corner of carbody	Rigidly attached to seat post under chair
UOL Chair 2	UOL Chair nearest to AL corner of carbody	Rigidly attached to seat post under chair

*Mattress will not be installed, but instrumentation will be placed in center of where mattress would be placed.

The appropriate frequency weighting will be applied to each measurement based on location and direction of measurement. Ride Quality for each measurement location and direction will be analyzed with regard to Health (ISO 2631-1 Annex B[5]), Comfort (ISO 2631-1 Annex C[5]), and Motion Sickness (ISO 2631-1 Annex D[5]).

4.2 Ride Quality Test Runs

The test runs specifically for Ride Quality testing are listed in Table 2 and described below:

- Run 1 -- From the North Gate to the South Gate at PCD with the test consist being pulled at up to 20 mph with B-end leading

- Run 2 -- From the South Gate to the North Gate at PCD with the test consist being pushed at up to 20 mph with A-end leading
- Run 34 -- From the North Gate to the South Gate at PCD with the test consist being pushed at up to 20 mph with A-end leading
- Run 35-- From the South Gate to the North Gate at PCD with the test consist being pulled at up to 20 mph with B-end leading

5.0 TEST SCHEDULE

Preliminary test schedule is after completion of the controlled site multiple car tests. Detailed scheduling will be based on resource and facility availability.

6.0 REFERENCES

1. AAR Manual of Standards and Recommended Practices, Car Construction Fundamentals and Details, Performance Specification for Trains Used to Carry High-Level Radioactive Material, Standard S-2043, Effective: 2003; Last Revised: 2017, Association of American Railroads, Washington, DC.
2. Safety Rule Book, TTCI, January 2018 or Latest Revision.
3. Operating Rule Book, TTCI, January 2018 or Latest Revision.
4. 49 CFR Part 213, Track Safety Standards, October 2011 or Latest Revision.
5. ISO 2631-1:1997/Amd 1:2010, Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration.
6. ISO 10326-1:2016, Mechanical vibration — Laboratory method for evaluating vehicle seat vibration.

APPENDIX – GUIDANCE FOR PERFORMING INSTRUMENTATION FUNCTIONAL TESTS

Functional checks of the instrumentation should be made to verify that all the measurements are working correctly. These functional checks are not a calibration but are done to verify the setup. Common setup errors include but are not limited to faulty transducers, cabling errors, and improper gain settings. Functional checks should be performed to verify that the cables and measure the right value. If a functional check of a transducer shows more than 10% error, look closely at the setup to make sure there are no mistakes.

- Record the functional checks in a data file so you can refer to them later if necessary.
- Perform the functional checks in a specific order and verify that the order matches what you observe in the data file.
- Pay attention to the sign of the output.

The following are typical functional checks for some transducers:

- Roll the accelerometers 90 degrees for a 1g input.
- Pull string pots and verify that extension is positive and that they read 1-inch when pulled one inch.
- Use a block of known size to check LVDTs and bending beams.
- Check speed measurements against GPS speed.
- Verify load cells with an R-cal resistor and a breakout box.
- If possible, apply a known force to a load cell. For example, use the car weight and the track grade from your Operating Rule Book to estimate the average expected force on the appropriate channel for a particular section of track during resistance testing.

Instrumented wheel sets are a special case. The following are suggested for functional tests of IWS. As IWS technology changes the steps might change.

- Verify the cable is connected where you think it is by disconnecting the cable at the wheelset and verifying that the “Disconnected” light comes on at the decoder box where you expect it to.

- Push the R-cal button on the decoder box and verify that you see the step change in the correct IWS channels.
- Record data on a portion of tangent track.
    - Vertical loads should match the scale weight to within 5%
    - Lateral loads should be small, resulting in L/V ratios of about 0.05. This may vary depending on truck design and condition.
    - Contact position output should be around zero. This may vary depending on truck design and condition.
    - If the wheelset is equipped with a torque bridge its average should be around zero. This may vary depending on truck design and condition.
- If a truck is fully instrumented with IWS, you can compare the net lateral load to a calculated value for a curve.

Appendix D - Test Plan TP-21-004 rev 3 Test Implementation Plan Revenue Service at Controlled Site

TEST IMPLEMENTATION PLAN

MULTIPLE CAR TEST OF THE
ATLAS HLRM TRAIN
IN ACCORDANCE WITH
ASSOCIATION OF AMERICAN RAILROADS STANDARD S-2043
(REVENUE SERVICE AT CONTROLLED SITE PORTIONS)

FOR THE U.S. DEPARTMENT OF ENERGY (DOE)

TEST PLAN TP-21-004 REV 3

Prepared by
Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads
Pueblo, Colorado USA
July 12, 2022

EXECUTIVE SUMMARY

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete multiple car testing of the U.S. Department of Energy (DOE) High-Level Radioactive Material (HLRM) train as required by the Association of American Railroads (AAR) Standard S-2043 entitled “Performance Specification for Trains used to Carry High-Level Radioactive Material,” Section 6.3 – Revenue Service Tests. This test plan addresses the requirements of S-2043 Paragraphs 6.3.1.2 (12-degree curve at a test facility), and the Class 5 and Class 6 track portions of 6.3.3 (ride quality). Separate test plans will be provided for the other requirements of 6.3.1, 6.3.2, and 6.3.3. TP-21-003 addresses the other portions of 6.3.2 not covered on other test plans.

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1.0 INTRODUCTION

1.1 Purpose

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete multiple car testing of the U.S. Department of Energy (DOE) Atlas HLRM train as required by the Association of American Railroads (AAR) Standard S-2043 entitled "Performance Specification for Trains used to Carry High-Level Radioactive Material" [1]. The train is being developed by DOE under the Atlas Railcar Design Project, which is intended to address the future need for large-scale transport of HLRM, including spent nuclear fuel.

This document describes testing to meet the requirements of Standard S-2043 Section 6.3 – Revenue Service Tests, specifically:

- Requirements of Paragraph 6.3.1 – Turnouts, Crossovers, and Tight Curves, specifically 6.3.1.2 12-degree curve portion (other aspects of 6.3.1.2 covered in test plans TP-21-003 and TP-21-005)
- The Class 5 and Class 6 track portions of Paragraph 6.3.3 – Ride Quality.

Separate test plans will be provided for:

- Paragraph 6.1 – Dynamic Tests at the Controlled Test Site (TP-20-001)
- Paragraph 6.2 – System Monitoring Tests (TP-21-002)
- Remaining portions of Paragraph 6.3 Revenue Service Tests (TP-21-003 and TP-21-005).

1.2 Train Description

The Atlas HLRM train to be tested consists of a cask car (the Atlas car), a rail escort vehicle (REV), and two buffer cars as shown in Figure 1. Table 1 provides additional details of the rail vehicles to be tested. The REV will be used as the instrumentation car. In addition, for testing purposes, it is anticipated that additional locomotives will be added to the other end of the train for braking purposes while testing with instrumented wheel sets installed. For some of the test sequences, locomotives might be placed at both ends of the train for expediency in conducting all the test runs. If necessary, additional braking cars might also be added to the train.

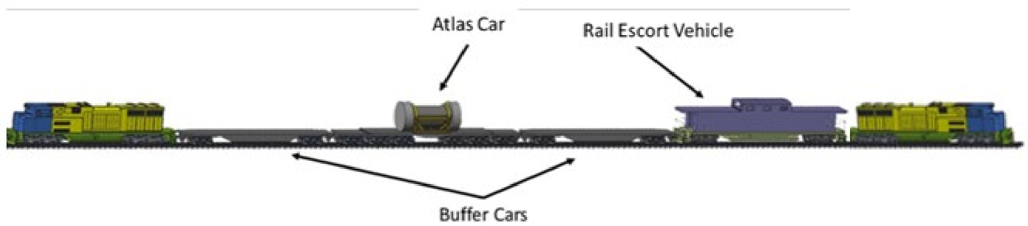

Figure 1. HLRM Train

Two Test loads were designed and built to meet both the expected minimum condition and expected maximum condition payloads:

- Minimum condition test load, which simulates an empty MP-197 Cask (199,000 pounds including cradle)
- Maximum condition test load, which simulates loaded HI-STAR 190XL Cask (487,000 pounds including cradle and end stops)

The tests described in this document will be conducted with the Atlas car loaded to the minimum test load condition.

Table 1. Test Train Details

Item	Type	Car Number	Gross Weight	Remarks
1	Locomotive	TBD	TBD	Provided by TTCI
2	Buffer Car	IDOX 20002	263,000 lbs.	
3	Atlas Cask Car	IDOX 10001	421,050 lbs.	(Minimum Test Load condition)
4	Buffer Car	IDOX 20001	263,000 lbs.	
5	REV	IDOX 30001	181,400 lbs.	See Note (1)

Notes:
(1) TTCI might use locomotives at both ends of the train to expedite testing in both directions.

1.3 Test Tracks

The tests described herein are to be conducted on tracks at the Transportation Technology Center (TTC). The reasons for conducting these tests at TTC rather than in revenue service include:

1. At the BNSF revenue service test site, the maximum curvature is 10 degrees. Paragraph 6.3.1.2 of S-2043 requires testing on a 12-degree curve at a test facility unless a curvature of 12 degrees or sharper is used in revenue service.

2. For the ride quality testing, tests of the Atlas train can be conducted up to a speed of 70 mph on selected tracks at TTC. In revenue service, the maximum allowable speed for the test train is limited to 45 mph by the BNSF timetable.

3. TTCI staff are not aware of any revenue service Class 5 or Class 6 track within reasonable proximity.

Paragraph 6.3.1.2 of S-2043 requires that the train be tested in a 12-degree with a normal freight speed of 20 mph or higher. The 12-degree curve on the Wheel-Rail Mechanism (WRM) loop will be used to satisfy the requirements of Paragraph 6.3.1.2 of S-2043. The curving test zone of the WRM loop is shown in Figure 2. The maximum speed allowed on the WRM loop 12-degree curve is 32 mph, according to TTCI Operating Rules[3] and the FRA Track Safety Standards[4] for the degree of curvature and amount of superelevation.

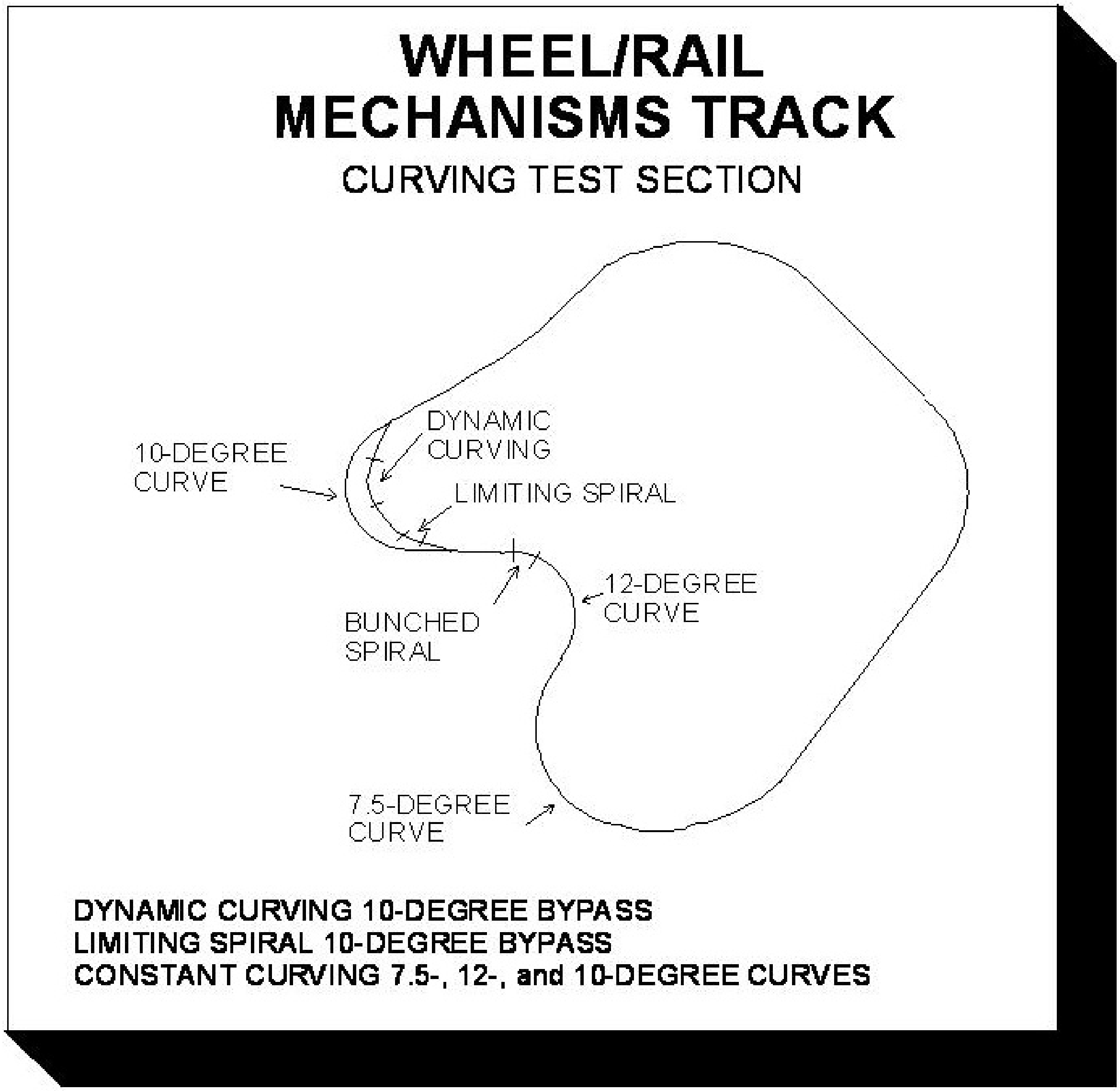

Figure 2: WRM Loop Curving Test Section

Paragraph 6.3.3.1 requires testing over track sections of FRA designations Class 2 through Class 6, at speeds up to the FRA freight speed limit for each class. The Transit Test Track (TTT) will be used for Class 5 and the Precision Test Track (PTT) will be used for Class 6 ride quality testing. Both are at TTC.

- The TTT is shown in Figure 3. The entire 9.1-mile loop will be traversed.

- The PTT contains a long tangent on the north end and a long mild curve (less than one degree) south of that. The PTT contains short perturbed-track sections for Pitch and Bounce, and Twist and Roll in the north tangent. It contains a short perturbed-track section for Yaw and Sway tests in a short tangent at the south end. The TTC speed limit for the PTT is 90 mph. The entire 6.5-mile length will be traversed.

The FRA freight speed limits for Class 5 and Class 6 tracks are 80 mph and 110 mph respectively. However, single-car S-2043 testing is required only to 70 mph, so that will be the maximum test speed for the HLRM train on these tracks.

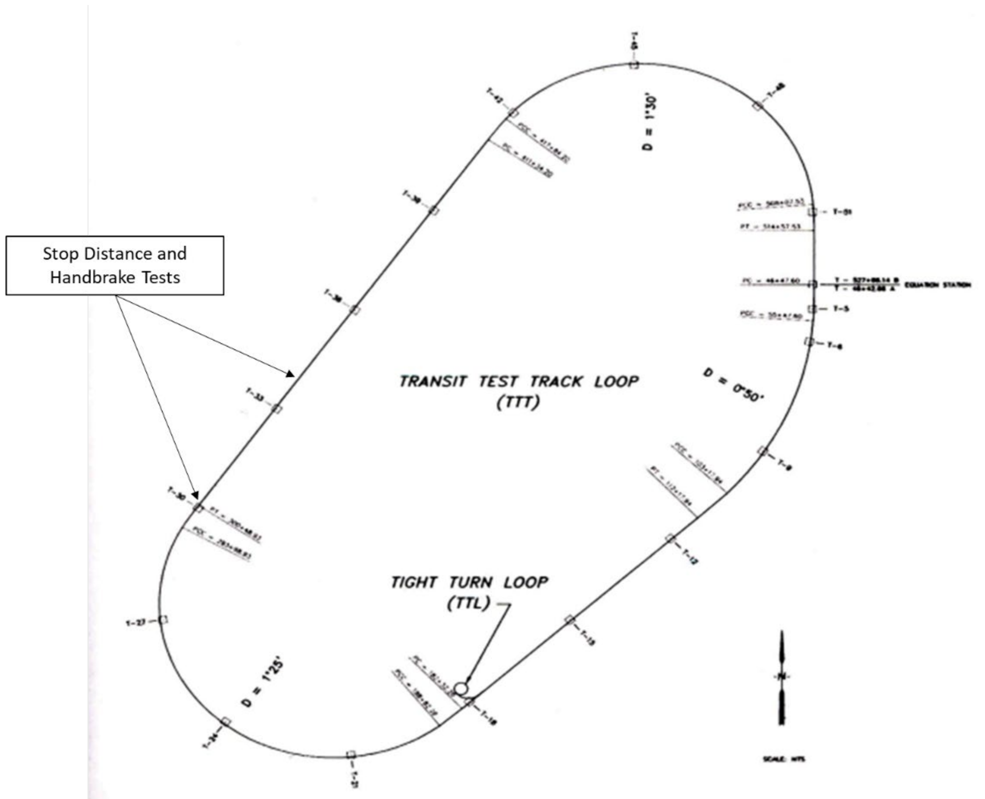

Figure 3. Transit Test Track (TTT)

Table 2 provides a summary of all tracks proposed for completion of S-2043 Section 6.3 -- Revenue Service Testing. The TTC tracks applicable to this document are shown in bold type.

Table 2. Tracks Proposed for Section 6.3 Revenue Service Tests

S-2043 Paragraph	Requirement	Test Location*
6.3.1	Turnouts, Crossovers, and Tight Curves	
6.3.1.1	No. 10 (or sharper) turnout	PCD No. 8 turnouts
	No. 10 (or sharper) crossover	PCD No. 8 crossover on 14'2" track centers
6.3.1.2	10-degree curve	BNSF Twin Peaks Sub near MP 274
	12-degree curve – controlled test site	**TTC WRM loop**
6.3.2	Class 2 Maintained Track	
	Minimum length of 20 route miles	Enroute to 10-degree curves
	5 miles of FRA class 2	PCD
	10-degree curve	PCD 10- and 12-degree curves
	No. 10 (or sharper) turnout	PCD No. 8 turnouts
	No. 12 (or sharper) crossover	PCD No. 8 crossover on 14' 2" track centers
6.3.3	Ride Quality -- Class 2 through Class 6	
	Class 2 (25 mph)	PCD
	Class 3 (40 mph)	Enroute to BNSF 10-degree curve
	Class 4 (60 mph)	Enroute to BNSF 10-degree curve
	Class 5 (80 mph)	**TTC TTT up to 70 mph**
	Class 6 (110 mph)	**TTC PTT up to 70 mph**

*Test locations:
PCD – Pueblo Chemical Depot, track jointly operated by TTCI and South Plains Railroad
BNSF – BNSF Railway

Speed restrictions per FRA Track Safety Standards and/or TTCI operating rules apply as follows:

- WRM Loop 12-degree curve 32 mph
- TTT 80 mph
- PTT 90 mph

Note that all tests will be performed on track that is not lubricated. Tribometer readings of rail friction coefficients, while not required by S-2043, will be taken to document the test conditions for tests on the WRM Loop only. The data might be useful for modelling simulations.

2.0 SAFETY

Work is to be conducted in accordance with the most current versions of TTCI's Safety Rulebook[2] and Operating Rulebook[3], which are maintained on TTCI's intranet site. It is the responsibility of the TTCI test team to determine the maximum safe test speed.

3.0 DYNAMIC TESTS

Table 3 summarizes limiting criteria for the dynamic tests as required under S-2043 Paragraphs 6.3.1 and 6.3.2. Figure 4 illustrates the application of 50-millisecond and 3-foot distance limits for L/V ratio and minimum vertical wheel load.

Table 3. Dynamic Limiting Criteria

Criterion	Limiting Value	Notes
Maximum car body roll angle (degree)	4	Peak-to-peak.
Maximum wheel L/V	0.8	Not to exceed indicated value for a period greater than 50 msec. and for a distance greater than 3 ft. per instance*.
95th percentile single wheel L/V (constant curving tests only)	0.6	Not to exceed indicated value. Applies only for constant curving tests.
Maximum truck side L/V	0.5	Not to exceed indicated value for a duration equivalent to 6 ft. of track per instance.
Minimum vertical wheel load (%)	25	Not to fall below indicated value for a period greater than 50 msec. and for a distance greater than 3 ft. per instance*.
Peak-to-peak car body lateral acceleration (G)	1.3 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum car body lateral acceleration (G)	0.75 0.35	For non-passenger-carrying railcars For passenger-carrying railcars
Car body lateral acceleration standard deviation (G)	0.13	Calculated over a 2000-ft sliding window every 10 ft. over a tangent track section that is a minimum of 4000 ft. long.
Maximum car body vertical acceleration (G)	0.90 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum vertical suspension deflection (%)	95	Suspension bottoming not allowed. Maximum compressive spring travel shall not exceed 95% of the spring travel from the empty car height of the outer load coils to solid spring height.
Maximum vertical dynamic augment acceleration (g)	0.9	Suspension bottoming not allowed. Vertical dynamic augment accelerations of a loaded car shall not exceed 0.9 G.

*Figure 4 illustrates the application of 50-millisecond and 3-foot distance limits for L/V ratio and minimum vertical wheel load.

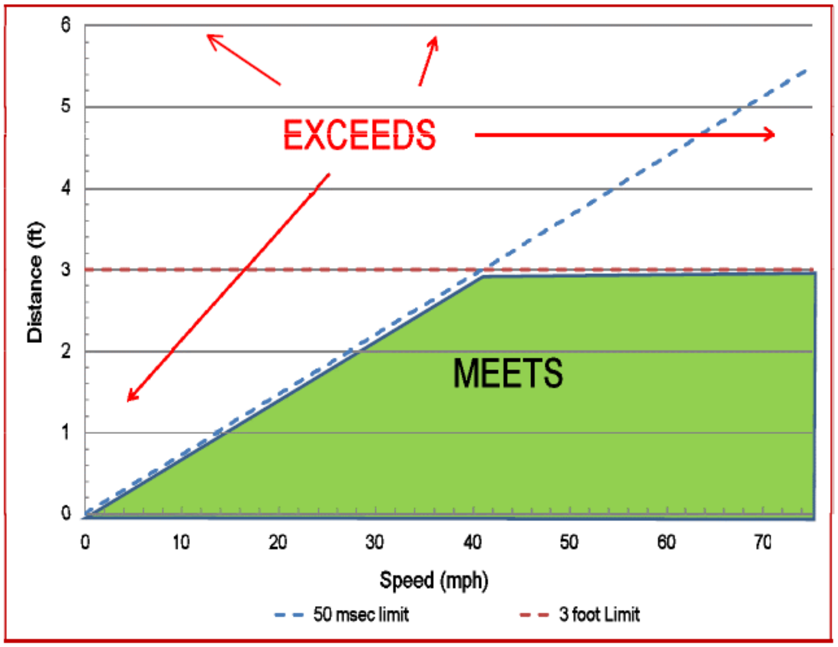

Figure 4. Time and Distance to Climb Limits

3.1 Instrumentation

The instrumentation and data collection package for these tests will be provided by TTCI and will include all the necessary transducers for comparison with S-2043 performance measures. Measurements for dynamic tests are listed in Table 4 through Table 6.

To provide precise measurements of wheel/rail forces, instrumented wheel sets[1] (IWS) will be installed in both axles of the various trucks, as noted below. The train will be tested traveling in both directions, so the IWS will be in both the leading and trailing positions during the test.

Carbody lateral acceleration, carbody roll angle measurements, and spring group vertical displacement will be taken on one end of each type of vehicle in the Atlas HLRM trains.

For the Atlas car, on-board data channels will include:

2 each – Roll Gyroscopes

2 each – Vertical Accelerometers

6 each – Lateral Accelerometers

[1] Instrumented wheelsets must meet requirements of M-1001, Appendix C

12 each – > 5 in. String Potentiometers

1 each – Speed Tachometer, may be located anywhere on the train, but location must be recorded. (additional tachometers are required for Stop Distance Tests)

For the second buffer car and the REV, data channels will include:

2 each – Roll Gyroscopes

2 each – Vertical Accelerometers

2 each – Lateral Accelerometers

4 each – >5 in. String Potentiometers

A single Automatic Location Device may be located anywhere on the train, but the location must be recorded.

Carbody lateral acceleration will be taken over truck or span bolster centers. Carbody roll angle measurements, and spring group vertical displacement will be taken on each end of each instrumented vehicle.

A total of 10 IWS will be used. For these tests, IWS will be placed in both axles of the trucks in the following locations in the Atlas HLRM train (Figure 5):

IWS locations (reference Figure 5):

- 6 – Trailing end of Atlas car
- 2 – Trailing end of trialing buffer car (next to REV)
- 2 – Leading end of REV.

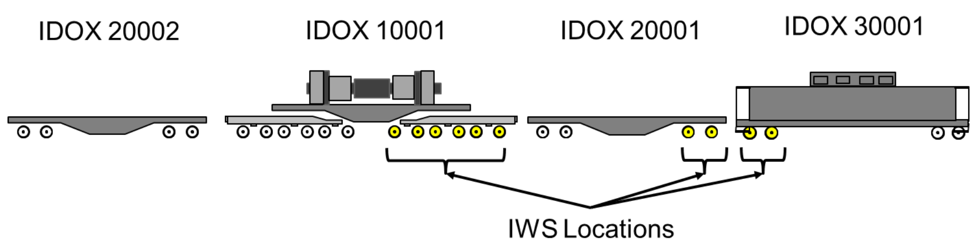

Figure 5. IWS Locations

Table 4. Measurement List for Atlas Car (IDOX 10001) (1 of 2)

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	Speed	Speed	0-80mph	0-1Hz	≥300Hz	better than 1%
2	ALD	Automatic Location Device	0-5V	≥15Hz	≥300Hz	better than 2%
3	VLX VRX LVLX LVRX TSLVLY TSLVRY X=Axle Num. Y=Truck Num.	IWS in Axle 7		≥15Hz	≥300Hz	better than 5%
4		IWS in Axle 8		≥15Hz	≥300Hz	better than 5%
5		IWS in Axle 9		≥15Hz	≥300Hz	better than 5%
6		IWS in Axle 10		≥15Hz	≥300Hz	better than 5%
7		IWS in Axle 11		≥15Hz	≥300Hz	better than 5%
8		IWS in Axle 12		≥15Hz	≥300Hz	better than 5%
9	ZACBB	B-end carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
10	ZACBA	A-End carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
11	YACBB	B-End carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
12	YACBA	A-End carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
13	YASBA1	A-End span bolster lead lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
14	YASBA2	A-End span bolster trail lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
15	YASBB1	B-End span bolster lead lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
16	YASBB2	B-End span bolster trail lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
17	ZDSNBL	Vertical Displacement B truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%

*Carbody accelerometers to be placed as closely as possible to the span bolster centers.

