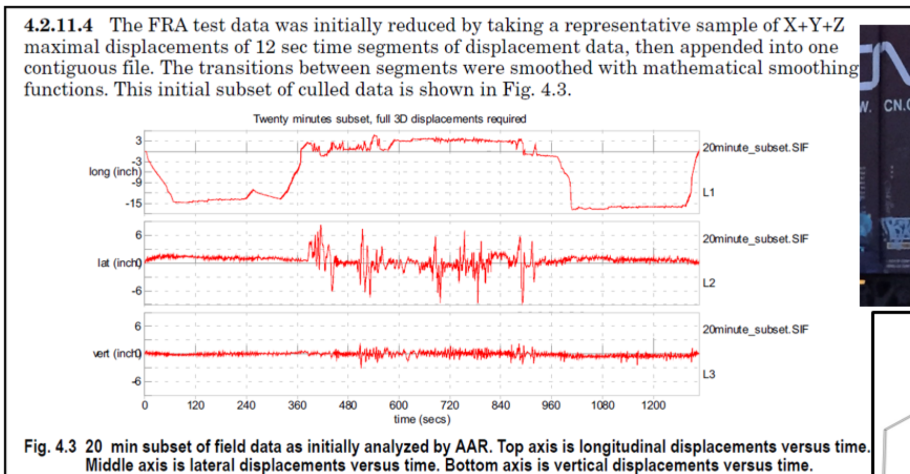
U.S. Department of Transportation

Federal Railroad Administration

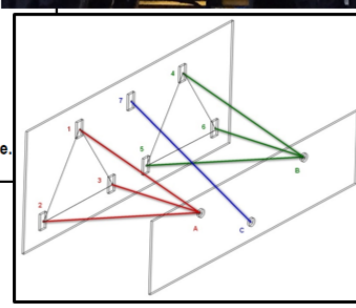
Measuring the Displacement Environment Between a Locomotive and Trailing Car

Office of Research, Development and Technology
Washington, DC 20590



4.2.11.4 The FRA test data was initially reduced by taking a representative sample of X+Y+Z maximal displacements of 12 sec time segments of displacement data, then appended into one contiguous file. The transitions between segments were smoothed with mathematical smoothing functions. This initial subset of culled data is shown in Fig. 4.3.

Fig. 4.3 20 min subset of field data as initially analyzed by AAR. Top axis is longitudinal displacements versus time. Middle axis is lateral displacements versus time. Bottom axis is vertical displacements versus time.



DOT/FRA/ORD-20/20

Final Report
May 2020

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	Published: May 2020	Technical Report September 23, 2015–December 31, 2015

4. TITLE AND SUBTITLE
Measuring the Displacement Environment Between a Locomotive and Trailing Car

5. FUNDING NUMBERS
DTFR53-11-D-00008
Task Order 348

6. AUTHOR(S)
Sharma & Associates, Inc. & Transportation Technology Center, Inc.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Railroad Administration
Office of Railroad Policy and Development
Office of Research, Development and Technology
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT/FRA/ORD-20/20

11. SUPPLEMENTARY NOTES
COR: Melissa Shurland

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the FRA website.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
The Federal Railroad Administration (FRA) funded a project conducted by Transportation Technology Center, Inc.'s (TTCI) Association of American Railroads' (AAR) Natural Gas Fuel Tender (NGFT) Technical Advisory Group (TAG) in developing industry standards for NGFT tenders. The objective was to measure and understand the triaxial displacement environment that interconnections (e.g., gas, cooling system loop, electrical, air, etc.) between the locomotive and adjacent tender vehicle will face during normal full-scale freight train operations in revenue service.

The worst-case scenario of a displacement environment between a common line-haul locomotive and a trailing vehicle (i.e., simulating a fuel tender) were documented. This included measuring and understanding the dynamic environment where equipment passing natural gas (NG) between the locomotive and tender will be required to survive in mainline train operations. The NGFT TAG analyzed the data gathered in the development of specification requirements for NG tender fuel transfer components (e.g., hoses, wires and connectors for gas/heat exchange fluids/electrical power/control), and testing of such components.

Additionally, this report describes the measurement of relative longitudinal, lateral and vertical displacements and accelerations between the locomotive and simulated fuel tender.

14. SUBJECT TERMS
Relative displacement, locomotive, natural gas fuel tender standards, locomotive to tender connection, rolling stock

15. NUMBER OF PAGES
29

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

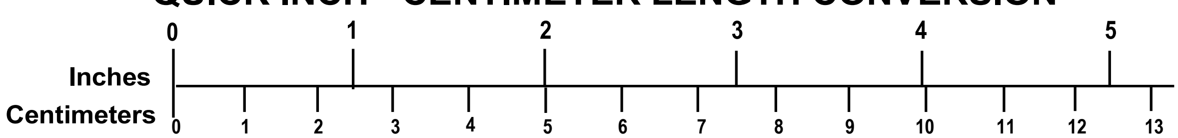
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

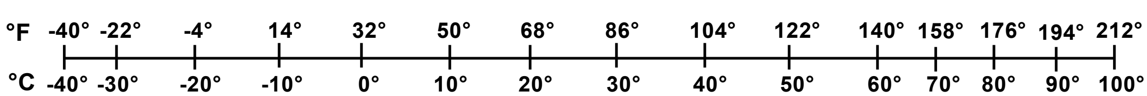
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

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Executive Summary

From September 23, 2015, to December 31, 2015, the Federal Railroad Administration (FRA) funded a project conducted by Transportation Technology Center, Inc.'s Association of American Railroads (AAR) Natural Gas Fuel Tender (NGFT) Technical Advisory Group (TAG) in developing industry standards for NGFT tenders. The objective of this effort was to measure and understand the triaxial displacement environment that interconnections (i.e., gas, cooling system loop, electrical, air, etc.) between the locomotive and adjacent tender vehicle during normal full-scale freight train operations in revenue service.

