APPENDIX G-2.7

ATLAS RAILCAR LASER MEASUREMENT

Appendix G-2.7.1 FARO Technologies
Example of FARO Laser Tracker and CAM2 Measure Training Certificate of Accomplishment

Certificate of Accomplishment

FARO AUTHORIZED TRAINING

This is to certify that

[redacted]

has successfully completed the training program requirements for

Faro Laser Tracker and CAM2 Measure Training

FARO

Awarded on:

December 6, 2012

Appendix G-2.7.2 FARO Technologies
Example of FARO Calibration Certificate

FARO

FARO Michigan Regional Office
46998 Magellan Drive
Wixom, MI 48393
USA

Phone 248-669-8620
Fax 248-669-8656

CALIBRATION CERTIFICATE
Laser Tracker Model Xv2

Date	12-Oct-16
Certification Number	X2466-12102016-MI
Tracker Serial Number	X01000802466
Customer	Contract Measurement Services P.O. Box 540784 Grand Prairie, TX 75054 USA
Date Calibrated	12-Oct-16
Certified By	Neil Maclean Laser Service Technician
Condition Found	In Tolerance
Condition Left	In Tolerance

The instrument listed above has been tested, inspected and compensated against FARO working standards that have been calibrated using National Institute of Standards and Technology (NIST) or other appropriate or internationally recognized standards.

Calibrations conforms to internal procedures and those developed in accordance with ISO9001:2008. Calibration results relate only to the items specified. This report shall not be reproduced except in full without the written consent of the FARO Technologies Laser Measurement Division

Revised: Oct 26, 2015

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FARO

Date	**12-Oct-16**
Certification Number	**X2466-12102016-MI**
Tracker Serial Number	**X01000802466**

Calibration Standards Traceability Data

HUMIDITY STANDARD

Sensiron Humidity Sensor Model SHT25

TEMPERATURE STANDARD

Cornerstone Sensors Inc. Model T243D103.DD
Calibration Date: **12-Oct-16**
Calibrated by FARO Technologies
Calibration Standard: **Fluke** Serial Number: **A85001**
Last Calibration: **20-Sep-16** Next Calibration: **20-Sep-17**
Trace Number: **6-A8T2E-20-1**

Allowable Deviation: ± 0.4°C as compared to Standard.

As Received (°C)			Post Calibration (°C		
Standard	Actual	Deviation	Standard	Actual	Deviation
22.00	**22.06**	**0.06**	**22.45**	**22.55**	**0.11**

PRESSURE STANDARD

Intersema Model MS5534BM Barometer Module
Calibration Date: **12-Oct-16**
Calibrated by FARO Technologies
Calibration Standard: **Druck** Serial Number: **74001875**
Last Calibration: **10-May-16** Next Calibration: **10-May-17**
Trace Number: **5-A6UOT-20-1**

Allowable Deviation: ± 1.4 mmHg as compared to Standard.

As Received (mmHg)			Post Calibration (mmHg)		
Standard	Actual	Deviation	Standard	Actual	Deviation
744.09	**744.03**	**0.06**	**743.60**	**743.59**	**0.01**

Calibrations conforms to internal procedures and those developed in accordance with ISO9001:2008. Calibration results relate only to the items specified. This report shall not be reproduced except in full without the written consent of the FARO Technologies Laser Measurement Division

Revised: Oct 26, 2015

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Appendix G-2.7.3 Kasgro Rail
Railcar Deck Measurement Data Report, Form 73, 9/23/14

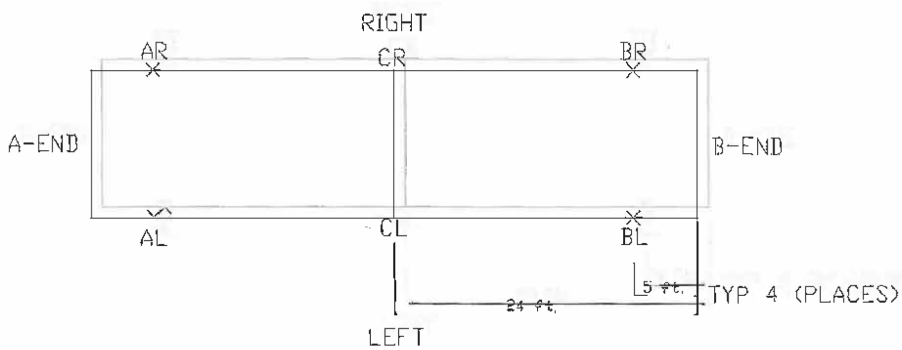
KASGRO RAIL CORP.

FORM 73

Date: 9/23/14

RAILCAR DECK MEASUREMENT DATA REPORT

Railcar Identification Number:________________



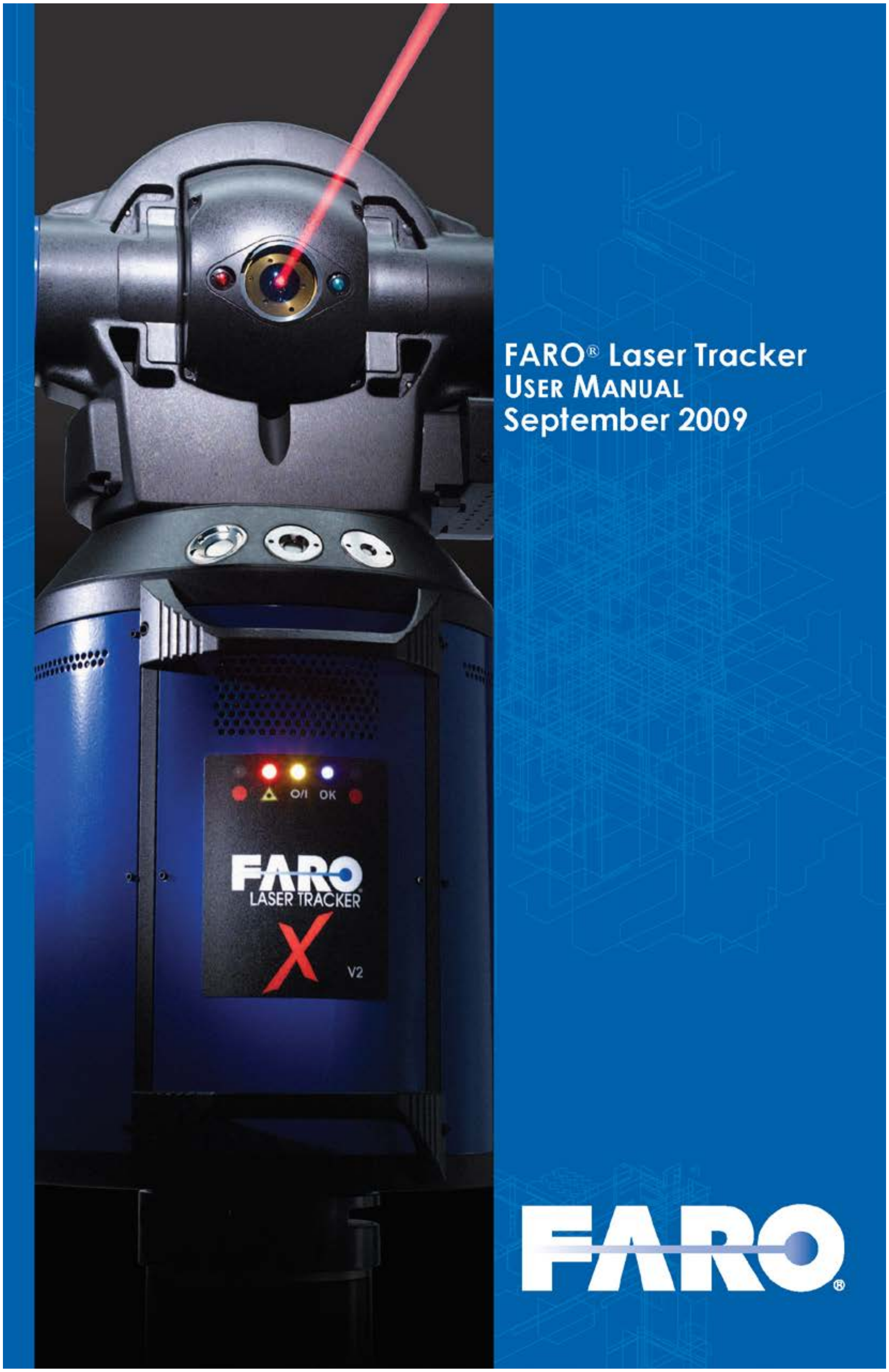
	Deck Height						Camber	
Locations	**AR**	**AL**	**BR**	**BL**	**CR**	**CL**	**Left**	**Right**
Empty (free state) (Top of Deck)								

TOOL NO'S:____

INSPECTOR SIGNATURE:__________________________DATE:________________

THE RECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTITIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELONY UNDER FEDERAL STATUTES.

Appendix G-2.7.4 FARO® Laser Tracker User Manual, September 2009



FARO Technologies Inc. Internal Control File Locations:
F:\CONTROL\REFERENC\08PRODUC\ENGLISH\Prdpub44\08m44e00 - FARO Laser Tracker - September 2009.pdf
F:\FARO Tracker Doc Control\RECORDS\05 Production\PARTSPEC\922-00-012 Rev. N - Laser Tracker User Manual - September 2009 - English.pdf

Table of Contents

Chapter 4 : Traceability of Key Components

Chapter 5 : Setting up the FARO® Laser Tracker

Chapter 6 : Understanding Measurement Accuracy

Chapter 12 :CAM2® Measure Devices Menu

Chapter 13 :CAM2® Q

Chapter 1: Introduction

Thank you for choosing the FARO® Laser Tracker. This introduction contains information on how to reach FARO, how to read the manual, and a brief overview of the FARO Laser Tracker X and Xi. Additional information about accessories and important guidelines on maintaining your new FARO Laser Tracker is also included. If you have any questions or need further instructions about any procedure, contact your Customer Service Representative by Phone, Fax or E-Mail. *See "Technical Support" on page 113.* You can also reach the Customer Service Applications and Training group via Internet e-mail at the following addresses:

- supportlaser@faro.com
- applications@faro.com
- training@faro.com

Visit the FARO Customer Service area on the Web at *www.faro.com* to search our technical support database. The database is available 24 hours a day, 7 days a week, and contains hundreds of solutions to product and application questions. Have your FARO Laser Tracker Serial Number and FARO Customer Order Number available before connecting to the site.

Listed below are some visual and typographical conventions used in each of the sections.

ALL CAPITAL text	Indicates directory names, menu names, buttons, tabs, key names, acronyms, and modes.
`monospaced` text	Indicates alpha/numeric characters or values you enter in a field on the screen. For example, "Type `0.005` for the tolerance setting."
bold text	Anything you must enter exactly as it appears on your keyboard. For example, to type **a:install**, you would see text in bold type exactly as it should be entered.
SMALL CAPS text	Indicates dialog box, icon names, and window names.

You may also see a few new words. It is important that you understand the meaning of these words before proceeding.

digitize	To record the XYZ coordinates of a point or location in 3D space. The word digitize is the same as the term *measure* when referring to points.
choose or select	Means that you are initiating an action. For example, "Select FILE < GRAPHICAL REPORTS < EXPORT DATA."
left-click, right-click, click, or press	Press and release the LEFT (or RIGHT) MOUSE button. Also used when referring to the FARO Laser Tracker buttons. For example, "After selecting a file from the OPEN FILE dialog box, *click* OK to open the file" or *"Press* ESC at anytime to cancel a command."
drag	Press and hold the LEFT MOUSE button down and move the mouse. Release the mouse button to finish. This word is often used when changing the size of a window or toolbar.

Overview

The FARO Laser Tracker is a portable, high accuracy, three-dimensional coordinate measurement device which has a measurement range of up to 115 feet (35 m). The Laser Tracker uses two rotary angular encoders and laser based distance measurement systems to track and measure the position of a Retroreflector target.

The FARO Laser Tracker has a compact and lightweight tracking head that is quick to set up and to relocate, and is easily operated by a single person.

A fully-integrated weather station is standard with every Laser Tracker to ensure accurate distance measurement.

FARO® Laser Tracker Model Xi

The FARO Laser Tracker Xi is a portable, high accuracy, large volume three dimension contact measurement device. The Laser Tracker emits a red helium neon laser that is reflected from a retroreflecting target, typically a Spherically Mounted Retroreflector (SMR). The orientation of the Laser Tracker's mechanical axis is continually updated based on feedback from a position sensing detector. The Laser Tracker determines the coordinates of the target by measuring two angles and a distance. The angles are measured by encoders mounted on the zenith and azimuth axes. The radial distance is measured by a fringe counting interferometer or a phase shift Absolute Distance Measuring System (XtremeADM).

FARO® Laser Tracker Model X

The FARO Laser Tracker X is the world's first ADM-only Laser Tracker. It uses XtremeADM to measure distance for static and dynamic measurements. The model X also has an instant-on laser and is ready to work immediately after power up.

Product Environmental Information

Legislation is now in place within the European Union (EU) that regulates waste from electrical and electronic equipment (WEEE). European Directive 2002/96/EC on Waste Electrical and Electronic Equipment (the WEEE Directive) stipulates that WEEE is now subject to regulations designed to prevent the disposal of such waste and to encourage design and treatment measures to minimize the amount of waste that is placed into the waste stream. The objective of the WEEE Directive is to preserve, protect and improve the quality of the environment, protect human health, and stimulate the practical use of natural resources. Specifically, the WEEE Directive requires that producers of electrical and electronic equipment be responsible for the collection, reuse, recycling and treatment of WEEE which the Producer places on the EU market after August 13, 2005.

FARO Technologies, Inc., as a producer of electrical and electronic equipment (EEE), has endeavored to meet these environmental responsibilities for managing WEEE. In so doing, FARO is providing the following to inform its customers about the WEEE collection process:

In order to avoid any potential dissemination of hazardous substances into the environment, FARO has labeled this product with the WEEE symbol (see below) in order to alert the end-user that it should be disposed of within the proper waste management system. That system will recycle, reuse, and dispose of materials from this product in an environmentally sound way.

The symbol represented below, and found on this FARO Technologies product, indicates that this product meets the European Directive 2002/96/EC on Waste Electrical and Electronic Equipment. This symbol, only applicable in European Union countries, indicates that when this product reaches the end of its useful life it should not be disposed of with normal household or municipal waste, but in an established waste stream for WEEE.

Each EU Member State country has established a system for the collection, disposal, and recycling of WEEE. End-users in the EU should contact their local waste administration system for collection instructions concerning this product.

Refer to *www.faro.com* for further environmental information concerning this product.

WEEE Symbol

Chapter 2: FARO® Laser Tracker Safety

The FARO Laser Tracker outputs a visible red laser beam. The source of the red light is a Helium Neon (HeNe) laser (Xi), or an instant-on pointer beam (X), which have an output of 1 milliwatt max/cw and are classified as a Class II laser. You should avoid direct exposure to your eye at all times even though the human blink reaction to bright light provides a natural mechanism of protection to this visible laser beam.

The FARO Laser Trackers also have an XtremeADM beam, which is an invisible infrared laser. The source of this beam is a distributed feedback (DFB) laser with less than 0.79 milliwatt output, and is classified as a Class I laser. This laser is harmless to your eye.

This equipment is classified as a Class II laser product and meets the requirements of the Food and Drug Administration, Center for Devices and Radiological Health, Register 21 CPR parts 1000 and 1040, and those of the international standard IEC EN 60825-1 2001-08.

The FARO Laser Tracker is certified to comply with the protection requirements of the Council Directives 89/336/EEC (Electromagnetic Compatibility) and 73/23/EEC (Low Voltage Directive on Electrical Safety) on the approximation of the laws of the Member States relating to Electromagnetic Compatibility, as amended by 93/68/EEC.

CAUTION: USE OF CONTROLS OR ADJUSTMENTS OR PERFORMANCE OF PROCEDURES OTHER THAN THOSE SPECIFIED HEREIN MAY RESULT IN HAZARDOUS RADIATION EXPOSURE.

The user must adhere to work safety laws as stated in UVV BGV B2, January 1993.

Laser Radiation Emission

When operating, a laser beam is emitted from the aperture on the Laser Tracker. See Figure 2-1 for the location of the laser beam aperture.

Figure 2-1 Laser Aperture

Laser Aperture Labels

The aperture warning labels indicate where laser radiation emits from the Laser Tracker. See Figure 2-2 for the locations of these labels. They contain the words, "AVOID EXPOSURE, Visible and/or invisible laser radiation is emitted from this aperture."

Figure 2-2 Laser Warning Labels on Aperture

Laser Emission Indicator

The emission indicator on the front of the Laser Tracker illuminates when the laser is energized and operating. See Figure 2-3 for the location of the laser emission indicator.

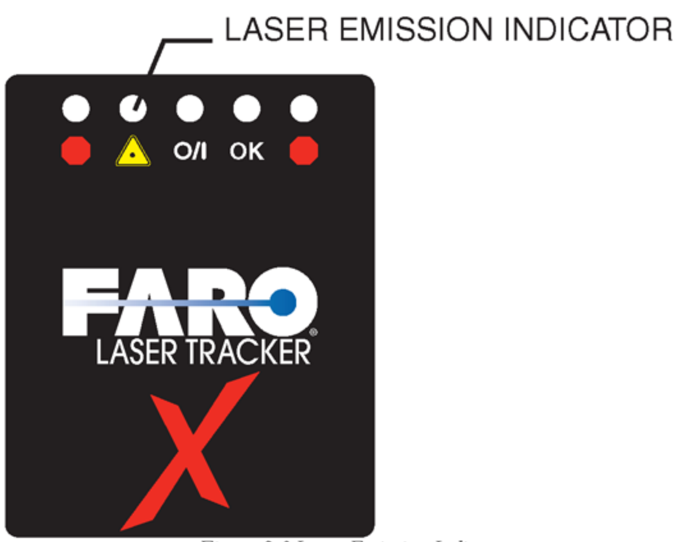


Figure 2-3 Laser Emission Indicator

Rear Composite Label

The composite label, located on the back of the Laser Tracker, combines the working logotype label, the certification label and the identification label into one. See Figure 2-4, "Rear Composite Label."

The top portion is the working logotype, which is required on all Class II laser products. It contains the wording:

LASER RADIATION, DO NOT STARE INTO BEAM.
633-635 nm Laser, 1 milliwatt max/cw.
CLASS II LASER PRODUCT.

Underneath the working logotype is the certification. It contains the wording:

PRODUCT COMPLIES WITH RADIATION PERFORMANCE STANDARDS UNDER THE FOOD, DRUG AND COSMETICS ACT AND INTERNATIONAL STANDARD IEC 60825-1 2001-08.

The bottom portion of the rear composite label contains the identification, which indicates the model number, the serial number, and the manufacturing date of your Laser Tracker.

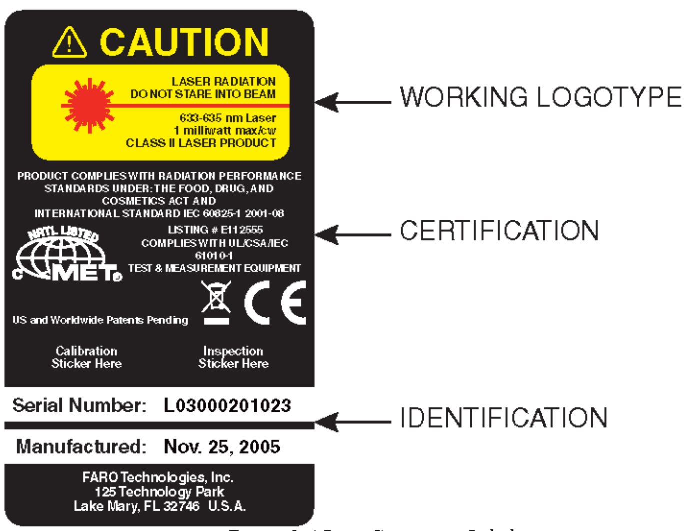


Figure 2-4 Rear Composite Label

Lifting the Laser Tracker

A safety label is located on the rear of the Laser Tracker above the rear lifting handle. Follow safe lifting procedures when removing the Laser

Tracker from its shipping containers. Always use safe lifting procedures when placing the Laser Tracker on, or removing the Laser Tracker from, the instrument stand. See Figure 2-5 for the location of the safety label.

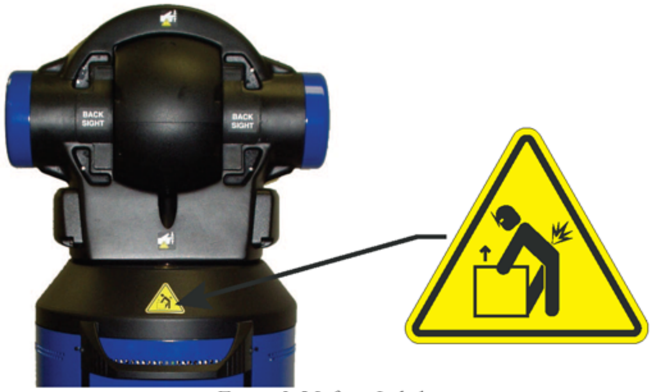


Figure 2-5 Lifting Label

Use the two handles on the front of the Laser Tracker when removing it from the shipping container. Use the upper front and back handles when mounting and carrying the Laser Tracker.