Table 4. Measurement List for Atlas Car (IDOX 10001) (2 of 2)

NO.	Channel Name	Measurement Description	Expecte d Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
18	ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
19	ZDSNCL	Vertical Displacement C truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
20	ZDSNCR	Vertical Displacement C truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
21	ZDSNDL	Vertical Displacement D truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
22	ZDSNDR	Vertical Displacement D truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
23	ZDSNEL	Vertical Displacement E truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
24	ZDSNER	Vertical Displacement E truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
25	ZDSNFL	Vertical Displacement F truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
26	ZDSNFR	Vertical Displacement F truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
27	ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
28	ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
29	RDCBB	Carbody roll rotation, B-end	±4deg	≥15Hz	≥300Hz	better than 1%
30	RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	better than 1%
31	GPS	GPS	n/a	≥1Hz	≥1Hz	better than 1%

*Carbody accelerometers to be placed as closely as possible to the span bolster centers.

Table 5. Measurement List for Buffer Cars (IDOX 20001 or 20002)

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	VLX VRX LVLX LVRX TSLVLY TSLVRY X=Axle Num. Y=Truck Num.	IWS in Axle 3 of trailing buffer		≥15Hz	≥300Hz	better than 5%
2		IWS in Axle 4 of trailing buffer		≥15Hz	≥300Hz	better than 5%
3	B(L)(T)-ZACBB	B-End carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
4	B(L)(T)-ZACBA	A-End carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
5	B(L)(T)-YACBB	B-End carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
6	B(L)(T)-YACBA	A-End carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
7	B(L)(T)-ZDSNBL	Vertical Displacement B truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
8	B(L)(T)-ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
9	B(L)(T)-ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
10	B(L)(T)-ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
11	B(L)(T)-RDCBB	Carbody roll rotation, B-end	±4deg	≥15Hz	≥300Hz	better than 1%
12	B(L)(T)-RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	better than 1%

*Carbody accelerometers to be placed as closely as possible to the truck centers.
*Channel names BL (Buffer Car Leading IDOX 20002) and BT (Buffer Car Trailing IDOX 20001) IWS will be placed only in the trailing buffer car.

Table 6. Measurement List for REV

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	VLX VRX LVLX LVRX TSLVLY TSLVRY X=Axle Num. Y=Truck Num.	IWS in Axle 1		≥15Hz	≥300Hz	better than 5%
2		IWS in Axle 2		≥15Hz	≥300Hz	better than 5%
3	E-ZACBB	B-End carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
4	E-ZACBA	A-End carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
5	E-YACBB	B-End carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
6	E-YACBA	A-End carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
7	E-ZDSNBL	Vertical Displacement B truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
8	E-ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
9	E-ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
10	E-ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
11	E-RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	better than 1%
12	E-RDCBB	Carbody roll rotation, B-end	±4deg	≥15Hz	≥300Hz	better than 1%

*Carbody accelerometers to be placed as closely as possible to the truck centers.

Note that additional instrumentation and channels that are required to complete the requirements for ride quality testing are included in Section 4.0.

Per request of the AAR Equipment Engineering Committee, additional monitoring will be performed in the south spiral of the 12-degree curve. Fish scales will be mounted on ties to measure rail head lateral deflection (both rails) in the south spiral of the WRM 12-degree curve. Exact location is to be determined by Russell Walker, probably about 10 to 20 feet into the spiral from the curve. The fish scales will be located in the same places as for the buff-draft curving test.

3.1.1 Data Acquisition

Data will be filtered at a rate greater than or equal to 15 Hz and less than or equal to sample rate divided by 2. The minimum sample rate is 300 Hz. Data will be post filtered as required (15 Hz) and analyzed in near-real time using the performance criteria for dynamic testing provided in Table 3.

3.1.2 Instrumentation Functional Checks

Functional checks of the instrumentation must be made to verify that all the measurements are working correctly. These functional checks are not a calibration function but are done to verify the setup. Guidance for performance of functional checks is provided in the Appendix.

3.2 Test Runs

The train will be operated in the Maximum Test Load condition on the 12-degree curve of the WRM track at speeds corresponding to three inches under balance, balance, and three inches over balance (15, 24, and 32 mph). Tests will be run in both clockwise and counterclockwise directions. Wheel L/V ratios will be monitored to ensure safe test operation. Table 7 provides a list of test runs to be conducted on the WRM Loop along with the applicable paragraph in S-2043.

Prior to each sequence of runs, a walking speed run will be performed to check for equipment clearances as well as track gage spreading and rail roll. Person(s) on the ground will be required for the visual observations of clearances and gage spreading. Fish scale readings of maximum lateral rail head displacement will be collected for each rail for both locomotives and the Atlas Car. Each run will be stopped so that the fish scales can be re-zeroed between the locomotives and the Atlas Car. Atlas Car readings will be compared to the readings from the locomotives after each run. Wheel/rail forces from the IWS will be observed in both the entry and exit spirals of the curve for these runs.

Table 7. List of runs at TTC WRM Loop

Run	Car End Leading	Loco Push/ Pull	Description	Speed	Require-ment
1	A	Pull	Slow speed run on the 12- degree curve to allow visual inspection for binding and interference. Also observe track for rail roll and track gage spreading. Take fish scale measurements under locomotives and Atlas Car.	Walking Speed	6.3.1.4
2	B	Push	Slow speed run on the 12- degree curve to allow visual inspection for binding and interference. Also observe track for rail roll and track gage spreading. Take fish scale measurements under locomotives and Atlas Car.	Walking Speed	6.3.1.4
3	A	Pull	12-degree curve	15	6.3.1.2
4	B	Push	12-degree curve	15	6.3.1.2
5	A	Pull	12-degree curve	24	6.3.1.2
6	B	Push	12-degree curve	24	6.3.1.2
7	A	Pull	12-degree curve	32	6.3.1.2
8	B	Push	12-degree curve	32	6.3.1.2
9			Turn train		
10	A	Pull	Slow speed run on the 12- degree curve to allow visual inspection for binding and interference. Also observe track for rail roll and track gage spreading. Take fish scale measurements under locomotives and Atlas Car.	Walking Speed	6.3.1.4
11	B	Push	Slow speed run on the 12- degree curve to allow visual inspection for binding and interference. Also observe track for rail roll and track gage spreading. Take fish scale measurements under locomotives and Atlas Car.	Walking Speed	6.3.1.4
12	A	Pull	12-degree curve	15	6.3.1.2

13	B	Push	12-degree curve	15	6.3.1.2
14	A	Pull	12-degree curve	24	6.3.1.2
15	B	Push	12-degree curve	24	6.3.1.2
16	A	Pull	12-degree curve	32	6.3.1.2
17	B	Push	12-degree curve	32	6.3.1.2

Between runs 8 and 10, friction coefficients will be measured near the middle of the 12-degree curve. A tribometer will be used to measure gage face and top-of-rail friction on both the inside and outside rails of each curve. Tribometer readings of rail friction coefficients, while not required by S-2043, will be taken to document the test conditions.

4.0 RIDE QUALITY TESTS

The REV will be evaluated for ride quality performance according to paragraph 6.3.3 of S-2043 and ISO 2631-1:1997/AMD 1:2010[5] standards. S-2043 states that track sections should be chosen to represent FRA Class 2 – Class 6 track; however, the planned revenue service route does not have any Class 5 or Class 6 track. The TTT will be used for the FRA Class 5 requirement. The PTT will be used for the FRA Class 6 requirement. Test train speeds will be limited to 70 mph as that is the maximum speed for S-2043 single car testing.

4.1 Ride Quality Instrumentation

Vibrations will be measured at the locations summarized in Table 8 using tri-axial accelerometers at each location. Accelerometers will be rigidly attached to the car floor. Mounting discs will be used for the 4 measurement locations that include cushioning. A disc similar to that shown in ISO 10326[6] but modified to be used with TTCI instrumentation will be used to mount the accelerometers. Weight will be placed on the disks to simulate a person. All accelerometer measurements will be taken at a sample rate of 800 Hz.

Table 8. Ride Quality Measurement Locations

Description	General Location	Attachment Point
Lead	Floor over lead bogie	Rigidly attached to floor of car interior
Trail	Floor over trail bogie	
Center	Floor center of car	
Bed	Upper and lower beds located at B-End of the car.	Mounting disk at center of mattress
Galley Seat	Galley seat located in corner of car interior	Mounting disk on seat pan

UOL Chair 1	UOL Chair nearest to AR corner of carbody	
UOL Chair 2	UOL Chair nearest to AL corner of carbody	

The appropriate frequency weighting will be applied to each measurement based on location and direction of measurement. Ride Quality for each measurement location and direction will be analyzed with regard to Health (ISO 2631-1 Annex B[5]), Comfort (ISO 2631-1 Annex C[5]), and Motion Sickness (ISO 2631-1 Annex D[5]).

4.2 Ride Quality Test Runs

Tests will be completed from 30 mph to 70 mph on each track in 10 mph increments. Test runs will consist of one complete lap for the TTT (9.1 miles) and one complete pass over the PTT (6.5 miles). PTT runs will pass through perturbed zones at speeds deemed safe by the test engineer based on previous results from the Pitch and Bounce, Twist and Roll, and Yaw and Sway tests. Perturbed zones will not be included in the ride quality analysis and speeds through the perturbed zones may need to be reduced or increased based on previous test results. At the completion of a PTT run the test train will be backed up at a determined safe speed to set up for the next run.

A summary of the runs to be performed are listed in Table 9. Additional runs may be added during the test by the test engineer if necessary. All runs will be conducted in the CW and CCW directions (both northward and southward for the PTT) for each speed and class of track.

AAR OT-55[7] limits the speed of key trains to 50 mph, but S-2043 requires that testing be conducted at speeds up to the FRA freight speed limit for the class of track. As the maximum safe operating speed of the HLRM cars for single-car testing was only required to be 70 mph, that will be the maximum test speed for the multiple-car test train.

Table 9. Ride quality run speeds for each track

Class 5 - TTT	Class 6 - PTT
30 MPH	30 MPH
40 MPH	40 MPH
50 MPH	50 MPH
60 MPH	60 MPH
70 MPH	70 MPH

5.0 TEST SCHEDULE

Preliminary test schedule is after completion of the controlled site multiple car tests. Detailed scheduling will be based on resource and facility availability.

6.0 REFERENCES

1. AAR Manual of Standards and Recommended Practices, Car Construction Fundamentals and Details, Performance Specification for Trains Used to Carry High-Level Radioactive Material, Standard S-2043, Effective: 2003; Last Revised: 2021, Association of American Railroads, Washington, DC.
2. Safety Rule Book, TTCI, July 2020 or Latest Revision.
3. Operating Rule Book, TTCI, July 2020 or Latest Revision.
4. 49 CFR Part 213, Track Safety Standards, October 2019 or Latest Revision.
5. ISO 2631-1:1997/Amd 1:2010, Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration.
6. ISO 10326-1:2016, Mechanical vibration — Laboratory method for evaluating vehicle seat vibration.
7. Association of American Railroads, Circular OT-55: Recommended Railroad Operating Practices For Transportation of Hazardous Materials, Effective May 1st. 2019.

APPENDIX – GUIDANCE FOR PERFORMING INSTRUMENTATION FUNCTIONAL TESTS

Functional checks of the instrumentation should be made to verify that all the measurements are working correctly. These functional checks are not a calibration but are done to verify the setup. Common setup errors include but are not limited to faulty transducers, cabling errors, and improper gain settings. Functional checks should be performed to verify that the cables and measure the right value. If a functional check of a transducer shows more than 10% error, look closely at the setup to make sure there are no mistakes.

- Record the functional checks in a data file so you can refer to them later if necessary.
- Perform the functional checks in a specific order and verify that the order matches what you observe in the data file.
- Pay attention to the sign of the output.

The following are typical functional checks for some transducers:

- Roll the accelerometers 90 degrees for a 1g input.
- Pull string pots and verify that extension is positive and that they read 1-inch when pulled one inch.
- Use a block of known size to check LVDTs and bending beams.
- Check speed measurements against GPS speed.
- Verify load cells with an R-cal resistor and a breakout box.
- If possible, apply a known force to a load cell. For example, use the car weight and the track grade from your Operating Rule Book to estimate the average expected force on the appropriate channel for a particular section of track during resistance testing.

Instrumented wheel sets are a special case. The following are suggested for functional tests of IWS. As IWS technology changes the steps might change.

- Verify the cable is connected where you think it is by disconnecting the cable at the wheelset and verifying that the “Disconnected” light comes on at the decoder box where you expect it to.

- Push the R-cal button on the decoder box and verify that you see the step change in the correct IWS channels.

- Record data on a portion of tangent track.

    - Vertical loads should match the scale weight to within 5%

    - Lateral loads should be small, resulting in L/V ratios of about 0.05. This may vary depending on truck design and condition.

    - Contact position output should be around zero. This may vary depending on truck design and condition.

    - If the wheelset is equipped with a torque bridge its average should be around zero. This may vary depending on truck design and condition.

- If a truck is fully instrumented with IWS, you can compare the net lateral load to a calculated value for a curve.

Appendix E - Test Plan TP-23-001 rev 2 Test Implementation Plan: Revenue Service BNSF

TEST IMPLEMENTATION PLAN:
MULTIPLE CAR TEST OF THE HLRM TRAIN
IN ACCORDANCE WITH
ASSOCIATION OF AMERICAN RAILROADS STANDARD S-2043
(REVENUE SERVICE BNSF PORTIONS)

FOR THE U.S. DEPARTMENT OF ENERGY (DOE)

TEST PLAN TP-23-001 REV 2

Prepared by
MxV Rail
A subsidiary of the Association of American railroads
Pueblo, Colorado USA
April 6, 2023

Executive Summary

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete multiple car testing of the U.S. Department of Energy (DOE) High-Level Radioactive Material (HLRM) train as required by the Association of American Railroads (AAR) Standard S-2043 entitled "Performance Specification for Trains used to Carry High-Level Radioactive Material," Section 6.3 – Revenue Service Tests. This document follows up on testing previously conducted during October 2022 in partial fulfillment of the requirements of Section 6.3. Sufficient data was collected then to complete the 20-mile requirement in 6.3.2, the Ride Quality runs in 6.3.3, and the walking speed runs over the 10-degree curve in 6.3.1.4. This test plan addresses the 10-degree curve requirement of S-2043 Paragraph 6.3.1.2. Separate test plans have been provided for the remainder of Paragraph 6.3.1, as well as Paragraphs 6.3.2 and 6.3.3.

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1.0 INTRODUCTION

1.1 Purpose

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete multiple car testing of the U.S. Department of Energy (DOE) Atlas High-Level Radioactive Material (HLRM) train as required by the Association of American Railroads (AAR) Standard S-2043 entitled "Performance Specification for Trains used to Carry High-Level Radioactive Material." [1] The train is being developed by the DOE under the Atlas Railcar Design Project that is intended to address the future need for large-scale transport of HLRM, including spent nuclear fuel.

This document describes testing to meet the requirements of Standard S-2043 Section 6.3 – Revenue Service Tests, specifically:

- The 10-degree curve requirements of Paragraph 6.3.1.2 – the "Tight Curves" portion of 6.3.1 – "Turnouts, Crossovers, and Tight Curves"

Separate test plans cover the following:

- Paragraph 6.1 – "Dynamic Tests at the Controlled Test Site" (TP-21-001)
- Paragraph 6.2 – "System Monitoring Test" (TP-21-002)
- Remaining portions of Paragraph 6.3.1 – "Turnouts, Crossovers, and Tight Curves" (TP-21-003)
- Walking-speed tests of Paragraph 6.3.1.4 (TP-21-005)
- The Class 2 track portion of Paragraph 6.3.2 (TP-21-003 and TP-21-005)
- The Class 2 through Class 6 track classes of Paragraph 6.3.3 – "Ride Quality" (TP 21-003, TP-21-004, and TP-21-005)

This document follows up on testing previously conducted on BNSF during October 2022 in partial fulfillment of TP-21-005. Sufficient data was collected then to complete the 20-mile requirement in 6.3.2, the Ride Quality runs in 6.3.3, and the walking speed runs over the 10-degree curve in 6.3.1.4. The only remaining test for qualification is the 10-degree curve in 6.3.1.2 at speeds up to the maximum track speed. The wheelsets in the test train will be updated from the AAR 1B profile (standard when the cars were built) to the AAR 2A profile (current standard). Analysis indicates this change to be the most effective to improve the curving performance in the 10-degree curve with the rail profiles as measured in conjunction with the October 2022 testing.

1.2 Train Description

The Atlas HLRM train to be tested consists of a cask car (the Atlas car), a rail escort vehicle (REV), and two buffer cars, as shown in Figure 1.

Table 1 provides additional details. The REV will be used as the instrumentation car. In addition, it is anticipated that approximately 19 to 23 additional **loaded** railcars (likely sand cars) will be placed in the train to meet braking requirements. Three cars of the HLRM train will have a total of 10 instrumented wheelsets (IWS) installed and the corresponding brakes disabled. For the buffer car with IWS and the REV, all brakes on those cars will be disabled. For the cask car, only the brakes on the trispan bolster with IWS installed will be disabled. The FRA requires that at least 85 percent of the axles on the test train have operative brakes, not including locomotives. In case braking cars develop defects during the course of testing, additional braking cars will be added so that testing can continue even if some must be set out. Locomotives will be placed at both ends of the test train.

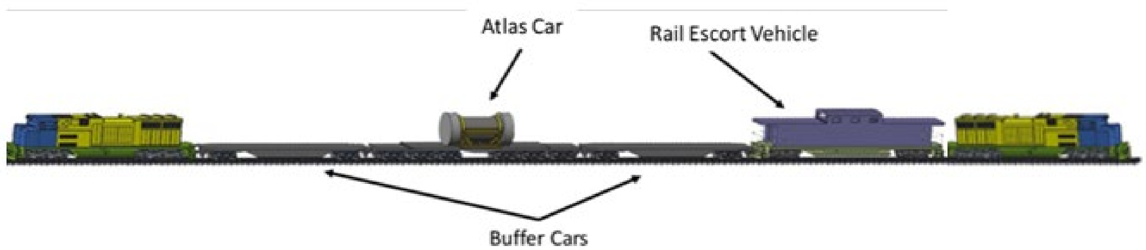

Figure 1. HLRM Train (additional braking cars not shown)

The FRA has requested the following conditions for the multiple car test train runs in revenue service under a permit for "One Time Movement for the purpose of testing":

1. Cars under test are to be appropriately stencilled in case any need to be set out during operation.
2. Locomotives used should have extended range dynamic braking, preferably AC 6-motor units or late model DC (Dash-9 series or newer) 6-motor units.
3. The test train is to be operated with locomotives at both ends of the train.
4. MxV Rail have a contingency plan in case of a car developing a defect. See section 4.2 of this document.

Two test loads were designed and built to meet both the expected minimum condition and expected maximum condition payloads:

- Minimum condition test load, simulating an empty MP-197 Cask (192,000 pounds including cradle)
- Maximum condition test load, simulating a loaded HI-STAR 190XL Cask (484,000 pounds including cradle and end stops)

The tests described in this document will be conducted with the Atlas car loaded to the minimum test load condition.

Table 1. Test Train Details

Item	Type	Car Number	Gross Weight	Remarks
1	Locomotive(s)	TBD	TBD	Provided by BNSF Railway (BNSF)
2	19 to 23 Braking Cars	TBD	263,000 lbs.	Provided by BNSF
3	Buffer Car	IDOX 20002	263,000 lbs.	
4	Atlas Cask Car	IDOX 10001	421,050 lbs.	(Minimum Test Load condition)
5	Buffer Car	IDOX 20001	263,000 lbs.	
6	REV	IDOX 30001	181,000 lbs.	
7	Locomotive(s)	TBD	TBD	Provided by BNSF. See Note (1).

Notes:

(1) BNSF will use locomotives at both ends of the train to expedite testing in both directions as well as train operations to and from the test curve location.

The requirements for multiple car revenue service tests are described in Section 6.3 of the AAR Standard S-2043. This standard requires that all multiple car tests and subsequent data analysis be witnessed by a qualified AAR observer. MxV Rail will provide the qualified AAR observer to meet this requirement of the specification.

1.3 Requirements for Operating Test Train in Revenue Service

For revenue service testing, there are some requirements that need to be checked prior to testing. These requirements include:

- Sufficient number of braked axles
- Loading applied to bridges
- Dimensional clearances for adjacent tracks and close clearance points

The test train will be operated by BNSF and the maximum speed for transport of the train is the maximum speed listed in the BNSF employee timetable for the tons per operative brake (TOB) of the train, typically 45 mph, unless otherwise restricted for curves, junctions, etc. During transport and testing of the train, the brakes on one half of the cask car, the second buffer car, and the escort car will be disengaged to accommodate the use of IWS that measure wheel-to-rail interaction forces. Loaded cars will be added to the train to provide additional braking capability.

For purposes of heavy load clearance, MxV Rail used the AAR Bridge1 program (Moment and Shear Tables for Heavy Duty Cars on Bridges) to analyze the HLRM train with six-axle freight locomotives at each end. The maximum outputs were E-72 or lower for all span lengths required. E-72 loading is equivalent to the maximum bridge loading generated by current six-axle freight locomotives and 286,000-pound gross rail load freight cars. Details of the analysis are available upon request.

In order to check the dimensional clearances, MxV Rail analyzed drawings of the Atlas car with the simulated test load. The analysis determined that the loaded Atlas car fits within AAR Plate C dimensions. Plate C is a basic set of dimensions for unrestricted interchange movement of freight cars.

1.4 Test Tracks

The tests described herein are to be conducted over BNSF Railway (BNSF) tracks between Avondale, CO and Folsom, NM. The route includes portions of the Pueblo subdivision between Pueblo and La Junta, CO (63 miles); the Raton subdivision between La Junta and Trinidad, CO (81 miles); the Twin Peaks subdivision between Trinidad, CO and Folsom, NM (76 miles); and possibly the Spanish Peaks Subdivision between Trinidad and Pueblo (88 miles). A small portion of the BNSF Boise City subdivision will be traversed in the La Junta terminal area. Figure 2 shows the test route. The portion of this route between Avondale and Trinidad via La Junta was used previously for the M-290 Car and train testing.

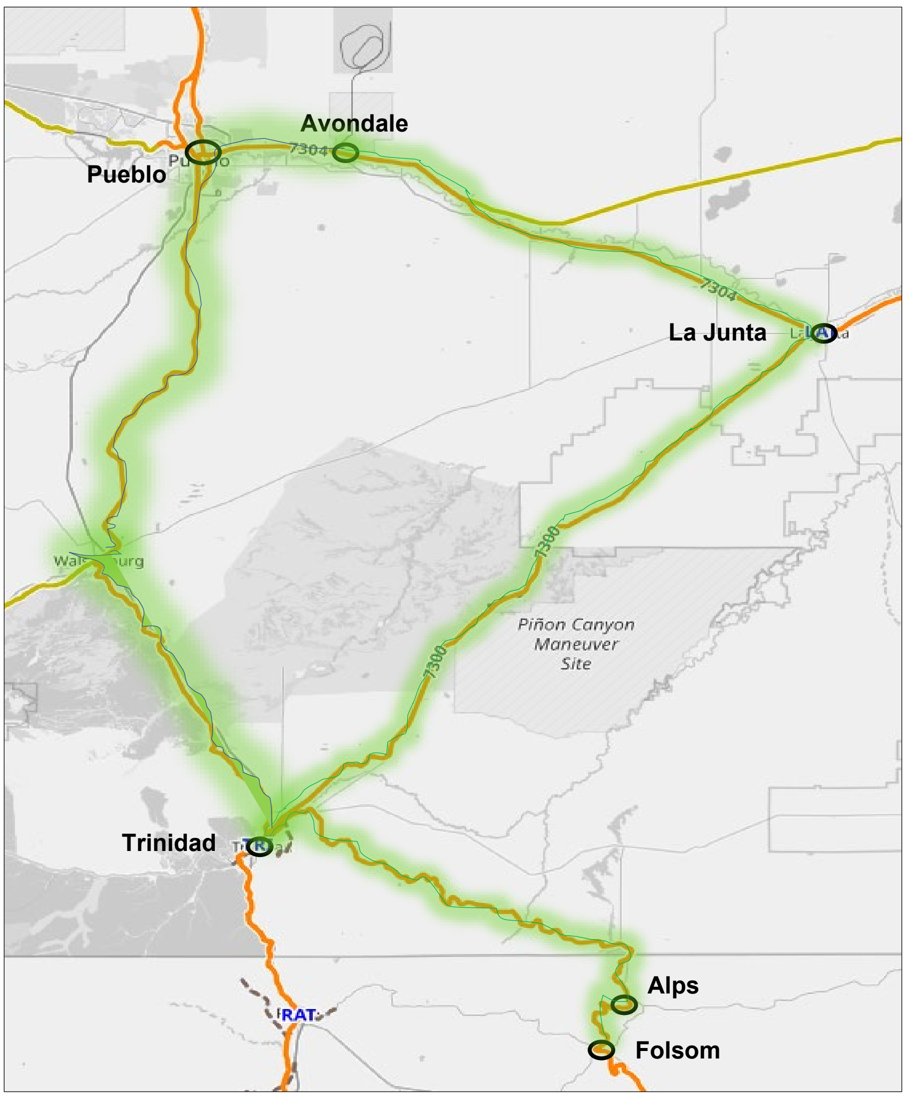

Figure 2. Route of Test Train

Table 2 provides a summary of all tracks proposed for completion of Section 6.3 Revenue Service Testing, including BNSF tracks as well as those to be used elsewhere. The tracks in bold are the tracks used in this test plan.