This effort was focused on documenting the worst-case displacement environment between a common line-haul locomotive and a trailing vehicle (i.e., simulating a fuel tender). This included measuring and understanding the dynamic environment where equipment passing natural gas (NG) between the locomotive and tender will be required to survive in mainline train operations. The data gathered was analyzed and used by the AAR NGFT TAG for the development of random vibration testing requirements for NG tender fuel transfer components (i.e., hoses, wires, and connectors for gas/heat exchange fluids/electrical power/control).

The AAR NGFT TAG used the data resulting from the FRA test to develop a 559 second representative test scenario of lateral, vertical, and longitudinal motions that hoses between a locomotive and tender would experience. The scenario is proposed in the AAR Manual of Standards and Recommended Practices' S-5025 and S-5026 to be repeated for a period of 40 hours to rigorously test the hoses:

Draft AAR Standard S-5025

"*Gaseous Natural Gas Supply Hose Unit for Natural Gas Fuel Tenders*"

> This standard outlines the requirements for a nominal 1 1/2- inch (also known as -24 size) hose for supplying low pressure (200 psig or less) gaseous NG from a tender to a dual-fuel NG locomotive.

Draft AAR Standard S-5026

"*Heat Exchange Fluid Hose Unit for Natural Gas Fuel Tenders*"

> This standard outlines the requirements for a nominal 2-inch (also known as -32 size) hose for conveying low pressure (75 psig or less) heat exchange fluid between a dual-fuel, NG locomotive and a NG fuel tender.

1. Introduction

The Federal Railroad Administration (FRA) sponsored Transportation Technology Center Inc. (TTCI) to collect and develop data/information to document the worst-case scenario regarding the displacement environment between a nominal line-haul locomotive and a trailing vehicle (i.e., simulating a fuel tender). TTCI contracted with Sharma & Associates (SA) to execute the research effort which took place between September 23, 2013, and December 31, 2015.

1.1 Background

The railroad industry has been focusing on developing possible alternative fuel opportunities for moving trains, with natural gas (NG) as one of the prime alternatives. FRA has provided funding for a program to complement work being conducted by AAR's Natural Gas Fuel Tender (NGFT) Technical Advisory Group (TAG) in developing industry standards for NGFT tenders. This standards development effort requires a detailed understanding of the extreme railroad environment experienced between a locomotive and an NGFT. Understanding this environment is important for optimizing the design for potential connections (e.g., cables, hoses, etc.) between the locomotive and tender. These connections are safety critical to the performance of the NG locomotive consist.

The data gathered as part of this test effort will provide input for testing future fuel transfer components (i.e., hoses, wires and connectors for gas/heat exchange fluids/electrical power/control) planned for use on the next generation of NG fuel tender vehicles.

1.2 Objectives

The objective of this test effort was to measure and document the triaxial displacement environment that interconnects (i.e., gas, cooling system loop, electrical, air, etc.) between the locomotive and adjacent tender vehicle that will be subjected to during normal full-scale freight train operations in revenue service.

1.3 Organization of the Report

This report is structured in the following sections: Section 1 summarizes the research effort by indicating that data was gathered and testing took place to develop possible alternatives to NG; Section 2 describes the steps taken when developing the Test Implementation Plan (TIP); Section 3 details the type of box car used to test a worst-case scenario regarding motion between the locomotive and adjacent railcar; Section 4 documents the fitting of the instrument and the data that was collected; Section 5 presents the displacement and acceleration data; and Section 6 provides concluding information of the research conducted and recommendations for future work.

2. Procedure

SA developed a TIP for the effort that identified a locomotive and a box car as test cars in collaboration with the Canadian National Railway (CN); identified a representative route for the test in collaboration with CN; and developed an instrumentation and data analysis plan that would effectively provide relative motion information, along with other relevant information including speed, distance, and Global Positioning System (GPS) locations.

Following the TIP, SA assembled the analysis, instrumentation and data acquisition package. This allowed the resolution of equations by collecting the displacements and accelerations to develop the actual linear displacements in the longitudinal, lateral and vertical directions.

This assembly consisted of preparing the frames and brackets needed to mount the string potentiometers in the specifically defined orientations. SA conducted a 'dry run' of the installation to validate the mechanical design of the instrument system. After SA received approvals for the test and the availability of the test consist, the instrumentation was installed at the locomotive/box car interface. Subsequently, data collection was for one round trip in revenue service. Data from all sensors were collected continuously, and analyzed and resolved the motions between the two vehicles.