Pinch Points

Two labels that indicate pinch points are located on both the frontsight and the backsight side of the Laser Tracker's center eye wheel. Avoid placing hands and fingers in these pinch points. See Figure 2-6 for the location of the pinch point labels.

Figure 2-6 Pinch Point Labels

Hot Plugging

On the back of the Laser Tracker above the cable connection socket is the hot plugging caution label. See Figure 2-7 for the location of the hot plugging caution label.

Figure 2-7 Hot Plugging Label

The cable connects the Laser Tracker to the Master Control Unit.

CAUTION: *Do Not* connect or disconnect this cable while power is applied to the Master Control Unit.

EMC Warning

Keep the Laser Tracker and External Temperature Sensor cables separate from any other cables in the area in order reduce the likelihood of cross-coupled interference.

Two way RF hand held transmitters may generate interference into the system. *Do Not* use these devices near the Laser Tracker during measurements.

One-way RF transmitters, such as the RF Remote and Voice System sold by FARO Technologies, Inc., *do not* cause interference.

Chapter 3: The FARO® Laser Tracker System

The major components of the FARO Laser Tracker system are the Laser Tracker Measuring Head, the Master Control Unit (MCU), a retroreflecting target, and the controlling computer running CAM2®.

Laser Tracker Measuring Head

The Laser Tracker Measuring Head contains the Tracker axis, lasers, optics, encoders, pressure and humidity sensors, and supporting electronics.

Figure 3-1 Tracker Measuring Head

The Laser Tracker Measuring Head lights indicate the following:

All Lights Blinking - Boot Sequence

Red Aperture Light

- Solid - Laser Tracker is measuring
- Blinking - Laser Tracker is measuring in scan mode (multiple measurements)

Green Aperture Light

- Solid - Locked on target, valid beam
- Blinking - Locked on target, invalid beam

NOTE: Before the Laser Tracker is initialized the green aperture may blink.

Base Yellow Lights

- Blinking - Laser Tracker has rotated to an end stop

Base Red Light

- Solid - Laser is On and stable
- Blinking - Laser is On and unstable
- Off - Laser is Off

Base Green Light

- Solid - Power On
- Off - Power Off

Base Blue Light

- Solid - All Electronic Systems working correctly
- Blinking - Smart Warm-up running
- Off - Electronic Problem

Master Control Unit

The Master Control Unit (MCU) provides power and communication to the Laser Tracker Measuring Head. On the left side of the MCU, there is a socket for a cable that connects to the Laser Tracker Head. See "Figure 3-2 MCU left side."

Figure 3-2 MCU left side

The front of the MCU has eight connectors for external temperature sensors, which can monitor the temperature of the ambient air or measured part. The RJ45 connector located on the bottom right of the front panel is used for the FARO TrackArm cable. Additionally, the MCU has two round 2-pin jacks for TTL triggering. The left jack is the input and right is the output. See "Figure 3-3 MCU front panel."

Figure 3-3 MCU front panel

The right side of the MCU has the AC power connection, the fuse drawer and the RJ-45 connection for the Ethernet connection to the computer. See "Figure 3-4 MCU front panel."

Figure 3-4 MCU front panel

For more information on connecting the MCU to the computer, see *"Hardware Configuration" on page 94*.

The MCU lights indicate the following:

O/I - Green, Power

Triangle - Red, Laser Emission

RX - Green, Ethernet Receive

TX - Green, Ethernet Transmission

Link - Yellow, Ethernet Connection

Coll - Yellow, Ethernet Collision

Optical Targets

A number of target types can be used with the FARO Laser Tracker. The most common types are described below.

Spherically Mounted Retroreflector

The Spherically Mounted Retroreflector (SMR) is the most commonly used target with the FARO Laser Tracker. It consists of a hollow cornercube mirror precisely mounted within a tooling sphere. The distance between the outside of the sphere and the center of the tooling sphere is known (the radius of the tooling sphere) and the CAM2 software uses this value to offset, or compensate, measurements. SMRs are available in 1.5" (38.1 mm), 7/8” (22.225 mm) and 0.5" (12.7 mm) diameters. The SMR will reflect a laser beam with an incident angle of up to ±30°.

Figure 3-5 Spherically Mounted Retroreflector (SMR)

You can attach the SMR to a target adapter. The combination of the SMR and the adapter will have a different compensation value. Adapters can be used to measure edges, inner and outer diameters and the position of bushed holes. There are a wide range of target adapters that are available on the FARO Electronic Product Catalog at *www.faro.com*. For more information, see “Probes” on page 95.

FARO RetroProbe

The FARO RetroProbe is an optional accessory product which greatly increases the versatility of the . There are two versions of the RetroProbe: 100 and 400. The FARO RetroProbe 100 facilitates the measurement of surface features such as holes, small pockets, corners, and other features which are difficult or impossible to probe with the standard SMR. The FARO RetroProbe 400 expands on the versatility of the FARO RetroProbe 100 by providing easier manipulation of the device and allowing measurements to be made in locations up to four inches in depth.

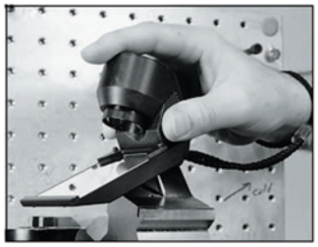


Figure 3-6 FARO RetroProbe 100

Break Resistant SMRs

Available in 7/8" (22.225 mm), 0.5" (12.7 mm) and 1.5" (38.1 mm) diameters, the Break Resistant SMR is an impact resistant target built with centering accuracy better than 0.002" (50 µm) for the 7/8" (22.225mm) and 0.5" (12.7 mm) targets and 0.0005" (12.7 µm) for the 1.5" (38.1 mm) target.

Figure 3-7 Break Resistant SMR

Repeatability Targets

The Repeatability Target is commonly used for repeatability and drift testing. Attach the target to a surface using hot glue or a similar adhesive. This target can only be used for repeatability measurements. It cannot be used for accuracy measurements.

Figure 3-8 Repeatability Targets

Controlling Computer

A PC based computer running a Microsoft® Windows® operating system controls the Laser Tracker. The computer communicates with the MCU using the TCP/IP network protocol. The cable connecting the computer and the MCU is a CAT5 patch cable with a crossover for network communications terminated with an RJ-45 connector.

Software - CAM2

CAM2 Measure and CAM2 Q are CAD-based measurement and analysis software programs developed for use with a variety of 3D measurement instruments, including the FARO Laser Tracker. Use CAM2 for simple go/no-go measurements or CAD-to-part comparison. CAM2 allows you to measure details, create coordinate systems based on known datums, apply tolerancing (rectangular and GD&T), and create graphical reports. Simplify repeat inspections by creating a part measurement program which records all measurement instructions and then prompts a user through the entire inspection routine.

Triggering Devices - RF Remote

The hand-held remote control is a wireless mouse with left and right click functions, four auxiliary buttons, and eight programmable gestures. Using the controlling software, these buttons are programmed to perform basic Laser Tracker commands from up to 100 feet away from the computer.

Refer the Quick Start Guide for the RF Remote, FARO Part Number XH08-0394, for setup and operation information.

Remote Input Trigger

The FARO Laser Tracker is capable of recording measurements at the command of a remote trigger connected to the MCU External Trigger Switch. This allows the Laser Tracker system to accept measurement commands from a controller of a robot, CNC, or other external device.

The trigger input to the MCU works by using a +5 Volt TTL signal. The standard way to do this when using isolated contacts is to have the contacts Normally Closed and supplying +5V to the trigger input. When the contacts are opened, the input is pulled down by an internal 50 Ohm resistor making this an active low trigger. When the MCU senses this change, a measurement is taken.

To trigger a measurement, FARO Technologies recommends opening the contacts for at least 1ms. The MCU will take subsequent measurements for as long as the contact remains open.

The cable from the machine controller to the MCU can be as long as is physically required for the application, provided that the voltage at the MCU is at least +3V. A shielded cable is recommended for use in electrically noisy environments. On the MCU's trigger port, the top pin should be connected to the +5V and the bottom pin should be connected to ground. FARO PN 288-01579 is a shielded 10' cable that can be used to connect the MCU to the controlling device.

The Remote Trigger can be used in FARO Insight, Software Developer's Kit, and FARO Measure Pad.

Chapter 4: Traceability of Key Components

When properly calibrated and maintained, the FARO Laser Tracker provides measurement data traceable to recognized international and national standards. Key components of the system traceable to these standards include the temperature sensor, atmospheric pressure sensor, the two angular encoders, the interferometer, and Absolute Distance Meter (ADM).

Weather Station

For the interferometer, the wavelength of the laser light in the air is a function of known wavelength in a vacuum and the prevailing environmental conditions. For the XtremeADM, the phase shift of the laser beam is a function of the frequency of a reference oscillator and the prevailing environmental conditions. Because both the interferometer and the XtremeADM depend on current environmental conditions, the accuracy of the temperature, pressure, and humidity sensors must be established.

Temperature Sensor

The remote temperature sensor in the FARO Laser Tracker is calibrated at the factory by comparing readings to a NIST traceable precision standard temperature sensor. Traceability requires annual calibration.

Pressure Sensor

The pressure sensor in the FARO Laser Tracker is calibrated at the factory by comparing its readings to a NIST traceable precision standard pressure sensor. Traceability requires annual calibration.

Humidity Sensor

The humidity sensor in the FARO Laser Tracker is verified at the factory by comparing its readings to an independent relative humidity reading.

Interferometer

The Helium Neon (HeNe) Laser source is calibrated to a NIST traceable HeNe source during the manufacturing process. This certification is valid for the life of the laser.

XtremeADM

The XtremeADM frequency oscillator is calibrated using the cesium clocks within the Global GPS Network. The XtremeADM system is factory compensated and calibrated with a NIST traceable IFM. These calibrations are one-time factory calibrations that are good for the life of the system.

Angular Encoders

The FARO Laser Tracker angular encoders are mapped against a NIST traceable reference encoder during the manufacturing process.

Spherically Mounted Retroreflector

The accuracy of measurements made with the FARO Laser Tracker system depend on characteristics of the Spherically Mounted Retroreflector (SMR) such as:

- the ball diameter
- vertex position
- polarization characteristics
- flatness of the optics
- dihedral angle errors.

The specifications for the FARO Laser Tracker system are valid when using SMRs certified by FARO. Mishandling of the SMR may change one or more of these characteristics and diminish the accuracy of the measurements taken with the FARO Laser Tracker.

Chapter 5: Setting up the FARO® Laser Tracker

This chapter describes the unpacking, mounting, connecting, powering up, startup checks, operational checks, compensations, and powering down of the FARO Laser Tracker System.

Unpacking the System

The FARO Laser Tracker head is packed in a shipping case. The Master Control Unit, cables, SMRs, tooling, and mounting hardware are packed together in a second shipping case.

CAUTION: When removing the FARO Laser Tracker from the container, grasp the handles located on the front of the Laser Tracker. Never grasp the beam steering assembly of the FARO Laser Tracker as this can cause damage.

FARO Laser Control Station System Contents

The FARO Laser Control Station includes the following:

- Laser Tracker measuring head.
- Master Control Unit (MCU) and 30-foot communication/power cable.
- Remote Air Temperature Sensor - With 30' cable and NIST traceable documentation.
- Optical Targeting with Compensation Kit - Optics required for measurement and field compensation. Includes one 1.5" Spherically Mounted Retroreflector (SMR), tripod, and tripod nest.
- Remote Control Unit - This wireless RF remote control unit can be used by the operator to control the FARO Laser Tracker system
- Computer - An Intel based computer with a monitor. The computer is pre loaded with a Microsoft Windows operating system, CAM2 Measure software and an Ethernet card.
- Computer to MCU Ethernet cable - 8 meter CAT5 100MHz crossover patch cable with RJ45 connectors.
- FARO CAM2 Software - The software used to perform measurements with the Laser Tracker.

- Quick Start Guides - Tripod (Box1), Laser Tracker (Box2), Computer (Box3).
- Instruction Manuals - The following documentation is provided: FARO Laser Tracker Users Manual, FARO CAM2 Users Manual, CAM2 SPC Graph Users Manual, and FARO SoftCheck Tool Managers Administrators Guide.

  NOTE: SPC Graph and Softcheck Tool Manager are sold with CAM2 Measure and not CAM2 Q, so manuals for these applications are not included with CAM2 Q.
- Quick Release Mandrel Mount - Allows for quick mounting to an instrument stand.
- Dust Cover - Cover to protect the Laser Tracker when not in use. The cover is only necessary when the Laser Tracker is left in very dirty environments.
- Cable Cover - 25-foot cover designed to protect the 30-foot cable. The 30-foot communication/power cable and remote temperature sensor can be bundled inside the cover.
- Documents - NIST traceable certification documentation.
- Heavy Duty shipping cases - One case for the Laser Tracker Head and one case for the MCU and accessories.

Optional Equipment

Your FARO Laser Tracker system may also include one or more of the following options:

- Instrument stand (Tripod) - A stand that allows for easy height adjustment and movement of the Laser Tracker around the work environment, and provides stability during measurements.
- Uninterruptible Power Supply (UPS) - Protects the Laser Tracker system from power spikes and provides a battery backup during a loss of power.
- High Accuracy Level Sensor - Allows measurement of a plane perpendicular to gravity.
- Remote Air and Material Temperature Sensors with 30' cable.
- Target Tooling Kit - Tooling for the 1.5" SMR. Includes drift nests, pin nests, a shankless nest, edge finders, etc.
- Various Optical Targets and Tooling.

- Wireless Ethernet - Provides wireless connection between the PC and the Laser Tracker.

Mounting

The FARO Laser Tracker is designed to mount on an instrument stand or on a trivet in the vertical or horizontal positions through the use of an expanding mandrel. The Laser Tracker operates in any orientation.

CAUTION: The expanding mandrel mount is designed to hold the Laser Tracker in only the upright vertical position or in the horizontal position. To mount the Laser Tracker upside down, bolt it directly into a mounting fixture.

Setting up the Instrument Stand

Place the instrument stand on a stable floor surface away from obstructions. Ensure that the instrument stand is resting on its adjusting pins and that the quick release mandrel mount is screwed firmly in place using the supplied "C" spanner wrench.

NOTE: For safety reasons, do not mount the Laser Tracker to a stand that is tilted more than 10° from vertical. When using the FARO Folding Stand (ACCS0137) with the legs in their lowest position, ensure that they are spread out as wide as possible with the center collar at the bottom of the center post. When the legs are extended, ensure that there is at least one meter between the legs for stability.

Mounting the Laser Tracker Head

The FARO Laser Tracker easily mounts to the instrument stand by lowering the Laser Tracker onto the mandrel mount. The Laser Tracker is locked in position by moving the locking lever clockwise (when viewed from above) by hand until it is tight.

Cable Connections

Power for the FARO Laser Tracker measuring head is provided by the MCU - the Laser Tracker measuring head does not have a power switch.

1 Make sure that the power switch on the MCU is in the "OFF" position.

2 Connect the power/communication cable to the socket on the back of the Laser Tracker measuring head and to the socket on the left side panel of the MCU.

3 Connect the MCU power cable into the power source, usually an Uninterruptible Power Supply.

CAUTION: Follow the above steps to prevent "*hot plugging*" the cable if the MCU is already switched on.

4 Connect the remote air temperature sensor to port 1 on the front of the MCU.

5 Connect the computer to the MCU using the Computer to MCU Ethernet cable from the right side of the MCU to the computers network port.

Powering Up

Apply power to the FARO Laser Tracker by pressing the switch on the right side of the MCU. Immediately after pressing the power switch, all five lights on the front of the Laser Tracker and the red and green lights next to the laser aperture blink while the Laser Tracker performs low-level diagnostics. These low level diagnostics are usually completed in 45 seconds.

NOTE: Apply power as soon as possible to begin the warm up. While the Laser Tracker is warming up, you can prepare other aspects of the inspection, such as programming or additional tooling.

The Laser Tracker then continues with the Smart Warm-up and Laser Stabilization.

Smart Warm-up

Immediately after applying power, your Laser Tracker starts the "Smart Warm-up." During this time, the blue light on the front of the Laser Tracker will blink and the Azimuth and Zenith motors will be on. When ready, the motors shut off and the Laser Tracker will spend approximately five minutes stabilizing its internal temperature. When the warm-up is complete, the blue light on the front of the Laser Tracker stops blinking. If measurement is required immediately, the Smart Warm-up routine can be skipped by running the Startup Checks and clicking on the SKIP WARM-UP button.

NOTE: A Laser Tracker that is stored in a cool environment and is brought into a hot environment will go through a longer warm-up than a Laser Tracker that has been stored in a hot environment.

Stabilization

On the Xi system, after the low level diagnostics successfully complete, the red laser indicator on the Laser Tracker continues to blink until the laser stabilizes, which takes 5 to 10 minutes. The model X does not require laser stabilization, so the red laser indicator will become solid red as soon as the low level diagnostics are complete.

To maintain a stable laser frequency, the laser tube adapts to large changes in ambient temperature (up to ±15°C) by varying its internal temperature to maintain a constant tube length. During Laser Stabilization, the laser tube heats to a temperature higher than the current ambient temperature for a brief period of time, and then stabilizes to a set point, from which the ambient temperature can vary up to ±15°C.

If the ambient temperature changes considerably from when the Model Xi was first energized, the laser may re-stabilize itself. The re-stabilization process it automatic and completes in less than five minutes.

After these low level diagnostics successfully complete, the red laser indicator and the blue OK indicator continue blinking until the laser is stabilized and the system warm up is complete. The laser will stabilize in five to ten minutes and the complete system warm-up can take between five and twenty five minutes depending on the ambient temperature.

Startup Checks

Each time the FARO Laser Tracker is powered up, or when power to the Laser Tracker is interrupted, the Laser Tracker must be initialized or started. This is done through the Startup Checks which initialize the angular encoders and the position-sensing detector. The Startup Checks automatically run in CAM2 when the FARO Laser Tracker is started as the current input device. For more information, see “Device Setup” on page 93.

1 Select CAM2 from the Windows Start menu.

2 CAM2 launches Startup Checks.

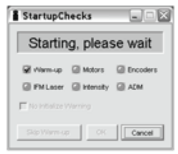


Figure 5-1 Startup Checks

NOTE: The Startup Checks wait for the Smart Warm-up to complete and the laser to stabilize.

Press the OK button to begin the Startup Checks. Keep your hands away from the Laser Tracker head as the motors turn on and the Laser Tracker rotates. This procedure takes approximately one minute.

Figure 5-2 Startup Checks

The Startup Checks are now complete. Click the OK button to continue.

Interim Test and Compensations

Just as with all high accuracy precision instruments, the FARO Laser Tracker must be verified regularly. Interim Tests allow you to test the Laser Tracker and Compensations allow you to adjust the parameters when necessary. Compensations also address several potential sources of Laser Tracker error and may be required after the Laser Tracker has been shipped or subjected to impact.

The FARO® CompIT chapter describes these compensations in detail. For more information, see “FARO® CompIT” on page 57.

Angular Accuracy Checks

The Angular Accuracy Checks routine checks the accuracy of the Laser Tracker with minimal disruption of the measurement in progress. Using

Angular Accuracy Checks, you can check the accuracy of the Laser Tracker anywhere in the Laser Tracker's measurement volume. This makes it possible to check the angular accuracy during the measurement of a part without moving or rotating the Laser Tracker. For more information, see "Angular Accuracy Checks" on page 58.

Self Compensation

Self Compensation is a routine that corrects for angular measurement error. It is a fully automated routine and is the primary method of compensating the Laser Tracker.

Click the SELF COMPENSATION button in the CompIT main menu to start the routine. When complete (approximately five minutes), the Laser Tracker is within the pointing accuracy specifications and ready to measure. For more information, see "Self Compensation" on page 63.

> **NOTE**: After the Self Compensation routine, check the backsights to verify accuracy.

Pointing CompIT

Pointing CompIT routine determines and corrects for backsight errors, or angular measurement error. Pointing CompIT is comprised of three parts:

- An Interim Test (IT)
- Compensation
- Self-Comp Optimization

The Interim Test uses measurements at predetermined locations and calculates the backsight error. After measuring, the Laser Tracker will pass or recommend to continue with the Pointing Compensation routine.

If obstructions prevent the measurement of any remote points, rotate the Laser Tracker on its stand. For more information, see "Pointing Compensation" on page 66.

ADM

The ADM (Absolute Distance Measurement) Interim Test checks the accuracy of the ADM radial measurement. The model Xi compares the ADM measurement to the Interferometer (IFM) measurement. The model X compares the ADM measurement to the angular measurement of the Laser Tracker. For more information, see "ADM Checks" on page 77.

Powering Down

Use the following steps to power down the Laser Tracker:

1 Exit CAM2 Measure and shut down the computer.

2 Press the switch on the right side of the MCU to power down the Laser Tracker.

3 Disconnect the communication/power cable from the back of the Laser Tracker measuring head and from the left side panel of the MCU.

4 Disconnect the Computer to MCU Ethernet cable from the front of the MCU and from the computers network port.

5 Disconnect the ambient temperature sensor from MCU.

6 Unlock the locking lever by moving the locking lever counterclockwise (when viewed from above) until it is loose, and carefully remove the Laser Tracker head from the stand by grasping the upper handles.