Table 2. Tracks Proposed for Section 6.3 Revenue Service Tests

S-2043 Paragraph	Requirement	Test Location*
6.3.1	Turnouts, Crossovers, and Tight Curves	
6.3.1.1	No. 10 (or sharper) turnout	PCD No. 8 turnouts
	No. 10 (or sharper) crossover	PCD No. 8 crossover on 14'2" track centers
6.3.1.2	10-degree curve	**BNSF Twin Peaks Sub near MP 274**
	12-degree curve – test site	Transportation Technology Center (TTC) WRM loop
6.3.2	Class 2 Maintained Track	
	Minimum length of 20 route miles	BNSF enroute to 10-degree curve**
	5 miles of FRA class 2	PCD
	10-degree curve	PCD 10- and 12-degree curves
	No. 10 (or sharper) turnout	PCD No. 8 turnouts
	No. 12 (or sharper) crossover	PCD No. 8 crossover on 14' 2" track centers
6.3.3	Ride Quality – Class 2 through Class 6	
	Class 2 (25 mph)	PCD up to 20 mph
	Class 3 (40 mph)	BNSF enroute to 10-degree curve**
	Class 4 (60 mph)***	BNSF enroute to 10-degree curve**
	Class 5 (80 mph)	TTC TTT up to 75 mph
	Class 6 (110 mph)	TTC RTT up to 75 mph

*Test locations:
PCD – Pueblo Chemical Depot, track jointly operated by MxV Rail and South Plains Railroad
BNSF – BNSF Railway
**Previously tested on BNSF revenue service test runs during October 2022.
***Top speed restricted to 45 mph on BNSF track.

Tight Curve testing is planned on the BNSF Twin Peaks Subdivision. The 10-degree curve requirements of 6.3.1.2 will be fulfilled by testing over the 10-degree curve near MP 274 near Alps, New Mexico. This portion of track has a 25-mph speed limit. Figure 3 shows an aerial view of the curve. Figure 4 shows a track chart of that portion of the BNSF.

Figure 3. Aerial view of 10-degree test curve near Alps, New Mexico

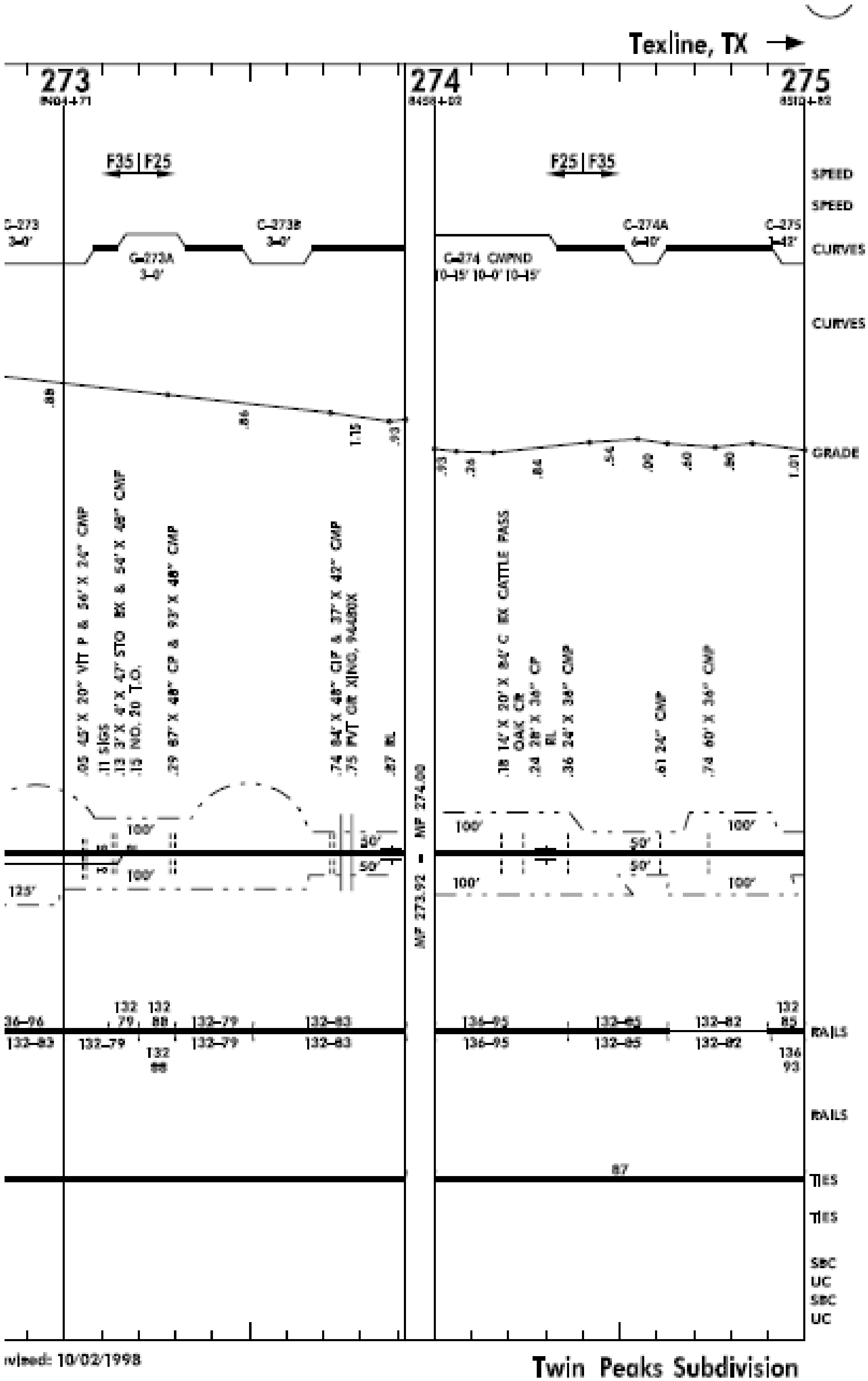

Figure 4. Track Chart showing 10-degree curve near MP 274

2.0 SAFETY

The operating and safety rules of BNSF will be followed for all work on BNSF property. Train operations will be conducted by BNSF train crews in coordination with the MxV Rail test engineer. Instrumentation and preparatory work are to be conducted in accordance with the most current versions of MxV Rail's Safety Rulebook[2] and Operating Rulebook,[3] both of which are maintained on MxV Rail's intranet site.

For testing on BNSF tracks, speeds will not exceed the BNSF timetable speed limit (45 mph for the HLRM train) for the track on which testing is being conducted.

3.0 DYNAMIC TESTS

Table 3 summarizes the limiting criteria for the dynamic tests required under S-2043 Paragraphs 6.3.1 and 6.3.2. Figure 5 illustrates the application of 50-msec and 3-foot distance limits for the L/V ratio and the minimum vertical wheel load.

Table 3. Dynamic Limiting Criteria

Criterion	Limiting Value	Notes
Maximum carbody roll angle (degree)	4	Peak-to-peak.
Maximum wheel L/V	0.8	Not to exceed indicated value for a period greater than 50 msec and for a distance greater than 3 feet per instance*.
95th percentile single wheel L/V (constant curving tests only)	0.6	Not to exceed indicated value. Applies only for constant curving tests.
Maximum truck side L/V	0.5	Not to exceed indicated value for a duration equivalent to 6 ft. of track per instance.
Minimum vertical wheel load (%)	25	Not to fall below indicated value for a period greater than 50 msec and for a distance greater than 3 feet per instance*.
Peak-to-peak car body lateral acceleration (G)	1.3 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum carbody lateral acceleration (G)	0.75 0.35	For non-passenger-carrying railcars For passenger-carrying railcars
Carbody lateral acceleration standard deviation (G)	0.13	Calculated over a 2000-ft. sliding window every 10 feet over a tangent track section that is a minimum of 4000 ft. long.
Maximum carbody vertical acceleration (G)	0.90 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum vertical suspension deflection (%)	95	Suspension bottoming not allowed. Maximum compressive spring travel shall not exceed 95% of the spring travel from the empty car height of the outer load coils to solid spring height.
Maximum vertical dynamic augment acceleration (g)	0.9	Suspension bottoming not allowed. Vertical dynamic augment accelerations of a loaded car shall not exceed 0.9 G.
*Figure 4 illustrates the application of 50-millisecond and 3-foot distance limits for L/V ratio and minimum vertical wheel load.		

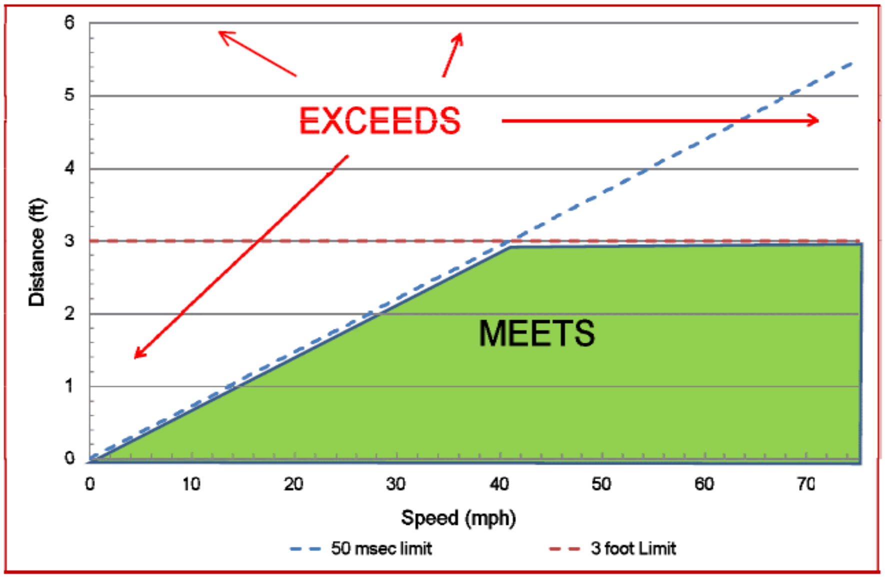

Figure 5. Time and Distance to Climb Limits

3.1 Instrumentation

The instrumentation and data collection package for these tests will be provided by MxV Rail, and this package will include all the necessary transducers for comparison with S-2043 performance measures. The measurements for the dynamic tests are listed in Tables 4 through 7.

To provide precise measurements of wheel/rail forces, two IWS[1] will be installed in both axles of the various trucks, as noted above. The train will be tested traveling in both directions, so the IWS will be in both the leading and trailing positions during the test.

Carbody lateral acceleration, carbody roll angle, and spring group vertical displacement will be measured on one end of each type of vehicle in the Atlas HLRM trains.

For the Atlas car, on-board data channels will include:

- 2 each – Roll gyroscopes
- 2 each – Vertical accelerometers
- 6 each – Lateral accelerometers
- 12 each – > 5-inch. String potentiometers
- 1 each – Speed tachometer, may be located anywhere on the train, but location must be recorded (additional tachometers are required for Stop Distance Tests)

For the buffer cars and the REV, data channels will include:

- 2 each – Roll gyroscopes

[1] Instrumented wheelsets must meet requirements of M-1001, Appendix C.

- 2 each – Vertical accelerometers
- 2 each – Lateral accelerometers
- 4 each – >5-inch String potentiometers

A single Automatic Location Device may be located anywhere on the train, but the location must be recorded.

The carbody lateral acceleration will be measured over truck or span bolster centers. Both the carbody roll angle and the spring group vertical displacement will be measured on each end of each instrumented vehicle.

A total of 10 IWS will be used. For these tests, the IWS will be placed in both axles of the trucks in the following locations in the Atlas HLRM train (Figure 6):

- IWS locations (reference Figure 6):
  - 6 – Trailing end of Atlas car
  - 2 – Trailing end of trailing buffer car (next to REV)
  - 2 – Leading end of REV

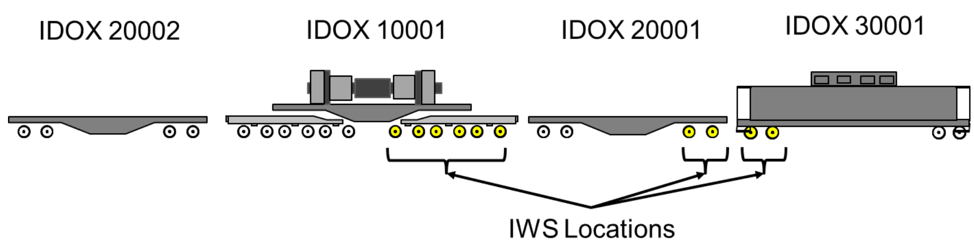

Figure 6. IWS Locations in cask, buffer, and REV cars

Table 4. Measurement List for Atlas Car (IDOX 10001) (1 of 2)

No.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	Speed	Speed	0-80mph	0–1Hz	≥300Hz	Better than 1%
2	ALD	Automatic Location Device	0-5V	≥15Hz	≥300Hz	Better than 2%
3	VLX VRX LVLX LVRX TSLVLY TSLVRY X=Axle Num. Y=Truck Num.	IWS in Axle 7		≥15Hz	≥300Hz	Better than 5%
4		IWS in Axle 8		≥15Hz	≥300Hz	Better than 5%
5		IWS in Axle 9		≥15Hz	≥300Hz	Better than 5%
6		IWS in Axle 10		≥15Hz	≥300Hz	Better than 5%
7		IWS in Axle 11		≥15Hz	≥300Hz	Better than 5%
8		IWS in Axle 12		≥15Hz	≥300Hz	Better than 5%
9	ZACBB	B-End carbody vertical acceleration*	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
10	ZACBA	A-End carbody vertical acceleration*	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
11	YACBB	B-End carbody* lateral acceleration	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
12	YACBA	A-End carbody lateral acceleration*	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
13	YASBA1	A-End span bolster lead lateral acceleration	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
14	YASBA2	A-End span bolster trail lateral acceleration	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
15	YASBB1	B-End span bolster lead lateral acceleration	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
16	YASBB2	B-End span bolster trail lateral acceleration	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
17	ZDSNBL	Vertical Displacement B truck Left Side	>5 inch	≥15Hz	≥300Hz	Better than 1%

*Carbody accelerometers to be placed as closely as possible to the span bolster centers.

Table 5. Measurement List for Atlas Car (IDOX 10001) (2 of 2)

No.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
18	ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
19	ZDSNCL	Vertical Displacement C truck Left Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
20	ZDSNCR	Vertical Displacement C truck Right Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
21	ZDSNDL	Vertical Displacement D truck Left Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
22	ZDSNDR	Vertical Displacement D truck Right Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
23	ZDSNEL	Vertical Displacement E truck Left Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
24	ZDSNER	Vertical Displacement E truck Right Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
25	ZDSNFL	Vertical Displacement F truck Left Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
26	ZDSNFR	Vertical Displacement F truck Right Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
27	ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
28	ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
29	RDCBB	Carbody roll rotation, B-end	±4deg	≥15Hz	≥300Hz	Better than 1%
30	RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	Better than 1%
31	GPS	GPS	n/a	≥1Hz	≥1Hz	Better than 1%

Table 6. Measurement List for Buffer Cars (IDOX 20001 and 20002)

No.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	VLX VRX	IWS in Axle 3 of Trailing Buffer		≥15Hz	≥300Hz	Better than 5%
2	LVLX LVRX TSLVLY TSLVRY X=Axle Num. Y=Truck Num.	IWS in Axle 4 of Trailing Buffer		≥15Hz	≥300Hz	Better than 5%
3	B(L)(T)-ZACBB	B-End carbody vertical acceleration*	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
4	B(L)(T)-ZACBA	A-End carbody vertical acceleration*	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
5	B(L)(T)-YACBB	B-End carbody lateral acceleration*	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
6	B(L)(T)-YACBA	A-End carbody lateral acceleration*	Between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
7	B(L)(T)-ZDSNBL	Vertical displacement B-truck Left Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
8	B(L)(T)-ZDSNBR	Vertical displacement B-truck Right Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
9	B(L)(T)-ZDSNAL	Vertical Displacement A-truck Left Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
10	B(L)(T)-ZDSNAR	Vertical displacement A=truck Right Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
11	B(L)(T)-RDCBB	Carbody roll rotation, B-end	±4 degrees	≥15Hz	≥300Hz	better than 1%
12	B(L)(T)-RDCBA	Carbody roll rotation, A-end	±4 degrees	≥15Hz	≥300Hz	Better than 1%
*Carbody accelerometers to be placed as closely as possible to the truck centers.						

*Channel names BL (Buffer Car Leading IDOX 20002) and BT (Buffer Car Trailing IDOX 20001)

Table 7. Measurement List for REV

No.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	VLX VRX LVLX LVRX TSLVLY TSLVRY X=Axle Num. Y=Truck Num.	IWS in Axle 1		≥15Hz	≥300Hz	Better than 5%
2		IWS in Axle 2		≥15Hz	≥300Hz	Better than 5%
3	E-ZACBB	B-End carbody vertical acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
4	E-ZACBA	A-End carbody vertical acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
5	E-YACBB	B-End carbody lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
6	E-YACBA	A-End carbody lateral acceleration	between ±2g and ±10g	≥15Hz	≥300Hz	Better than 1%
7	E-ZDSNBL	Vertical displacement B-truck Left Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
8	E-ZDSNBR	Vertical displacement B-truck Right Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
9	E-ZDSNAL	Vertical displacement A-truck Left Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
10	E-ZDSNAR	Vertical displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	Better than 1%
11	E-RDCBB	Carbody roll rotation, E-end	±4deg	≥15Hz	≥300Hz	Better than 1%
12	E-RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	Better than 1%

3.1.1 Data Acquisition

Data will be filtered at a rate ≥15 Hz and ≤ (sample rate/2). The minimum sample rate is 300 Hz. Data will be post filtered as required (15 Hz) and analyzed in near real time using the performance criteria for dynamic testing provided in Table 3.

3.1.2 Instrumentation Functional Checks

Functional checks of the instrumentation must be made to verify that all the measurements are working correctly. These functional checks are not a calibration function but are done to verify the setup. Guidance for performance of functional checks is provided in the Attachment.

3.2 Test schedule for Twin Peaks Subdivision

Revenue service tests according to the requirements of Paragraph 6.3.1.2 (Tight Curve, 10-degrees) will be performed near Alps, New Mexico on the BNSF Twin Peaks Subdivision. This subdivision is used almost exclusively for northbound freight traffic.

Test runs will be performed in both directions through the 10-degree test curve with the IWS in both leading and trailing positions on the various cars. The train shall be pushed and pulled through the test curve to capture the effects of car-to-car interactions, worst case wheel-to-rail forces, and L/V ratios as measured during the single car tests. BNSF will provide a locomotive at each end of the test train. The locomotives will be operated to provide the required buff or draft conditions in the train as specified in S-2043. The maximum allowable speed over the test curves is 25 mph.

For planning purposes, MxV Rail estimates approximately 4 days to transport the train (round trip) and complete testing. Additional days may be required if problems are encountered or if weather is unfavorable (rain, snow). Table 8 shows the preliminary test schedule for the revenue service test. Coordination and BNSF planning may change the schedule shown.

Table 8. Preliminary Schedule of Revenue Service Test

Day(s)	Effort
1	Transport the train from Avondale to Trinidad via La Junta.
2	Perform the first set of test runs on the Twin Peaks Subdivision.
Overnight	Turn the train in La Junta.
3	Complete the 2nd set of test runs on the Twin Peaks Subdivision.
4	Return the train to Avondale via either Pueblo or La Junta (BNSF choice).

The 10-degree curve tests will be performed in the 10-degree curve near MP 274, about a mile south of the Alps controlled siding. In the unlikely event of an incident, MxV Rail test personnel shall immediately contact Steven Belport at (719) 251-6627 or Russell Walker at (719) 584-0505, either of whom will contact the appropriate person at DOE.

During the evenings between test days, the train will be sided near Trinidad. Security will be contracted via BNSF to guard the train and blue signal protection will be provided by MxV Rail.

3.3 Test Runs

Table 9 provides a list of test runs for the 10-degree test curve on the BNSF Twin Peaks Subdivision near Alps, New Mexico.

Table 9. List of Test Runs on BNSF near Alps, New Mexico

Test Runs on BNSF Twin Peaks Subdivision				
Alps 10-Degree Curve MP 274				
Train Orientation: Southbound				
Run	**Direction**	**Speed**	**Draft**	**Cask Car IWS Truck**
1	SB	10 mph	Tension	Trailing
2	NB	10 mph	Compression	Leading
3	SB	15 mph	Tension	Trailing
4	NB	15 mph	Compression	Leading
5	SB	20 mph	Tension	Trailing
6	NB	20 mph	Compression	Leading
7	SB	25 mph	Tension	Trailing
8	NB	25 mph	Compression	Leading
9	SB	10 mph	Compression	Trailing
10	NB	10 mph	Tension	Leading
11	SB	15 mph	Compression	Trailing
12	NB	15 mph	Tension	Leading
13	SB	20 mph	Compression	Trailing
14	NB	20 mph	Tension	Leading
15	SB	25 mph	Compression	Trailing
16	NB	25 mph	Tension	Leading
Turn entire train at La Junta				
Train Orientation: Northbound				
Run	**Direction**	**Speed**	**Draft**	**Cask Car IWS Truck**
17	SB	10 mph	Tension	Leading
18	NB	10 mph	Compression	Trailing
19	SB	15 mph	Tension	Leading
20	NB	15 mph	Compression	Trailing
21	SB	20 mph	Tension	Leading
22	NB	20 mph	Compression	Trailing
23	SB	25 mph	Tension	Leading
24	NB	25 mph	Compression	Trailing
25	SB	10 mph	Compression	Leading
26	NB	10 mph	Tension	Trailing
27	SB	15 mph	Compression	Leading
28	NB	15 mph	Tension	Trailing
29	SB	20 mph	Compression	Leading
30	NB	20 mph	Tension	Trailing
31	SB	25 mph	Compression	Leading
32	NB	25 mph	Tension	Trailing

At the beginning and end of each test day, friction coefficients will be measured near the middle of the 10-degree curve. A tribometer will be used to measure the gage face and the top-of-rail friction on both the inside and outside rails of the curve. If no flange contact is evident on the gage face of the inside rail, that measurement can be waived.

4.0 Test Schedule

The preliminary schedule for testing is after completion of the installation of wheel sets with AAR 2A wheel profiles. More detailed date scheduling will be based on resource and facility availability.

4.1 Daily Test Schedule

Daily testing will need to clear for other trains. The nearest control point locations to clear up for revenue traffic are:

- Alps (MP 272.3) to the north of the test curve
- Folsom (MP 284.5) to the south of the test curve.

Proposed staging and overnight stops: Trinidad, Colorado, near MP 208.

4.2 Contingency Plan for Cars or Locomotives Developing Defects

In case of a car or locomotive in the test train developing a defect during the test run, the following procedures will be followed depending on the defective car and the nature of the defect:

1. **Defective braking car:** If the defect requires setting out the car, operate at allowable safe speed to nearest location where the car can be set out. If need be, set out a second car to provide necessary handbrakes to keep the defective car in place. At least 2 extra braking cars should be included in the train to cover this possibility and allow for continuation of testing.

2. **Defective locomotive:** If the defect requires setting out the unit, operate at allowable safe speed to nearest location where the locomotive can be set out. If need be, set out a braking car to provide necessary handbrakes to keep the defective locomotive in place. Continue testing if sufficient remaining locomotive capability is available to complete remaining test runs. Otherwise continue testing after a replacement locomotive is available.

3. **Defective test car (including buffer cars, cask car, and escort car):** If a defect develops in any of these cars that requires setting out the car, operate at allowable safe speed to the nearest location where all 4 test cars can be set out. All test cars are to be kept coupled together due to the instrumentation cabling. If need be, sufficient braking cars can also be set out provide the necessary handbrakes to keep the test cars in place. MxV Rail test personnel shall immediately contact Steven Belport at (719) 251-6627 or Russell Walker at (719) 584-0505, either of whom will contact the appropriate person at DOE. Further test train movements will be made after discussions between BNSF, DOE, and MxV Rail and will depend on the nature of the defect(s).

5.0 References

1. Association of American Railroads. 2021. *AAR Manual of Standards and Recommended Practices,* Standard S-2043, Car Construction Fundamentals and Details, Performance Specification for Trains Used to Carry High-Level Radioactive Material, Effective: 2003; Last Revised: 2021. Washington, D.C.
2. *MxV Rail Safety Rule Book.* August 2022 or Latest Revision. MxV Rail, Pueblo, CO.
3. *TTCI Operating Rule Book.* July 2020 or Latest Revision. MxV Rail, Pueblo, CO.
4. 49 CFR Part 213, Track Safety Standards, October 2019 or Latest Revision.

ATTACHMENT – Guidance for Performing Instrumentation Functional Tests

Common setup errors include, but are not limited to, faulty transducers, cabling errors, and improper gain settings. Perform functional checks to verify that the cables go where they are supposed to and measure about the right value. If a functional check of a transducer shows more than 10 % error, look closely at the setup to make sure there are no mistakes.

- Record the functional checks in a data file so you can refer to them later if necessary.
- Perform the functional checks in a specific order and verify that the order matches what you observe in the data file.
- Pay attention to the sign of the output.

The following are typical functional checks for some transducers:

- Roll the accelerometers 90 degrees for a 1g input.
- Pull string pots and verify that extension is positive and that they read 1-inch when pulled 1 inch.
- Use a block of known size to check LVDTs and bending beams.
- Check speed measurements against GPS speed
- Verify load cells with an R-cal resistor and a breakout box.
- If possible, apply a known force to a load cell. For example, use the car weight and the track grade from the MxV Rail Operating Rule Book to estimate the average expected force on the appropriate channel for a particular section of track during resistance testing.

Instrumented wheelsets are a special case. The following are suggested for functional tests of IWS. Note: As IWS technology changes, the steps might change.

- Verify the cable is connected where expected by disconnecting the cable at the wheelset and verifying that the "Disconnected" light comes on at the decoder box where expected.
- Push the R-cal button on the decoder box and verify that you see the step change in the correct IWS channels.
- Record data on a portion of tangent track.
    - Vertical loads should match the scale weight to within 5%
    - Lateral loads should be small, resulting in L/V ratios of about 0.05. This may vary depending on truck design and condition.
    - Contact position output should be around zero. This may vary depending on truck design and condition.
    - If the wheelset is equipped with a torque bridge, its average should be around zero. This may vary depending on truck design and condition.
- If a truck is fully instrumented with IWS, the net lateral load can be compared to a calculated value for a curve.