3. Vehicles and Logistics

CN supplied the locomotive and high-cube box car for this testing. The leading locomotive's long hood end was connected to the box car's A-end. Both vehicles were kept together and used throughout the testing from Gary, IN, to Memphis, TN, and back. The AAR NGFT TAG intended to test a worst-case scenario regarding motion between the locomotive and adjacent railcar; therefore, a box car was chosen per the following reasons:

a. The selected boxcar has a larger overhang from the truck bolsters than a common tank car, thereby offering more relative motion between it and an adjacent locomotive, especially in territory with track curvatures.

b. The selected boxcar utilized a 15-inch cushion unit that allowed for the possibility of extreme longitudinal movement between the vehicles.

   i. Few legacy tenders exist and are typically being utilized for other test/development programs, and new tender standards and designs are neither fully completed nor available for use.

Figure 1 and Figure 2 are photos of the two vehicles supplied by CN and utilized for this testing.

Figure 1. Empty box car, DWC793490, used in the testing

Figure 2. GP-38 locomotive CN7027 used in the testing

The test route included 1,032 miles from Kirk Yard in Gary, IN, to Harrison Yard in Memphis, TN, and back. Figure 3 shows a GPS plot of the route traversed. A summary of the route information is provided in Table 1.

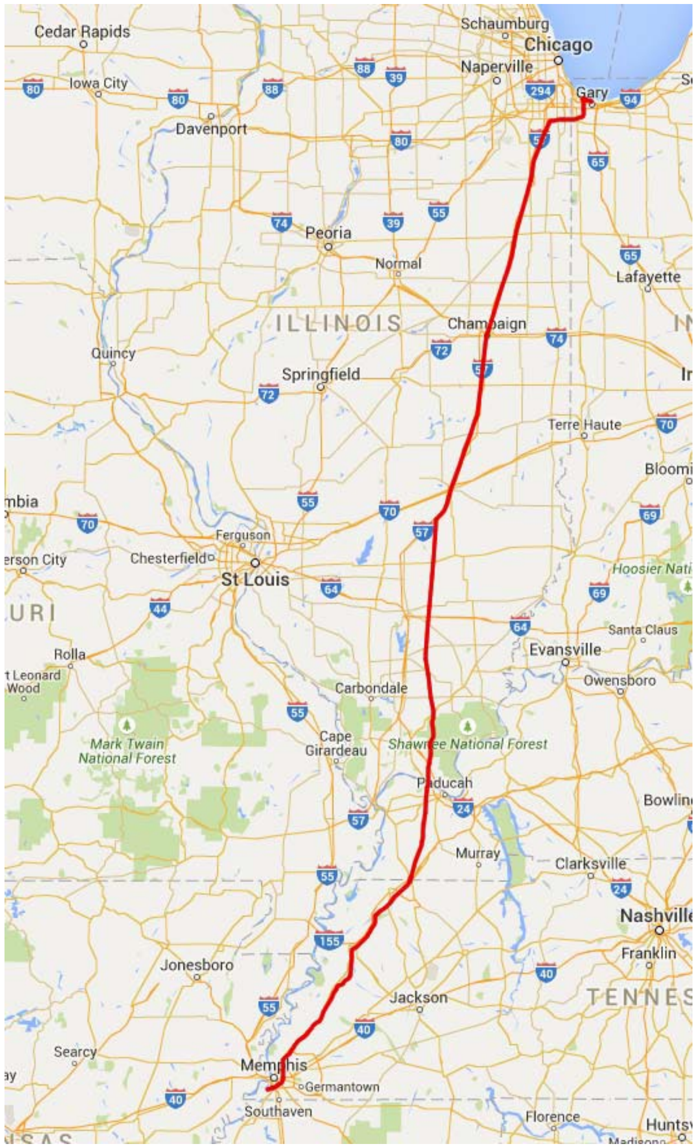

Figure 3. Map of route traversed

Table 1. Summary of test, general information

Description	Value
Minimum speed, mph	0.0
Maximum speed, mph	53.8
Average speed, mph	13.5
Total time, hours	76.5
Time spent in motion, hours	42.3
Time spent in idle, hours	34.2
Distance travelled, miles	1,031.9

4. Instrumentation and Data Collection

Instrumentation included displacement measurements between the adjacent ends of the locomotive and box car located 77 inches above the top of the rail (see Figure 4, Figure 5, and Figure 6). Additionally, triaxial accelerations were collected in similar locations but lower on the vehicles strikers. See Figure 7 for a picture of the accelerometer mounting location on the box car and Figure 8 for a picture of the other accelerometer mounted on the locomotive end sill.