7 Store the SMR and other targets in their protective cases.

Chapter 6: Understanding Measurement Accuracy

As a general rule of thumb, plan a measuring session to achieve accuracy equal to 10% of the smallest tolerance of the part. This is known as the "10 to 1" rule.

For example, if the smallest tolerance on your part is 1.0 mm, the measurement device should be accurate to at least 0.1 mm.

In order to determine the uncertainty associated with a particular measuring session, carefully estimate the contribution of errors from all identifiable sources. However, since the effects of some environmental factors are difficult to quantify, good metrology practice requires that the effects of all sources of error be minimized or eliminated. If the effects of environmental errors are left completely uncontrolled, the accuracy of the measurements may degrade to such an extent that the entire measuring session has to be rejected. Whenever possible, measure your part in a location where environmental factors are closely controlled and kept stable.

Effects of Atmospheric Conditions

As the temperature, barometric pressure, and relative humidity of air change, so does its index of refraction. A 1 part per million change in the index of refraction occurs for a 3 mmHg change in pressure, a 1°C in temperature, or a 40% change in relative humidity at 40°C. The index of refraction cannot be calculated correctly without the current atmospheric condition values. Your Laser Tracker is equipped with weather sensors that measure the temperature, pressure, and humidity of the air around the Laser Tracker every five seconds.

Thermal gradients, air turbulence, or air pockets of different temperatures in the path of the laser beam will affect the direction of the laser beam and cause errors in the angular measurement taken by the Laser Tracker. Avoid these errors by not measuring near heating and air conditioning ducts or any other source of these thermal effects.

Environmental Effects

Environmental Effects such as excess vibration, mounting stability, and temperature can affect the accuracy of the measurements. Eliminate these outside factors whenever possible.

Do not move heavy objects near the part before or during a measurement session. The magnitude of the effect depends largely on the weight of the object and the stability of the workshop floor foundations. In some cases, the floor may shift enough to disrupt measurement sessions for days after an object has been moved.

Support the part in the same manner for measurement as its intended function. This ensures that differential loading does not result in distortions in the part when it is put to use.

For high accuracy measurements, power up the Laser Tracker in the environment before measuring and allow it to reach thermal stability in the local environmental conditions.

For high accuracy work, use redundant readings for each measurement. Taking redundant readings provides a means of detecting gross errors or blunders, may reduce the environmental effects that you have not been able to eliminate, and provides better statistical sampling. For example, measure a planar surface with more than three readings.

Targets

Regularly check the target nest and the SMR for metal filings or debris that may prevent the target from seating in the nest.

Dimensional inaccuracies of target offsets are a frequent source of error during a measurement session. Check the Probe settings to select any additional tooling before measuring. For more information, see "Probes" on page 95.

Physical Changes in the Part or Stand

Regularly inspect the Laser Tracker stand and the part to make sure that both remain stable throughout measuring; any unknown change to the position of the Laser Tracker stand and the part degrades the measurement accuracy.

Radiant energy from the sun, hot lights, or space heaters during measurement can introduce non-uniform expansion in the measurement equipment or the part, degrading the measurement accuracy. Whenever possible, shield the Laser Tracker and the Part from external heat sources.

Angular Accuracy Checks

The Laser Tracker reads the azimuth and zenith angles and the distance to the target for each reading in a measurement. The readings are compensated using a kinematic model. The model has parameters for the laser's four degrees of freedom (two rotational and two translational), and two parameters for the gimbal (axis offset and axis non-squareness).

Verify the Laser Tracker accuracy using the Angular Accuracy Checks. For more information, see “Angular Accuracy Checks” on page 58. These checks compare a point reading taken in frontsight mode with one taken in backsight mode. The resulting deviation reports twice the worst-case error for a point measured at the range and position of the backsight reading. The error in a backsight reading is effectively an error that is not compensated for by the kinematic model.

Although the kinematic model is highly effective in minimizing Laser Tracker measurement error, there are still many factors that are not accounted for by the model. Target quality, atmospheric induced errors, and thermal expansion are some of the errors not addressed by the model. Most of these errors are taken into account in formulating the specification for the Laser Tracker.

Measurement Strategy

Understanding how the Laser Tracker measures plays an important role in achieving high accuracy results. Laser Tracker measurements are comprised of two angular measurements and one distance measurement. The distance accuracy specifications are higher than the angular specifications. This means that if the features measured with the Laser Tracker are measured primarily in line with the path of the beam with very little angular encoder movement, the accuracy will be higher than features measured primarily with the angular encoders.

For example, if a scale bar is placed horizontally in front of the Laser Tracker, the distance between points at either end of the bar will be measured predominantly with the azimuth encoder. If the bar is placed in line with the laser beam, the distance will be measured primarily with the distance measurement. The accuracy achieved in the horizontal case will be within the specifications of the Laser Tracker system, however, the accuracy achieved in the in-line case will likely be much higher. In fact, a well-aligned Tracke can measure with interferometer accuracy when the angular measurements are minimized.

To improve accuracy, set up the Laser Tracker to minimize the angle in a measurement session, but take care not to make the distance too great. When setting up to measure a rectangular part, the best position for the Laser Tracker is a couple meters away from the end of the rectangle. If the rectangle is over 15 meters long, it may be better to move the Laser Tracker to the side of the rectangle but still close to one end. Placing the Laser Tracker in the middle of the long side of the rectangle will result in an angular measurement volume of over 120 degrees compared with only a 30 degree volume from the end.

Chapter 7: Care of the FARO® Laser Tracker

Use care in handling the FARO Laser Tracker system, especially while moving it from and one place to another; there are no user replaceable parts.

Optical Target Care

Optical Targets are an important part of the FARO Laser Tracker Systems. Handle them with great care to ensure their accuracy and longevity.

Target care includes:

- Never touching the optical surfaces of the target.
- Never dropping the target.
- Keeping the target free of dust and moisture by storing it in the case.
- Cleaning the target only when necessary.

If the Laser Tracker does not lock onto the target, use the Operational Checks command to check your SMR. If the Return Power value is "GOOD" your SMR does not need cleaning.

CAUTION: Unnecessary cleaning will degrade the reflective surface of the SMR.

Cleaning the Optical Targets

In many cases, the optical surfaces of the target are simply dusty and just require cleaning with compressed air.

CAUTION: Do not clean with compressed air available from a hose in a workshop - this is seldom clean and may coat the SMR with oil or some other contaminant.

Spray the air away from SMR for a few seconds before spraying it onto the optical surfaces.

NOTE: Always hold the can upright and never shake the can when spraying compressed air.

If the target is still not functional after blowing off any dust, use the following target specific procedures.

CAUTION: Never use a dry cotton swab or tissue to clean the optical surfaces because these will scratch the optical surfaces. Cleaning with any improper chemicals will destroy the reflective surface.

Standard SMRs and RetroProbes (Silver Coated)

1 Breathe on the optical surfaces.

2 Gently slide a cotton swab in one direction while rotating it in the opposite direction. Use one cotton swab for each pass and then discard it. You may need several swabs to clean the optical surfaces thoroughly.

3 If this does not successfully remove the residue, clean the optical surfaces with Optima Grade acetone.

4 Moisten a clean cotton swab with acetone.

5 Gently slide the cotton swab in one direction while rotating it in the opposite direction.

6 Remove any remaining cotton dust with canned compressed air.

Break Resistant SMRs (Gold Coated)

1 Moisten a clean soft tissue with the Optima Grade acetone.

2 Gently place the moistened tissue on the optical surface and slowly pull it across.

3 Remove any remaining tissue lint with canned compressed air.

Cleaning the Laser Trackers Optics

The Laser Tracker's aperture window and the embedded target covers may need occasional cleaning.

- Remove any dust from the window using canned compressed air.
- If more cleaning is necessary, use water vapor and a clean cotton swab in the same manner as the SMRs (above). If water vapor does not successfully remove the residue, use denatured alcohol.

Storage

When storing for long periods of time, pack the Laser Tracker in its shipping cases to protect it from environmental hazards, dust, and dirt.

Store the Laser Tracker in an environment where it will not be subject to extreme temperatures, environmental conditions, or heavy vibrations.

Transportation

When transporting the Laser Tracker around a shop floor, keep it mounted on a heavy-duty stand with wheels. Before moving the Laser Tracker, fully lower the tripod's extension tube. Avoid any divots or large gaps in the floor. Do not slide the stand and Laser Tracker across the floor - lower the tripod's wheels to raise the tripod off the floor.

When transporting the Laser Tracker long distances or between facilities, pack the Laser Tracker in its shipping cases. Always place the shipping cases on a pallet when using a forklift, and gently lift and lower the pallet.

Chapter 8: Getting Help

This chapter describes the different resource tools you should use to get help with your FARO Laser Tracker system. These include electronic Help files, printed documentation, and the FARO Customer Support Department.

Online Help

FARO CAM2 Measure is the primary software product used with the FARO Laser Tracker and contains a help file that covers an extensive range of topics.

Documentation

This User Manual covers topics associated with the use of the FARO Laser Tracker main hardware components. Also included in this guide are supplemental FARO Guides that detail procedures for performing diagnostic checks and completing various calibration and compensation routines.

See "Operational Checks" on page 49. See "FARO® CompIT" on page 57.

Other FARO Publications include the FARO CAM2 Q Manual which details the use of CAM2 Q, FARO CAM2 Measure Manual which details the use of CAM2 Measure, and the FARO RetroProbe User's Guide which covers the use of the FARO RetroProbe 100/400.

FARO Customer Support

FARO is proud to provide its customers with the best support in the industry. Our commitment to servicing our customers needs is evident in our products, services, and customer satisfaction. The following section explains how FARO Customer Support may be contacted with any technical questions.

How to Contact FARO

To aid in our responsiveness, FARO asks that customers use one of the following methods to contact the Help desk with technical questions:

Internet
Visit the FARO WEB site at *www.faro.com* and enter the Support Center found under Customer Care.

Electronic Communication
Phone, Fax or E-Mail. *See "Technical Support" on page 113.*

Mailing Address
FARO Technologies, Inc.
Laser Division
222 Gale Lane
Kennett Square, PA 19348

International Mailing Address

FARO Europe GmbH & Co. KG Lingwiesenstrasse 11 D-70825 Korntal-Münchingen Germany	FARO Japan 716 Kumada, Nagakute-cho, Aichi-gun, Aichi-Ken 480-1144 JAPAN
FARO China Floor 1, Building 29 No.396 Guilin Road Shanghai 200030, CHINA	FARO Singapore Pte. Ltd. 3 Changi South Street 2 #01-01 Xilin Districentre Building B SINGAPORE 486548

Chapter 9: Product Specifications

This chapter contains the FARO Laser Tracker technical specifications for all FARO Laser Trackers built after January 4, 2006. For Laser Trackers built prior to this date, please consult the original User Manual that shipped with the Laser Tracker.

General Specifications and Rated Conditions

SIZE

Laser Tracker Head (X/Xi)	280 x 552 mm (11 x 21 3/4 in.)
Master Control Unit	160 x 180 x 280 mm (6 x 7 x 11 in.)

WEIGHT

Laser Tracker Head X Model	20 kg (44 lbs.)
Laser Tracker Head Xi Model	22 kg (48 lbs.)

RATED CONDITIONS

Measurement Envelope	
Distance	Min 0 m, Max 35 m
Range of horizontal angle	360 degrees
Range of vertical angle	125 degrees
a. *Temperature Range*	
Operating	Min -15°C (5°F), Max 50°C (122°F)
Thermal Gradient Limits	Max any °C/m Max any °C/hr
b. *Humidity*	
Operating	Min 0% RH, Max 95% RH
c. *Barometric Pressure Range*	
Operating	Min 652 mmHG, Max 825 mmHG
d. *Ambient Light*	Direct exposure to sunlight or flash lamps may compromise Laser Tracker performance.

e. *Electrical*

Voltage	88 - 264 VAC ± 10%
Current	5A (US), 2.5A (EU)
Frequency	50/60 Hz
Surge	1000 V common, 500 V differential, 1.25/50µs waveform
Sag	70% Nominal Voltage, 0.5s, 40% Nominal Voltage, 5.0s
Max Transient Voltages and Duration	1000 V common, 500v differential, 5/50 ns, 1 min waveform

f. *Probe Type*

Diameter	1.5 in.
Reflector Type	Spherically Mounted Retroreflector (SMR)

g. *Sampling Strategy*

Acquisition time	1 sec
Frequency	1000 points/sec

LIMITING CONDITIONS

h. *Temperature Range*	Min -20°C (-4°F), Max 70°C (158°F)
i. *Humidity Range*	Min 0% RH, Max 100% RH
j. *Barometric Pressure Range*	Min 0 mmHG, Max 1500 mmHG

* Any temperature gradient can be accommodated if (1) appropriate formulas are used to compensate for air refraction effects and (2) an interim test is periodically performed and an angular compensation (pointing compensation or self compensation) carried out as required.

Measurement Specifications

Angular Encoders (transverse)

Horizontal Envelope ±270°

Vertical Envelope +75° to -50°

Maximum Angular Measurement Velocity 180°/sec.

XtremeADM (radial)

Sample Rate 10,000 samples/second

Resolution 0.5 µm

Minimum Working Range 0 m

Maximum Working Range 35 m

Interferometer (radial Model Xi only)

Maximum Radial Velocity 4 m/sec.

Resolution 0.158 µm

Minimum Working Range 0 m

Maximum Working Range 35 m

Level

Accuracy +/- 2 arc seconds

Data Acquisition

System Sample Rate 1,000 samples per second

Point Acquisition Rate 350 points per second

Accuracy Specification and Formulas

The following discussion presents details on the accuracy for the FARO Laser Tracker per the ASME B89.4.19 Standard. Accuracy is expressed as Maximum Permissible Error (MPE). Typical performance is half the MPE values.

The performance specifications for the FARO Laser Tracker are given in Table 1. Measurement accuracy is affected not only by Laser Tracker performance but also by the variation in air temperature, as quantified in Table 2.

Laser Tracker Subsystem	Symbol	Maximum Permissible Error	
Interferometer (IFM)	e_{IFM}	$4\mu m + L \cdot 0.8\mu m/m$	(1)
Absolute distance meter (ADM)	e_{ADM}	$20\mu m + L \cdot 0.8\mu m/m$	(2)
R0 parameter (R0)	e_{R0}	$20\mu m$	(3)
Transverse	e_r	$36\mu m + L \cdot 6\mu m/m$	(4)

Measurement Type	Symbol	Error	
Radial (IFM or ADM)	E_{TEMPR}	$L \cdot (\Delta T_{AVE}/°C) \cdot (1\mu m/m)$	(5)
Transverse	E_{TEMPT}	$0.5 \cdot (L^2 \partial T/\partial x)_{EFF} \cdot (1/°C) \cdot (1\mu m/m)$	(6)

The geometrical arrangement of a Laser Tracker that measures the coordinates of points 1 and 2 is shown in Figure 9-1. From these coordinates, the length d is determined. The maximum permissible error (MPE) in this length measurement is the maximum error permitted by the performance verification tests. The MPE of measured length d is calculated using Equation (7) below. In this equation, the quantities that contain the subscripts R1 or R2 refer to either the IFM or ADM specifications in Table 1, depending on whether the IFM or ADM is used.

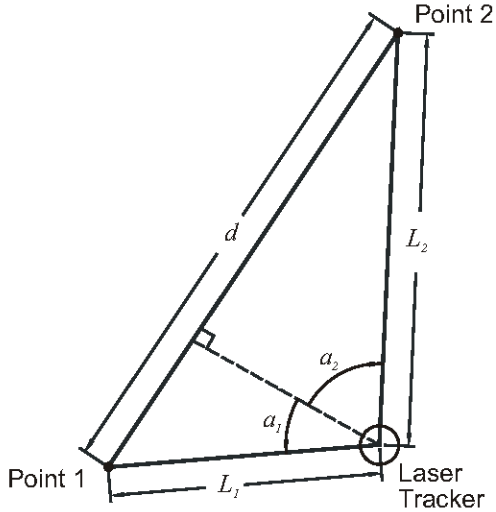


Figure 9-1 Laser Tracker Geometry

$$MPE_d = \left(e_{R1}^2 \sin^2 a_1 + e_{R2}^2 \sin^2 a_2 + e_{R0}^2 (\sin a_1 + \sin a_2)^2 + e_{T1}^2 \cos^2 a_1 + e_{T2}^2 \cos^2 a_2 + E_{TEMPR1}^2 \sin^2 a_1 + E_{TEMPR2}^2 \sin^2 a_2 + E_{TEMPT1}^2 \cos^2 a_1 + E_{TEMP2}^2 \cos^2 a_2\right)^{\frac{1}{2}} \quad (7)$$

The angles a1 and a2 are positive in the directions shown in Figure 1 and negative in the opposite directions. The quantities eR1, eR2, eR0, eT1, and eT2 are calculated using Equations (1) - (4). The subscript 1 refers to path 1 and the subscript 2 refers to path 2. So, for example, $e_{T1} = 36\mu m + L_1 \cdot 6\mu m/m$. The quantities $E_{TEMPR1}, E_{TEMPR2}, E_{TEMPT1}$ and E_{TEMPT2} are calculated using Equations (5) and (6). The quantity ΔT_{AVE} in Equation (5) is the average temperature of the air through which the laser beam passes minus the temperature of the air at the Laser Tracker's air temperature sensor. For a laser beam that travels through path 2, $E_{TEMPR2} = L_2 \cdot (\Delta T_{AVE2}/°C) \cdot (1\mu m/m)$. The quantity $(\partial T/\partial x)_{EFF}$ in Equation (6) is the maximum effective thermal gradient in the direction transverse (perpendicular) to the path of the laser beam. Transverse temperature gradient is defined as the number of degrees of temperature change per unit distance in the direction transverse to the laser path. For path 1, $E_{TEMPT1} = 0.5 \cdot L_1^2 (\partial T/\partial x)_{EFF1} \cdot (1/°C) \cdot (1\mu m/m)$. In ordinary factory environments, the last four terms in Equation (7) - the thermal terms - can be ignored. In the testing of Laser Trackers at the FARO factories and service centers, these thermal terms in Equation (7) are omitted in the calculation of MPE.

A special case is the outside buck-in measurement in which the Laser Tracker is aligned with points 1 and 2 as shown in Figure 9-2.

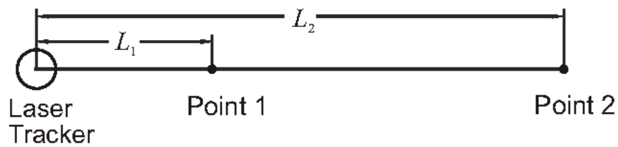


Figure 9-2 Laser Tracker Buck-In Geometry

Point 1 establishes the reference for the Laser Tracker measurement, much as the home position establishes the reference point for many other Laser Tracker measurements. Also, in this case, the air temperature of the beam path between the Laser Tracker and point 1 is the same for both measurements. Under these conditions, the two coordinate measurements are correlated, permitting Equation (7) to be rewritten as:

$$MPE_d = e_{R12} + E_{TEMPR12} \qquad (8)$$

Here, the quantity e_{R12} refers to either the ADM or IFM specifications in Table 1. In Equations (1) and (2), the length is equal to the distance between the points; in other words, $L = L_2 - L_1$. Also, the quantity $E_{TEMPR12} = (L_2 - L_1) \cdot (\Delta T_{AVE12}/°C) \cdot (1 \mu m/m)$, where ΔT_{AVE12} is the average temperature of the air between points 1 and 2 minus the temperature of the air at the Laser Tracker's air temperature sensor.

Another special case is that of the two-face measurement. In this measurement, the coordinates of a point are first measured in the usual mode, referred to as front-sight mode, and then in the backsight mode. To put the Laser Tracker in backsight mode, the azimuth axis is rotated by 180 degrees and then flipped about the zenith axis to point the laser beam back at the target. The transverse distance between the frontsight and backsight coordinates is the backsight error. The two-face test is a challenging test of Laser Tracker performance because most of the Laser Tracker transverse errors are doubled. The two-face MPE is:

$$MPE_{two-face} = 2e_{R1} \qquad (9)$$

The following tables list MPE tolerances for scale bar and outside buck-in tests based on the B89.4.19 Standard (equations described above). Ranges in the table are taken directly from the B89.4.19 specification.

Scale Bar Measurement (2.3m)

Test Positions (Range)	MPE_{IFM}	MPE_{ADM}
Horizontal (0.2 m)	43	51
Horizontal (2.8 m)	72	73
Horizontal (6.2 m)	103	103
Vertical (2.8 m)	72	73
Vertical (6.2 m)	103	103
Right-Diagonal (2.8 m)	72	73
Right-Diagonal (6.2 m)	103	103
Left-Diagonal (2.8 m)	72	73
Left-Diagonal (6.2 m)	103	103
Two-Face (1.2 m)	92	92
Two-Face (3 m)	111	111
Two-Face (6 m)	145	145

Outside Buck-In Measurements

Test (Distance Between Points)	MPE_{IFM}	MPE_{ADM}
IFM Ranging Test (6 m)	9	--
IFM Ranging Test (12.5 m)	14	--
IFM Ranging Test (19 m)	19	--
IFM Ranging Test (25 m)	24	--
ADM Ranging Test (6 m)	--	25
ADM Ranging Test (12.5 m)	--	30
ADM Ranging Test (19 m)	--	35
ADM Ranging Test (25 m)	--	40

Chapter 10: Operational Checks

This chapter describes the Operational Checks for the FARO Laser Tracker. These checks use commands found in FARO CAM2.