Appendix F - Test Plan TP-23-002 Test Implementation Plan: Revenue Service Test Demonstration Run

TEST IMPLEMENTATION PLAN:
MULTIPLE CAR TEST OF THE HLRM TRAIN
IN ACCORDANCE WITH
ASSOCIATION OF AMERICAN RAILROADS STANDARD S-2043
(REVENUE SERVICE TEST DEMONSTRATION RUN)

FOR THE U.S. DEPARTMENT OF ENERGY (DOE)

TEST PLAN TP-23-002

Prepared by
MxV Rail
A subsidiary of the Association of American railroads
Pueblo, Colorado USA
August 15, 2023

Executive Summary

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete multiple car testing of the U.S. Department of Energy (DOE) High-Level Radioactive Material (HLRM) train as required by the Association of American Railroads (AAR) Standard S-2043 entitled "Performance Specification for Trains used to Carry High-Level Radioactive Material," Section 6.3 – Revenue Service Tests. This test plan addresses the requirements of S-2043 Paragraph 6.3.4, Demonstration Run.

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1.0 INTRODUCTION

1.1 Purpose

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete multiple car testing of the U.S. Department of Energy (DOE) Atlas High-Level Radioactive Material (HLRM) train as required by the Association of American Railroads (AAR) Standard S-2043 entitled "Performance Specification for Trains used to Carry High-Level Radioactive Material." [1] The train is being developed by the DOE under the Atlas Railcar Design Project that is intended to address the future need for large-scale transport of HLRM, including spent nuclear fuel.

This document describes testing to meet the requirements of Standard S-2043 Section 6.3 – Revenue Service Tests, specifically the requirements of Paragraph 6.3.4 – Demonstration Run.

Separate test plans cover the following:

- Paragraph 6.1 – "Dynamic Tests at the Controlled Test Site" (TP-21-001)
- Paragraph 6.2 – "System Monitoring Test" (TP-21-002)
- Remaining portions of Paragraph 6.3 – "Revenue Service Tests" (TP-21-003, TP-21-004, TP-21-005).

The demonstration test run is planned to be from MxV Rail's interchange at Avondale, Colorado to the Idaho National Laboratory rail access at Scoville, Idaho, all on Union Pacific Railroad. This test run is scheduled for September 2023.

1.2 Train Description

The Atlas HLRM train to be tested consists of a cask car (the Atlas car), a rail escort vehicle (REV), and two buffer cars, as shown in Figure 1. This test load is a dummy load made of steel. It is not a cask for carrying spent nuclear fuel. The dummy load has weight and center of gravity to closely match that of a cask.

Table 1 provides additional details on the Atlas train. The REV will be used for the test crew documenting the demonstration test run.

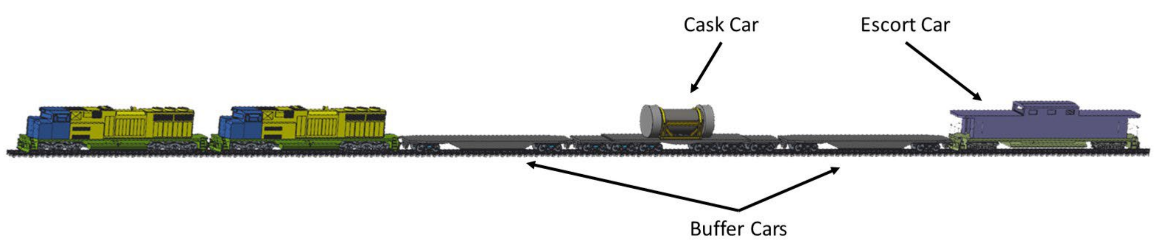

Figure 1. HLRM Train

A test load was designed and built to meet the expected maximum condition payload:

- Maximum condition test load, simulating a loaded HI-STAR 190XL Cask (484,000 pounds including cradle and end stops)

The tests described in this document will be conducted with the Atlas car loaded to the maximum test load condition using this test load. This test load is a dummy load made of steel. It is not a cask for carrying spent nuclear fuel. The dummy load has weight and center of gravity to closely match that of a cask.

Table 1. Test Train Details

Item	Type	Car Number	Gross Weight	Remarks
1	Locomotive 1	TBD	TBD	Provided by railroads
2	Locomotive 2	TBD	TBD	Provided by railroads
3	Buffer Car	IDOX 20001	263,000 lbs.	
4	Atlas Cask Car	IDOX 10001	710,700 lbs.	(Maximum Test Load condition)
5	Buffer Car	IDOX 20002	263,000 lbs.	
6	REV	IDOX 30001	181,000 lbs.	

The requirements for multiple car revenue service tests are described in Section 6.3 of the AAR Standard S-2043. This standard requires that all multiple car tests and subsequent data analysis be witnessed by a qualified AAR observer. Per the AAR Engineering Equipment Committee (EEC) meeting minutes of January 19, 2023, the EEC notes that having two DOE personnel and two MxV Rail personnel on board for this demonstration is sufficient.

1.3 Requirements for Operating Test Train in Revenue Service

The demonstration test train is to be operated in accordance with Key Train requirements per AAR Circular OT-55. The test train is technically not a Key Train due to the dummy load instead of spent nuclear fuel. However, the purpose of the test train is to demonstrate an actual service run.

For revenue service testing, there are two dimensional load requirements that need to be checked prior to testing. These requirements include:

- Loading applied to bridges from the test train
- Dimensional clearances for adjacent tracks and close clearance points.

The test train will be operated by Union Pacific Railroad (UP). The train will be operated in accordance with the operating rules and restrictions of the UP for the various lines traversed.

For purposes of heavy load clearance, MxV Rail used the AAR Bridge1 program (Moment and Shear Tables for Heavy Duty Cars on Bridges) to analyze the HLRM train with a pair of six-axle freight locomotives. The maximum outputs were E-72 or lower for all span lengths required. E-72 loading is similar to the maximum bridge loading generated by current six-axle freight locomotives and 286,000-pound gross rail load freight cars. Details of the analysis are available upon request.

To check the dimensional clearances, MxV Rail analyzed drawings of the Atlas car with the simulated test load. The analysis determined that the loaded Atlas car fits within AAR Plate C dimensions. Plate C is a basic set of dimensions for unrestricted interchange movement of freight cars. The buffer cars also fit Plate C dimensions. The REV fits within the slightly taller AAR Plate E dimensions.

1.4 Demonstration Test Run Service Route

The demonstration test run is to be conducted over UP tracks between Avondale, CO and Scoville, ID. Avondale is the junction to MxV Rail's testing facility. Scoville is the junction to the line that serves the DOE's Idaho National Laboratory facility. Routing will be entirely on UP lines. Different routings are possible between Denver, CO and Pocatello, ID. The possible routings are highlighted in yellow in Figure 2Figure 2. One routing could be via Grand Junction, CO. Other routings would be via Laramie, WY, with one routing being via Ogden, UT, and another via a more direct route between Granger, WY and Pocatello, ID. It is likely that the most northern route, which is the shortest, will be used.

Figure 2: Possible Routing for Demonstration Test Run on UP

Return routing will be via the same railroad. Exact lines to be used in each direction will be determined by the UP. Routing might not be the same in each direction. The actual routes taken will be logged by the on-board monitoring system.

2.0 SAFETY

The operating and safety rules of the UP will be followed for all work on UP property. Train operations will be conducted by UP train crews in coordination with the MxV Rail on-board test crew. Preparatory work is to be conducted in accordance with the most current versions of MxV Rail's Safety Rulebook[2] and Operating Rulebook,[3] both of which are maintained on MxV Rail's intranet site.

All riders (both MxV Rail and DOE/national labs) of the HLRM train during the demonstration run should have completed railroad security and safety certification for the UP through eRailSafe (https://erailsafe.com/usa/applicant-login/). This process can take a few weeks and needs to be completed prior to the beginning of the demonstration test run. The eRailSafe photo ID/badge may need to be presented to railroad personnel upon request or worn in a visible manner.

Please note that only US citizens are allowed inside the Rail Escort Vehicle. No photographs are allowed inside the Rail Escort Vehicle.

3.0 DOCUMENTATION

The system monitoring equipment will log parameters such as train speed and train location throughout the entire trip. This information will be used to produce the map of the actual route taken, for reporting purposes. The S-2043 standard requires the following to be submitted as part of the test report:

- Operator's log must be kept throughout the trip to document train operation and any problems that occur.
- Route map
- Photo documentation. No photographs are allowed inside the Rail Escort Vehicle.

No additional instrumentation is required beyond the normal system monitoring equipment.

The system monitoring equipment will log the parameters listed in Article 4.5.4.1 of the S-2043 standard throughout the entire trip. The data from the system monitoring equipment will be stored both locally on the REV and on the vendor's storage system off the train. The system monitoring equipment will include the basic monitoring system as required by S-2043. In addition, a prototype of a more advanced monitoring system, which is currently under development by DOE/national labs, will be operated in its own test mode during this test run.

3.1 Operator's Log

The operator's log should document the general route taken, major cities passed through, crew change points, and locations where the HLRM train is inspected. The log should also describe any problems encountered enroute, particularly any usual conditions encountered such as a highway grade crossing incident, irregular track conditions, etc. The log should note any exceptions found during periodic train inspections during the demonstration run.

3.2 Photo Documentation

Photo documentation should be provided to support any problems or unusual conditions found during the demonstration run. In particular, photos should be provided for any usual conditions encountered such as a highway grade crossing incident, irregular track conditions, etc. Photos should also be taken of any exceptions noted during periodic train inspections during the demonstration run. However, no photographs are allowed inside the Rail Escort Vehicle.

To document the route traversed, photos should be taken showing the HLRM train at recognizable locations, including readily identifiable landmarks (scenic features, bridges/major river crossings, unique structures) as well as railroad stations and/or signage.

3.3 Mechanical Inspections

A full mechanical inspection is to be performed before departure on the demonstration test run. A full mechanical inspection is to be performed upon completion of the demonstration test run. This inspection will be completed by a UP carman or anyone else who is qualified.

Intermediate mechanical inspections are to be performed at selected stops, interchange points, or crew change points, following the inspection checklist provided in the Appendix. Some portions of the checklist will not be applicable for the Demonstration Test Run.

4.0 Test Schedule

The preliminary schedule for testing is during September 2023.

4.1 Contingency Plan for Cars or Locomotives Developing Defects

In case of a car or locomotive in the test train developing a defect during the demonstration test run, the following procedures will be followed depending on the defective car and the nature of the defect:

1. **Defective locomotive:** If the defect requires setting out a locomotive unit, operate at allowable safe speed to nearest location where the locomotive can be set out and necessary handbrakes, skates, or wheel chocks applied to keep the defective locomotive in place. Continue demonstration test run to next reasonable location for adding replacement power if sufficient remaining locomotive capability is available to do so. Otherwise continue demonstration test run after a replacement locomotive is available.
2. **Defective test car (including buffer cars, cask car, and escort car):** If a defect develops in any of these cars that requires setting out the car, operate at allowable safe speed to the nearest location where all 4 test cars can be set out. All test cars are to be kept coupled together. Further test train movements will be made after discussions between UP, DOE, and MxV Rail and will depend on the nature of the defect(s).

5.0 References

1. Association of American Railroads. 2021. *AAR Manual of Standards and Recommended Practices,* Standard S-2043, Car Construction Fundamentals and Details, Performance Specification for Trains Used to Carry High-Level Radioactive Material, , Effective: 2003; Last Revised: 2021. Washington, D.C.
2. *MxV Rail Safety Rule Book.* August 2022 or Latest Revision. MxV Rail, Pueblo, CO.
3. *TTCI Operating Rule Book.* July 2020 or Latest Revision. TTCI, Pueblo, CO.
4. 49 CFR Part 213, Track Safety Standards, October 2019 or Latest Revision.

APPENDIX
MECHANICAL INSPECTION CHECKLIST

RAILCAR INSPECTION CHECKLIST SIGH-OFF

USER FACILITY:		SHIPMENT DESTINATION:	
RAILCAR TYPE:		DATE OF INSPECTION:	
RAILCAR SERIAL/IDOX NO.		INSPECTION PERFORMED BY:	
AAR-IR YEAR REVISION USED:		(PRINT)	
WARNING: Before initiating an inspection of a railcar, ensure that hand brakes are securely applied, the brake shoes firmly contact the wheels, and the conditions are safe around the railcar.			

Paragraph Number	Description	Recorded Measurements/Remarks[3]	Condition[1,2]	
			A-End	B-End
COUPLERS (AAR-IR 16, 17, 18, 21, 88 & 90)				
4.1.1.1 and 4.1.1.2	**General:** Check for cracks, broken or missing sections and prohibited items.			
4.1.1.3	**Type:** Check to ensure DOE railcars are equipped with:			
	(a) Bottom-shelf or F-head coupler, or			
	(b) For Atlas flatcars, top-and-bottom shelf couplers.			
4.1.1.4	**Knuckle pins:** Check for broken, bent, missing, or cracked pins.			
4.1.1.5	**Side clearance:** Check for movement in the horizontal plane.			
4.1.1.6	**Striker castings:** Check for cracks or breaks; securement, wear and rivets.			
4.1.1.7	**Coupler height:** Record height of couplers from top of rail			
	E: 32 3/4" - 35"			
	L: 31 3/4" - 34			
4.1.1.8	**Coupler assemblies:** Check coupler body and components for proper securement with adjacent car.			
4.1.1.9	**Coupler/knuckle contour:** Check for worn or distorted contour.			
4.1.1.10	**Shank:** Check for wear.			
4.1.1.11	**Carrier plates and securement fasteners:** Check parts are not broken, bent, cracked, or missing.			
Uncoupling Levers, Support Brackets and Toggle Clearance (AAR-IR 22)				
4.1 n.1.12	**Uncoupling Lever/Support Bracket:** Check for missing parts, wear, bends, or broken levers and support brackets, and proper operation.			

4.1.1.13	**Toggle clearance:** Record clearance (Reg. 1/4" to 1/2").			
YOKE (AAR-IR 19, 20)				
4.1.2	**Yokes:** Check for missing, bent, broken or cracked sections.			

Paragraph Number	Description	Recorded Measurements/Remarks[3]	Condition[1,2]	
			A-End	B-End
END-OF-CAR CUSHIONING UNITS (AAR-IR 59)				
4.1.3.1	Check for broken springs, missing components on restoring mechanism and leaks (excessive amount of oil on carrier plate).			
	Check cotter pin is installed through slotted castle nut.			
4.1.3.2	Inspect indicator pin on gas end-of-car cushioning device to confirm acceptable pressure.			
	Check for damaged or missing parts in accordance with AAR-IR 59.A.			
Storage greater than 6 months – see Section 1.5.3				
4.1.3.1	Check for broken springs, missing components on restoring mechanism and leaks (excessive amount of oil on carrier plate).			
	Check cotter pin is installed through slotted castle nut.			
4.1.3.2	Inspect indicator pin on gas end-of-car cushioning device to confirm acceptable pressure.			
	Check for damaged or missing parts in accordance with AAR-IR 59.A.			
AIR BRAKE HOSES AND BRAKE OPERABILITY TESTING (AAR IR 3, 4, and 5)				
4.2.1.1	**Hoses:** Check for missing, worn, deteriorated, or damaged hoses.			
4.2.1.2	**Supports:** Check air hose supports for broken, missing, or bent parts. Ensure that the supports maintain the required air hose height.			
4.2.1.3	**End air hose:** Check and record dates on end air hoses.			
4.2.1.4	**Air lines/Valves:** Check for bent, broken, worn, missing or inoperative brake line brackets, angle cocks, retainer valves, cutout cocks, piping, and parts.			
4.2.2	**Operability testing:** Check air brake system for operability and loose or defective fittings and audible leaks.			
Storage greater than 6 months – See Section 1.5.3				
4.2.1.1	**Hoses:** Check for missing, worn, deteriorated, or damaged hoses.			
4.2.1.2	**Supports:** Check air hose supports for broken, missing, or bent parts. Ensure that the supports maintain the required air hose height.			
4.2.1.3	**End air hose:** Check and record dates on end air hoses.			

Paragraph Number	Description	Recorded Measurements/Remarks[3]	Condition[1,2]	
			A-End	B-End
4.2.1.4	**Air lines/Valves:** Check for bent, broken, worn, missing or inoperative brake line brackets, angle cocks, retainer valves, cutout cocks, piping, and parts.			
4.2.2	**Operability testing:** Check air brake system for operability and loose or defective fittings and audible leaks.			
BRAKE SHOES, LINKAGES AND HANDBRAKES (AAR IR 6, 7, 8 and 12)				
4.3.1	**Brake shoes:** Check brake shoes and shoe keys that are either missing, or broken and partially missing. Check thickness of brake shoes (Note 2).			
Note 2: For Atlas flatcars (IDOX 10000 railcar series), brake shoes shall be replaced when worn to 1-inch or less thickness (including lining and backing plate) in lieu of 3/8-inch per AAR IR 12.A.1.e.				
4.3.2.1	**Linkages:** Check brake levers, brake beams, hanger pins, bolts, guides, and brake connection rods for missing or broken parts, wear and freedom of movement.			
4.3.2.2	**Cotter pins:** Check all linkage to ensure cotter pins (keys) are in place.			
4.3.2.3	**Rigging:** Check to ensure brake rigging is not riding on or contacting wheels or axles.			
4.3.3	**Handbrake:** Check to ensure handbrake is in proper position and operable.			
WHEEL BEARINGS AND BEARING ADAPTERS (AAR IR 35, 37)				
4.4.1.1	**Size:** Check for correct size roller bearings and roller bearing adapters.			
4.4.1.2	**Condition:** Check for indications of defective roller bearings (i.e., discoloration due to overheating or a visible accumulation of fresh grease).			
4.4.1.3	**External parts:** Check roller bearing for external parts visibly cracked, broken, bent, loose or missing.			
4.4.2	**Adapter:** Check bearing adapters are not cracked or broken. For the Atlas flatcar, check that the four lateral stops on each bearing adapter are not cracked, broken, or missing.			
TEMPERATURE MONITORING SYSTEM (DOECognizant Equipment; IDOX Railcar Series)				
4.4.3	Check for proper operation of on-board bearing temperature monitoring system.			
Storage greater than 6 months – See Section 1.5.3				
4.4.3	Check for proper operation of on-board bearing temperature monitoring system.			
TRUCKS AND CAR BODY				
Trucks				
4.5.1.1	**Trucks:** Check truck bolsters, transoms, spring planks and side frames for broken,			
4.5.1.3	**Bowls:** Check truck bowl for cracks or missing pieces.			
4.5.1.4	**Castings:** Check bolster castings thoroughly for cracks.			

4.5.1.5	**Wear plate:** Check for missing, broken, or excessively worn truck bolster and side frame friction casting wear plates.			
4.5.1.6	**Sideframe/Equalizer:** Check equalizer blocks, shims, pins, and bushings on IDOX railcar series.			
	Visually inspect the side frame to equalizer interface for any evidence of fresh contact. Record if found.			
Car Body				
4.5.2.1	**Body:** Visually inspect accessible areas of car body, span bolsters, and draft sills for cracked or broken parts.			
4.5.2.2	**Depressed center car curvature:** On depressed center type cars check body curvature for failure.			
4.5.2.3	**Deck:** Check railcar deck to ensure that it appears suitable for the intended load.			
Side Bearings				
4.5.3.1	**Side bearings:** Check that no part of the bearing assemblies are missing, cracked, worn or broken. Check and record the side bearing clearance.	See attached Addendum D		
4.5.3.2	**Side bearing – constant contact:** Check and record constant contact side bearing setup height.	See attached Addendum D		
Rail Clearance				
4.5.4	**Rail clearance:** Measure and record minimum clearance between railcar and top of rail; minimum clearance is 2-3/4 inches.			
WHEELS AND AXLES (AAR IR 41, 43)				
4.6.1	**Wheels:** Check wheels for cracked, broken, or chipped flanges; cracked, broken, shattered, or spread rims; shelled, built-up or grooved tread; cracked, broken, dented, or gouged plates. Check for overheated wheels, thermal cracks, and loose wheels.			
4.6.1.1	**Flange height/thickness:** Check wheels for worn flanges and correct flange height and thickness.			
4.6.1.2	**Flat spots:** Check wheels for flat spots.			
4.6.1.3	**Rim:** Check wheels for worn tread and thin rim.			
4.6.1.4	**Gage:** Check for out-of-gage and wrong size wheels.			
4.6.1.5	**Diameters:** Check for correct wheel diameter.			
4.6.2	**Axles:** Check axles are not broken, bent or visually cracked; there is no damage 1/8 inch or deeper between wheel seats; there is no damage due to overheated or fused roller bearings.			
SPRINGS AND HYDRAULIC RIDE STABILIZERS (AAR IR 50)				
4.7.1	**Springs:** Check for broken, missing, and out-of-position springs.			
4.7.2	**Hydraulic stabilizers:** Check for broken, missing, and out-of-position hydraulic stabilizers. Check for leaks, oil level and proper installation.			

Storage greater than 6 months – See Section 1.5.3				
4.7.2	**Hydraulic stabilizers:** Check for broken, missing, and out-of-position hydraulic stabilizers. Check for leaks, oil level and proper installation.			
DOORS, PLACARDS AND SAFETY APPLIANCES				
4.8.1	**Doors:** Check railcar doors can be operated for loading and unloading.			
4.8.2	**Markings/placards:** Check for emergency placards and any other special signs. Contact the revenue service testing crew if emergency placards are damaged/missing.			
4.8.3	**Safety appliances:** Check for broken, bent, missing, or excessively worn safety appliances.			
Paragraph Number	**Description**	**Recorded Measurements/Remarks[3]**	**Condition[1,2]**	
			A-End	**B-End**
SECTION 5.0 INSPECTIONS AND MAINTENANCE GUIDELINES SPECIFIC TO ATLAS FLATCARS				
WHEEL/TRUCK ASSEMBLIES				
5.1.1	**Grounding straps:** Check straps are secure. Fasteners are not cracked, broken, or missing. Damage to the braided straps does not exceed 50% of the conductive path.			
5.1.2	**Bearing adapter/Pedestal roof:** Check and record bearing adapter to side frame pedestal roof clearance.	See attached Addendum H		
5.1.3	**Friction wedge rise:** Check rise does not exceed limit.			
SAFETY SYSTEM MONITORING EQUIPMENT (DOE Cognizant Equipment)				
5.2.1	**Wireless sensor:** Check mounting plates are firmly adhered to the side frames. Wireless sensors are firmly secured to the mounting plates. No fasteners are missing. Metal spring arms are in place and in contact with the wheel bearings.			
5.2.2	**Pedestal:** Check pedestal assemblies are firmly secured to the end platforms and the side cover fasteners are in place.			
5.2.3	**Solar power caps:** Check caps are firmly secured, and solar panels are not cracked, broken or missing.			
5.2.4	**Antennae:** Check they are firmly secured.			
5.2.5	**Tamper Indication Seals:** Confirm that the tamper indication features are in place and not broken.			
5.2.6	**Wired Sensor Mounting Plate:** Check mounting plates are secure. Wired sensors are secured to the mounting plates. No fasteners are missing.			
5.2.7	**Conduit/cable:** Check that the cable is not damaged and is firmly secured to the sensor.			
5.2.8	**Clamps:** All clamps that secure the conduit are in place and secure.			
BRAKE CYLINDER PISTON TRAVEL ADJUSTMENT				
5.4	Adjust piston travel, if necessary, per Addendum J (empty or unloaded railcar) or Addendum K (loaded railcar).			

SIGNATURES

(1) Signature of qualified railcar inspector (either user facility qualified inspector or independent qualified inspector – see Section 1.2, 1.3 and 3.1) certifying that the railcar inspections have been performed in accordance with the specified requirements. Check (√) if satisfactory, (X) if discrepant, "NA" if not applicable. Enter measurements in Remarks column.

NAME	QUALIFIED INSPECTOR	DATE

(2) If an independent qualified inspector performs the inspections, the user facility shall verify, based on personal observation, and certify by signature that the action has actually been performed in accordance with the specified requirements (see Section 3.1).

NAME	USER FACILITY (If Required)	DATE

(3) List discrepant conditions separately on the Listing of Railcar Discrepancies.

Signature of railroad representative certifying that the railcar meets the requirements of the Association of American Railroads and is acceptable for use.

NAME	RAILROAD	DATE

Appendix G - One-Time Move (OTM) Authorization

U.S. Department of Transportation
Federal Railroad Administration

District IV

1200 New Jersey Avenue, SE
Washington DC 20590

May 24, 2023

Steven Belport
Principal Investigator II
Engineering Manager – Vehicle/Track Interaction
MxV Rail
350 Keeler Parkway
Pueblo, CO, 81001
+1 719 251 6627

Dear Mr. Belport,

This is in response to your letter dated May 18, 2023, requesting a One-Time Move (OTM) authorization for freight cars IDOX 10001, IDOX 20001, IDOX 20002, and IDOX 30001 for continued testing of prototype equipment.

This request for one-time movement authority (OTM) for the purpose of testing is being filed to perform testing on BNSF lines in Southern Colorado and Northern New Mexico. MxV Rail will utilize 10 instrumented wheel sets (IWS) for the conduct of tests to ascertain the Atlas car's performance to AAR requirements in section 6.3 of the S-2043 standard.

The Federal Railroad Administration will take no exception to this one time move, provided the following conditions are met:

1. All train crews involved in the movement of these cars must be notified in writing of their presence and specific testing parameters. They shall be given a copy of the FRA letter concerning this move, and it shall be maintained in the lead locomotive.

2. The following restrictions must be adhered to as stated in the initial request later:

   Point of origin and final destination, including specific route:
   • Avondale, Colorado to Folsom, New Mexico via La Junta, Colorado and Trinidad, Colorado.
   • Return to Avondale, Colorado via Trinidad, Colorado and Pueblo, Colorado.

Restrictions that should be applied to the movement:
• The 4 test cars are to be kept coupled together for the entire movement.
• Locomotives will be used at each end of the test train.
• A locomotive engineer will be operating at each end of the test train.
• Locomotives used will be AC or newer DC (Dash-9 series equivalent or newer) with extended range dynamic braking.
• A minimum of 19 braking cars will be part of the test train to ensure that more than 85% of the axles are braked.

3. The District 4 & 6 MP&E Specialist must be notified in writing or by email when test cars IDOX 10001, IDOX 20002, IDOX 20002, and IDOX 3001 reach their destination at the end of testing. The District 4 & 6 MP&E Specialist must be notified if any accident or incident occurs during the movement of the subject cars.