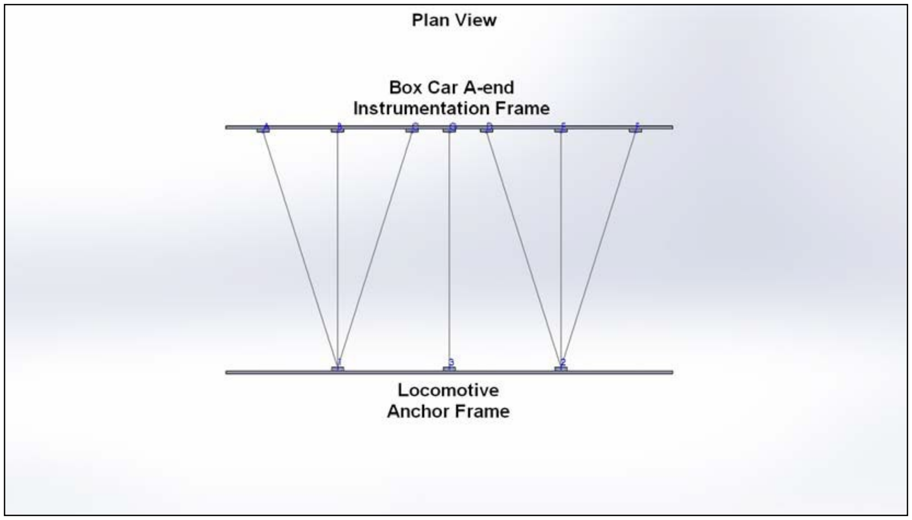

Figure 4. Plan (top) view of the string potentiometer orientation

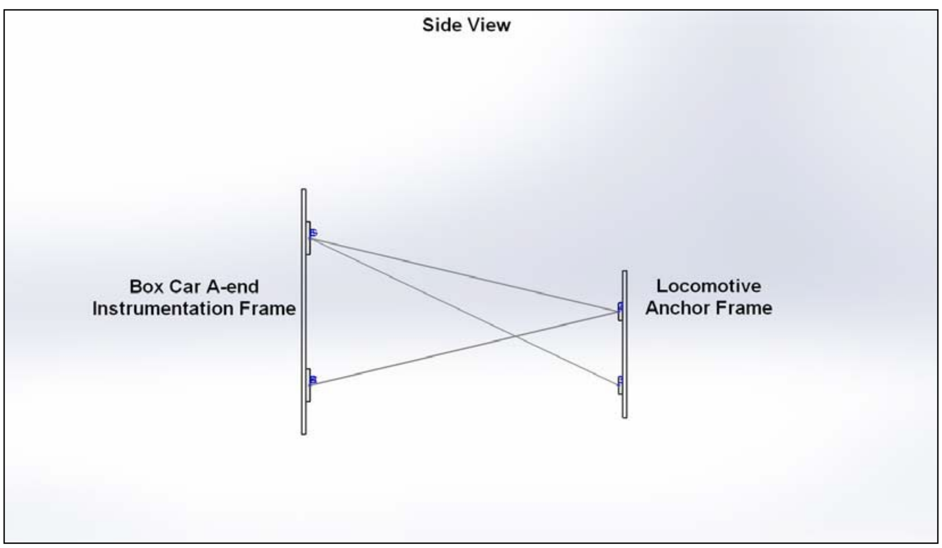

Figure 5. Side view of the string potentiometer orientation

Figure 6. String potentiometers connected between locomotive and box car

Figure 7. Triaxial accelerometer mounted on box car prior to testing

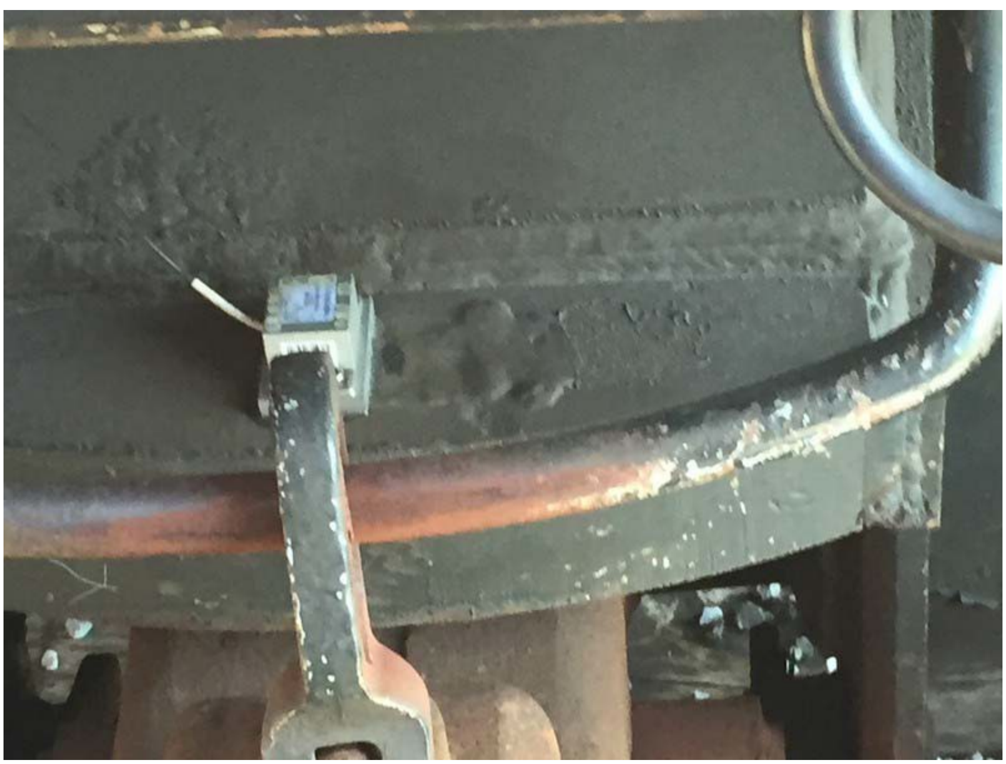

Figure 8. Accelerometer mounted on the locomtoive end sill

GPS data were also collected, and the antenna was installed on the top of the locomotive's short hood as shown in Figure 9.