The Operational Checks determine the operating condition of the Laser Tracker as well as verifying that environmental factors such as air movement and vibration will not degrade measurement accuracy.

References

FARO Laser Tracker Quick Start Guide - FARO part number 922-01212

Chapter 11: FARO® CompIT. *See "FARO® CompIT" on page 57.*

Equipment

1 FARO Laser Tracker and support equipment
2 Spherically Mounted Retroreflector (SMR)
3 Calibration Tripod, or nest, to hold the SMR securely at the reference position

When to Perform

Run Operational Checks to ensure that the Laser Tracker is performing at the expected level of stability and accuracy. Run these checks after the Laser Tracker has been moved to a new operating environment.

Preparation

Set up, supply power to, and start the Laser Tracker. For more information, see "Setting up the FARO® Laser Tracker" on page 23.

NOTE: Powering down the Laser Tracker is not necessary at the end of the day; restarting is only necessary just after powering up.

Start your computer and the CAM2 software.

Procedure

The following procedures cover the Operational Checks of the FARO Laser Tracker.

Select DEVICES < LASER TRACKER < OPERATIONAL CHECK (Alt S, L, O) in CAM2. This displays the OPERATIONAL CHECKS dialog box.

Figure 10-1 Operational Checks dialog box

General Page

View the Weather information and verify the SMR Return Power on the GENERAL PAGE tab of the OPERATIONAL CHECKS dialog box.

Use the SAVE and SAVE AS buttons to save the test results to an ASCII text file.

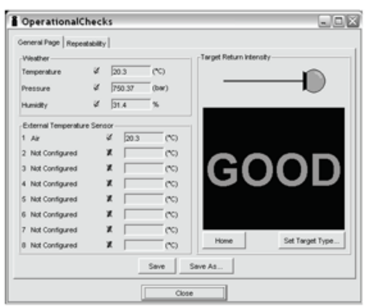


Figure 10-2 General Page of the Operational Checks

Weather

View the temperature, pressure, and humidity of the measuring environment. An icon indicates the source of the reading:

- Lightning Bolt - the reading originates from the Laser Tracker's internal sensors.
- Pencil - the reading has been manually entered.

SMR Return Power

The SMR Return Power value is the measure of the laser intensity as it returns to the Laser Tracker from an SMR. Intensity is indicated as:

- Good
- Marginal
- Bad

  NOTE: A dirty SMR is the most common cause for low SMR Return Power.

To check the SMR Return Power:

1 Choose the SET TARGET TYPE... button and select your SMR. Click OK to continue.

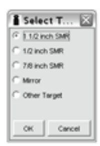


Figure 10-3 Set Target Type

2 Place the SMR at the Home position on the Laser Tracker and press the HOME button.

Figure 10-4 Return Power Display

Repeatability

The Repeatability Checks test the distance measurement and encoders, and ensure that the Laser Tracker is consistent in its measurements. The repeatability of the measurements depends on the mounting of the Laser Tracker, the stability of the Target, and the environment.

Repeatability Checks

Choose the REPEATABILITY tab of the OPERATIONAL CHECKS dialog box to start the Repeatability Checks.

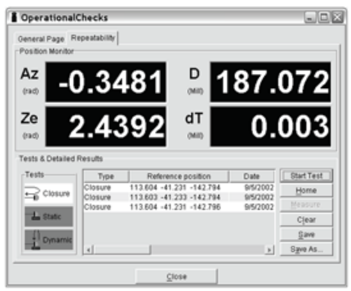


Figure 10-5 Return Power Display

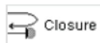
- The POSITION MONITOR section displays the real time position of the target expressed in the Laser Tracker's spherical coordinate system: Azimuth angle (Az), Zenith angle (Ze), and Radial distance (D). The "dT" value displays the last measurement result.
- The "Tests" section contain buttons to activate one of the three repeatability tests.
  - The START TEST and MEASURE buttons are used to carry-out the specific tests, while the HOME button can be used to reset the laser should a beam break occur.
- The "Tests & Detailed Results" section displays the results of each test in detail. Use the CLEAR button to remove any test results.
- Use the SAVE and SAVE AS buttons to save the test results to an ASCII text file.

Closure (For Interferometer Equipped Laser Trackers Only)

The Closure check verifies that the interferometer is counting properly. An out of tolerance result on the test may also indicate a bad SMR or debris in the TMR.

1 Place the SMR in the TMR.

2 From the REPEATABILITY tab of the Operational Checks dialog box, click the HOME button to reset the laser.

3 Select the 

button and click START TEST.

4 Remove the SMR from the TMR and move it around the measurement volume, making sure that the SMR is constantly being tracked.

NOTE: Make sure to move the SMR throughout the entire measurement volume, and that the furthest point, or farther, in the measurement volume is included.

5 Return the SMR to the TMR and click MEASURE to record the repeatability.

NOTE: The Total value in the Test Results section should be in the following range: -0.005mm < Total < +0.005mm.

6 Repeat this procedure two (2) more times making sure that the above criteria are maintained. Click STOP TEST to finish.

7 If the criteria in Step (5) is not met, re-home the Laser Tracker and repeat Steps (3) through (5) above. If the Closure Test still fails, contact FARO for further instructions.

Static Repeatability

The Static Repeatability check determines whether the Laser Tracker can repeat the measured position of the SMR in a fixed position. The SMR remains at the reference position and does not move at all during the test. This check is critical for determining whether the Laser Tracker, part, and drift points are stable.

1 Place the SMR in the TMR.

2 From the REPEATABILITY tab of the OPERATIONAL CHECKS dialog box, click the HOME button to reset the laser.

3 Position the tripod or use an available nest approximately six (6) meters from the Laser Tracker. Angular position is not critical to this check. Use a control point on the part if the position is approximately six (6) meters from the Laser Tracker.

4 Remove the SMR from the home position and track to the reference position.

5 Select the 

button and click on START TEST.

- Enter a time delay between measurements, or use the default, and press OK.

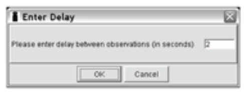


Figure 10-6 Enter Delay

- The Laser Tracker first measures the reference position, then after the time delay, measures the reference position again. Allow the Laser Tracker to collect about ten (10) measurements.

6 Click STOP TEST and review the results.

- Look at the “Total” values in the TEST RESULTS section. The total error should be less than 0.025mm.

7 If the total error is greater than 0.025mm, repeat this check at two other locations.

NOTE: If the total error is consistently high, check the stability of the Laser Tracker, mandrel, stand and the tripod/nest before repeating the Static Repeatability Test. If the Static Repeatability Test continues to fail, contact FARO Customer Support.

Dynamic Repeatability

This check determines whether the Laser Tracker can repeat the measured position of the SMR at multiple positions throughout the measurement volume. This check is critical for determining whether the Laser Tracker, part, and drift points are stable while measuring with the SMR.

1 Place the SMR in the TMR.

2 From the REPEATABILITY tab of the OPERATIONAL CHECKS dialog box, click the HOME button to reset the laser.

3 Use an available monument/nest affixed to a stable stand or on the object being measured as the reference position approximately six (6) meters from the Laser Tracker. Use a control point on the part if the position is approximately six (6) meters from the Laser Tracker.

NOTE: The calibration tripod supplied with the Laser Tracker is NOT a suitable stand to use for this test.

4 Remove the SMR from the TMR and track to the reference position.

5 Select the 

button and click on START TEST.

- The Laser Tracker first measures the reference position. Then, track the SMR around the measurement volume.

6 Return the SMR to the Reference position and click MEASURE.

7 Click STOP TEST and review the results.

- Look at the “Total” values in the TEST RESULTS section. The total error should be less than 0.025mm.

8 If the total error is greater than 0.025mm, repeat this check at two other locations.

NOTE: If the total error is consistently high, check the stability of the Laser Tracker, mandrel, stand and the nest before repeating the Static Repeatability Test. If the Dynamic Repeatability Test continues to fail, contact FARO Customer Support.

Following the Checks

Your Laser Tracker is now ready to measure accurately. In addition to these Operational Checks, always complete Angular Accuracy Checks and Self Compensation prior to any measurement session to verify the accuracy of the Laser Tracker. *See “Angular Accuracy Checks” on page 58, and “Self Compensation” on page 63.*

Chapter 11: FARO® CompIT

This chapter serves as a tutorial for FARO CompIT. Before continuing, you must have a working knowledge of the FARO Laser Tracker System and FARO CAM2.

The FARO CompIT software provides interim tests that allow for quick assessment of the Laser Tracker's accuracy. It also provides compensation routines to adjust parameters that compensate the Laser Tracker's pointing accuracy, ADM accuracy, and precision level.

Getting Started


In CAM2 Measure, choose DEVICES < HARDWARE CONFIG to open the HARDWARE CONFIGURATION dialog box.

Figure 11-1 Hardware Configuration dialog box

Start the FARO CompIT program by pressing the CompIT button.

CompIT is also accessible directly from the Windows Start menu by opening the FARO Utilities program and clicking CompIT.

Figure 11-2 FARO Utilities dialog box

Standard Tab

Clicking the CompIT button displays the CompIT dialog box.

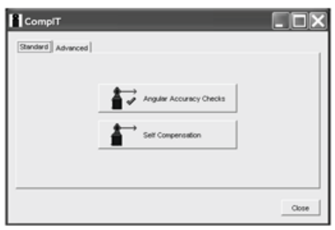


Figure 11-3 FARO CompIT dialog box

The Standard tab of the CompIT dialog box contains the two most frequently used functions: Angular Accuracy Checks and Self Compensation.

Angular Accuracy Checks starts the Angular Accuracy test. *See "Angular Accuracy Checks" on page 58.*

Self Compensation starts the Self Compensation routine. *See "Self Compensation" on page 63.*

Angular Accuracy Checks

This check should be performed after Startup Checks, before each measurement session, or if the temperature has changed more than 5° Fahrenheit. The Angular Accuracy Check verifies the Laser Tracker's accuracy during the course of a measurement session with minimal disruption. The CompIT Angular Accuracy Check measures the SMR in both frontsight and backsight, and calculates the difference between the two measurements, or the Backsight Error. The Angular Accuracy Check can collect backsight deviations anywhere in the Laser Tracker's measurement volume.

Equipment

1 FARO Laser Tracker and support equipment

2 1.5" Spherically Mounted Retroreflector (SMR)

3 Calibration Tripod

Procedure

Set up, power up, and start the FARO Laser Tracker. *See "Setting up the FARO® Laser Tracker" on page 23.*

1 In the CompIT dialog box, click the Angular Accuracy Checks button. The SELECT MODE dialog box appears.

Figure 11-4 Select Mode dialog box

Select GUIDED POINTS and click OK to move the SMR to a specific location. Select USER SELECTED POINTS and click OK to move the SMR to any location. If you select both check boxes, first move the SMR to a specific location, and then to any location for additional points. Always use a stable nest for the SMR, such as the Laser Tracker's calibration tripod.

NOTE: For USER SELECTED POINTS, complete a minimum of three locations, but make sure that you cover the measurement volume of your part or tool.

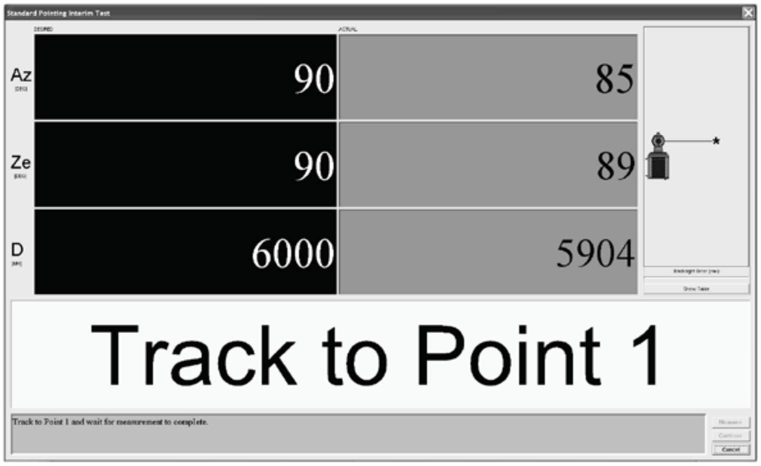


Figure 11-5 Track to Point 1

- **DESIRED** value: The target values for Azimuth, Zenith, and Radial Distance.
- **ACTUAL** value: The current Azimuth, Zenith, and Radial Distance values of the SMR. The angle and distance values are red until you track the SMR to desired values. The values switch to green when the SMR is in an acceptable zone around the desired values. The Radial distance value switches to yellow if the SMR is beyond its desired value. When all of the values are green, the Laser Tracker waits five (5) seconds for stability before measuring the SMR.

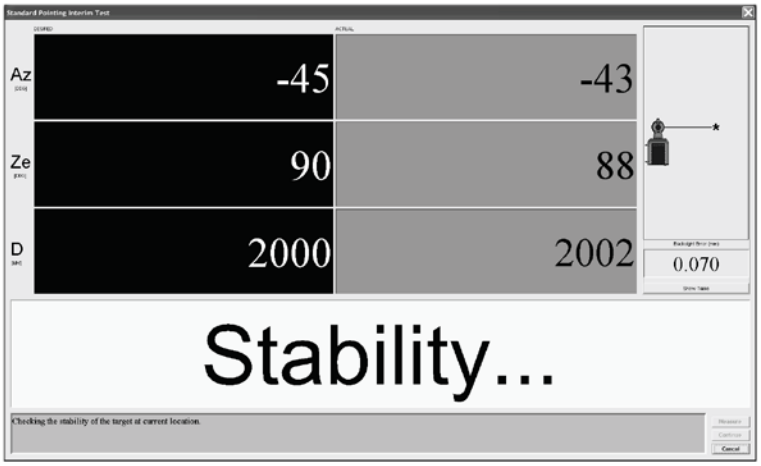


Figure 11-6 Stability

If the SMR does not stabilize within 60 seconds, an error message appears. Check the stability of the SMR and the Laser Tracker before trying again.

NOTE: You can change the stability delay by clicking the Customize button in the Advanced tab of the CompIT dialog box. *See "General" on page 90.* You can disable the Auto Measure function by clicking the Settings button in the Advanced tab of the CompIT dialog box. *See "Settings" on page 91.* When Auto Measure is disabled, take measurements by clicking the Measure button.

Click the SHOW TABLE button to display a list of any previous backsight errors.

2 When the backsight measurements at the first location are complete, move the SMR to another location. Track the SMR to the next point and wait for stability.

3 After completing the last backsight measurement, click the Continue button. You will see the results of this check in the ANGULAR ACCURACY RESULTS dialog box.

Figure 11-7 Angular Accuracy Results dialog box

4 Click DONE to continue, or click DETAILS to see the results.

Click REPORT to save the results to a text file. The tolerances for the Angular Accuracy Checks are calculated for the Maximum Permissible Error (MPE) based on the specifications of your Laser Tracker per the ASME B89.4.19 Standard.

Click the ANGULAR ACCURACY CHECK DEVIATIONS tab to view the detailed results.

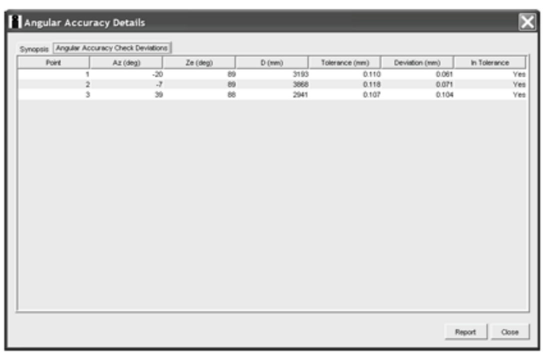


Figure 11-8 Angular Accuracy Check Deviations tab

5 Click CLOSE to continue.

If the results of the Angular Accuracy Checks are not within tolerance, click CONTINUE to run the Self Compensation Routine.

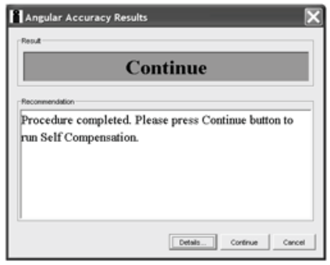


Figure 11-9 Angular Accuracy Check complete

Self Compensation

Run the Self Compensation routine before any measurement session to optimize the Laser Tracker's accuracy. Self Compensation will adjust the Laser Tracker's angular accuracy to within specification for the full range of the Laser Tracker. FARO recommends running the Angular Accuracy Checks first to verify angular accuracy prior to running Self Compensation.

NOTE: If the Angular Accuracy Checks pass, then Self Compensation is not necessary.

Equipment

1 FARO Laser Tracker and support equipment.

Procedure

Set up, power up, and start the FARO Laser Tracker. *See "Setting up the FARO® Laser Tracker" on page 23.*

1 In the CompIT dialog box, click the Self Compensation button.

2 CompIT begins the Self Compensation routine. This routine is automatic.

3 After completing the routine, you will see the results in the SELF COMPENSATION RESULTS dialog box.

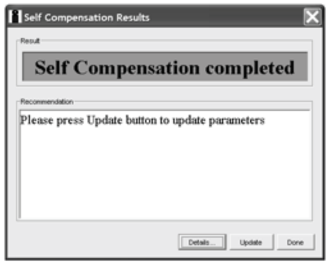


Figure 11-10 Self Compensation results

- Click UPDATE to save the results to the Laser Tracker.
- Click DONE to exit the Self Compensation routine.
- Click DETAILS to see detailed results.

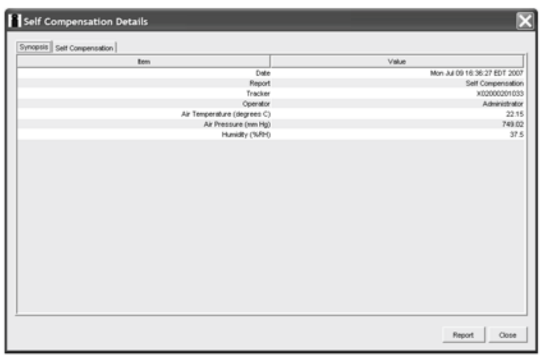


Figure 11-11 Synopsis tab

- Click Report to save the results to a text file.

Click the SELF COMPENSATION tab to view the Before, After and Change in Laser Tracker Parameters. Self Compensation adjusts the two rotational (RX and RY) and two translational (CTX and CTY) parameters.

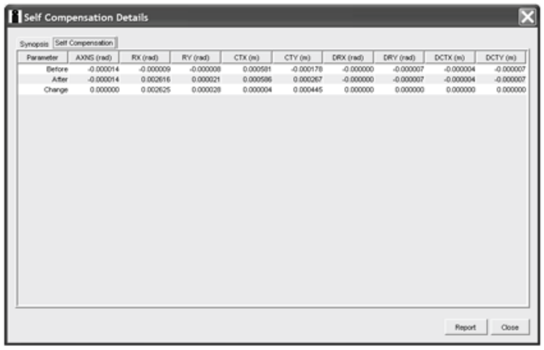


Figure 11-12 Self Compensation tab

After completing the Self Compensation routine you can start the Angular Accuracy Checks if you did not run them prior to Self Compensation. *See "Angular Accuracy Checks" on page 58.* Click YES to run the Angular Accuracy Checks, or NO to exit.

If Self Compensation can not adequately compensate the parameters, a message appears to continue to the Pointing Interim Test.

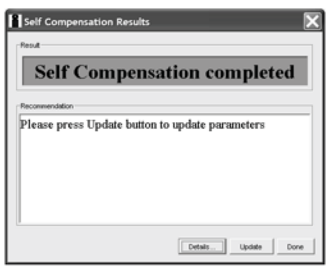


Figure 11-13 Self Compensation routine complete

Advanced Tab

Clicking the CompIT button displays the CompIT dialog box.

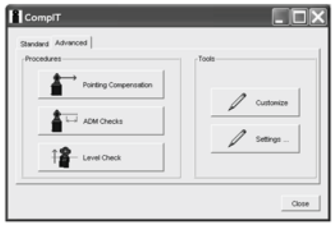


Figure 11-14 FARO CompIT dialog box

The Advanced tab of the CompIT dialog box contains: Pointing Compensation, ADM Checks, Level Check, Customize and Settings.

Pointing Compensation starts the Pointing Compensation routine. *See "Pointing Compensation" on page 66.*

ADM Checks starts the ADM Interim Test. *See "ADM Checks" on page 77.*

Level Check starts the Level Check routine. *See "Level Check" on page 88.*

Customize changes the CompIT default settings. *See "Customize" on page 89.*

Settings changes Auto Measure function. *See "Settings" on page 91.*

Pointing Compensation

The Pointing Compensation routine checks and corrects any angular errors of the FARO Laser Tracker. Pointing Compensation is divided into three parts:

- Interim Test: A preliminary check of the backsight deviations around the Laser Tracker's working volume.
- Pointing and Axis Non-Squareness Compensation: A procedure to improve the backsight deviations.
- Self Compensation Optimization: A procedure to improve the performance of the Self Compensation routine. *See "Self Compensation" on page 63.*

Self Compensation should be used for most applications; however, there are some instances in which Pointing Compensation should be performed:

- Applications that require the highest possible accuracy.
- Applications that require high accuracy at long range (20 plus meters).
- Instances in which the Self Compensation routine does not adequately improve backsight accuracy. In this case, Pointing Compensation should be run using the Axis Non-squareness option followed by a Self Compensation Optimization.