4. The movement of this equipment is at the risk of the railroads performing the move. The granting this OTM does not relieve the railroads from liability in a proceeding to recover damages for death or injury of a railroad employee or anyone else arising from the movement of this equipment.

Any questions regarding this letter may be directed to Mr. Mick Lodge, MP&E Specialist at cell 312-343-1280, or email michael.lodge@dot.gov.

Sincerely,

MP & E Specialist

Motive Power & Equipment

Appendix H - Ride Quality Plots

Ride Quality

This appendix shows all the plots that were made for each of the ride quality tests conducted on the REV. The ride quality test plots include the comfort level and RMS or MTVV value based on the crest factor threshold for each location, track, and configuration combination.

1.1 FRA Class 2. Mainline from north gate to south gate at PCD

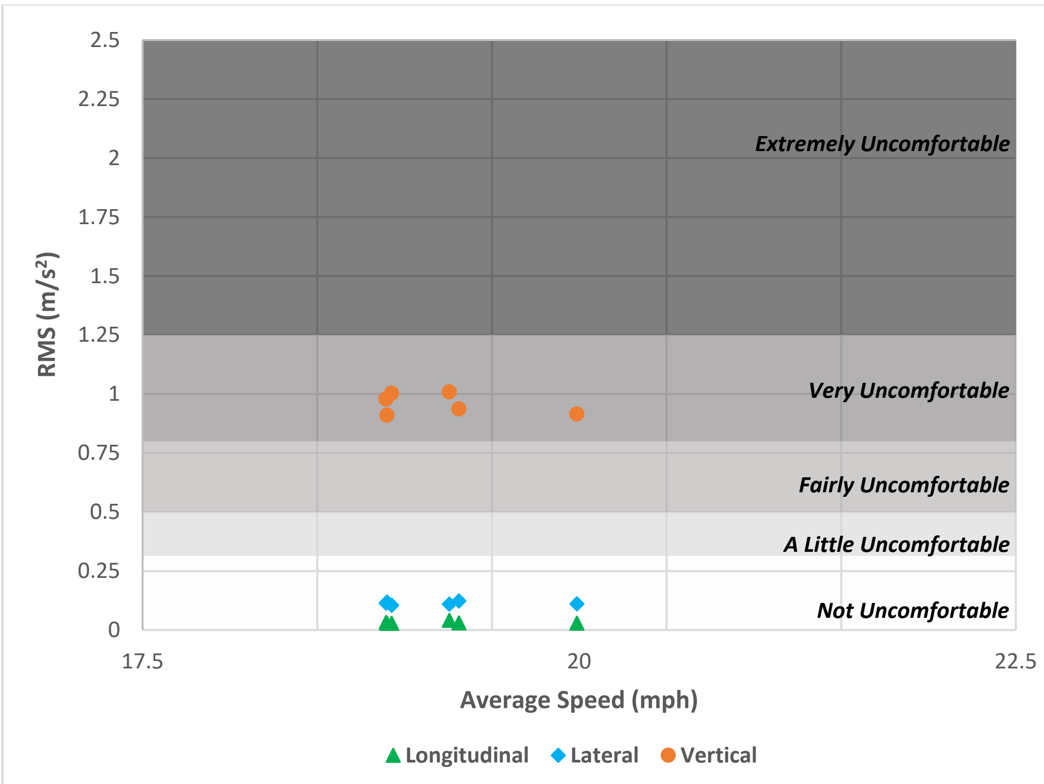

Figure 1. A-End Carbody Comfort – Class 2 Track (PCD)

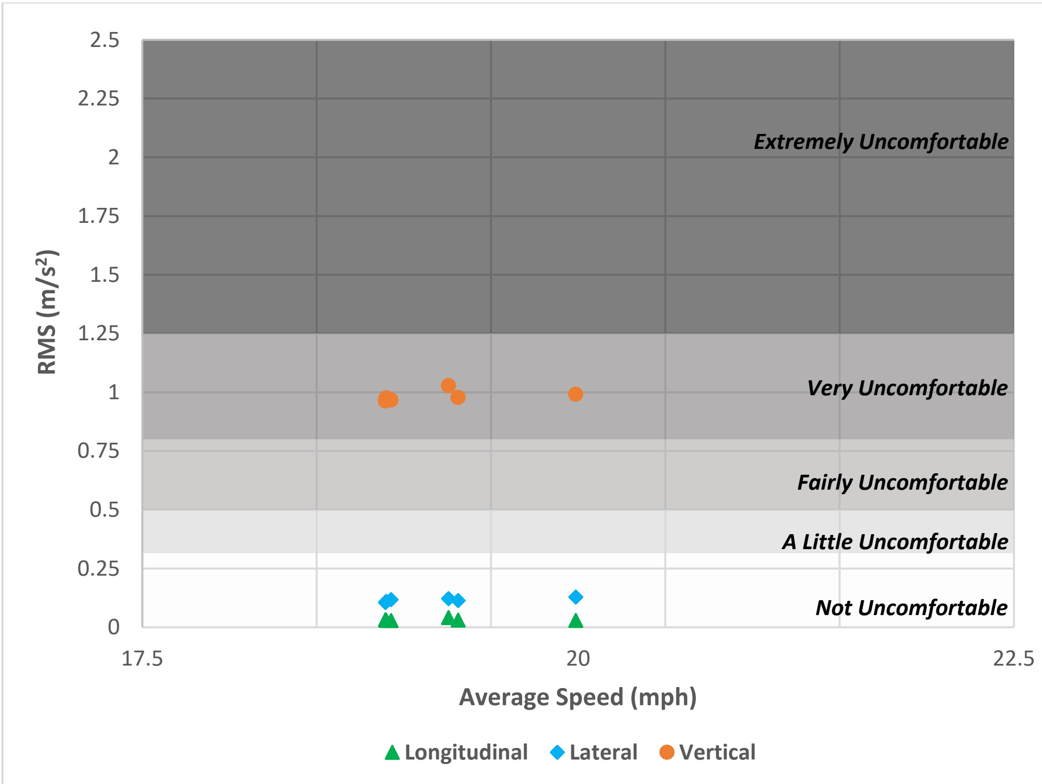

Figure 2. B-End Carbody Comfort – Class 2 Track (PCD)

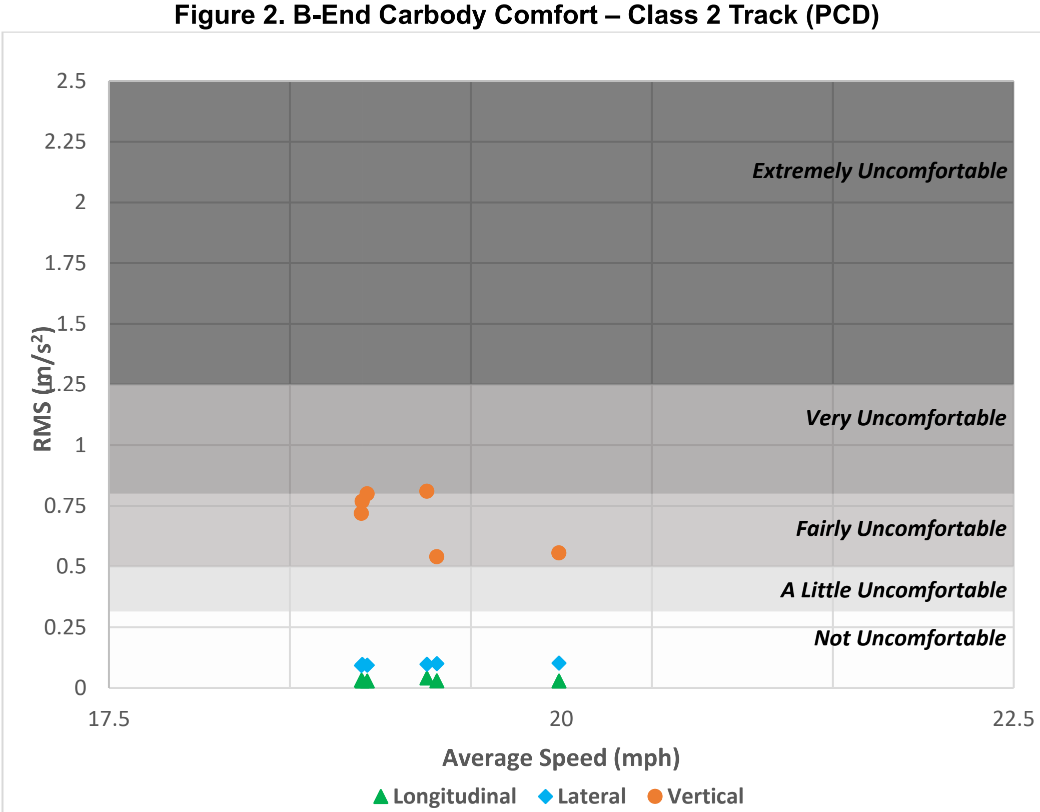

Figure 3. Center Carbody Comfort – Class 2 Track (PCD)

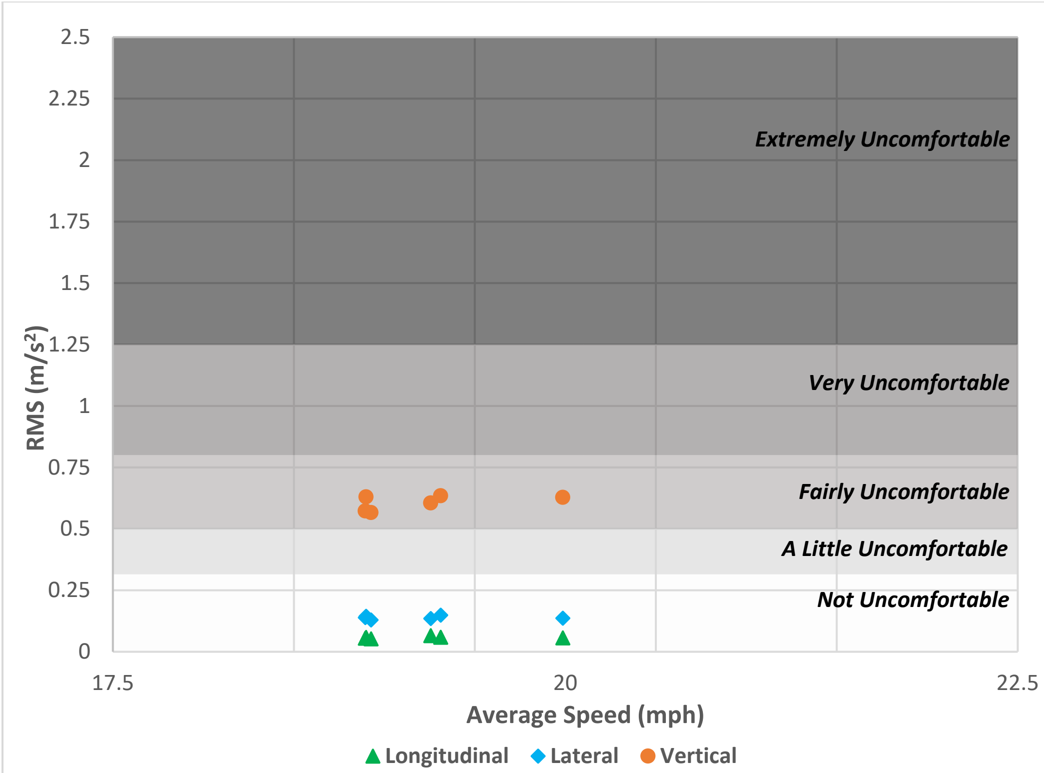

Figure 4. Galley Seat Comfort – Class 2 Track (PCD)

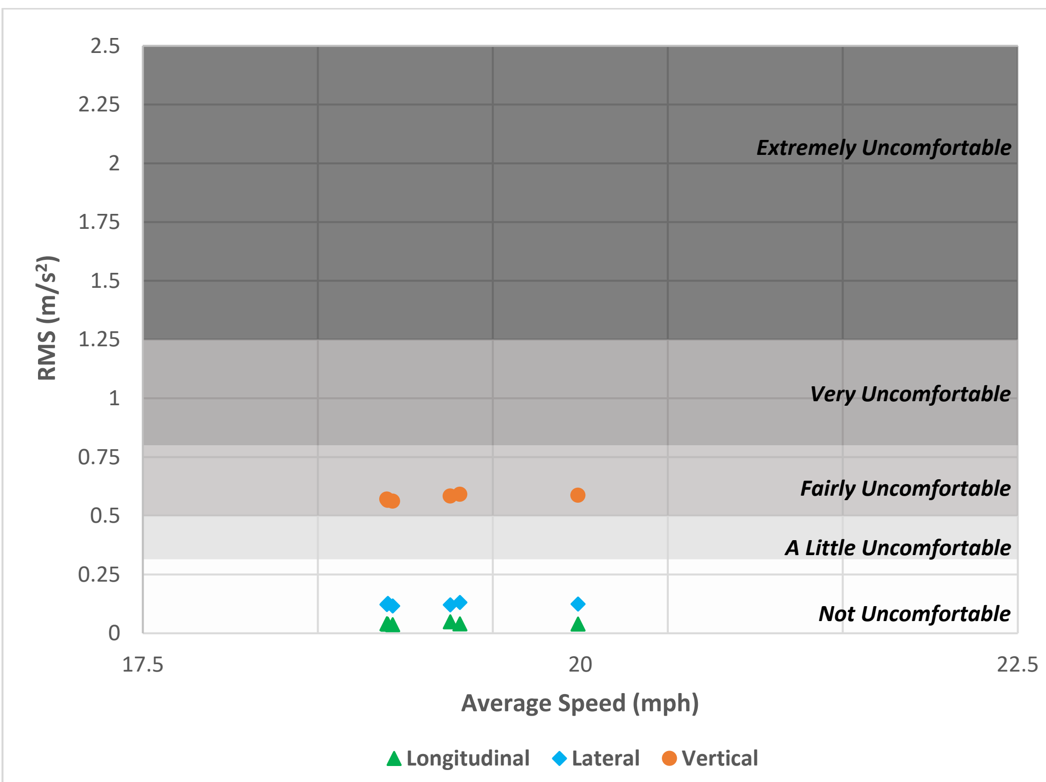

Figure 5. Lower Bed Comfort – Class 2 Track (PCD)

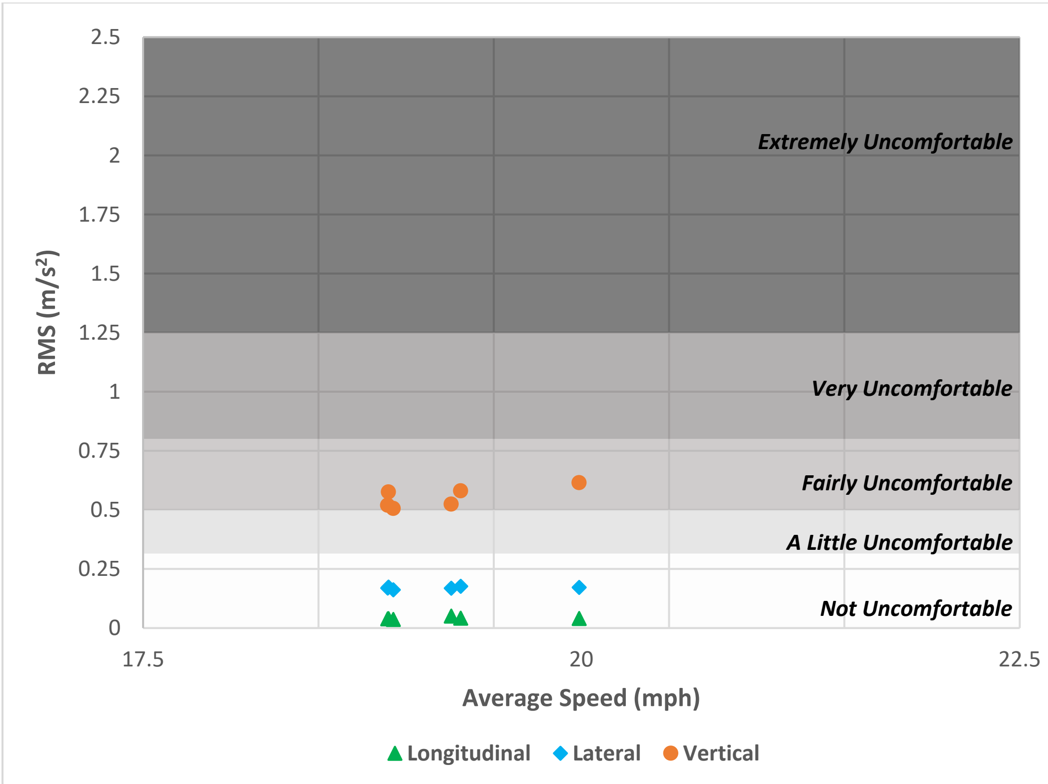

Figure 6. Upper Bed Comfort – Class 2 Track (PCD)

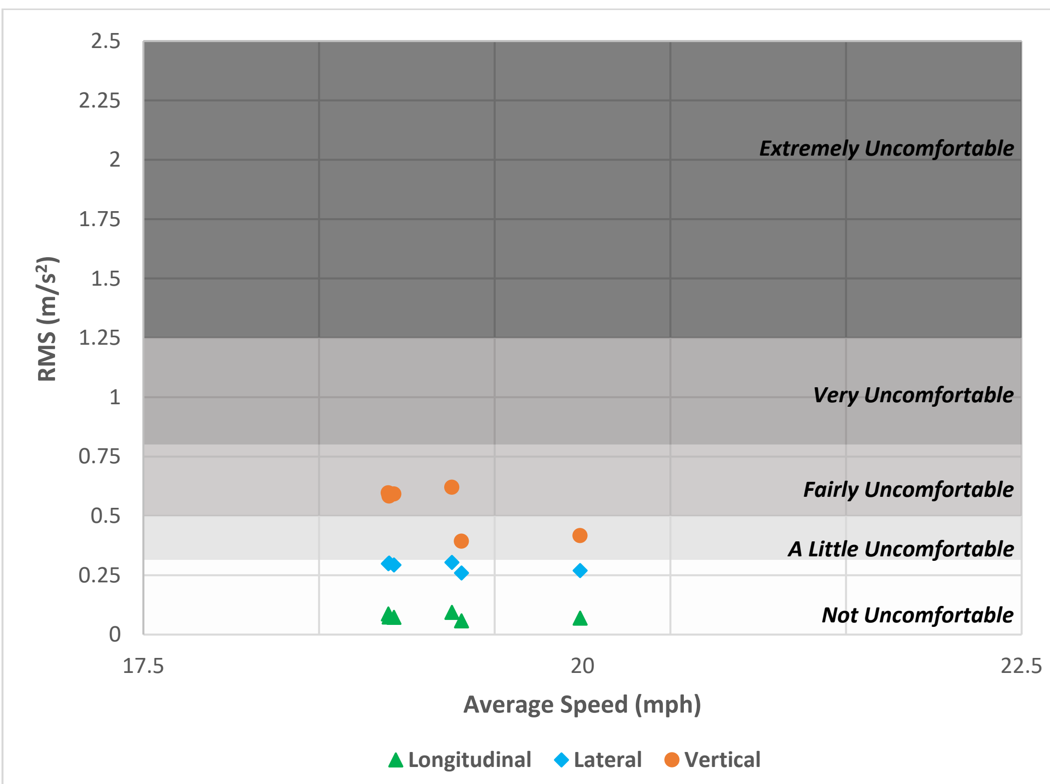

Figure 7. Left UOL Chair Comfort – Class 2 Track (PCD)

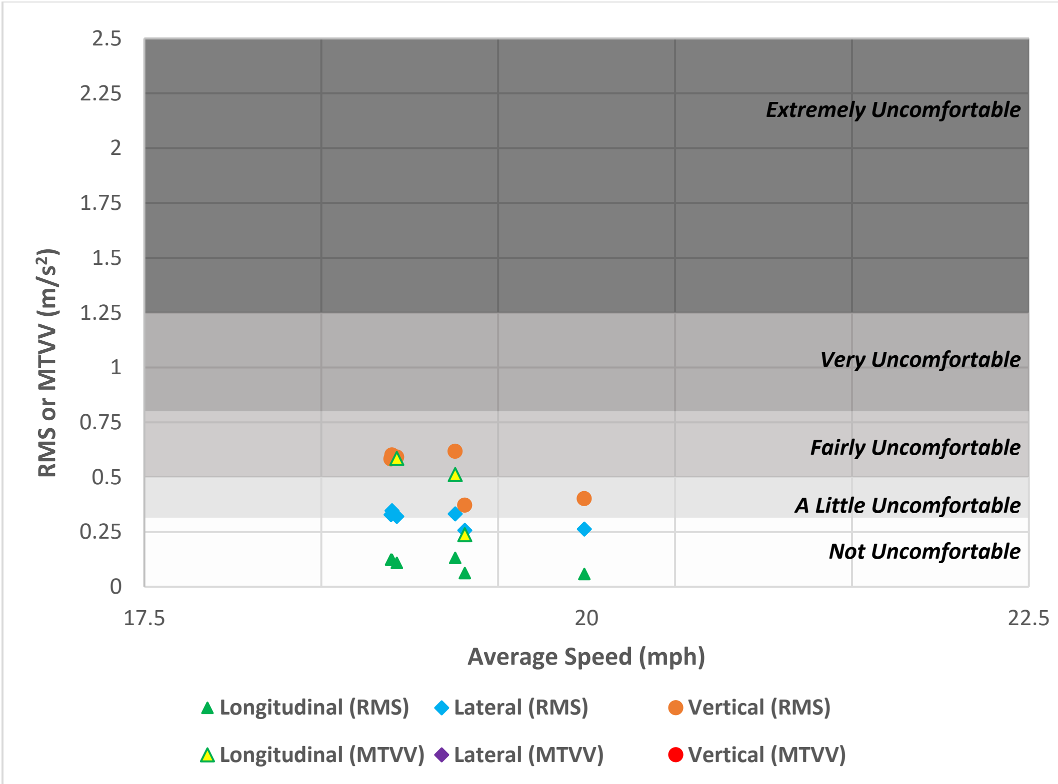

Figure 8. Right UOL Chair Comfort – Class 2 Track (PCD)

1.2 FRA Class 3. BNSF Raton Sub from Trinidad to Folsom

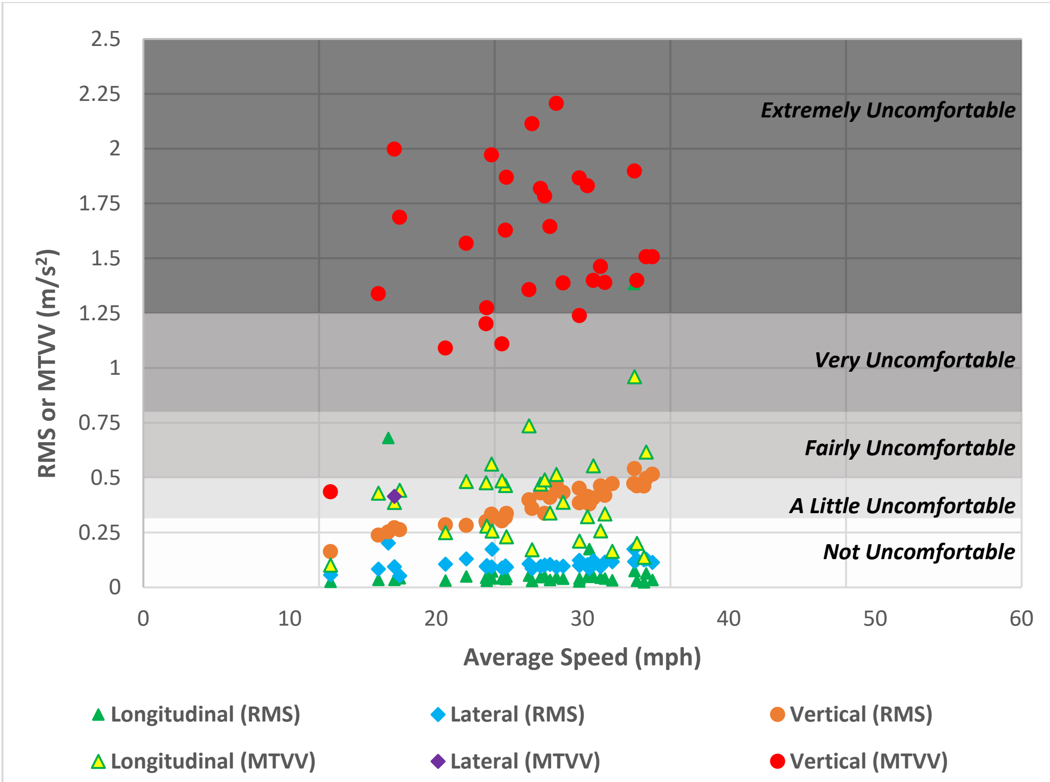

Figure 9. A-End Carbody Comfort – Class 3 Track (BNSF)

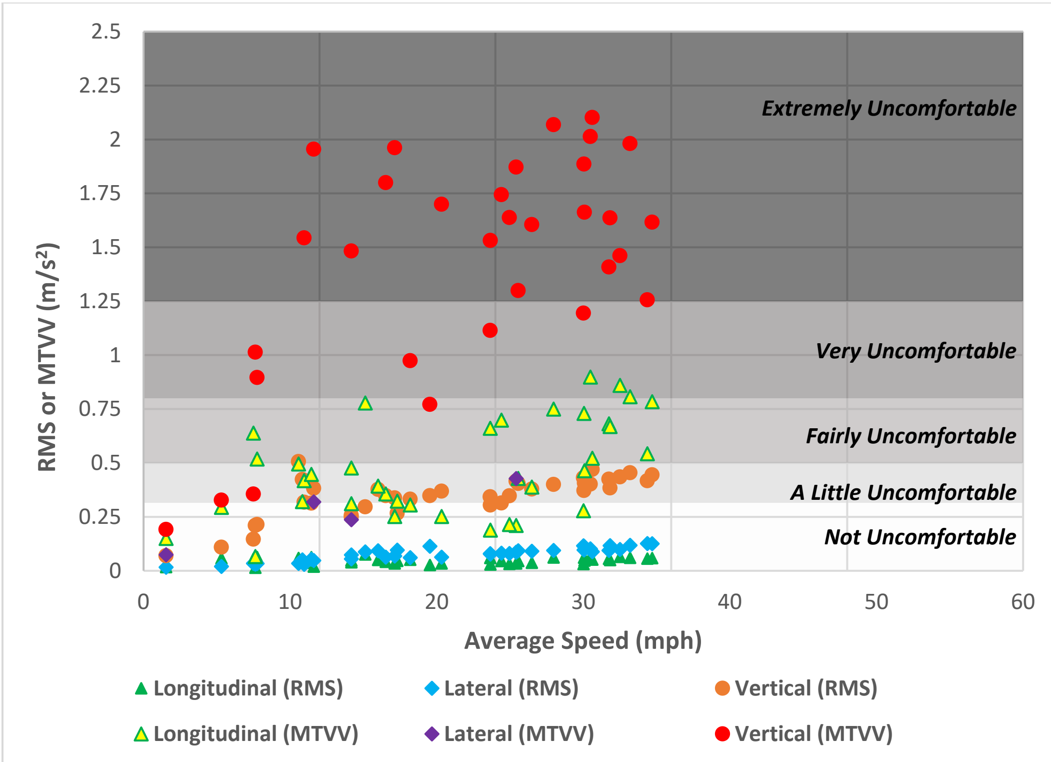

Figure 10. B-End Carbody Comfort – Class 3 Track (BNSF)