Figure 9. GPS antenna installed on locomotive short hood

4.1 Description of Data Channels

Data channels for the test program consisted of seven displacement measurements, a GPS measurement, and six axial acceleration measurements. The orientation and number of displacement transducers (string potentiometers) allowed for redundancy in the measurements of the displacements in case there had been a malfunction of a string potentiometer during the test. Table 2 summarizes the data acquisition system and instrumentation count and types.

Table 2. Instrumentation summary

Type of Instrumentation	Quantity	Channel Count
String potentiometers	7	7
Triaxial accelerometers	2	6
GPS device	1	1

4.2 Definition of Coordinate Axes

For both string potentiometers and accelerometers, X, Y, and Z axes are in the longitudinal, lateral and vertical directions, respectively. When setup and zeroed in the initial condition, string extension was positive and string retraction was negative. Both triaxial accelerometers were oriented in the same direction with positive X pointing toward the locomotive; positive Y pointing to the left when facing the locomotive from the box car, and positive Z facing up. Please see Figure 10 below.

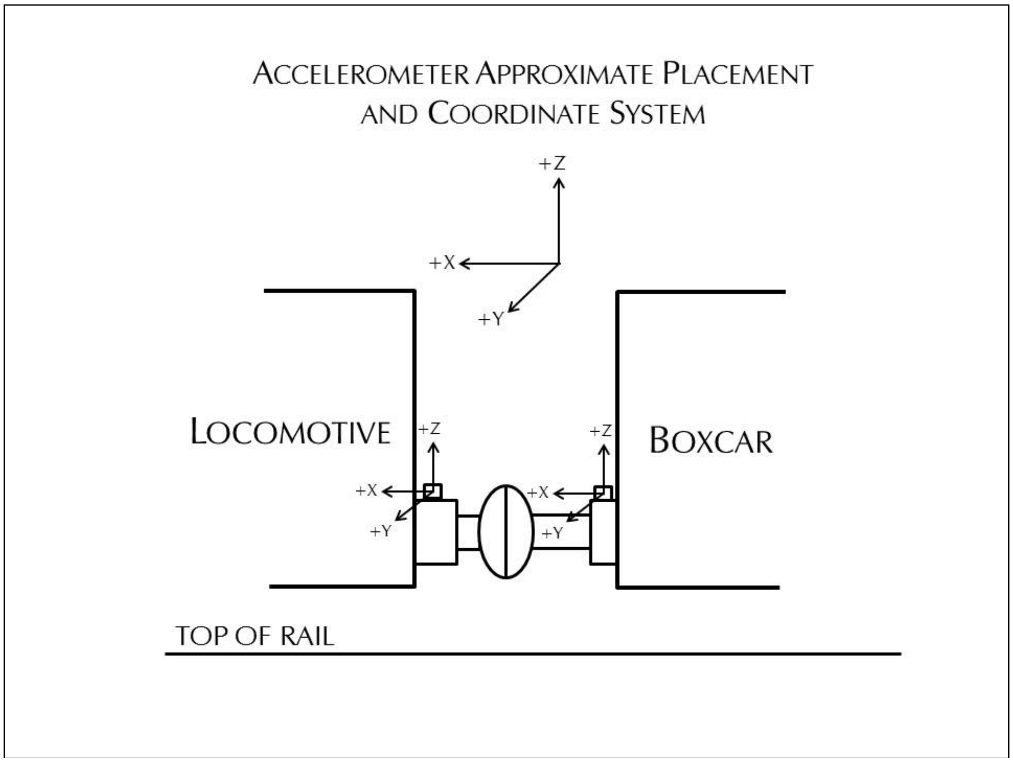

Figure 10. Accelerometer approximate placement locations and coordinate system

4.3 Data Acquisition

Data were recorded using a SoMat eDAQlite data acquisition system. Accelerometer data were sampled at 500 samples-per-second (s/s) and anti-alias filtered at 75 Hz, and displacement data were sampled at 200 s/s and anti-alias low pass filtered at 30 Hz, then digitally low pass filtered at 7.5 Hz. Figure 11 and Figure 12 show the string potentiometer setup on the box car and an image of the coupled vehicles just before departure early morning on July 21, 2015, respectively.

Figure 11. String potentiometer setup on the box car

Figure 12. In Kirk Yard prior to start of the test, early morning July 21, 2015

5. Displacement Data

All displacement data recorded were post processed using equations to extract linear translations in longitudinal (X), lateral (Y), and vertical (Z) directions. Rain-flow analyses were accomplished to complement the statistical analysis of the time histories. SA used a trilateration technique which allows for the determination of the location of a point of interest using three independent distance measurements from three unique locations. The implemented instrumentation plan used this technique to measure the location of two distinct points on the locomotive using six string potentiometers arranged in two tetrahedral formations. A seventh string potentiometer was included to allow determination of a third unique point on the locomotive. The seven displacement measurements are sufficient to determine the relative displacements and rotations between the tender car and the locomotive (see Figure 13). Trilateration using lengths 1A, 2A, and 3A provided the location of point A. Similarly, trilateration using lengths 4B, 5B, and 6B provided the location of point B. Finally, trilateration using lengths 7C, AC, and BC provided the location of point C.