Equipment

1 FARO Laser Tracker and support equipment
2 1.5" Spherically Mounted Retroreflector (SMR)
3 Calibration Tripod
4 One (1) Heavy Duty Nest

Setup

This procedure is intended to be performed with the Laser Tracker in the normal upright position and requires an area that can accommodate the following:

- Placing a target located at the same elevation as the Laser Tracker at a distance of 10 meters.
- The origin of the Laser Tracker (center of the beam steering assembly) approximately 1.25 m to 1.65 m above the floor.

Procedure

Set up, power up, and start the FARO Laser Tracker. *See "Setting up the FARO® Laser Tracker" on page 23.*

NOTE: For best results, it is recommended that the Laser Tracker be allowed to stabilize in its working environment.

Interim Test

1 In the CompIT dialog box, click the Advanced tab and then click the Pointing Compensation button.
2 Follow the prompts and move the SMR to the Home position, and then to various default positions as indicated. Rotate the Laser

Tracker on the mandrel mount to adjust the Azimuth angle to the target.

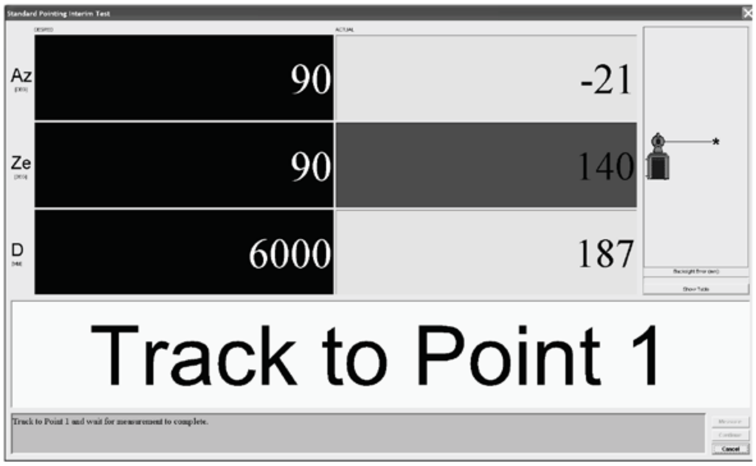


Figure 11-15 Track to Point 1

- **DESIRED** value: The target values for Azimuth, Zenith, and Radial Distance.
- **ACTUAL** value: The current Azimuth, Zenith, and Radial Distance values of the SMR. The angle and distance values will be either red or yellow until you track the SMR to the desired values. The values switch to green when the SMR is in an acceptable zone. The Radial distance value switches to yellow if the SMR is beyond its desired value. When all of the values are green, the Laser Tracker waits five (5) seconds for stability before measuring the SMR.
- **Backsight Error**: The last backsight error. Press the SHOW TABLE button to display a list of any previous backsight errors.
- **Cancel**: Exits the Interim Test without saving any data or parameters.

3 Place the SMR in the calibration tripod or in another stable nest. The first desired location is:

- 90 degrees azimuth, 90 degrees zenith, 6 meters distance.

4 Move the SMR and/or rotate the Laser Tracker until the actual numbers for all three values are green.

Once the SMR is in the correct location, it is automatically checked for stability, and when stable is measured in both frontsight and backsight modes. The calculated difference between the two measurements is the Backsight Error.

The remaining desired locations are:

- -45 degrees azimuth, 90 degrees zenith, 2 meters distance.
- 45 degrees azimuth, 135 degrees zenith, 2 meters distance.

5 Move the SMR and/or rotate the Laser Tracker until the actual numbers for all three values are green for the second location. Repeat for the third.

You can continue measuring “user-defined locations.” These locations should be within in the Laser Tracker’s working volume. Examples include control points and points near the extreme of your part.

6 After completing the last measurement, press CONTINUE. You will see the results of this test in the ANGULAR ACCURACY RESULTS dialog box.

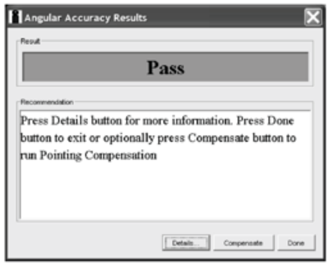


Figure 11-16 Angular Accuracy Results dialog box

7 If the results are within tolerance, click DONE to accept them and exit, or click DETAILS to view the results. Click COMPENSATE to continue with the Pointing Compensation routine.

- Click DETAILS and REPORT to save the results to a text file.

Pointing and Axis Non-Squareness Compensation

Clicking COMPENSATE in the ANGULAR ACCURACY RESULTS dialog box displays the STANDARD POINTING COMPENSATION dialog box.

1 Place the SMR in the calibration tripod or in another stable nest. The first desired location is:

- any azimuth position, 90 degrees zenith, 2 meters distance.

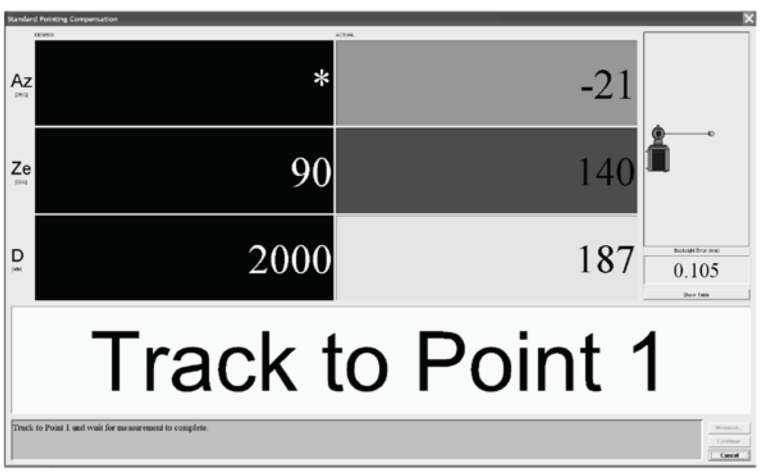


Figure 11-17 Track to Point 1

- **DESIRED** value: The target values for Azimuth, Zenith, and Radial Distance.
- **ACTUAL** value: The current Azimuth, Zenith, and Radial Distance values of the SMR. The angle and distance values will be either red or yellow until you track the SMR to the desired values. The values switch to green when the SMR is in an acceptable zone. The Radial distance value switches to yellow if the SMR is beyond its desired value. When all of the values are green, the Laser Tracker waits five (5) seconds for stability before measuring the SMR.
- **Backsight Error**: The last backsight error. Click SHOW TABLE to display a list of any previous backsight errors.
- **Cancel**: Exits the Pointing Compensation without saving any data or parameters.

2 Move the SMR and/or rotate the Laser Tracker until the actual numbers for all three values are green.

Once the SMR is in the correct location, it is automatically checked for stability, and when stable is measured in both frontsight and backsight modes. The calculated difference between the two measurements is the Backsight Error.

The remaining desired locations are:

- any azimuth position, 90 degrees zenith, 3.6 meters distance.
- any azimuth position, 90 degrees zenith, 5.2 meters distance.
- any azimuth position, 90 degrees zenith, 6.8 meters distance.
- any azimuth position, 90 degrees zenith, 8.4 meters distance.
- any azimuth position, 90 degrees zenith, 10 meters distance.

3 After completing the last measurement, click CONTINUE. You will see the results of this test in the ANGULAR ACCURACY RESULTS dialog box.

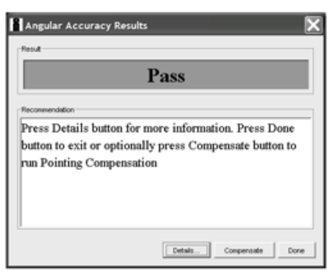


Figure 11-18 Pointing CompIT - Pointing Compensation Results dialog box

- Click DETAILS to view the results.
- Click INTERIM TEST DEVIATIONS tab to see the updated results of the initial Interim Test Backsight Errors.
- Click DETAILS to see detailed results.

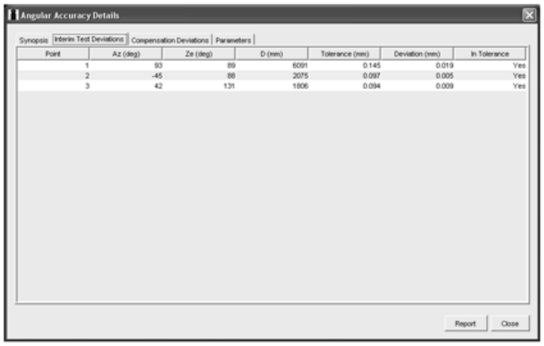


Figure 11-19 Pointing CompIT - Pointing Compensation Results dialog box - Interim Test Deviations

Click the PARAMETERS tab to view the Before, After and Change in Laser Tracker Parameters. Self Compensation adjusts the two rotational (RX and RY) and two translational (CTX and CTY) parameters.

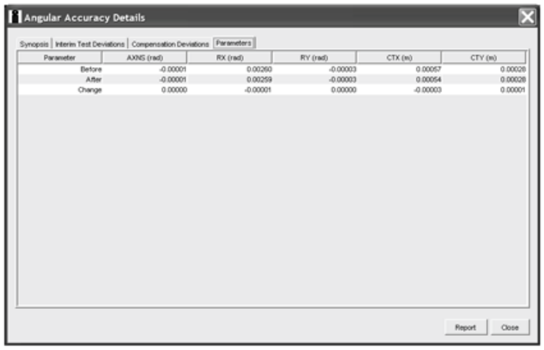


Figure 11-20 Pointing CompIT - Pointing Compensation Results dialog box - Parameters

NOTE: The information presented on the PARAMETERS tab is for information only.

- Click REPORT to save the results to a text file.
- Click CLOSE to exit and return to the ANGULAR ACCURACY RESULTS dialog box.

4 If a passing condition is indicated in the ANGULAR ACCURACY RESULTS dialog box, the user may select from the following options.

- Click UPDATE to save the results to the Laser Tracker and exit.
- Click DONE to exit the Pointing Compensation routine without saving the results.
- Click COMPENSATE to continue to the Axis Non-squareness Compensation. This should be done if the user wishes further improve the results by performing and Axis Non-squareness Compensation.

5 If the Pointing Compensation can not adequately adjust the parameters to bring the results within tolerance, a message appears

prompting the user to continue to the Axis Non-squareness Compensation.

Figure 11-21 Pointing Compensation routine complete

Axis Non-Squareness

1 Follow the prompts and move the SMR to the Home position, then to various positions as indicated.

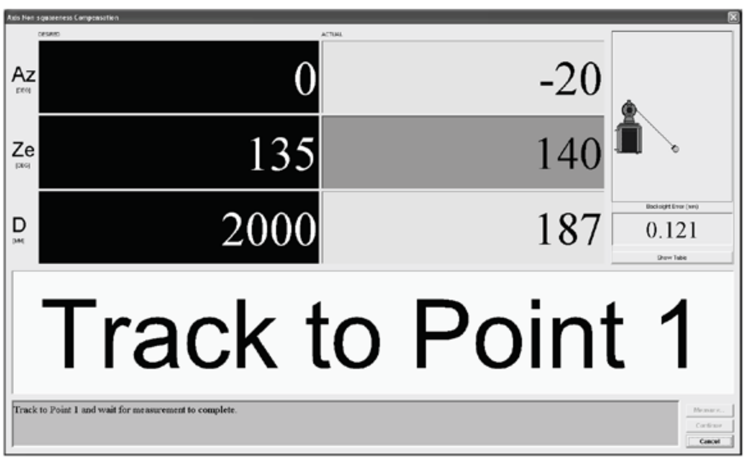


Figure 11-22 Axis Non-squareness - Track to Point 1

2 Move the SMR and/or rotate the Laser Tracker until the actual numbers for all three values are green.

Once the SMR is in the correct location, it is automatically checked for stability, and when stable is measured in both frontsight and backsight modes. The calculated difference between the two measurements is the Backsight Error.

The remaining desired locations are:

- 0 degrees azimuth position, 110 degrees zenith, 4.0 meters distance.
- 0 degrees azimuth position, 102 degrees zenith, 6.0 meters distance.

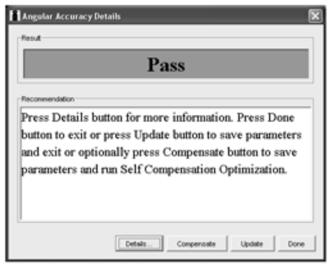


Figure 11-23 Axis Non-squareness - Angular Accuracy Results dialog box

- Click UPDATE to save the results to the Laser Tracker.
- Click DONE to exit the Axis Non-squareness routine without saving the results.
- Click DETAILS to see the results.
- Click COMPENSATE in the ANGULAR ACCURACY RESULTS dialog box to proceed with a Self Compensation Optimization. This should be done if the Self Compensation routine is unable to sufficiently bring the backsight results into tolerance. *See "Self Compensation" on page 63.*

Self Compensation Optimization

1 CompIT begins the Self Compensation routine. This routine is automatic.

2 After completing the routine, you will see the results in the SELF COMPENSATION OPTIMIZATION RESULTS dialog box.

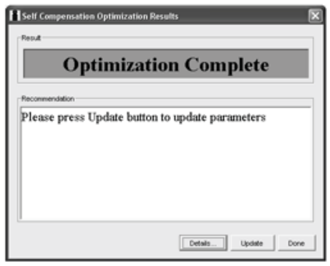


Figure 11-24 Axis Non-squareness - Angular Accuracy Results dialog box

- Click UPDATE to save the results to the Laser Tracker.
- Click DONE to exit the Self Compensation routine.
- Click DETAILS to see detailed results.

ADM Checks

The ADM Interim Test tests the accuracy of XtremeADM (Absolute Distance Measurement). There are two different procedures, depending on your Laser Tracker model. The model Xi procedure compares XADM measurements to Interferometer (IFM) measurements. The model X procedure compares XADM measurements to angular measurements. The tests take only a few minutes and may be run weekly.

ADM IT - Model Xi

The model Xi procedure compares XADM measurements to Interferometer (IFM) measurements. This test completes in a few minutes and should be run once a week.

Equipment

1 FARO Laser Tracker and support equipment

2 1.5" Spherically Mounted Retroreflector (SMR)

3 One (1) Heavy Duty Nest

Procedure

Set up, power up, and start the FARO Laser Tracker. *See "Setting up the FARO® Laser Tracker" on page 23.*

1 In the CompIT dialog box, click the Advanced tab and then click the ADM Checks button. The SELECT MODE dialog box appears.

Figure 11-25 Select Mode dialog box

Select GUIDED POINTS and click OK to move the SMR to a specific location. Select USER SELECTED POINTS and click OK to move the SMR to any location. If you select both check boxes, first move the SMR to a specific location and then to any location for additional points. Always, use a stable nest for the SMR, such as the Laser Tracker's calibration tripod.

NOTE: Since CompIT is comparing IFM to ADM measurements, Auto Home is active; if the beam breaks (loss of IFM count), return the SMR to the home position for an automatic reset.

The laser beam moves to the Home position, and runs an Auto-adjust. The radial distance to Point 1 (Home) is measured with both the interferometer and the ADM.

2 Track the SMR to a nest that is the desired distance (3m) away from the Laser Tracker (Point 2). When the SMR is within a pre-specified tolerance, the actual distance value will turn green. If the SMR is at a distance greater than the desired distance, the actual distance will turn yellow. After the SMR has been tracked out to Point 2, it is automatically checked for stability, and when stable the radial distance to Point 2 is measured with both the interferometer and the ADM.

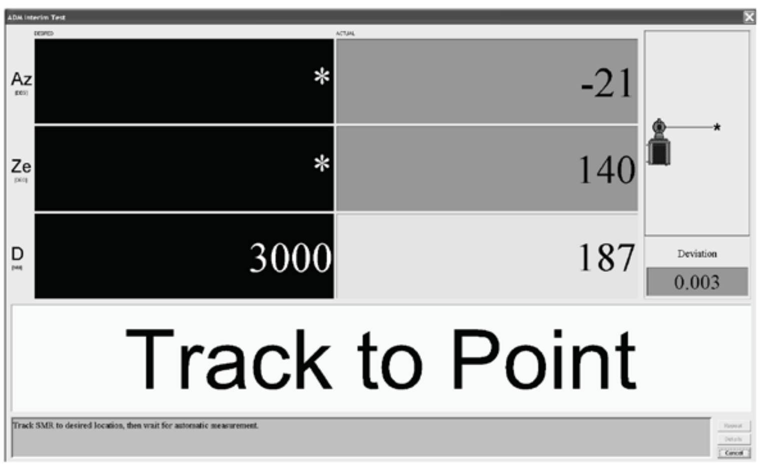


Figure 11-26 ADM Interim Test

3 Track the SMR to the next desired distance (7m) away from the Laser Tracker (Point 3).

- **DESIRED** value: The target values for Azimuth, Zenith, and Radial Distance.
- **ACTUAL** value: The current Azimuth, Zenith, and Radial Distance values of the SMR. The angle and distance values are red until you track the SMR to desired values. The values switch to green when the SMR is in an acceptable zone around the desired values. The Radial distance value switches to yellow if the SMR is beyond its desired value. When all of the values are green, the

Laser Tracker waits five (5) seconds for stability before measuring the SMR.

- **Deviation**: The last ADM error. Click SHOW TABLE to display a list of any previous ADM errors.
- **Cancel**: Exits the ADM Interim Test without saving any data or parameters.

If any point is out of tolerance, Track Home to check for Closure. Return the SMR to the TMR position without breaking the beam.

4 After completing the last measurement, click DONE or DETAILS to see the results.

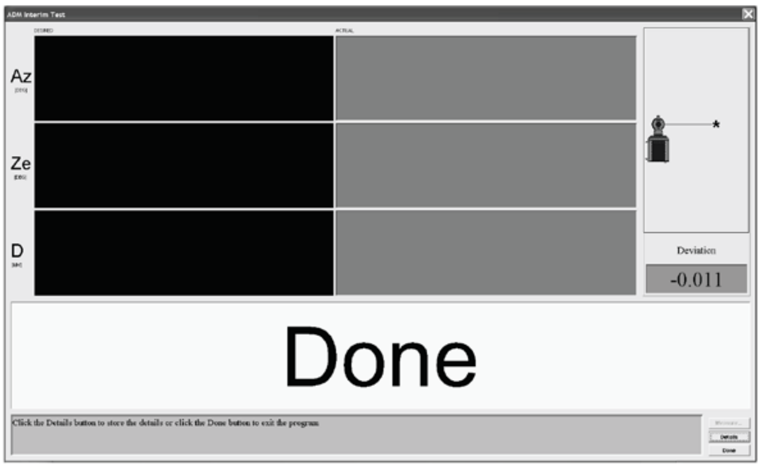


Figure 11-27 ADM Interim Test Results

You will see the results of this test in the ADM INTERIM TEST RESULTS dialog box. Select the ADM INTERIM TEST RESULTS tab to view the ADM-IFM values.

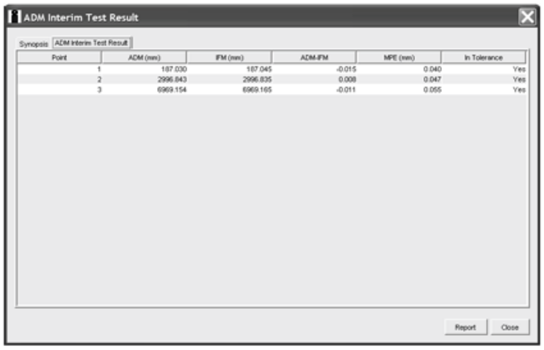


Figure 11-28 ADM Interim Test Results

- **ADM-IFM**: The results of the Interim Test.
- **MPE**: Maximum Permissible Error per the Laser Tracker's specifications and the ASME B89.4.19 Standard

5 Click CLOSE to exit the ADM Interim Test Results.

6 Click DONE to exit the ADM Checks procedure.

ADM IT - Model X

The ADM Interim Test provides a procedure to evaluate the accuracy of XtremeADM (XADM). The routine compares the Laser Tracker's angular accuracy to its distance accuracy by measuring the distance between two targets from two Laser Tracker positions. Alternatively, the test can be run using a bar with two fixed targets. The bar can then be measured in two orientations by the Laser Tracker in a single position while following the same procedure.

Equipment

1 FARO Laser Tracker and support equipment

2 1.5" Spherically Mounted Retroreflector (SMR)

3 Two (2) Heavy Duty Nests

Procedure

Set up, power up, and start the FARO Laser Tracker. *See "Setting up the FARO® Laser Tracker" on page 23.*

1 In the CompIT dialog box, click the Advanced tab and then click the ADM Checks button.

The first position for the interim test is with the Laser Tracker set up to measure two points from the side. This setup should maximize the use of the Laser Tracker's angular encoders. It is recommended to set up the Laser Tracker three (3) meters away from two points that are one (1) or more meters apart. After the second point is measured, the software reports the percentage of the measurement that is made with the encoders. A percentage of 80% or higher is recommended to obtain a meaningful result in this test.