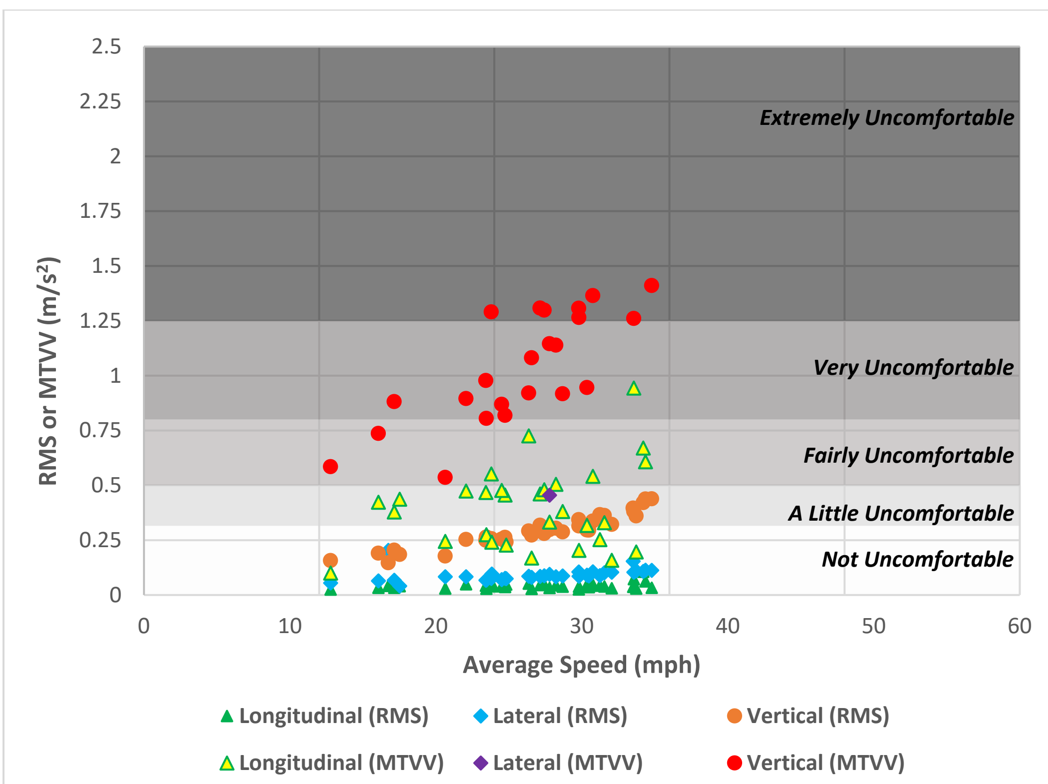

Figure 11. Center Carbody Comfort – Class 3 Track (BNSF)

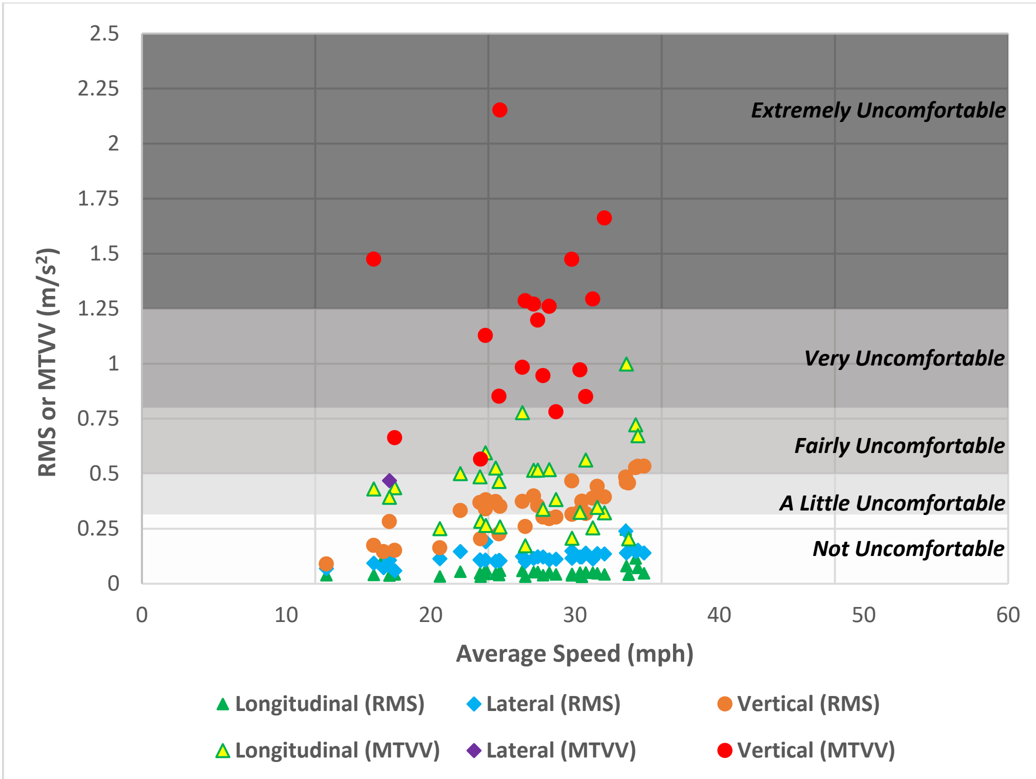

Figure 12. Galley Seat Comfort – Class 3 Track (BNSF)

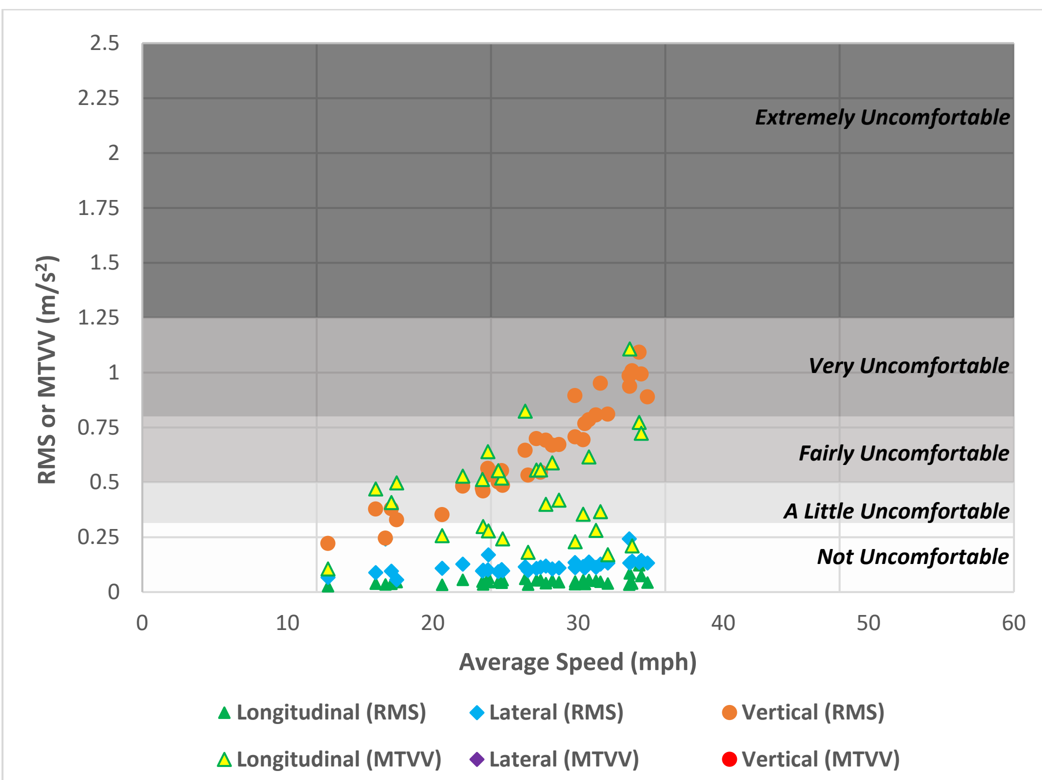

Figure 13. Lower Bed Comfort – Class 3 Track (BNSF)

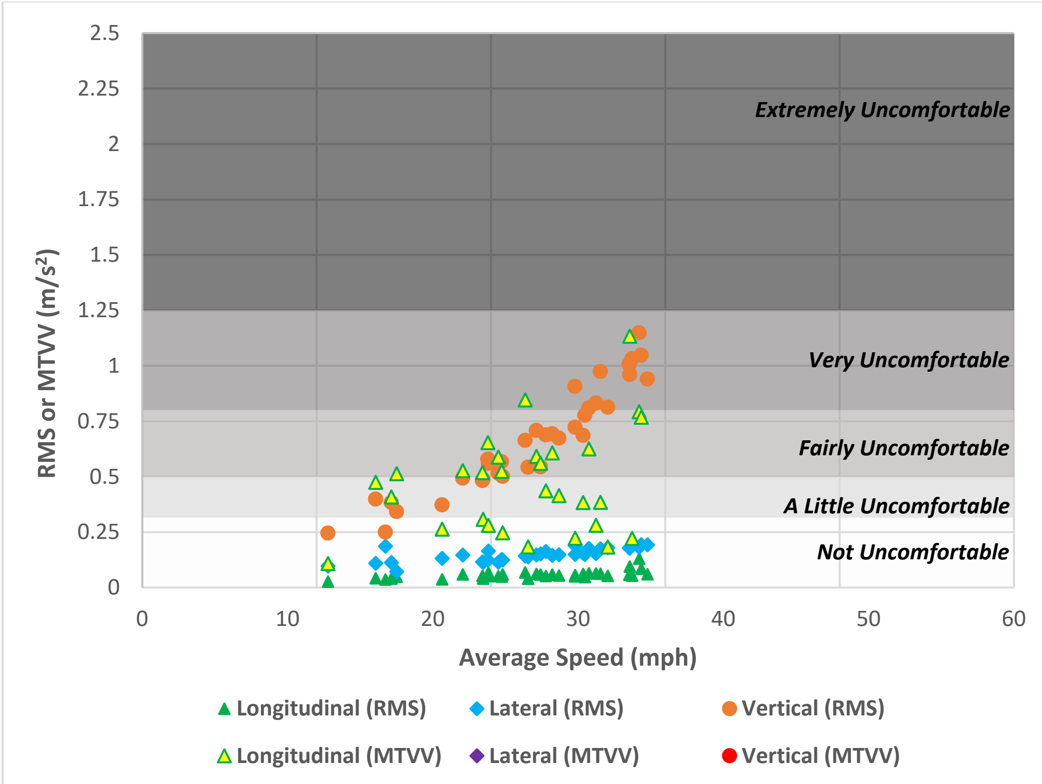

Figure 14. Upper Bed Comfort – Class 3 Track (BNSF)

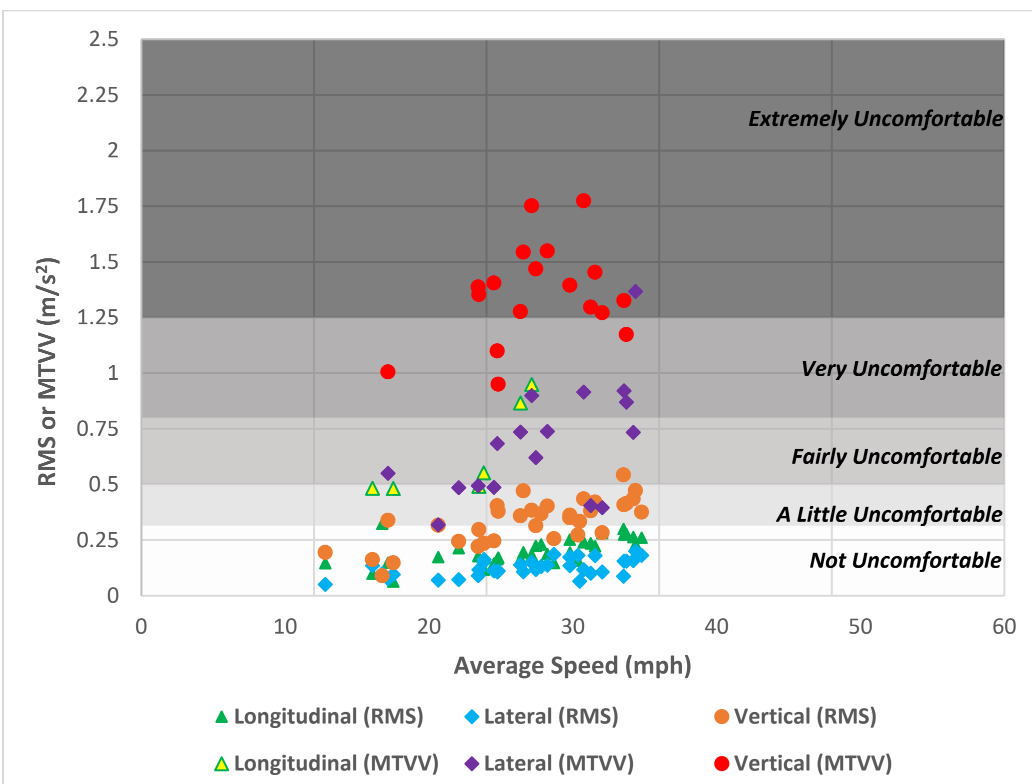

Figure 15. Left UOL Chair Comfort – Class 3 Track (BNSF)

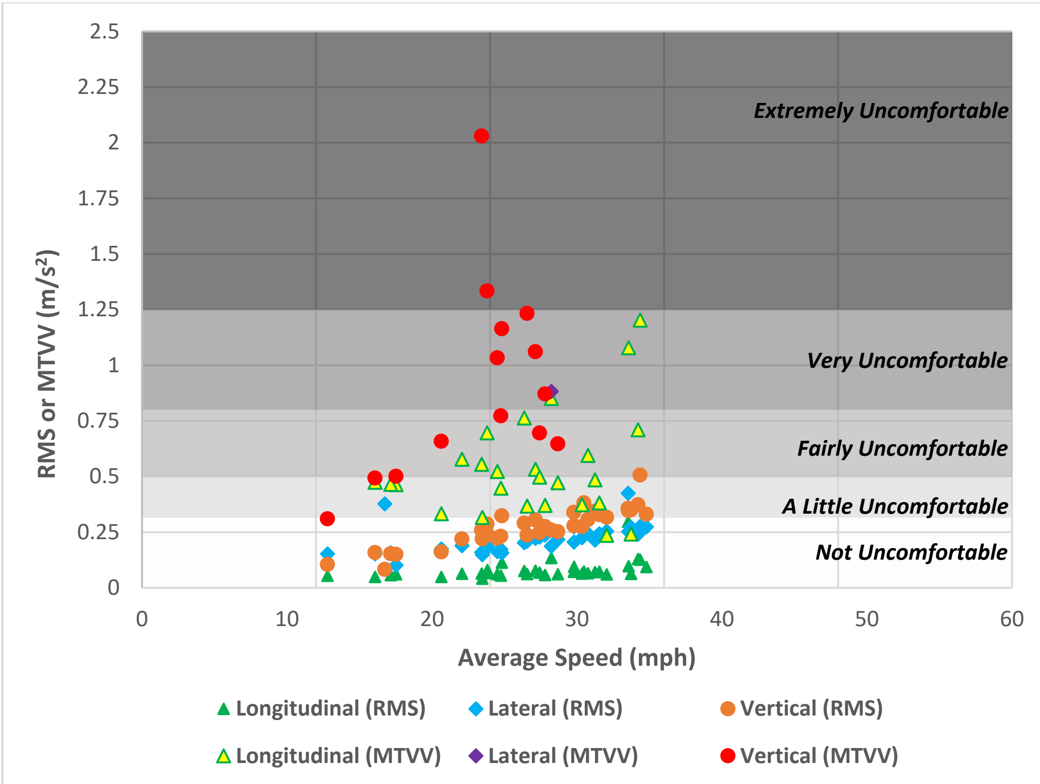

Figure 16. Right UOL Chair Comfort – Class 3 Track (BNSF)

1.3 FRA Class 4. BNSF Pueblo Subdivision from Avondale to La Junta and BNSF Raton Subdivision from La Junta to Trinidad

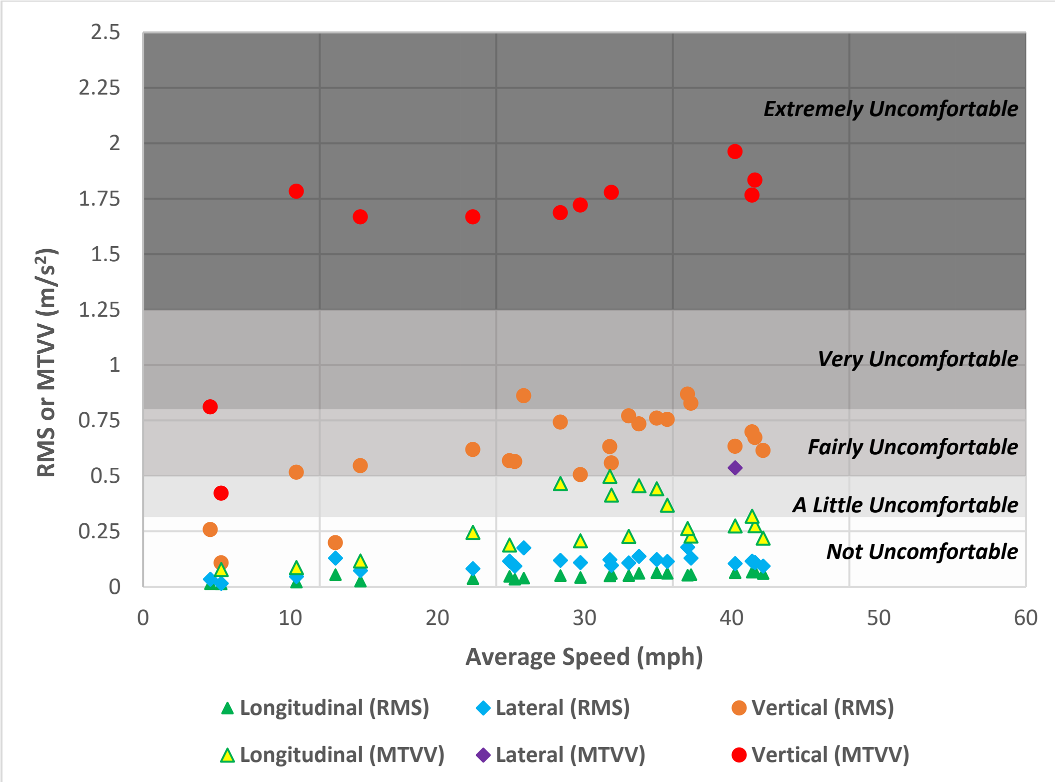

Figure 17. A-End Carbody Comfort – Class 4 Track (BNSF)

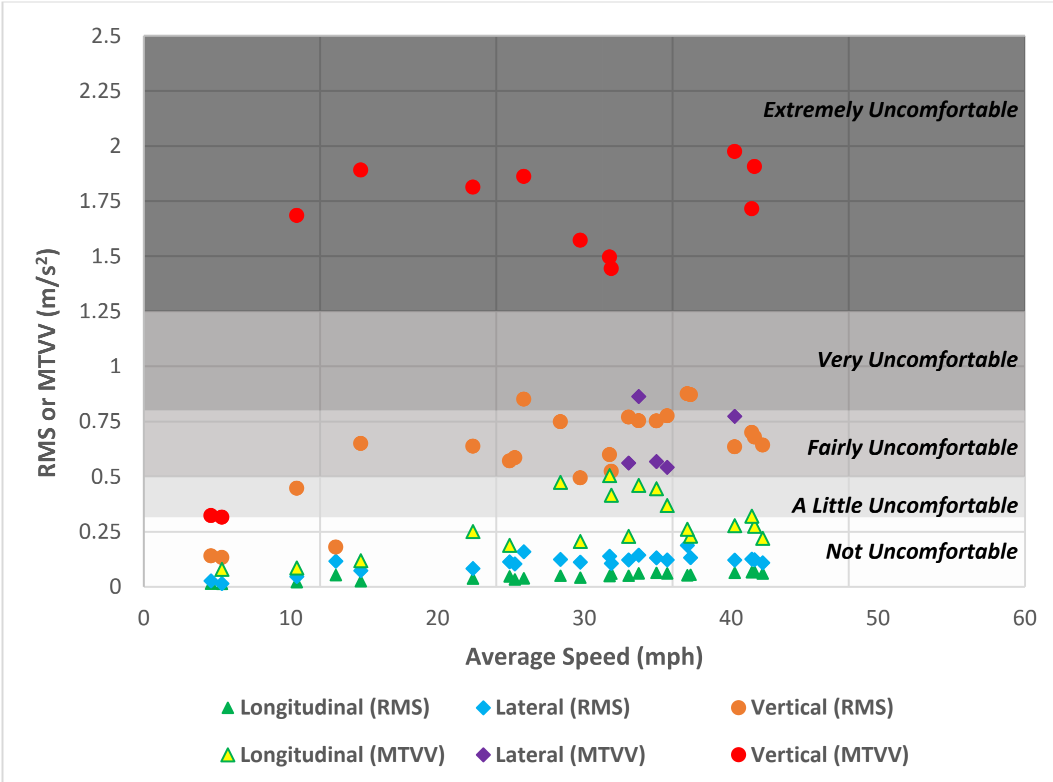

Figure 18. B-End Carbody Comfort – Class 4 Track (BNSF)

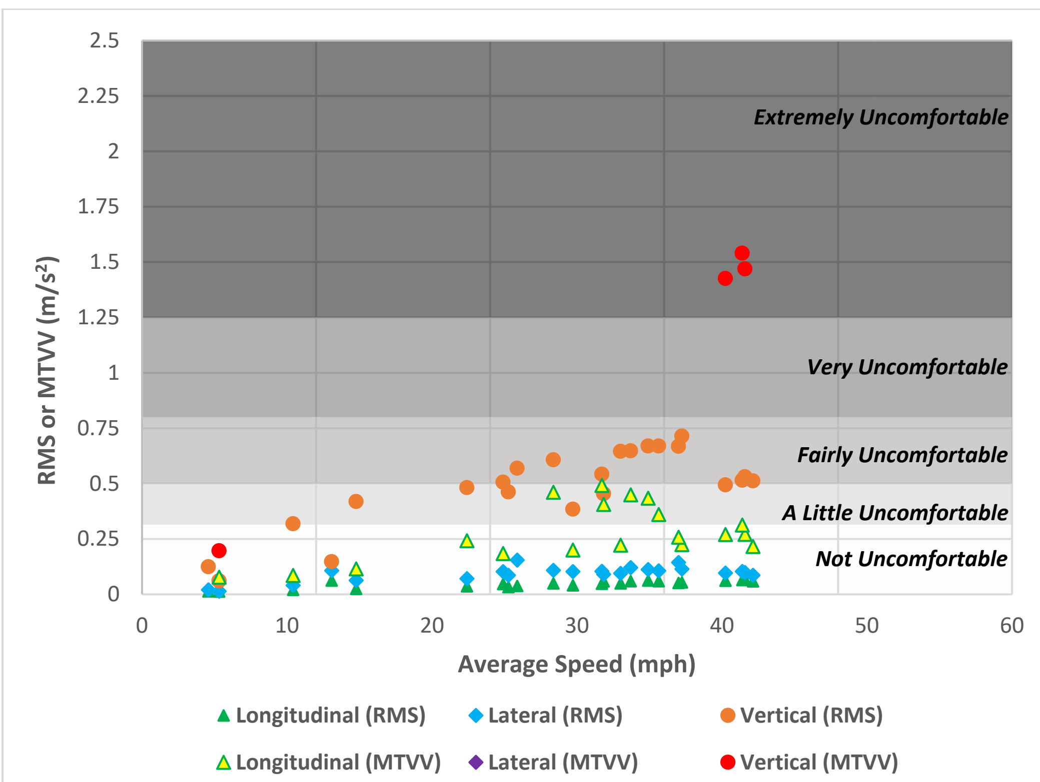

Figure 19. Center Carbody Comfort – Class 4 Track (BNSF)

Figure 20. Galley Seat Comfort – Class 4 Track (BNSF)