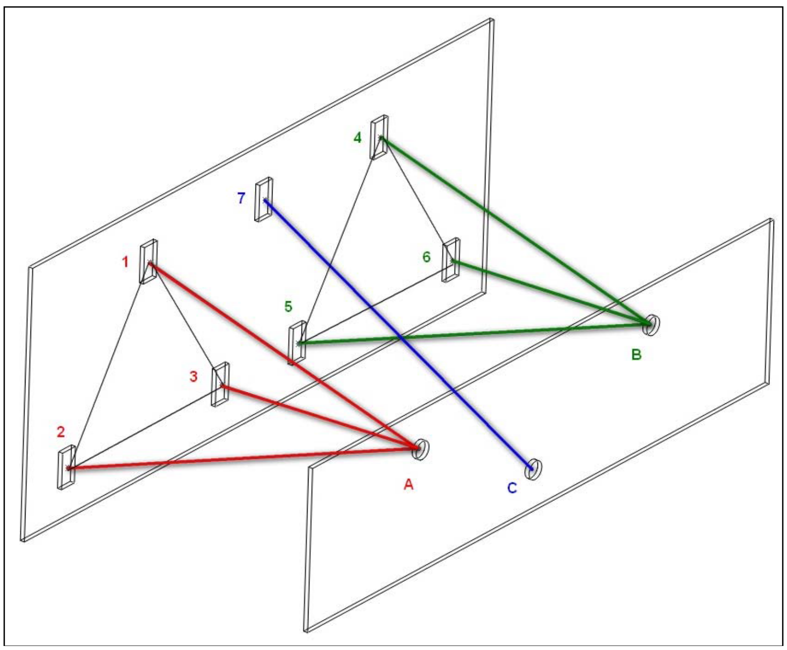

Figure 13. Trilateration using string potentiometers

Table 3 is a summary of the relative displacement data collected and processed over the entire trip.

Table 3. Relative linear displacement low pass filtered 7.5 Hz data summary

RELATIVE LINEAR DISPLACEMENT DATA – ENTIRE TRIP	Inches
Longitudinal maximum compression from zero point	-17.70
Longitudinal maximum tension from zero point	5.97
Longitudinal displacement range	23.67
Longitudinal zero point	0.00
Lateral maximum from zero point: Loco displaced right w.r.t box car as facing direction of travel with loco leading	-8.96
Lateral maximum from zero point: Loco displaced left w.r.t box car as facing direction of travel with loco leading	9.36
Lateral displacement range	18.31
Lateral zero point	0.00
Vertical maximum from zero point: Loco displaced lower w.r.t. box car	-3.96
Vertical maximum from zero point: Loco displaced higher w.r.t. box car	4.31
Vertical displacement range	8.27
Vertical zero point	0.00

As seen in Table 3, the data collected and processed of relative displacements are within values expected at a location of approximately 77 inches above the top of rail. Time histories and scenarios surrounding the peak values were studied to ensure that the measurements were reasonable. For example, Figure 14 shows a time history of the maximum vertical box car displacement of 4.31 inches during an approximate 37 mph train speed.

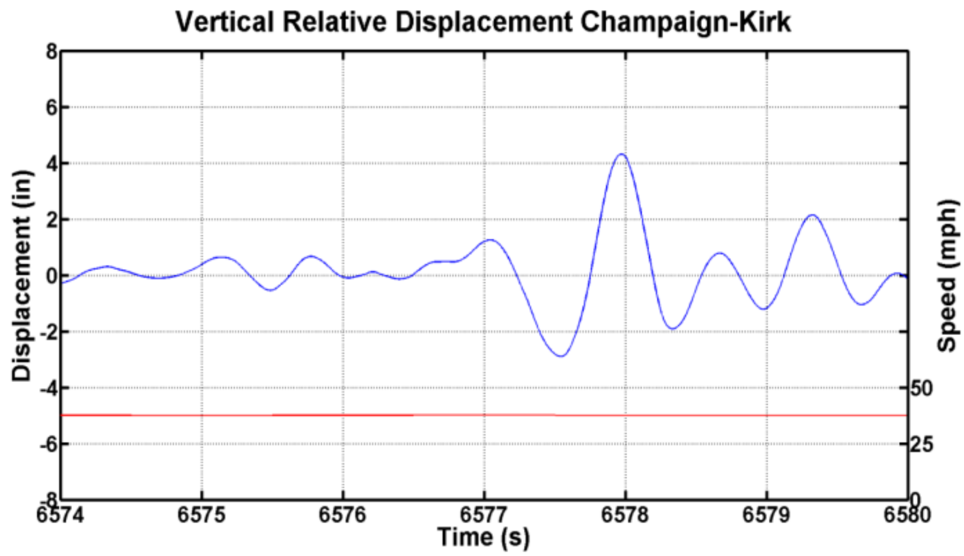

Figure 14. Exemplar displacement and speed plot of 4.31 inch relative vertical displacement

5.1 Acceleration Data

All acceleration data were collected at 500 s/s and low-pass anti-aliased filtered at 75 Hz during collection. Prior to any processing, the data were digitally low pass filtered at 15 Hz. Table 4 summarizes the acceleration data over the entire trip.