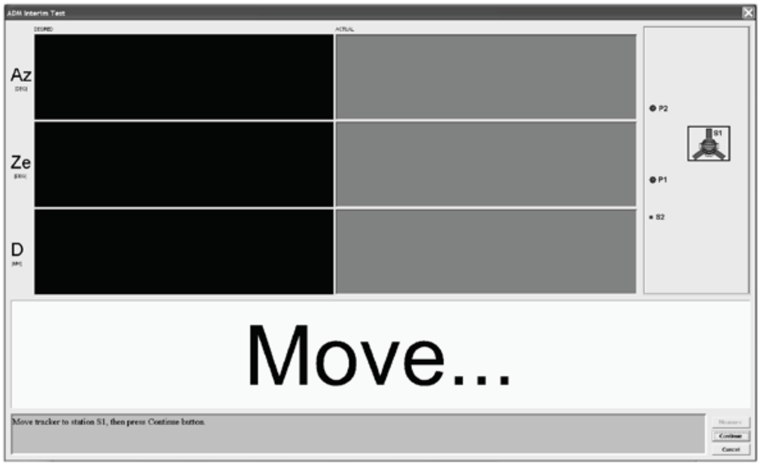


Figure 11-29 Move to Station S1

2 Move the Laser Tracker to Station S1 and click CONTINUE.

3 Move the SMR to the Home position. An auto-adjust completes at the Home position to normalize the ADM for the test.

4 Track or send the beam to Point 1. To send the beam, click MOTORS

OFF and manually steer the beam to the target.

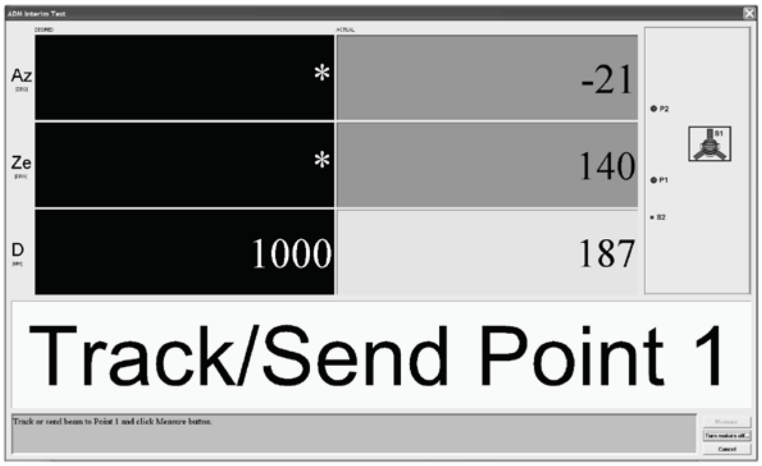


Figure 11-30 Beam to Point 1

5 Measure Point 1 by clicking MEASURE. A check is made to ensure the target is stable and then the measurement is taken.

6 Track, or send, the beam to Point 2. A pie chart indicates the percentage of the measurement that is made with the angular encoders. It is recommended to achieve a percentage of greater than 80%. If the target position yields a number lower than 80%, a message box appears and tells you where to move the SMR.

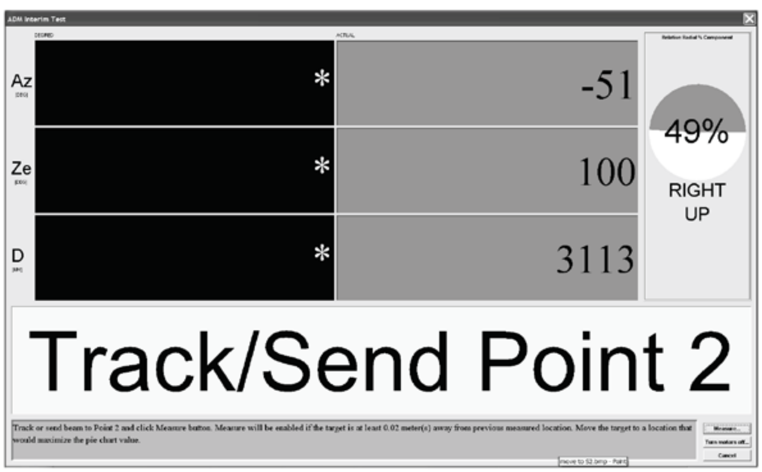


Figure 11-31 Beam to Point 2

7 Click MEASURE to measure Point 2.

8 If the pie chart shows a percentage greater than 80%, the setup for the first measurement is good. Click CONTINUE to proceed. If the percentage is less than 80% it is recommended that you re-measure. Click RETRY to re-measure the two points with a setup that yields greater than 80%.

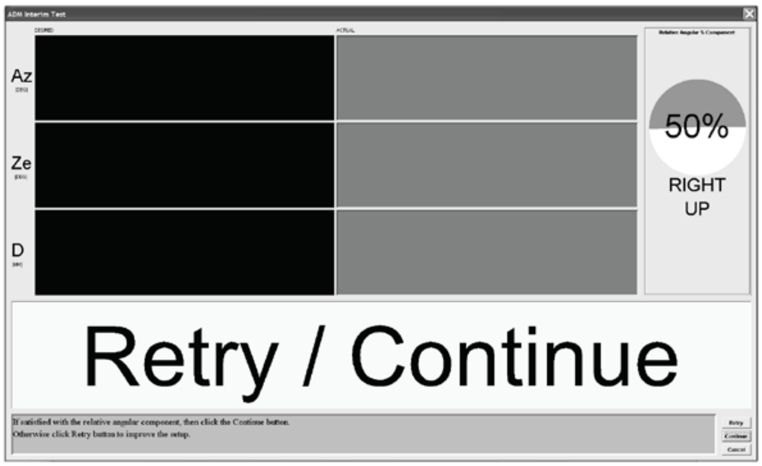


Figure 11-32 Retry/Continue 2

9 Move the Laser Tracker to Position 2. Position 2 should orient the Laser Tracker in such a way as to maximize the distance measurement component of the measurement; that is, the Laser Tracker's beam should be in line with the two points being measured. A range of 2

meters from point one is suggested; however, any distance can be used.

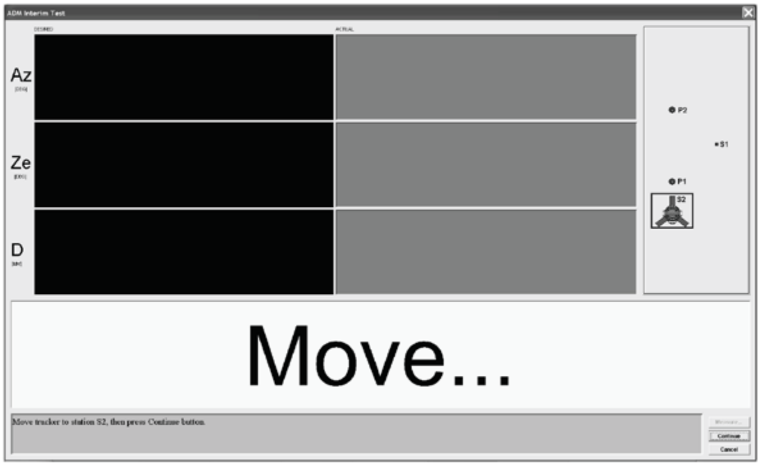


Figure 11-33 Move to Position 2

10Click MEASURE to measure Point 1. A check is made to ensure the target is stable before the measurement is taken.

11Track or send the beam to Point 2. A pie chart indicates the percentage of the measurement that is made with XtremeADM. It is recommended to use a percentage of greater than 80%. If the target position yields a number lower than 80%, a message box appears and tells you where to move the Laser Tracker (or bar if a bar with two targets is used).

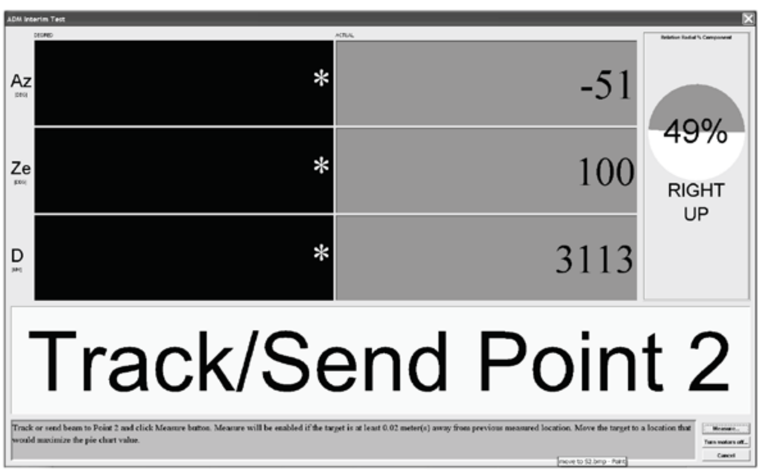


Figure 11-34 Beam to Point 2

12Click MEASURE to measure Point 2.

13If the pie chart shows a percentage greater than 80%, then the setup for the second position is good. Click CONTINUE to proceed. If the percentage is less than 80% it is recommended that you move the Laser Tracker and re-measure. Click RETRY to re-measure the two points with a setup that yields greater than 80%.

14The ADM IT results dialog indicates the distances measured between the two points from the two setups. The percentage of angular and distance measurements is also shown. A result from setups with greater than 80% indicates a valid test. The difference between the two measurements is shown along with the Maximum Permissible Error (MPE), which is derived from the Laser Tracker angular specifications. A result (Pass/Fail) will also be displayed.

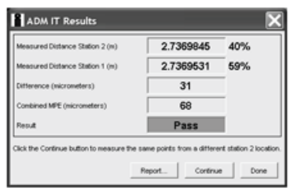


Figure 11-35 ADM IT Results dialog box

15Clicking on the REPORT button opens a dialog to save the results to a comma delimited text file. A check box is available to append the report to a previous report. Appending the report creates a log file of the test results. Click DONE to close the results page.

16The MEASURE MORE POINTS button returns to the Move screen and prompts for another set of two points from another Laser Tracker (or bar) position. This allow for additional distances to be measured in the testing of the XADM. For example, measure from two (2), four (4), and six (6) meters.

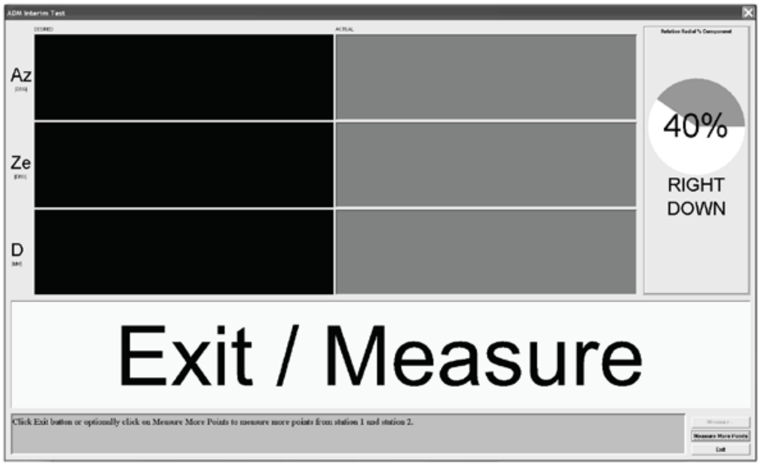


Figure 11-36 Measure More Points

17Click EXIT to end the test.

Level Check

The Level Check routine verifies the accuracy of level measurements made with the FARO Laser Trackers internal precision level. If the level is not measuring to within tolerance, the Level Check automatically corrects the system.

Equipment

1 FARO Laser Tracker and support equipment

Procedure

Set up, power up, and start the FARO Laser Tracker. *See "Setting up the FARO® Laser Tracker" on page 23.*

1 In the CompIT dialog box, click the Advanced tab and then click the Level Check button.

Customize

Use the Customize command to change the default settings of CompIT. The factory default settings *always* load when CompIT starts; any previous changes do not effect your calibration.

CAUTION: Changing parameters may result in a less than optimal compensation and decreased measurement accuracy.

Procedure

Set up, power up, and start the FARO Laser Tracker. *See "Setting up the FARO® Laser Tracker" on page 23.*

In the CompIT dialog box, click the Advanced tab and then click the Customize button.

This opens the CUSTOMIZE FARO CompIT dialog box which has four separate tabs which allow you to customize the General, Pointing Compensation, Repeatability, and Pointing Interim Test settings.

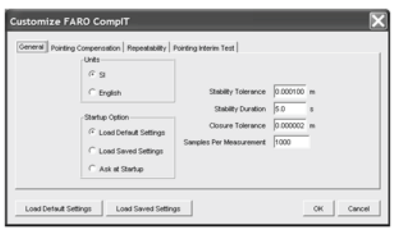


Figure 11-37 Customize dialog box

- Click LOAD DEFAULT SETTINGS to load the default or factory settings.
- Click LOAD SAVED SETTINGS to load any settings that you have previously saved.
- Click OK to apply any changes and continue.
- Click CANCEL to exit without applying changes.

General

Use the GENERAL tab in the CUSTOMIZE FARO COMPIT dialog box to set the general parameters of CompIT.

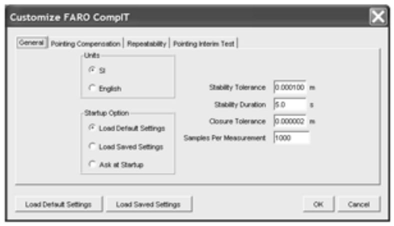


Figure 11-38 General tab

- Units - The unit of measurement, Inches or Millimeters, for all of the routines.
- Stability Tolerance - The maximum distance in all stability checks.
- Stability Duration - The wait time in all stability checks. This is the time the SMR must remain stable before the any measurement starts.
- Closure Tolerance - The maximum interferometer closure error.
- Samples Per Measurement - The number of measurement samples for each measurement. Each measurement is an average of the samples.

Pointing Compensation

Use the POINTING COMPENSATION tab in the CUSTOMIZE FARO COMPIT dialog box to set the parameters for the Pointing Compensation routine.

Figure 11-39 Pointing Compensation tab

Use the STANDARD Compensation Type or choose the CUSTOM radio button and set the following parameters:

- **Maximum Range**: The maximum distance for the ADM CompIT routine. Each desired distance locations is a proportional distance of the maximum distance.

- **Number of Targets**: The number of targets to measure in the routine.

Repeatability

Use the REPEATABILITY tab in the CUSTOMIZE FARO COMPIT dialog box to set the repeatability parameters for CompIT.

Figure 11-40 Repeatability tab

- **Repeatability Tolerance**: Set the maximum error for consecutive measurements for each measurement.
- **Repeatability Iterations**: Set the number of repeating consecutive measurements for each measurement.
- **Repeatability Max Iterations**: Set the maximum number of measurement attempts for each measurement.

Pointing Interim Test

Use the POINTING INTERIM TEST tab in the CUSTOMIZE FARO COMPIT dialog box to set the parameters for all Pointing Interim Tests.

Figure 11-41 Pointing Interim Test tab

- Select the USE CUSTOM TARGET LOCATIONS check box and enter values for more than three target locations.

Settings

Use the Customize command to change the default settings of CompIT. The factory default settings *always* load when CompIT starts; any previous changes do not effect your calibration.

Procedure

Set up, power up, and start the FARO Laser Tracker. *See "Setting up the FARO® Laser Tracker" on page 23.*

In the CompIT dialog box, click the Advanced tab and then click the Settings button.

This opens the CompIT SETTINGS dialog box which has three check boxes to set the Auto Measure function for ADM, Angular Accuracy and Pointing Interim Tests.

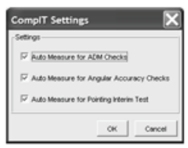


Figure 11-42 CompIT Settings dialog box

If any Auto Measure setting is cleared, a Measure button is available in each dialog box. Click this button to manually start measuring in any of the tests.

- Click OK to apply any changes and continue.
- Click CANCEL to exit without applying changes.

Chapter 12: CAM2® Measure Devices Menu

The DEVICES menu contains all the commands used to configure a measuring device. These commands are also available on the Devices toolbar and the Device Position toolbar.

Device Setup

Select DEVICES < DEVICE SETUP from the DEVICES menu. Choose a primary input measuring device from the DEVICE SETUP dialog box. The default device is the FARO Laser Tracker. To change the primary input device, select the device name and click the START button. This establishes communications with the selected device.

CAM2 Measure attempts to initialize communication with the primary input device. A startup device cannot be saved in a settings file.

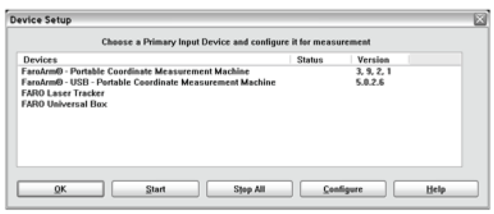
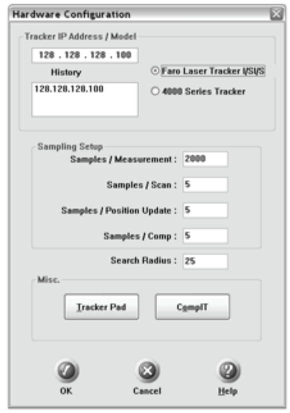


Figure 12-1 Device Setup dialog box

Hardware Configuration



Select DEVICES < HARDWARE CONFIG. In the HARDWARE CONFIGURATION dialog box you can:

- View the current IP Connection that CAM2 Measure will use to communicate with the FARO Laser Tracker.
- Set the Samples per Measurement.
- Set the Samples per Scan.
- Set the Samples per Position Update.
- Set the Samples per Comp.
- Set the Search radius.
- Access the Tracker Pad.
- Access the CompIT routine.

Click OK to accept the changes. Click the CANCEL button to discard any changes and exit the command. Changes made in the HARDWARE CONFIG dialog box are saved.

Tracker IP Address/Model: Enter the IP address of the Laser Tracker. The History area lists any previously used IP address. Choose the model of your Laser Tracker.

Samples/Measurement: The number of measurement samples for each measurement in Single Point Mode. Each measurement is an average of the samples.

Samples/Scan: The number of measurement samples for each measurement in Scan Mode. Each measurement is an average of the samples.

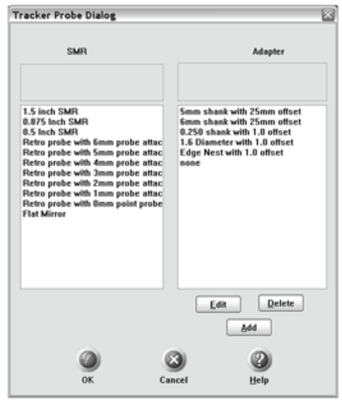
Samples/Position Update: The number of samples between position updates in any CAM2 Measure DRO window.

Samples/Comp: The number of samples for a compensation point at the end of a measurement command. The compensation point determines the direction of probe compensation for a feature measurement.

Search Radius: The size of the searching radius during a Survey. For more information, see "Survey" on page 101.

Probes

Select DEVICES < PROBES. In the PROBES dialog box you can:



- Select the diameter SMR or Retroprobe stylus diameter.
- Select an adapter to be used with the selected SMR.
- Add a new probe.
- Edit an existing custom probe.

Edit Probe

Click the EDIT button in the PROBES dialog box to modify the details of the current probe. Change the name, height, offset, or units settings and click the OK button to accept the changes. Click the CANCEL button to discard the changes and exit the command.

NOTE: The default probes and adapters cannot be edited.

To create a new probe:

1 Click the ADD button in the PROBES dialog box.

2 In the SMR SIZE drop-down box, choose the SMR size for the new adapter.

3 Enter a name in the NAME box.

4 In DIMENSIONS, enter the correct height and offset for the new adapter.

5 Choose the units for height and offset.

6 Click OK to accept the new adapter. Click the CANCEL button to exit the command.

NOTE: In CAM2 Measure, "P" is the Hot Key for the PROBES command. See the CAM2 Measure software manual for more information about Hot keys.

Laser Tracker Menu

The Laser Tracker menu contains the unique commands for the FARO Laser Tracker.

TrackerPad

Select DEVICES < LASER TRACKER < TRACKER PAD. In the TRACKERPAD dialog box, you can:

- Initialize the Laser Tracker.
- Point the Laser Tracker to the specified reset location.
- Turn the Tracker motors Off/On.
- Turn tracking Off/On.
- Switch the Laser Tracker into backsight or frontsight measurement.
- Initiate a search for a target.
- Highlight the beam.
- Specify a drive option.
- View and configure the weather measurement settings.
- View the temperature sensor configuration and change each sensors alarm settings.
- View the bubble level.
- Manually set a distance to the target.

Initialize: Runs the angular encoder initialization sequence. This is necessary if the motors shut down and can not be turned back on with the TURN MOTORS OFF button. The Laser Tracker motors will shut down as a protective measure if the axis is forced or over-torqued.

Home: Points the Laser Tracker to the reset location.

Motors Off: Switches the motors off. If off, switches the motors on.

Turn Tracking Off: Switches the tracking of the laser off. If off, switches the tracking on.

Backsight: Switches the Laser Tracker between frontsight and backsight modes.

Search: Initiates a search for a target.

Highlight Beam: Moves the laser beam in a brief rotation.

Drive Options: These options allow you to manually move, or drive, the laser beam to locations where tracking the SMR is difficult.