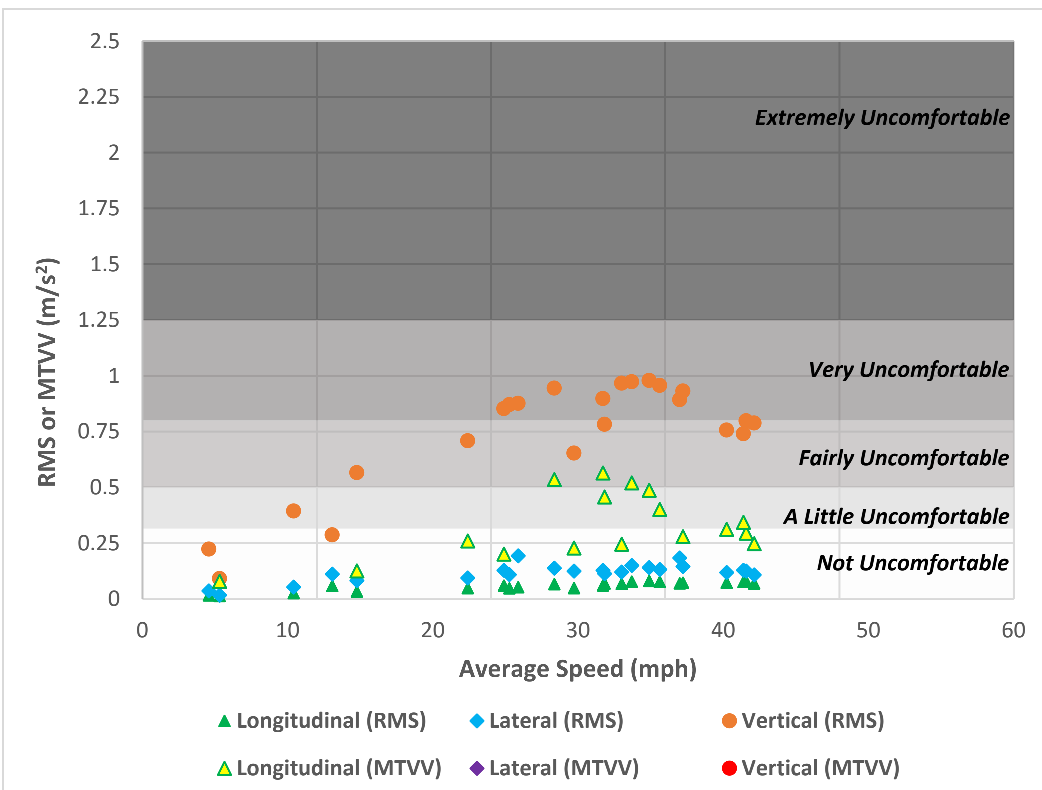

Figure 21. Lower Bed Comfort – Class 4 Track (BNSF)

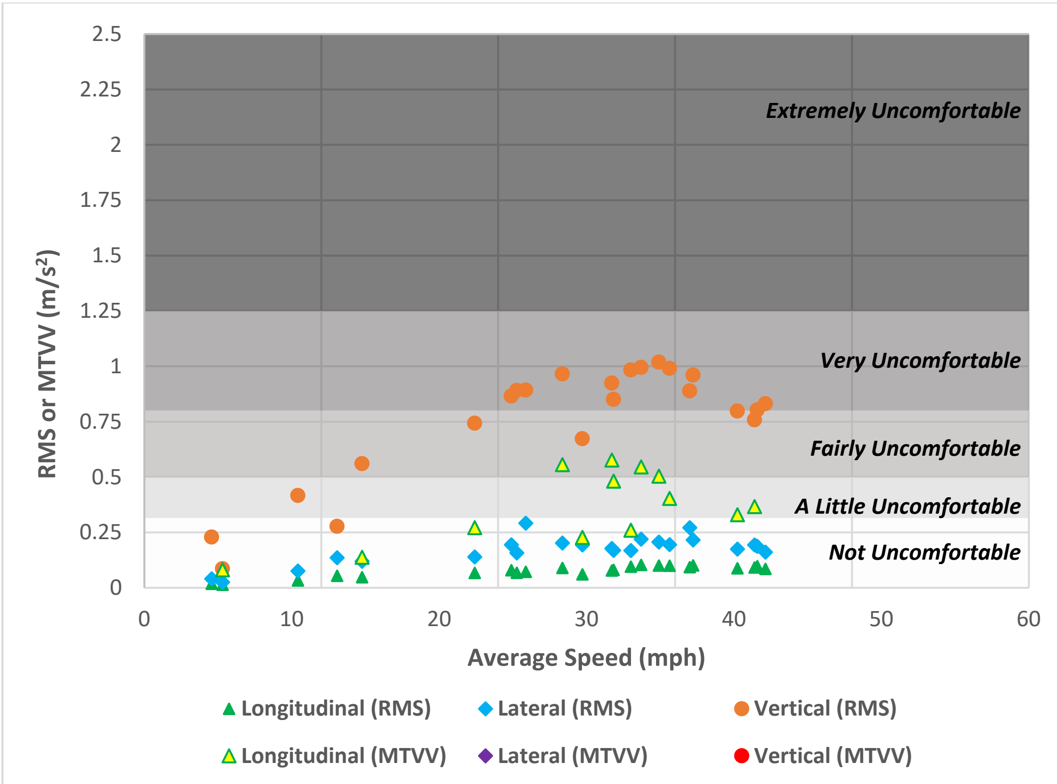

Figure 22. Upper Bed Comfort – Class 4 Track (BNSF)

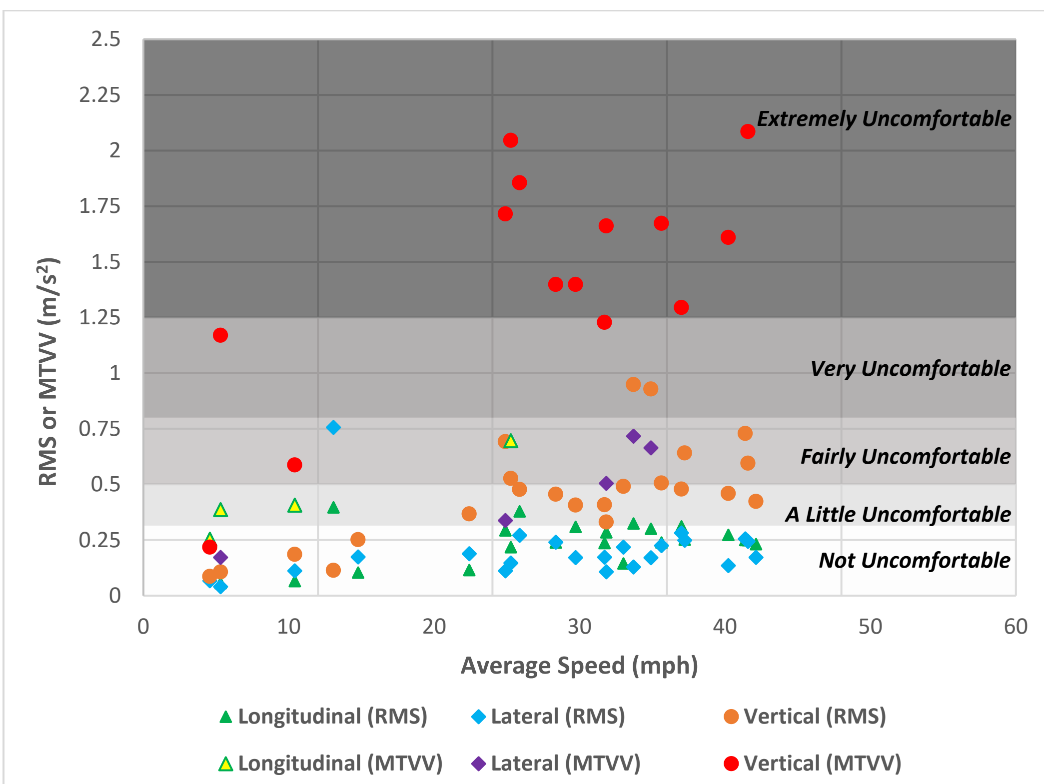

Figure 23. Left UOL Chair Comfort – Class 4 Track (BNSF)

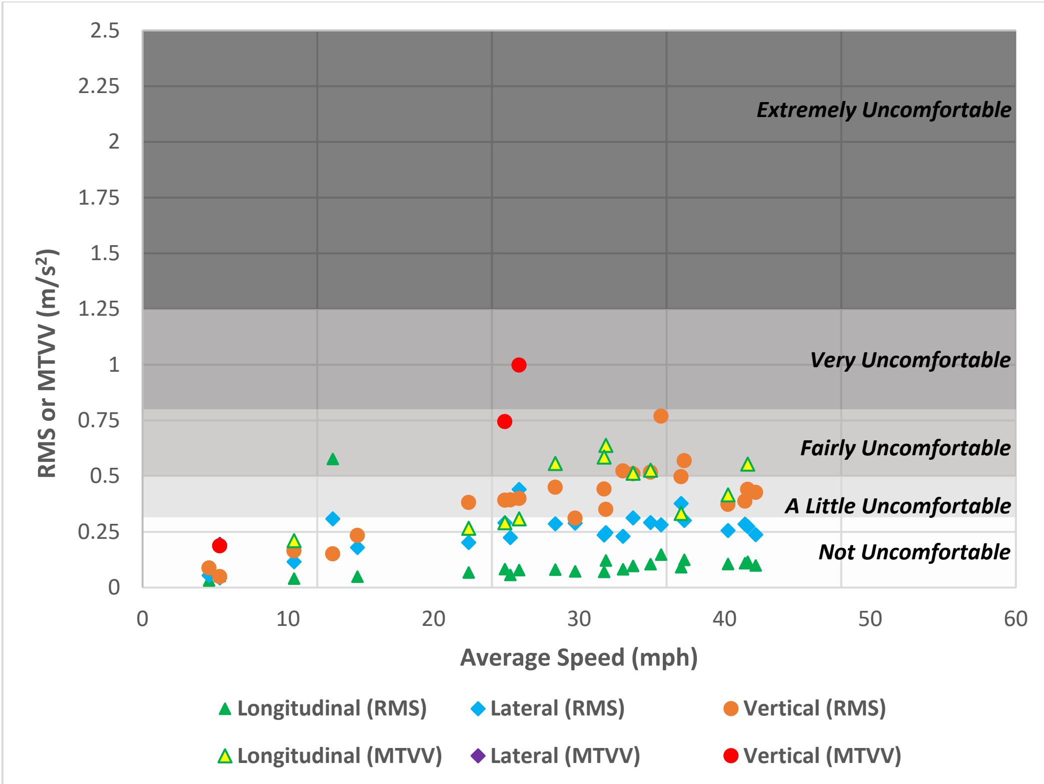

Figure 24. Right UOL Chair Comfort – Class 4 Track (BNSF)

1.4 FRA Class 5. Transit Test Track (TTT) at TTC

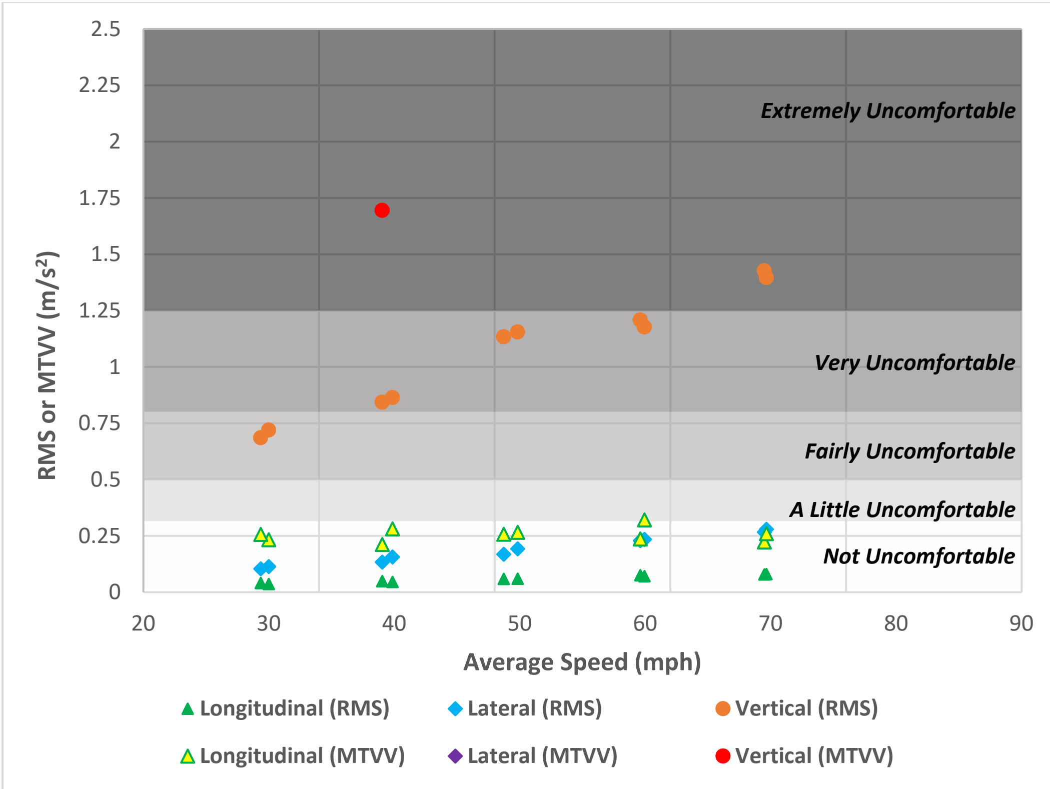

Figure 25. A-End Carbody Comfort – Class 5 Track (TTT)

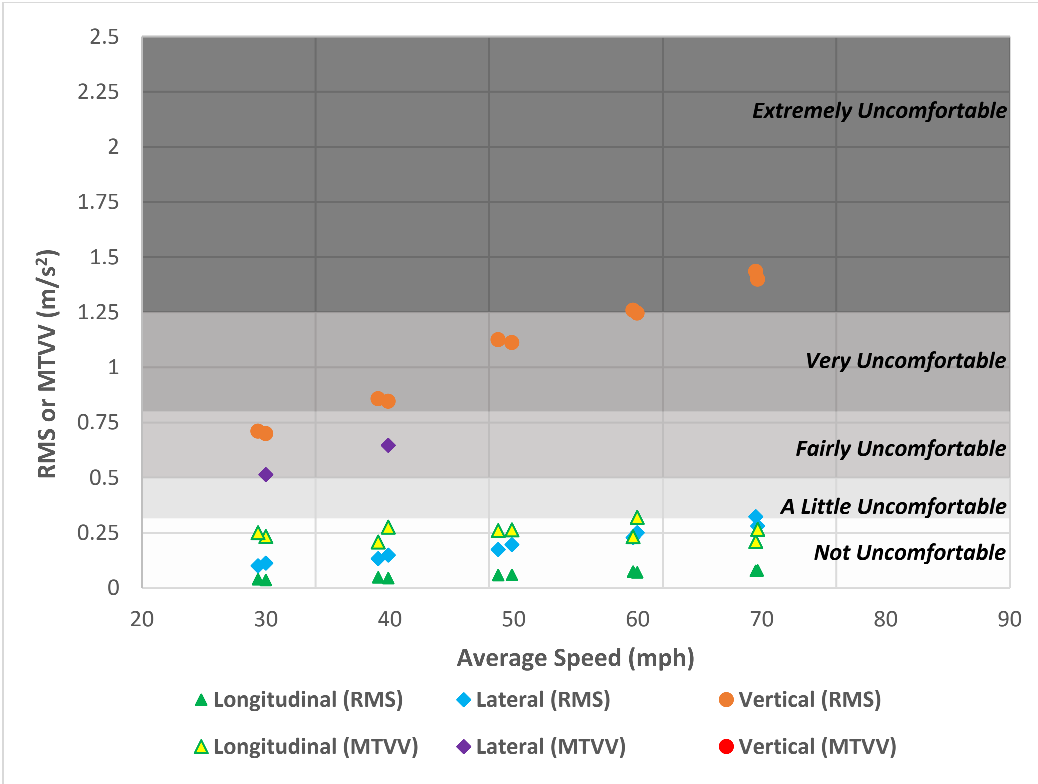

Figure 26. B-End Carbody Comfort – Class 5 Track (TTT)

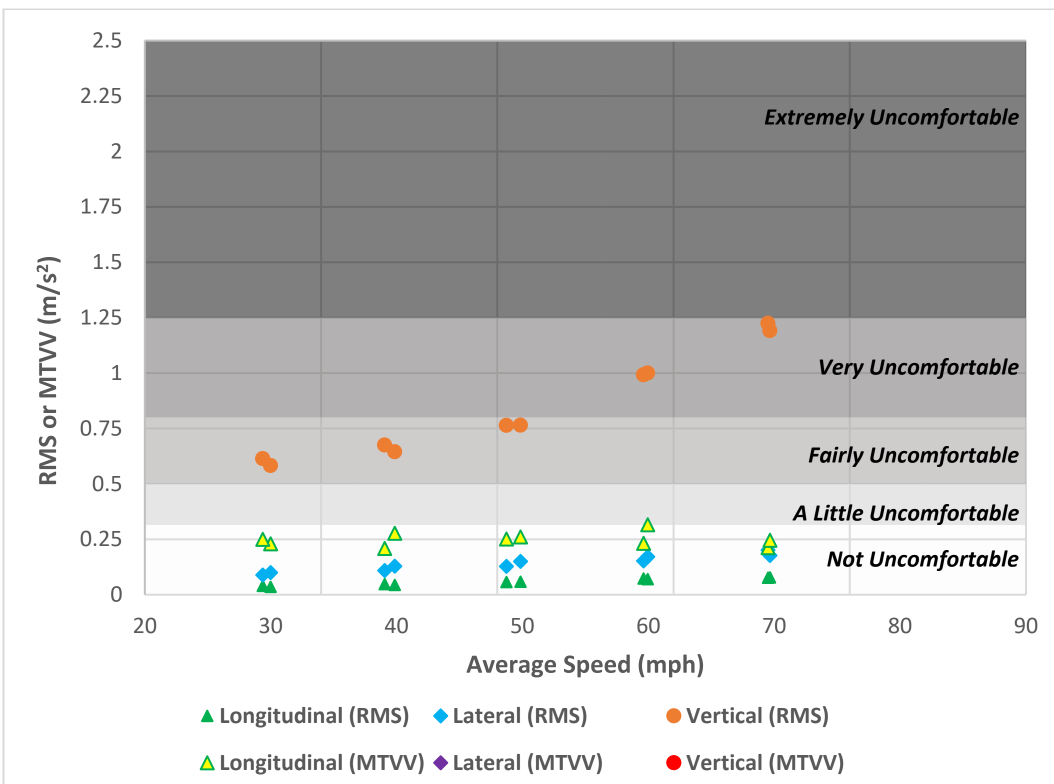

Figure 27. Center Carbody Comfort – Class 5 Track (TTT)

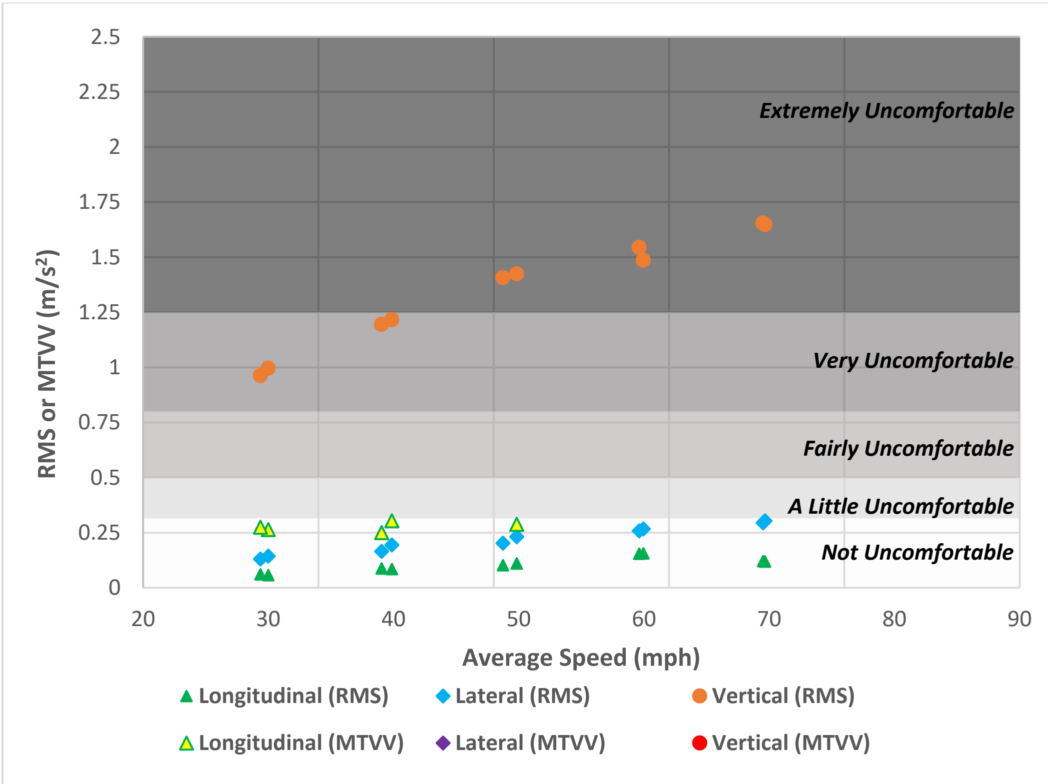

Figure 28. Galley Seat Comfort – Class 5 Track (TTT)

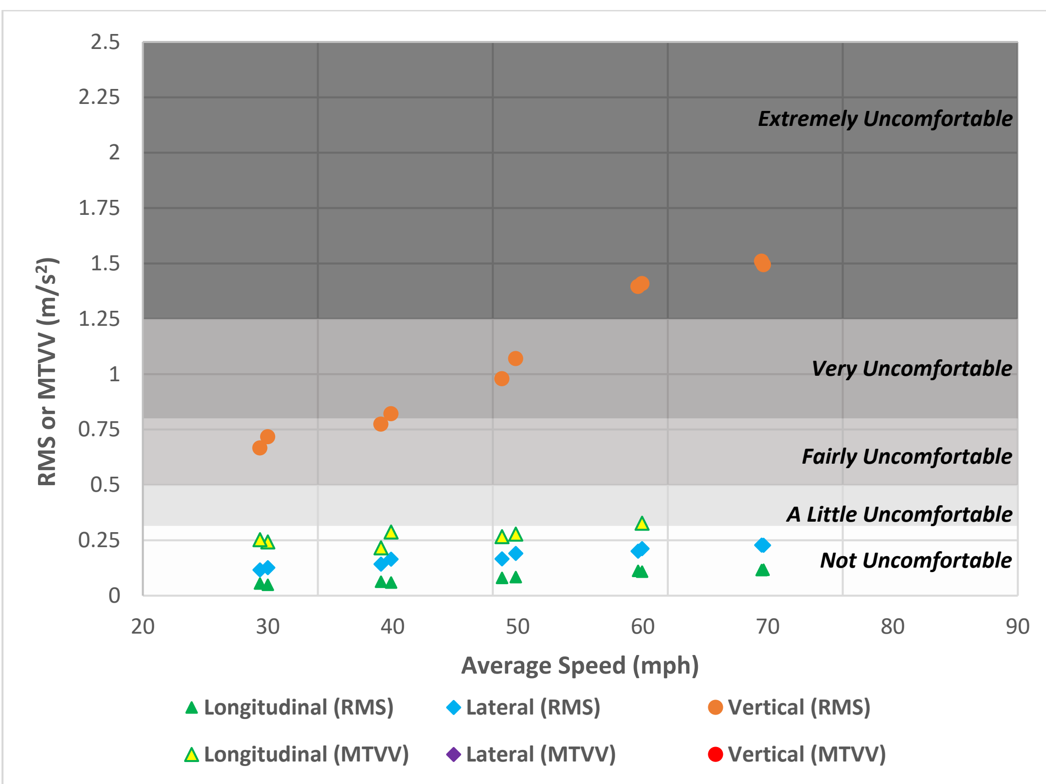

Figure 29. Lower Bed Comfort – Class 5 Track (TTT)

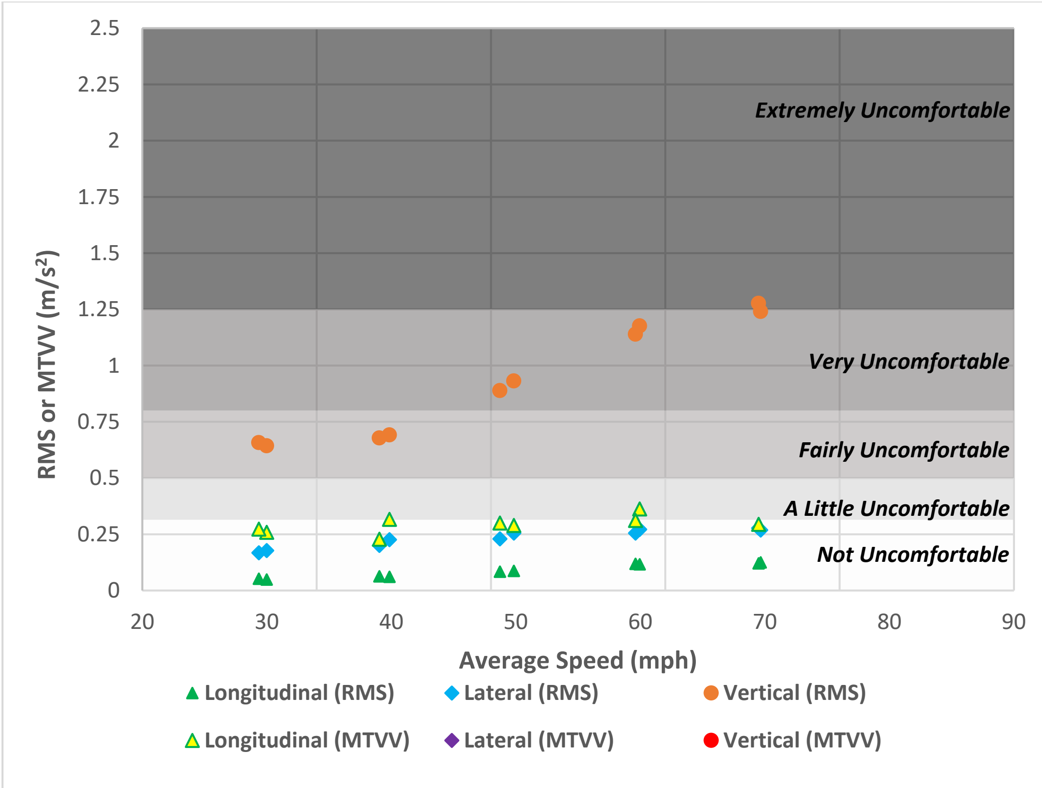

Figure 30. Upper Bed Comfort – Class 5 Track (TTT)