Table 4. Triaxial aceleration summary for both locomotive and box car—entire trip

ACCELERATION SUMMARY—ENTIRE TRIP	*Acceleration (g)*
Minimum Box Car Longitudinal Acceleration	-0.97
Maximum Box Car Longitudinal Acceleration	1.24
Root mean^2 (RMS) Box Car Longitudinal Acceleration	0.11
Average Box Car Longitudinal Acceleration	0.11
Minimum Box Car Lateral Acceleration	-0.58
Maximum Box Car Lateral Acceleration	0.43
RM S Box Car Lateral Acceleration	0.03
Average Box Car Lateral Acceleration	0.02
Minimum Box Car Vertical Acceleration	-0.74
Maximum Box Car Vertical Acceleration	1.34
RM S Box Car Vertical Acceleration	0.05
Average Box Car Vertical Acceleration	-0.04

ACCELERATION SUMMARY—ENTIRE TRIP	*Acceleration (g)*
Minimum Locomotive Longitudinal Acceleration	-0.36
Maximum Locomotive Longitudinal Acceleration	0.54
RM S Locomotive Longitudinal Acceleration	0.04
Average Locomotive Longitudinal Acceleration	0.05
Minimum Locomotive Longitudinal Acceleration	-0.28
Maximum Locomotive Longitudinal Acceleration	0.24
RM S Locomotive Longitudinal Acceleration	0.02
Average Locomotive Longitudinal Acceleration	-0.01
Minimum Locomotive Longitudinal Acceleration	-0.68
Maximum Locomotive Longitudinal Acceleration	0.70
RM S Locomotive Longitudinal Acceleration	0.03
Average Locomotive Longitudinal Acceleration	0.00

All acceleration data correlated well between directions, as expected. In general, based on experience, when a vehicle travels over a bump or dip in the track, vertical accelerations correlate well with longitudinal accelerations. Two examples of this fact, one each for the box car and the locomotive, are shown in Figure 15 and Figure 16, respectively.