Visual Drive: Move the laser beam to a target using your computers mouse or arrow keys.

To use the Visual Drive option:

1 Click and hold near the cross hairs in the center of the dialog box.

2 Slowly drag the mouse in any direction until the Laser Tracker is pointing near the target. The arrow keys can also be used to direct the beam.

3 Click the SEARCH… button, key in the search parameters, and click the SEARCH button to acquire the target.

4 Click the CLOSE button to exit the command.

Angular Drive: Move the laser beam to a target by keying in specific azimuth and zenith positions.

To use the Angular Drive option:

1 Enter the Azimuth and Zenith positions in radian units. If necessary, select the USE ESTIMATED DISTANCE check box and enter the estimated distance.

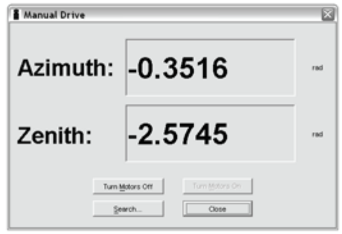
2 Click the MOVE button to move the laser beam to the position. Repeat until the laser beam is pointing near the target.

3 Click the SEARCH… button, key in the search parameters, and click the SEARCH button to acquire the target.

4 Click CLOSE to exit the command.

Manual Drive: Manually move the laser beam to a target.

To use the Manual Drive option:



1 Click the TURN MOTORS OFF button to switch the motors off.

2 Carefully move the Laser Tracker head and move the laser beam near the target.

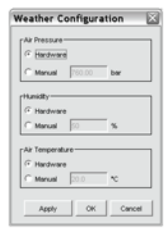
3 Click the TURN MOTORS ON button.

4 Click the SEARCH button to acquire the target.

5 Click the CLOSE button to exit the command.

Weather Settings: Select and configure the source for the weather information. The HARDWARE option uses the Laser Tracker's integrated weather station. The MANUAL option uses the entered weather information.

To manually enter weather information:



1 Click each MANUAL radio button.

2 Enter the weather information.

3 Click the APPLY button to apply the changes, and then click OK to exit the command.

NOTE: Clicking the CANCEL button before clicking the APPLY button exits the command *without* making changes.

Temperature Sensor Configuration: View and configure any temperature sensors connected to the MCU.

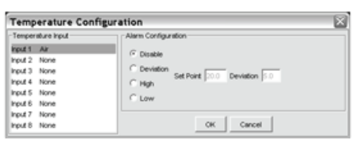
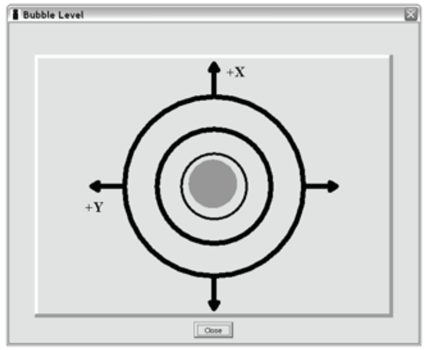
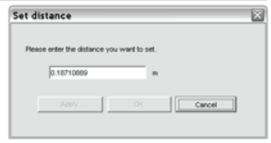


Figure 12-2 Temperature Sensor Configuration dialog box

Bubble Level: View the orientation of the Laser Tracker with respect to gravity.



Set distance: Enter the distance to a location.



To use the set distance option:

1 Acquire a target with the Laser Tracker.

2 Move the target to a location.

3 Enter the distance.

4 Click the APPLY button to accept the changes, and then click OK to exit the command.

NOTE: Clicking the CANCEL button before clicking the APPLY button exits the command *without* making changes.

Manage Reset Points

Select DEVICES < LASER TRACKER < MANAGE RESET POINTS. In the MANAGE RESET POINTS dialog box, you can:

- Enable or disable the Auto Reset feature.
- Select a Reset Point feature.
- View selected Reset Point feature on screen.

To set the Reset Point:

1 Choose the feature.

2 Click OK to assign the new reset location.

Create Reset Point

Select DEVICES < LASER TRACKER < CREATE RESET POINT. You are then prompted to measure a point. For information on point measurements, see the CAM2 Measure Users Manual.

> **NOTE**: This command does not automatically assign the point as the current Reset Point. To set the point as the new reset location, use the Manage Reset Points command. *See "Manage Reset Points" on page 99.*

Set Distance Mode

Select DEVICES < LASER TRACKER < SET DISTANCE MODE. In the SET DISTANCE MODE dialog box you can:

- Set the distance mode to Interferometer Only, Interferometer Set by ADM, or ADM Only.

Interferometer Only: This mode uses only the interferometer laser for distance measurements. If the Laser Tracker loses acquisition of the target, use the RESET command to re-acquire the target. *See "Reset" on page 101.* You can also re-acquire the target at the TMR (Tracker-Mounted Reset) by running the HOME command on the Tracker pad.

Interferometer Set by ADM: This mode uses the interferometer laser for distance measurement. If the Laser Tracker loses acquisition of the target, the target can be re-acquired using the ADM. Once the distance to the target is set with the ADM laser, distance measurement resumes using the interferometer laser. This eliminates using the RESET command. *See "Reset" on page 101.*

ADM Only: This mode uses only the ADM laser for distance measurements. If the Laser Tracker loses acquisition of the target, the target can be re-acquired using the ADM. This eliminates using the RESET command. *See "Reset" on page 101.*

> **NOTE**: In CAM2 Measure, "N" is the Hot Key for the SET DISTANCE MODE command. See the CAM2 Measure software manual for more information about Hot keys.

Reset

Select DEVICES < LASER TRACKER < RESET. The Laser Tracker will move to the current Reset Point location.

NOTE: In CAM2 Measure, "T" is the Hot Key for the Reset command. See the CAM2 Measure software manual for more information about Hot Keys.

Aim

Select DEVICES < LASER TRACKER < AIM. In the AIM dialog box you can:

- Select a feature for Aim.

To use the Aim command:

1 Choose a feature in the AIM dialog box. The laser beam moves to the features position. If the Laser Tracker does not acquire the target, run the Search command.

2 Click the OK or CANCEL buttons to exit the command.

Search

Select DEVICES < LASER TRACKER < SEARCH. Selecting this command initiates a target search. The laser beam will automatically move in a circular pattern and search for a target.

Survey

Select DEVICES < LASER TRACKER < SURVEY. A Survey is an automatic measurement of a group of features.

NOTE: In this command, all of the targets for each location must be the same type.

In the Survey dialog box you can:

- Enter the settings for a new survey.
- Select a previous survey.

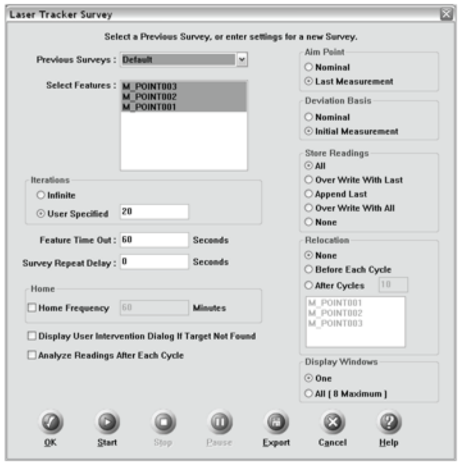


Figure 12-3 Survey dialog box

Previous Surveys: Click the down arrow to choose any previous survey. Choosing a previous survey loads the settings into the dialog box and is often a good starting point for a new survey.

Select Features: Choose the features for the survey.

Iterations: The number of times the group of survey features is measured. Choose INFINITE, or USER SPECIFIED and enter a number.

- Infinite - Measures the group of features until you click the STOP button in the LASER TRACKER SURVEY dialog box.
- User Specified - Measures the group of features and stops after the last iteration is complete.

Feature Time Out: Enter a time, in seconds, for the Laser Tracker to remain at a feature location to wait for the target.

Survey Repeat Delay: Enter a delay time between the end of an iteration and the start of the next iteration.

Home Frequency: Select the HOME FREQUENCY check box and enter a time, in seconds. This sets how often the Laser Tracker resets to Home. In ADM mode, the Home command runs an auto-adjust to retain the highest ADM accuracy.

NOTE: If you choose select the Home Frequency option, there *must* be a target present at the Home location during the survey.

Display User Intervention Dialog If Target Not Found: Select this check box to display a message when a target is not found.

Analyze Readings After Each Cycle: Select this check box to display the ANALYZE READINGS dialog box after a Cycle, the measurement of the selected features, is completed. You can accept or reject the readings from the Cycle.

Aim Point: Choose the Aim point.

- Nominal - For each feature, the laser beam aims at the location of the associated nominal of the feature.
- Last Measured - For each feature, the laser beam aims at the features last measured location.

Deviation Basis: Choose the measurement deviation reporting option.

- Nominal - For each feature, the deviation value is the comparison of the measurement and nominal values.
- Last Measurement - For each feature, the deviation value is the comparison of the measurement and the last measurement value.

Store Readings: Choose a storage option for the measurements, or readings, for the group of features. Use the REVIEW FEATURES command to view the readings for any feature.

- All - All measurements add readings to each feature in the current file.
- Over Write With Last - The last measurement adds a reading to each feature, and replaces all existing readings in the current file.
- Append Last - The last measurement adds a reading to each feature in the current file.
- Over Write With All - All measurements add readings to each feature, and replaces all existing readings in the current file.
- None - None of the Survey measurements add to the current file.

Relocation: Choose an option for a relocation. A relocation uses a set of measurements to define a new Device Position.

- None - No relocation.

- Before each Cycle - Choose three or more features from the list for the relocation. Before measuring the survey group of features, these features create a Device Position.
- After Cycle - Choose three or more features from the list for the relocation, and enter a number. After the number of cycles is complete, these features create a Device Position before measuring the next survey group of features.

Display Windows: Choose the option for the Digital Readout Windows. During the measurement of the group of features, a DRO window(s) opens.

- One - a single DRO window opens and the displays the data from the current measurement.
- All - A DRO window opens for each feature. The maximum number windows is eight (8).

To begin a survey:

1 Measure the points for the survey.

2 Select DEVICES < LASER TRACKER < SURVEY.

3 Choose features for measurement in the SELECT FEATURES window.

4 If necessary modify the options in the LASER TRACKER SURVEY dialog box.

NOTE: Select a previous survey from the PREVIOUS SURVEYS drop-down box.

5 Click the START button to begin measuring the features.

- Click the PAUSE button, at any time, to pause the command after a measurement cycle is completed. Click the Start button to begin the next cycle.

6 After you press the STOP or PAUSE button, or the number of iterations is complete, click the EXPORT button to save the measurement data to a text file.

NOTE: Readings marked unused do not export.

7 Click the OK button to complete the command. The Readings for each feature are modified according to the selected STORE READINGS radio button.

8 Click the “X” in the upper right-hand corner of the LASER TRACKER SURVEY dialog box, or the CANCEL BUTTON to end the command and discard any measurements.

Interferometer Check

Select DEVICES < LASER TRACKER < INTERFEROMETER CHECK to run the interferometer check (Xi only). The Closure window displays the distance from the target to the Home position. *See "Manage Reset Points" on page 99.*

Figure 12-4 Closure Window

NOTE: Model Xi only.

Operational Checks

Select DEVICES < LASER TRACKER < OPERATIONAL CHECK. This command starts the Operation Checks for the FARO Laser Tracker.

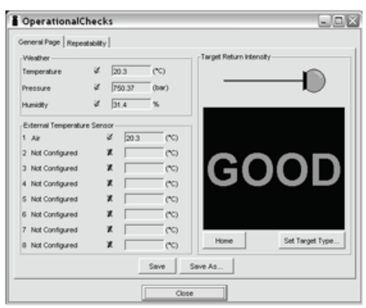


Figure 12-5 Operational Checks dialog box

For more information, see "Operational Checks" on page 49.

Chapter 13: CAM2® Q

The DEVICE CONTROL panel contains all the commands for configuring a measuring device. In CAM2 Q choose DEVICE < DEVICE CONTROL PANEL to show the panel. You can also press the P hot key on the keyboard.

Device Control Panel

The DEVICE CONTROL panel appears when CAM2 Q is launched, and contains a list of all active (detected) devices. The DEVICE CONTROL panel contains a list of all active devices with the properties of each associated device. You can also press the P hot key on the keyboard.

Figure 13-1 Device Control Panel

Choose a FARO Laser Tracker from the list to see the probe details.

- Click the >> button to hide the list of devices.
- Click the << button to show the list of devices.

Add a Device

From the DEVICE CONTROL panel, click the ADD NEW DEVICE button. Select an eligible device from the ADD NEW DEVICE dialog, enter your FARO Laser Tracker's IP address and click CONNECT.

NOTE: The default IP address for a FARO Laser Tracker is 128.128.128.100.

Multiple Laser Tracker Users

A lock system prohibits two or more users on different computers from performing write functions (such as changing probes, changing distance modes, etc.) to the same FARO Laser Tracker concurrently. Read functions (such as taking readings) are not affected by the lock system.

The DEVICE CONTROL panel will overwrite the probe setting in the FARO Laser Tracker with the probe setting from the local file on startup, which creates a conflict if two users attempt to access the FARO Laser Tracker with two different probe sizes.

Probes

The Probes section of the DEVICE CONTROL panel shows the current SMR and Adapter for the current FARO Laser Tracker.

Change Probe

From the DEVICE CONTROL panel, click the CLICK HERE TO CHANGE link button to show the FARO LASER TRACKER PROBE MANAGER dialog box.

- Choose an SMR.
- Choose an Adapter, if necessary.
- Click the OK button.

Controls

The Controls section of the DEVICE CONTROL panel contains all of the buttons to configure and control the FARO Laser Tracker.

Home

Click the HOME button to send the FARO Laser Tracker beam to the Home position.

CompIT

Click the COMPIT button to start FARO CompIT. For more information, see "FARO® CompIT" on page 57.

TrackerPad

Click the TRACKERPAD button to start FARO CompIT. For more information, see "TrackerPad" on page 96.

Drive Beam

Click the DRIVE BEAM button to move the FARO Laser Tracker's laser beam.

Visual Drive: Move the laser beam to a target using your computers mouse or arrow keys.

To use the Visual Drive option:

1. Click and hold near the cross hairs in the center of the dialog box.
2. Slowly drag the mouse in any direction until the Laser Tracker is pointing near the target. The arrow keys can also be used to direct the beam.
3. Click the SEARCH… button, key in the search parameters, and click the SEARCH button to acquire the target.
4. Click the CLOSE button to exit the command.

Angular Drive: Move the laser beam to a target by keying in specific azimuth and zenith positions.

To use the Angular Drive option:

1 Enter the Azimuth and Zenith positions in radian units. If necessary, select the USE ESTIMATED DISTANCE check box and enter the estimated distance.

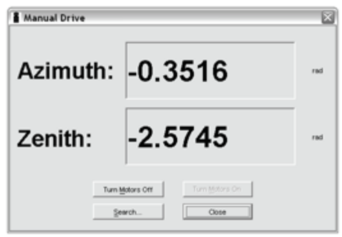
2 Click the MOVE button to move the laser beam to the position. Repeat until the laser beam is pointing near the target.

3 Click the SEARCH… button, key in the search parameters, and click the SEARCH button to acquire the target.

4 Click CLOSE to exit the command.

Manual Drive: Manually move the laser beam to a target.

To use the Manual Drive option:



1 Click the TURN MOTORS OFF button to switch the motors off.

2 Carefully move the Laser Tracker head and move the laser beam near the target.

3 Click the TURN MOTORS ON button.

4 Click the SEARCH button to acquire the target.

5 Click the CLOSE button to exit the command.

Camera: Move the laser beam to a target using the FARO TargetCAM accessory. For more information, see the TargetCAM section of the FARO Laser Tracker Accessories Manual.

Motors

Click the MOTORS button to switch on or off the motors that control the movement of the laser beam.

Settings

Click the SETTINGS button to control some the FARO Laser Tracker's settings.

Measurement Mode:

- Single Point Mode - The number of measurement samples for each measurement in Single Point Mode. Each measurement is an average of the samples.
- Distance Based Mode - The number of measurement samples for each measurement. Enter the distance between measurements.
- Single Point Mode - The number of measurement samples for each measurement. Enter the time between measurements.

Search: The size of the searching radius when the FARO Laser Tracker is automatically searching for an SMR.

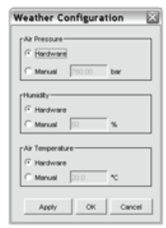
Weather Settings: Select and configure the source for the weather information. The HARDWARE option uses the Laser Tracker's integrated weather station. The MANUAL option uses the entered weather information.

To manually enter weather information:

1 Click each MANUAL radio button.

2 Enter the weather information.

3 Click the APPLY button to apply the changes, and then click OK to exit the command.



NOTE: Clicking the CANCEL button before clicking the APPLY button exits the command *without* making changes.

Temperature Sensors: View and configure any temperature sensors connected to the MCU.

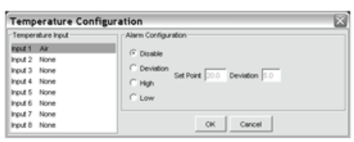


Figure 13-2 Temperature Sensor Configuration dialog box

Closure: button to open the FARO Laser Tracker's CLOSURE dialog box. The CLOSURE dialog box displays the distance from the target to the Home position.

Figure 13-3 Closure Window

Environment Check

Click the ENVIRONMENT CHECK button to start the Operation Checks. For more information, see "Operational Checks" on page 49.

Disconnect

In the list of devices, select a FARO Laser Tracker and click the DISCONNECT button to disconnect it from CAM2 Q. Use the ADD NEW DEVICE button to search for devices connected to your computer. *See "Add a Device" on page 107.*

Technical Support

FARO Technologies, Inc. is committed to providing the best technical support to our customers. Our Service Policy is detailed in *Appendix C: Industrial Products Service Policy* of this manual. If you have any problem using one of our products, please follow these steps before contacting our Technical Support Team:

- Be sure to read the relevant sections of the documentation to find the help you need.
- Visit the FARO Customer Care area on the Web at *www.faro.com* to search our technical support database. This is available 24 hours a day 7 days a week.
- Document the problem you are experiencing. Be as specific as you can. The more information you have, the easier the problem will be to solve.
- If you still cannot resolve your problem, have your device's Serial Number available *before calling*.

North American Technical Support hours are from 8:00 a.m. to 8:00 p.m. Eastern Standard Time (EST), Monday through Friday. European Technical Support Hours are from 8:00 a.m. to 5:00 p.m. Central European Standard Time (CET). You can also e-mail or fax any problems or questions 24 hours a day.

- **Phone**
  North America:
  800 736 2771, +1 407 333 3182 (Worldwide)
  Europe:
  +800 3276 7378, +49 7150 9797-400 (Worldwide)

  Asia:
  +65 6511 1350

  Japan:
  +81 561 63 1411

  China:
  +86 21 6191 7600

  India:
  +91 11 4167 6330/1
- **Fax**
  North America:
  FaroArm/FARO Gage +1 407 333 8056

FARO Laser Tracker +1 610 444 2323
FARO Laser Scanner +1 610 444 2323

Europe:
All Products +800 3276 1737, +49 7150 9797-9400 (Worldwide)

Asia:
+65 6543 0111

Japan:
+81 561 63 1412

China:
+86 21 6494 8670

India:
+91 11 4167 6332

- **E-Mail**
  North America:
  FaroArm/FARO Gage support@faro.com
  FARO Laser Tracker supportlaser@faro.com
  FARO Laser Scanner supportlaser@faro.com

  Europe:
  All Products support@faroeurope.com

  Asia:
  All Products salesap@faro.com

  Japan:
  All Products support_japan@faro.com

  China:
  All Products chinainfo@faro.com

  India:
  All Products infoindia@faro.com

E-Mails or Faxes sent outside regular working hours (8:00 a.m. to 8:00 p.m., Monday through Friday) usually are answered before 12:00 p.m. the next working day. Should our staff be on other calls, please leave a voice mail message; calls are always returned within 4 hours. Please remember to leave a detailed description of your question and your device's Serial Number. Do not forget to include your name, fax number, telephone number and extension so we can reach you promptly.

Appendix A: Software License Agreement

This Software License Agreement is part of the Operating Manual for the product and software System which you have purchased from FARO TECHNOLOGIES, INC. (collectively, the "Licenser") By your use of the software you are agreeing to the terms and conditions of this Software License Agreement. Throughout this Software License Agreement, the term "Licensee" means the owner of the System.

I. The Licenser hereby grants the Licensee the non-exclusive right to use the computer software described in this Operating Manual (the "software"). The Licensee shall have no right to sell, assign, sub-license, rent or lease the software to any third party without the Licenser's prior written consent.

II. The Licenser further grants the Licensee the right to make a backup copy of the software media. The Licensee agrees that it will not decompile, disassemble, reverse engineer, copy, transfer, or otherwise use the software except as permitted by this section. The Licensee further agrees not to copy any written materials accompanying the software.

III. The Licensee is licensed to use the Software only in the manner described in the Operating Manual. Use of the Software in a manner other than that described in the Operating Manual or use of the software in conjunction with any non-Licenser product which decompiles or recompiles the software or in any other way modifies the structure, sequence or function of the software code, is not an authorized use, and further, such use voids the Licenser's set forth below.