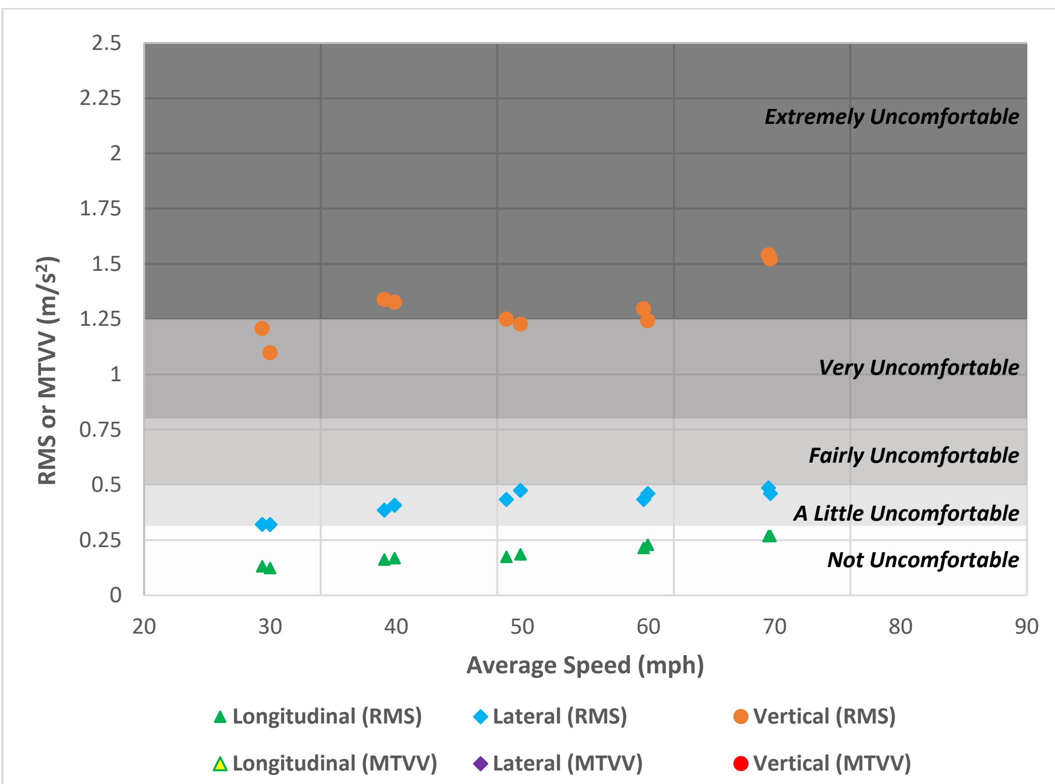

Figure 31. Left UOL Chair Comfort – Class 5 Track (TTT)

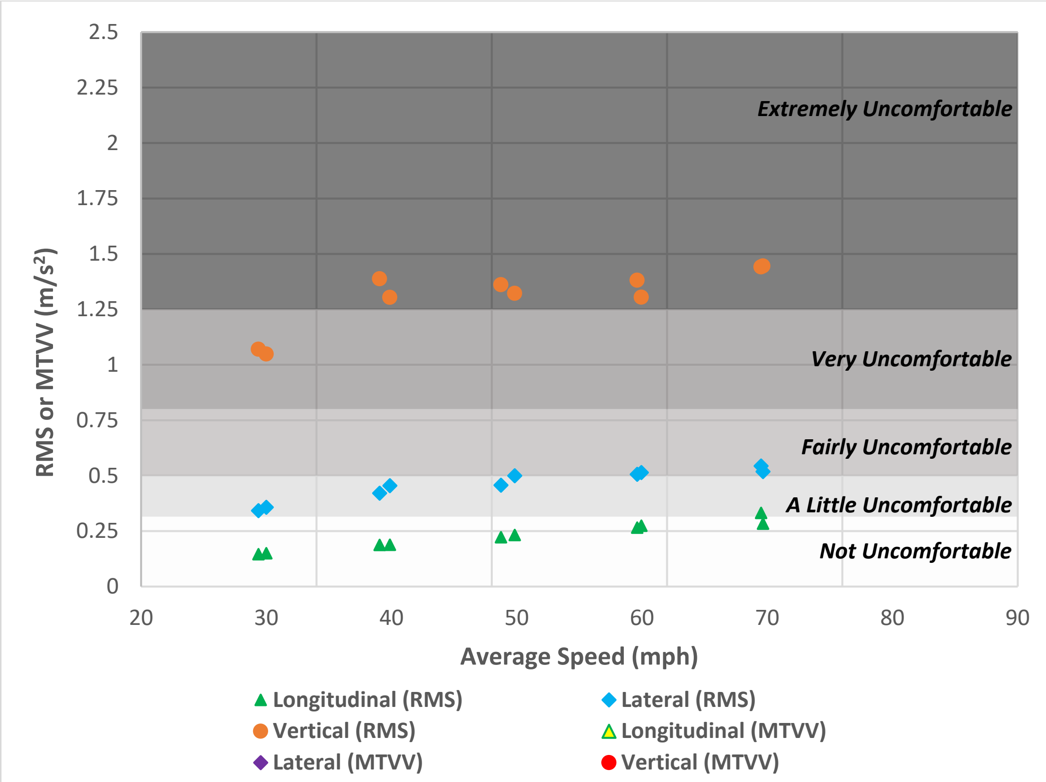

Figure 32. Right UOL Chair Comfort – Class 5 Track (TTT)

1.6 FRA Class 6. Precision Test Track (PTT) at TTC

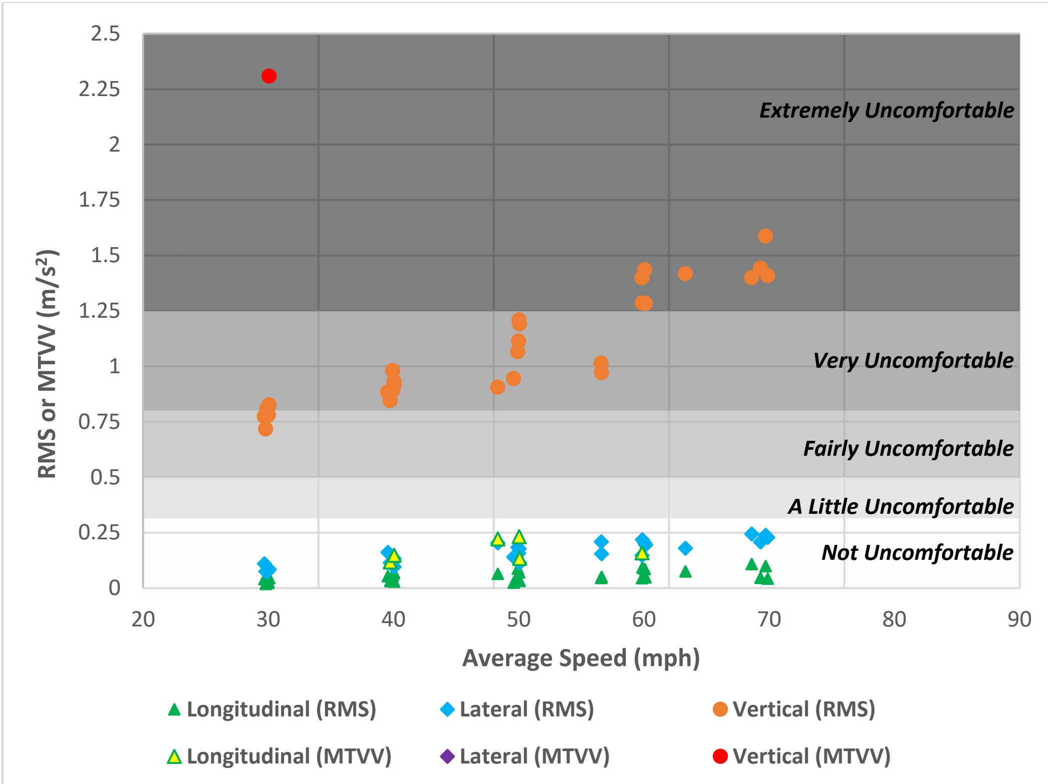

Figure 33. A-End Carbody Comfort – Class 6 Track (PTT)

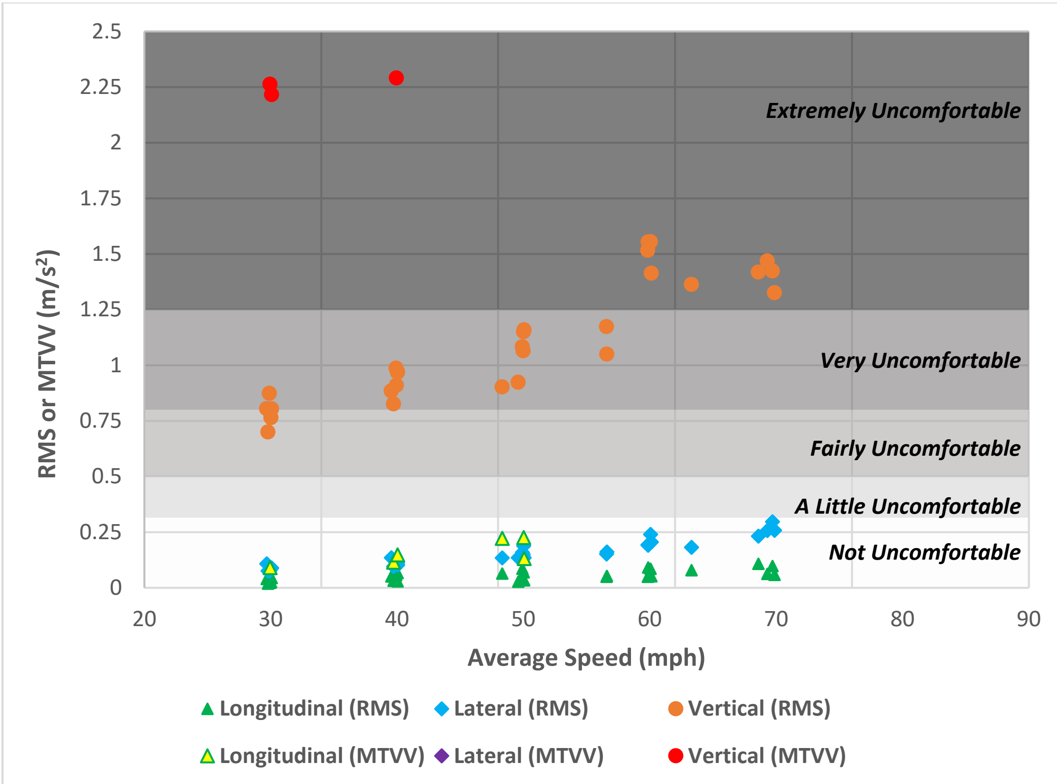

Figure 34. B-End Carbody Comfort – Class 6 Track (PTT)

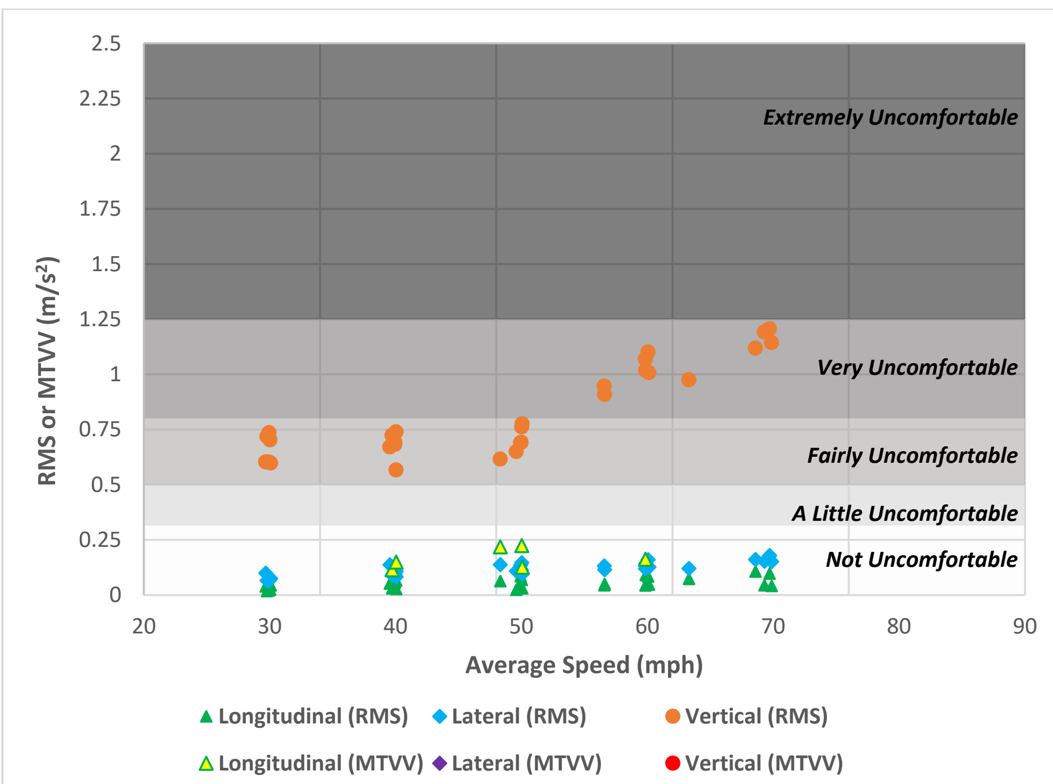

Figure 35. Center Carbody Comfort – Class 6 Track (PTT)

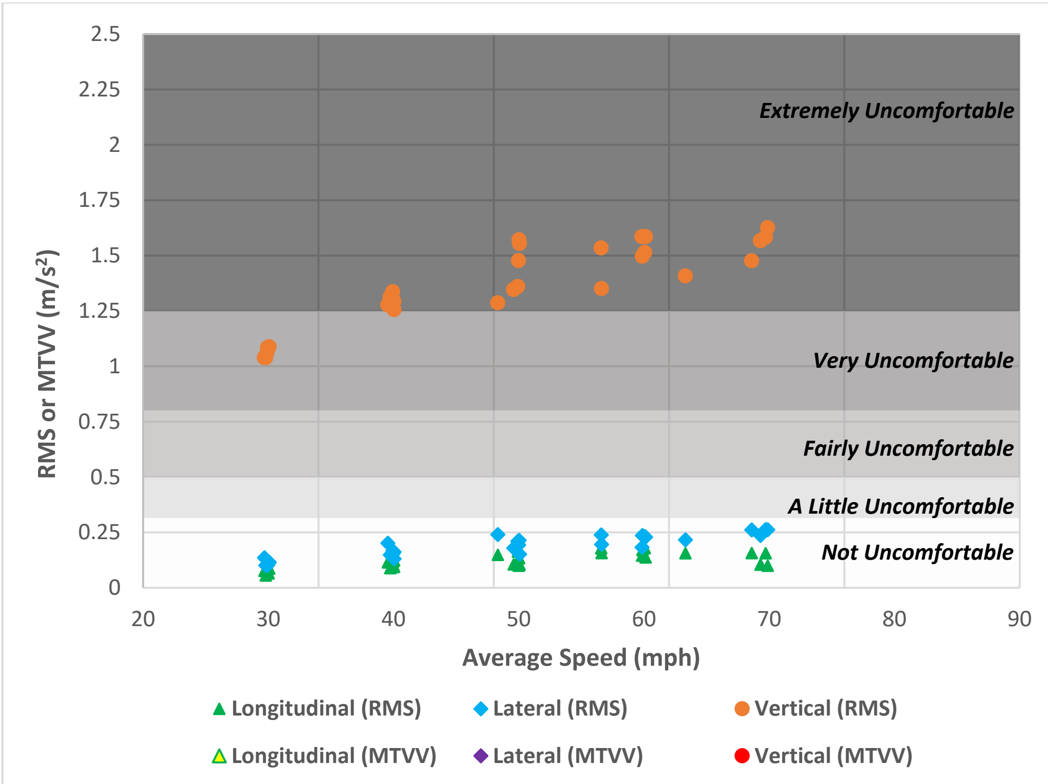

Figure 36. Galley Seat Comfort – Class 6 Track (PTT)

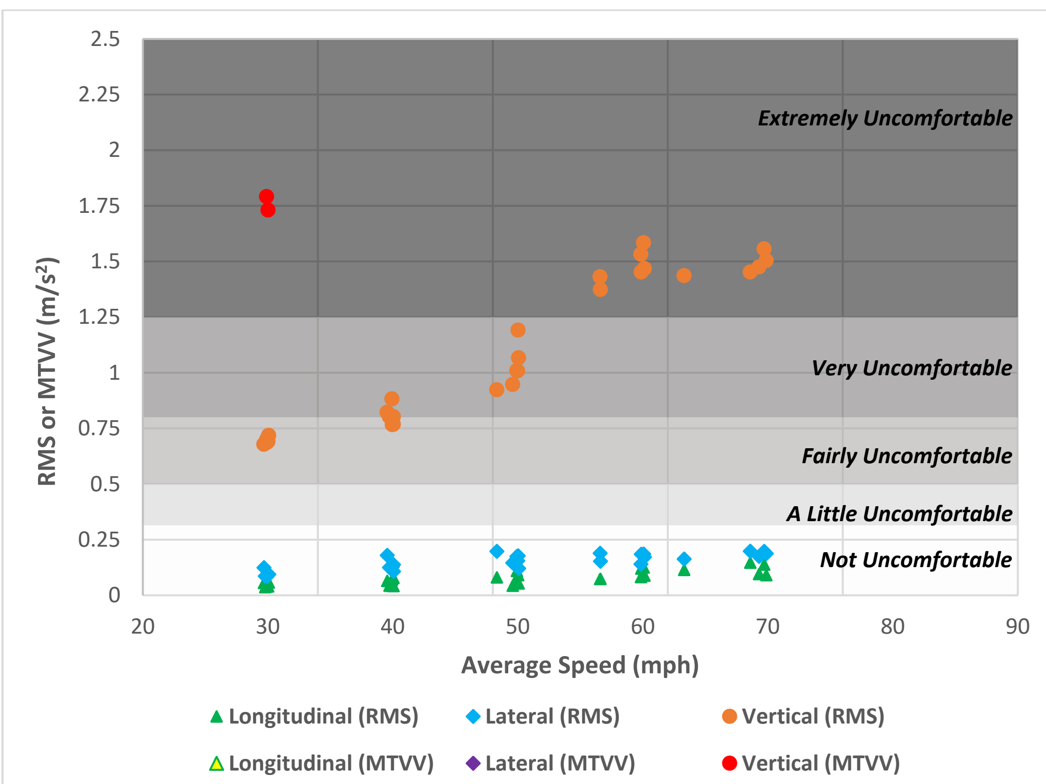

Figure 37. Lower Bed Comfort – Class 6 Track (PTT)

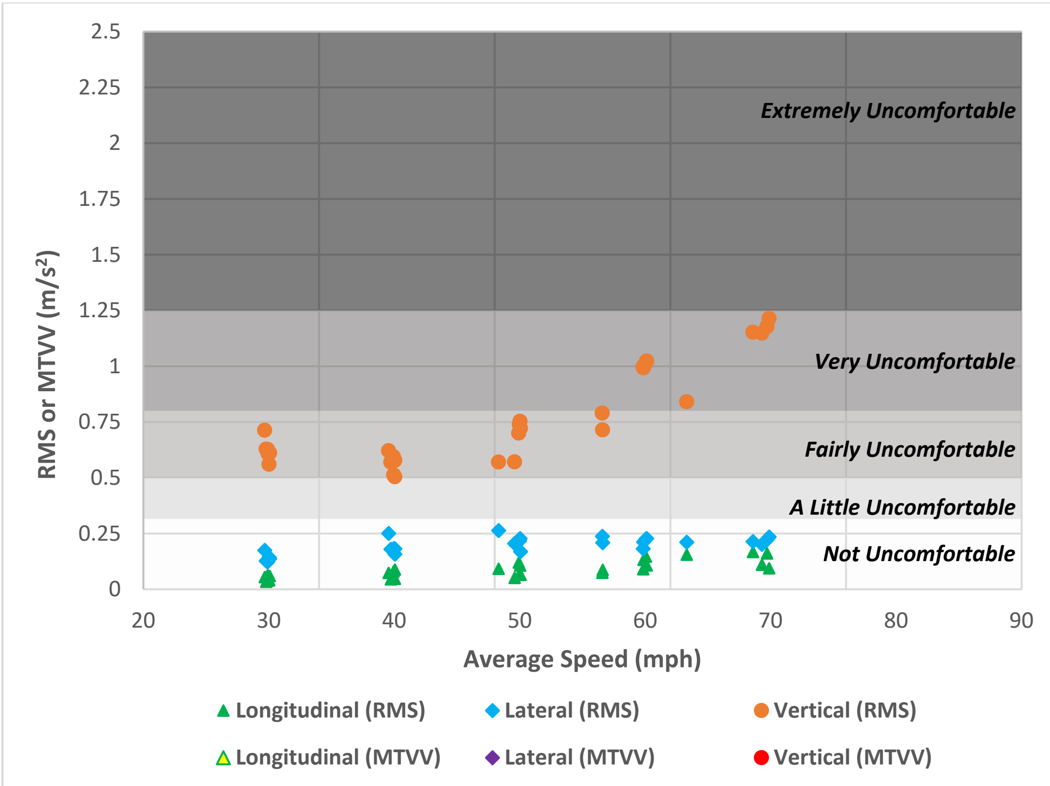

Figure 38. Upper Bed Comfort – Class 6 Track (PTT)

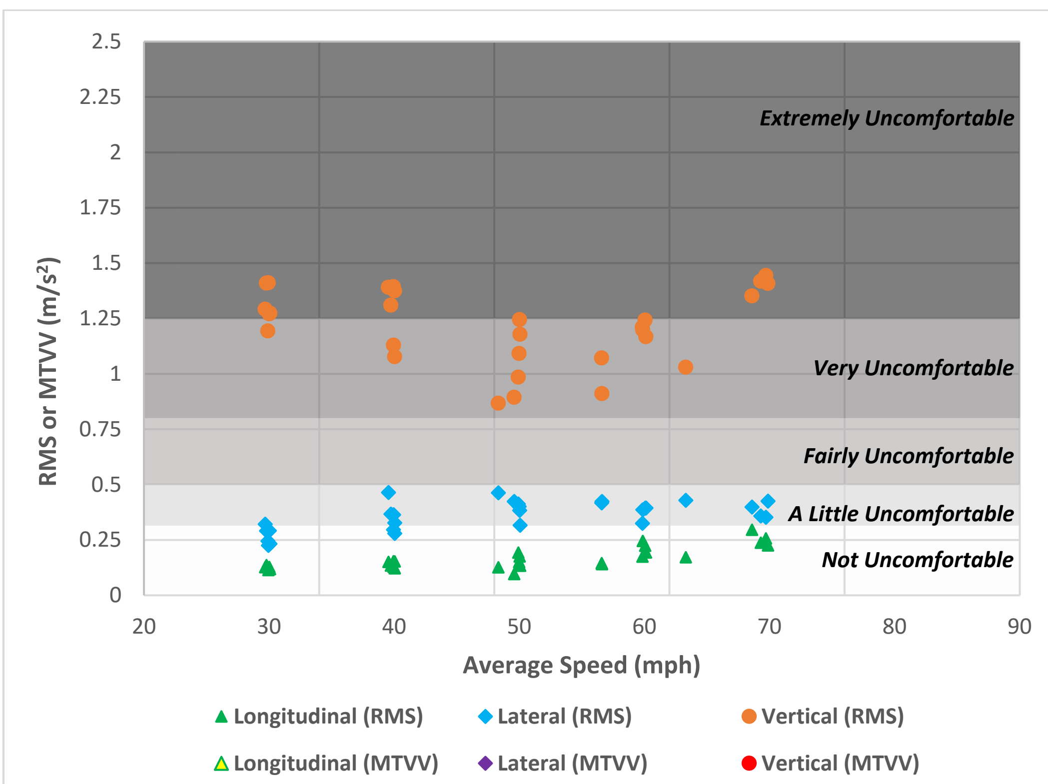

Figure 39. Left UOL Chair Comfort – Class 6 Track (PTT)

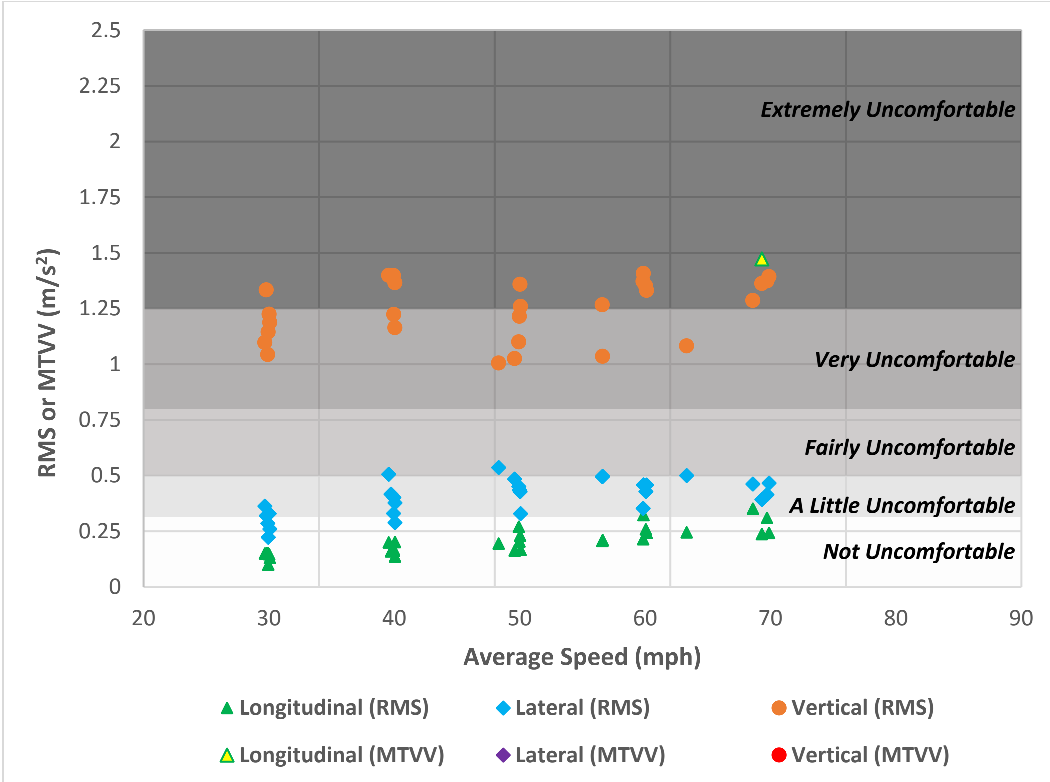

Figure 40. Right UOL Chair Comfort – Class 6 Track (PTT)

For questions or comments on this document, contact russ_walker@aar.com

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