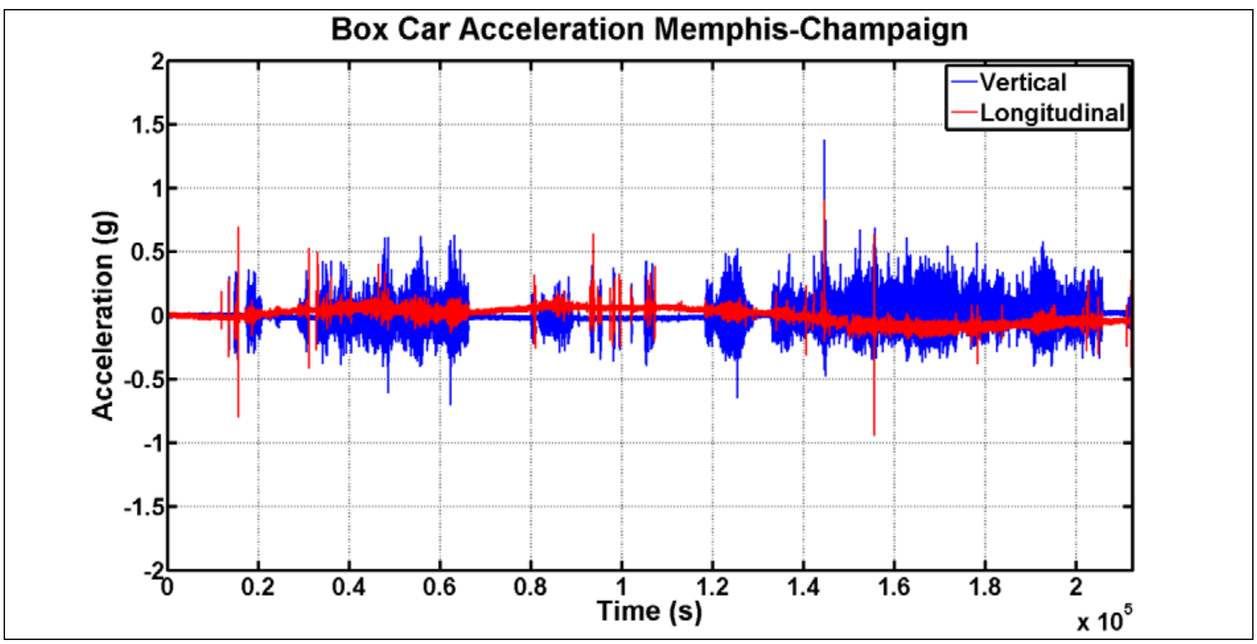

Figure 15. Exemplar box car longitudinal and vertical acceleration correlation

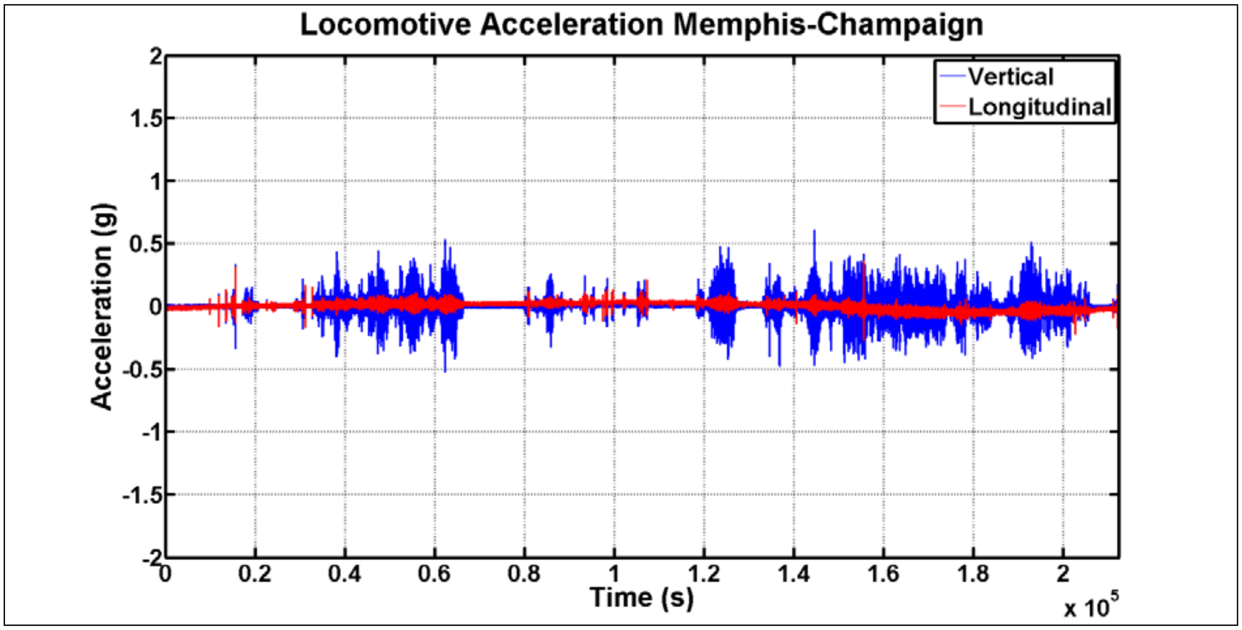

Figure 16**. Exemplar locomotive longitudinal and vertical acceleration correlation**

Accelerations were also processed for jerk information. Table 5 summarizes the processed jerk data.

Table 5. Triaxial jerk summary for both locomotive and box car—entire trip

JERK SUMMARY—ENTIRE TRIP	*g* s/s
Minimum Box Car Longitudinal Jerk	-43.10
Maximum Box Car Longitudinal Jerk	43.20
RM S Box Car Longitudinal Jerk	0.42
Minimum Box Car Lateral Jerk	-26.50
Maximum Box Car Lateral Jerk	30.90
RM S Box Car Lateral Jerk	0.52
Minimum Box Car Vertical Jerk	-58.10
Maximum Box Car Vertical Jerk	57.10
RM S Box Car Vertical Jerk	1.81
Minimum Locomotive Longitudinal Jerk	-11.30
Maximum Locomotive Longitudinal Jerk	13.50
RM S Locomotive Longitudinal Jerk	0.28
Minimum Locomotive Lateral Jerk	-6.53
Maximum Locomotive Lateral Jerk	6.27

JERK SUMMARY—ENTIRE TRIP	*g* s/s
RM S Locomotive Lateral Jerk	0.27
Minimum Locomotive Vertical Jerk	-29.20
Maximum Locomotive Vertical Jerk	28.10
RM S Locomotive Vertical Jerk	0.76

6. Conclusion

From September 23, 2015, to December 31, 2015, the SA team developed an innovative technique to readily measure relative displacement between rail vehicles under Over-The-Road revenue service conditions. This technique was employed to successfully measure the relative linear displacement in longitudinal, lateral and vertical directions, between a locomotive and a box car that had a long over-hang from its end trucks, and 15-inch cushion units.

Data were collected over a 1,032-mile revenue service test running between Kirk Yard in Gary, IN, and Harrison Yard in Memphis, TN.

Processed test data were delivered—with and without dwell times—to TTCI in electronic format. These data were submitted via four files, one file for each leg of the test: Kirk Yard to Champaign, Champaign to Harrison Yard, and back. This held true for displacement (i.e., time histories and rain-flow data), acceleration, jerk, and GPS. Displacement, acceleration and jerk were all delivered in tab-delimited text files without headers. There were additional text files submitted that notes the channel order and the sample rate. Because of the smaller file size, GPS was delivered in .csv format with headers. GPS data includes latitude, longitude, altitude, and speed (mph). These data are ear-marked for use in in-laboratory inter-vehicle connector testing by simulating the displacement environment that a locomotive and NG tender car could see in revenue service.

Abbreviations and Acronyms

ACRONYMS	EXPLANATION
g	Acceleration
AAR	Association of American Railroads
CN	Canadian National Railway
FRA	Federal Railroad Administration
GPS	Global Positioning System
NG	Natural Gas
NGFT	Natural Gas Fuel Tender
RMS	Root Mean Square
s/s	Samples-per-Second
SA	Sharma & Associates, Inc.
TAG	Technical Advisory Group
TIP	Test Implementation Plan
TTCI	Transportation Technology Center, Inc.