IV. The only warranty with respect to the software and the accompanying written materials is the warranty, if any, set forth in the Quotation/Purchase Order and *Appendix B: Purchase Conditions* pursuant to which the software was purchased from the Licenser.

V. THIS WARRANTY IS IN LIEU OF OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE WITH RESPECT TO THE SOFTWARE AND WRITTEN MATERIALS. IN NO EVENT

WILL THE LICENSER BE LIABLE FOR DAMAGES, INCLUDING ANY LOST PROFITS OR OTHER INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OR INABILITY TO USE THE SOFTWARE, NOTWITHSTANDING THAT THE LICENSER HAVE BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, THE LICENSER WILL NOT BE LIABLE FOR ANY SUCH CLAIM BY ANY OTHER PARTY.

VI. In the event of any breach by the Licensee of this Agreement, the license granted hereby shall immediately terminate and the Licensee shall return the software media and all written materials, together with any copy of such media or materials, and the Licensee shall keep no copies of such items.

VII. The interpretation of this Agreement shall be governed by the following provisions:

A. This Agreement shall be construed pursuant to and governed by the substantive laws of the State of Florida (and any provision of Florida law shall not apply if the law of a state or jurisdiction other than Florida would otherwise apply).

B. If any provision of this Agreement is determined by a court of competent jurisdiction to be void and non-enforceable, such determination shall not affect any other provision of this Agreement, and the remaining provisions of this Agreement shall remain in full force and effect. If any provision or term of this Agreement is susceptible to two or more constructions or interpretations, one or more of which would render the provision or term void or non-enforceable, the parties agree that a construction or interpretation which renders the term of provision valid shall be favored.

C. This Agreement constitutes the entire Agreement, and supersedes all prior agreements and understandings, oral and written, among the parties to this Agreement with respect to the subject matter hereof.

VIII. If a party engages the services of an attorney or any other third party or in any way initiates legal action to enforce its rights under this Agreement, the prevailing party shall be entitled to recover all reasonable costs and expenses (including reasonable attorney's fees before trial and in appellate proceedings).

Appendix B: Purchase Conditions

All Purchase Orders (hereafter, the "Order") for FARO-provided products and services (hereafter, the "Product") are subject to the following terms and conditions, which are agreed to by the Purchaser. All capitalized terms are defined in Section 8.00 Definitions hereafter.

1.00Payment of Purchase Price

1.01Purchaser hereby promises to pay to the order of FARO all deferred portions of the Purchase Price, together with interest on late purchase price payments payable at 1.5% per month (18% per annum).

1.02The Purchaser grants to FARO a security interest in the products sold pursuant to the Order, which may be perfected by UCC-1 Financing Statements to be recorded in the applicable County of the Purchaser's business location and filed with the Secretary of State's Office, which security interest will remain in effect until payment in full of the purchase price together with interest on late purchase price payments payable thereon had been received by FARO.

1.03If the Purchaser fails to make full payment of the purchase price within the period set out in the Order, FARO shall at its option have the following remedies, which shall be cumulative and not alternative:

a) the right to cancel the Order and enter the Purchaser's premises to re-take possession of the Product, in which event the Purchaser agrees that any down-payment or deposit shall be forfeited to FARO, as liquidated damages and not as a penalty, and all costs incurred by FARO in connection with the removal and subsequent transportation of the Product shall be payable by the Purchaser upon written demand;

b) the right to enter the Purchaser's premises and remove any Software, components of the Product or other items necessary in order to render the Product inoperative;

c) the right to withhold all services which would otherwise be required to be provided by FARO pursuant to the Warranties set out in Section 4.00 Warranties and Limitation of Liability hereof;

d) terminate any existing software license agreement and

e) pursue any other available remedy, including suing to collect any remaining balance of the purchase price (i.e., accelerate the payment of the purchase price causing the entire balance to immediately become due and payable in full).

f) Customer will be charged a 20% restocking fee for refusal to accept equipment as delivered. Equipment must be returned unopened within 10 business days of receipt at customer facility.

1.04If Purchaser fails to make payment(s) in accordance with the terms of this Order, the Purchaser's Products may be rendered inoperable until such payment terms are met.

No waiver by FARO of its rights under these conditions shall be deemed to constitute a waiver of subsequent breaches or defaults by the Purchaser. In the event more than one Product is being purchased pursuant to the Order, unless otherwise set forth herein, each payment received by FARO from Purchaser shall be applied pro rata against the cost of each product rather than being applied to the purchase price of any product.

2.00Delivery and Transportation

2.01Delivery dates are estimates and not guarantees, and are based upon conditions at the time such estimate is given.

2.02FARO shall not be liable for any loss or damage, whether direct, indirect or consequential, resulting from late delivery of the Product. The Purchaser's sole remedy, if the Product is not delivered within 90 days of the estimated delivery date, shall be to cancel the Order and to recover from FARO without interest or penalty, the amount of the down-payment or deposit and any other part of the purchase price which has been paid by the Purchaser. Notwithstanding the foregoing, such right of cancellation shall not extend to situations where late delivery is occasioned by causes beyond FARO's control, including, without limitation, compliance with any rules, regulations, orders or instructions of any federal, state, county, municipal or other government or any department or agency thereof, force majuere, acts or omissions of the Purchaser, acts of civil or military authorities, embargoes, war or insurrection, labor interruption through strike or walkout, transportation delays and other inability resulting from causes beyond FARO's control to obtain necessary labor, manufacturing facilities or materials from its usual sources. Any delays resulting from such causes shall extend estimated delivery dates by the length of such delay.

2.03Responsibility for all costs and risks in any way connected with the storage, transportation and installation of the Product shall be borne entirely by the Purchaser. If any disagreement arises as to whether or not damage to the Product was in fact caused in storage, transit or on installation, the opinion of FARO's technical advisors, acting reasonably, shall be conclusive.

3.00Installation and Operator Training

3.01The Purchaser shall be responsible for installation of the Product, including, without limitation, the preparation of its premises, the uncrating of the Product and setting up of the Product for operation. Purchaser may elect to order contract services from FARO to perform this service should they elect to do so.

4.00Warranties and Limitation of Liability

4.01FARO warrants that (subject to Section 4.06), the Product shall be free from defects in workmanship or material affecting the fitness of the Product for its usual purpose under normal conditions of use, service and maintenance. A complete statement of FARO's maintenance/ warranty service is set forth in *Appendix B: Purchase Conditions*.

4.02FARO warrants that the Software shall operate according to specifications and the System shall operate and perform in the manner contemplated in connection with the usual purpose for which it is designed.

4.03The maintenance/warranty set out in paragraphs 4.01 shall expire at the end of the twelve (12) month period commencing on the date of shipment from the FARO factory (the "Maintenance/Warranty Period").

4.04Subject to the limitations contained in Section 4.06, the Warranties shall apply to any defects found by the Purchaser in the operation of the FARO Laser Tracker and reported to FARO within the Maintenance/ Warranty Period. If the FARO Laser Tracker or the Software is found by FARO, acting reasonably, to be defective, and if the defect is acknowledged by FARO to be the result of FARO's faulty material or workmanship, the FARO Laser Tracker will be repaired or adjusted to the extent found by FARO to be necessary or at the option of FARO, replaced with a new FARO Laser Tracker or parts thereof at no cost to the Purchaser.

4.05Claims under the Warranties shall be made by delivering written notice to FARO of the defect in the System, the FARO Laser Tracker. Within a reasonable time of receipt of such notice, FARO shall have the System and FARO Laser Tracker diagnosed by its service personnel, and maintenance/warranty service will be provided at no cost to the Purchaser if the System and FARO Laser Tracker is found by FARO to be defective within the meaning of this Section.

(If, in the reasonable opinion of FARO after diagnosis of the system and the FARO Laser Tracker are not defective, the Purchaser shall pay the cost of service, which shall be the amount that FARO would otherwise charge for an evaluation under a non-warranty service evaluation.

4.06The Warranties do not apply to:

a) Any defects in any component of a System where, if in the reasonable opinion of FARO, the FARO Laser Tracker, Software or System has been improperly stored, installed, operated, or maintained, or if Purchaser has permitted unauthorized modifications, additions, adjustments and/or repair to any hard drive structure or content, or any other part of the System, or which might affect the System, or defects caused or repairs required as a result of causes external to FARO workmanship or the materials used by FARO. As used herein, “unauthorized” means that which has not been approved and permitted by FARO.

b) The Warranties shall not cover replacement of expendable items, including, but not limited to, fuses, diskettes, printer paper, printer ink, printing heads, disk cleaning materials, or similar items.

c) The Warranties shall not cover minor preventive and corrective maintenance, including, but not limited to, replacement of fuses, disk drive head cleaning, fan filter cleaning and system clock battery replacement.

d) Any equipment or its components which was sold or transferred to any party other than the original Purchaser without the expressed written consent of FARO.

4.07Factory Repairs

a) IF SYSTEM IS UNDER MAINTANENCE/WARRANTY: The Purchaser agrees to ship the Product to FARO in the original packing containers. FARO will return the repaired or replacement Product.

FARO will incur the expense of the needed part and all return shipping charges to the Purchaser. FARO may authorize the manufacturer of a component of the Product to perform the service.

b) IF SYSTEM IS UNDER PREMIUM SERVICE PLAN: When practical and subject to availability, FARO will make available to the Purchaser substitute component parts or FARO Laser Tracker's ("Temporary Replacements") while corresponding parts of the Purchaser's system or FARO Laser Tracker are undergoing repair at FARO's factory. Shipping charges for these "Temporary Replacement" parts or FARO Laser Tracker's will be the responsibility of FARO.

c) IF SYSTEM IS NOT UNDER MAINTANENCE/WARRANTY: The Purchaser is responsible for the cost of the replacement part or software, and all shipping charges. All charges shall be estimated and prepaid prior to commencement of repairs.

4.08Nothing herein contained shall be construed as obligating FARO to make service, parts, or repairs for any product available after the expiration of the Maintenance/Warranty Period.

4.09Limitation of Liability

FARO shall not be responsible under any circumstances for special, incidental or consequential damages, including, but not limited to, injury to or death of any operator or other person, damage or loss resulting from inability to use the System, increased operating costs, loss of production, loss of anticipated profits, damage to property, or other special, incidental or consequential damages of any nature arising from any cause whatsoever whether based in contract, tort (including negligence), or any other theory of law. FARO's only liability hereunder, arising from any cause whatsoever, whether based in contract, tort (including negligence) or any other theory of law, consists of the obligation to repair or replace defective components in the System or FARO Laser Tracker subject to the limitations set out above in this section.

This disclaimer of liability for consequential damage extends to any such special, incidental or consequential damages which may be suffered by third parties, either caused directly or indirectly resulting from test results or data produced by the system or any component thereof and the Purchaser agrees to indemnify and save FARO harmless from any such claims made by third parties.

4.10The foregoing shall be FARO's sole and exclusive liability and the Purchaser's sole and exclusive remedy with respect to the system.

THE SOLE RESPONSIBILITY OF FARO UNDER THE WARRANTIES IS STATED HEREIN AND FARO SHALL NOT BE LIABLE FOR CONSEQUENTIAL, INDIRECT, OR INCIDENTAL DAMAGES, WHETHER THE CLAIM IS FOR BREACH OF WARRANTY, NEGLIGENCE, OR OTHERWISE.

OTHER THAN THE EXPRESS WARRANTIES HEREIN STATED, FARO DISCLAIMS ALL WARRANTIES INCLUDING IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS.

4.11FARO does not authorize any person (whether natural or corporate) to assume for FARO any liability in connection with or with respect to the Products. No agent or employee of FARO has any authority to make any representation or promise on behalf of FARO, except as expressly set forth herein, or to modify the terms or limitations of the Warranties. Verbal statements are not binding upon FARO.

4.12The Maintenance/Warranties extend only to the Purchaser and are transferable, only under the following conditions:

- The FARO Laser Tracker is currently under maintenance/warranty.
- New owner is, or becomes, a certified user.
- A FARO maintenance/warranty transfer form is completed, and submitted to Customer Service.

All claims under the Warranties must originate with the Purchaser, or any subsequent owner, and the Purchaser will indemnify and save FARO harmless from any claims for breach of warranty asserted against FARO by any third party.

4.13Oral representations of FARO or its sales representatives, officers, employees or agents cannot be relied upon as correctly stating the representations of FARO in connection with the system. Refer to this purchase order, any exhibits hereto and any written materials supplied by FARO for correct representations.

4.14PURCHASER ACKNOWLEDGES THAT IT HAS PURCHASED THE SYSTEM BASED UPON ITS OWN KNOWLEDGE OF THE USES TO WHICH THE SYSTEM WILL BE PUT. FARO SPECIFICALLY DISCLAIMS ANY WARRANTY OR LIABILITY RELATED TO THE FITNESS OF THE SYSTEM FOR ANY PARTICULAR PURPOSE OR ARISING FROM THE INABILITY OF THE PURCHASER TO USE THE SYSTEM FOR ANY PARTICULAR PURPOSE.

5.00Design Changes

5.01The FARO Laser Tracker, the Software and the System are subject to changes in design, manufacture and programming between the date of order and the actual delivery date. FARO reserves the right to implement such changes without the Purchaser’s consent, however, nothing contained herein shall be construed as obligating FARO to include such changes in the FARO Laser Tracker, Software or System provided to the Purchaser.

6.00Non-Disclosure

6.01All Software including, without limitation, the Operating System Program and any FARO special user programs, provided to the Purchaser as part of the system, either at the time of or subsequent to the delivery of the FARO Laser Tracker, is the intellectual property of FARO. The Purchaser shall not reproduce or duplicate, disassemble, decompile, reverse engineer, sell, transfer or assign, in any manner the Software or permit access to or use thereof by any third party. The Purchaser shall forthwith execute any further assurances in the form of non-disclosure or licensing agreements which may reasonably be required by FARO in connection with the software.

7.00Entire Agreement / Governing Law / Miscellaneous / Guarantee

7.01These Purchase conditions constitute the entire agreement between FARO and the Purchaser in respect to the Product. There are no representations or warranties by FARO, express or implied, except for those herein contained and these conditions supersede and replace any prior agreements between FARO and the Purchaser.

7.02No representative of FARO has any authority to modify, alter, delete or add to any of the terms or conditions hereof. Any such modifications shall be absolutely void unless made by instrument in writing properly executed by an actual authorized employee or agent of FARO.

7.03The terms and conditions hereof shall be binding upon FARO and the Purchaser, and shall be construed in accordance with the laws of the State of Florida, United States of America.

7.04FARO shall be entitled to recover all of its reasonable fees and costs including, but not limited to, its reasonable attorney's fees incurred by FARO in connection with any dispute or litigation arising thereunder or in connection herewith, including appeals and bankruptcy or creditor reorganization proceeds.

7.05These conditions shall not be construed more strictly against one party than another as a result of one party having drafted said instrument.

8.00Definitions

8.01"FARO" means FARO Technologies, Inc.

8.02"Purchaser" means the party buying the Product and who is legally obligated hereunder.

8.03"Software" means all computer programs, disk drive directory organization and content, including the computer media containing such computer programs and disk drive directory organization and content, sold pursuant to the Order.

8.04"Product" means the FARO Laser Tracker, the Software, operating manuals and any other product or merchandise sold pursuant to the Order. If the Purchaser is buying only a FARO Laser Tracker, or the Software, Product will mean the product being purchased by the Purchaser pursuant to the Order.

8.05"System" means a combination of the FARO Laser Tracker, the Software, the Computer, and optional parts and accessories associated with the FARO Laser Tracker.

8.06"Certified user" means any person who has completed and passed the written exam issued by FARO. The exam is available upon request.

8.07"Purchase Order" means the original document issued from the Purchaser to FARO, listing all parts and/or services to be purchased and the agreed purchase price.

8.08"Maintenance/Warranty Transfer Form" means a document to be completed for the transfer of the FARO Maintenance/Warranty. This document is available from FARO upon request.

Appendix C: Industrial Products Service Policy

A one-year maintenance/warranty comes with the purchase of new FARO manufactured hardware products. Supplemental Service Plans are also available at additional cost. See *Appendix D: Industrial Service Policy* for further details.

FARO Hardware under Maintenance/ Warranty

The following is a summary of what services can be obtained under the original warranty or Supplemental Service Plan.

1 Factory repairs on FARO-manufactured hardware products.

2 Factory repairs are targeted for completion within 7 (FaroArms) or 14 (FARO Laser Trackers and Laser Scanners) working days of FARO's receipt of the defective item. The customer is responsible for returning the hardware to FARO in the original packing container or custom case.

3 FARO will return the hardware via 2-day air service to the Continental U.S. Outside the Continental U.S., FARO will return the hardware to the customs broker via 2-day air service. Expedited service can be arranged at the customer's expense.

4 Upon expiration of original warranty a Supplemental Service Plan may be purchased and can be renewed annually on FARO-manufactured hardware products.

5 All Supplemental Service Plans will be due for renewal at the end of the month in which the Service Plan or warranty was purchased, plus 12 months.

6 The original warranty and Supplemental Service Plan are transferable to subsequent owners under certain conditions:

- The FARO Laser Tracker is currently under the original warranty and Supplemental Service Plan.
- New owner is, or becomes, a certified user.
- A FARO Transfer of Original Warranty or Service Plan Agreement form is completed and submitted to Customer Service.

FARO Hardware NOT under Maintenance/ Warranty

Factory assessments and repairs on FARO-manufactured products will follow the following procedure:

1 The customer obtains a service number from FARO's Customer Service Department.

2 The customer sends the part to FARO with the service number on the label along with payment or a corporate purchase order for system testing and evaluation, which includes calibration and recertification.

3 The payment will be applied toward the total service cost beyond the initial payment. The estimated repair cost will be given to the customer prior to the repair. The total cost must be paid prior to beginning the service.

4 System testing and evaluation can take up to 30 days. FARO-manufactured part repairs can take up to 60 days. However, the part will be scheduled for service as soon as it arrives at FARO's factory.

5 The customer is responsible for all shipping charges to and from FARO, including import and export fees for international customers.

FARO Software

All FARO Software users will receive maintenance releases until the end of life for the version at no charge electronically or at a minimal fee for the computer media package. All enhancement and functionality upgrades will be available for purchase upon release.

Hardware & Software Training

FARO's training program is designed to instruct trainees in the operation of FARO's hardware and software, which the customer has purchased. The training classes are set up for each trainee to obtain valuable hands on application exposure. This will help the trainees in their everyday use of the hardware and software. FARO also feels that once the trainee completes the training, finding solutions to problems or applying applications will be simpler. Details are as follows:

1 The training class will prepare attendees to successfully attain an operators certification (see *Certification Requirements* section for more details).

2 The fee schedules for advanced additional training courses can be obtained from Customer Service, or the Sales department.

Certification Requirements

The FARO Laser Tracker operator's inherent ability to understand 3D concepts may be in their background training. However, the precision with which the operator performs 3D measurements with the FARO Laser Tracker is critical in establishing the accuracy and repeatability of the results of subsequent measurements.

In order to establish the proficiency of FARO Laser Tracker operators, FARO has instituted an Operator Certification program, where each operator's knowledge and understanding of the FARO Laser Tracker is evaluated. The successful operator is awarded a certificate which identifies him/her as an accredited FARO Laser Tracker operator. The requirements are as follows:

1 Attend a FARO-conducted basic training course, either at a FARO Facility or on site at your facility.

2 Certification will be awarded once the class has been completed, and then the certified user will be registered for hardware and software support.

To certify an operator, call FARO's Training Department, 800.736.0234 (North America), +1 407.333.9911 (Worldwide), for updated information.

FARO Laser Tracker Repair Fee Schedule

(Out of Maintenance/Warranty Owners Only!)

System Testing and Evaluation Fee - Contact your local FARO Service Center for pricing.

A fee is charged for any system testing and evaluation. This includes system diagnosis, calibration and/or recertification, and applies to all FARO Laser Trackers. However, this fee does not include disassembly/ repair costs if required. An estimated cost for disassembly/repair will be given to the customer prior to the repair. The disassembly/repair charges must be paid in full prior to the actual disassembly/repair. However, if no repairs are needed the fee will be applied to the cost of system testing and evaluation. All evaluations contain a recertification. Re-certification will be performed on an "as needed" basis.

Contact your local FARO Service Center for the current system testing and evaluation fee pricing.

Repair Times

Calibration and/or Recertification Only - Can take up to 14 days to complete.

Disassembly and Repair - Can take up to 60 days to complete. This time is dependent on the supply of purchased components.

*Includes Calibration and Recertification

Transfer of Original Warranty or Service Plan Agreement

____

(SELLER'S CORPORATE OR INDIVIDUAL NAME AS APPLICABLE),
hereby waives all rights under the warranty service policy for
FARO Laser Tracker Serial Number______________________________
CAM2 Port Lock Number __________________
purchased originally on ______________________(DATE).

____

(BUYER'S CORPORATE OR INDIVIDUAL NAME AS APPLICABLE),
hereby assumes all rights and obligations of the Hardware and/or Software Warranty Service Policy from __________________ (DATE OF TRANSFER).
This transfer is only valid under the following conditions.

1 The FARO Laser Tracker is currently under maintenance/warranty
2 New owner is, or becomes, a certified user.
3 This maintenance/warranty transfer form is completed and submitted to FARO Customer Service.

AGREED

(PRINT SELLER'S CORPORATE OR INDIVIDUAL NAME AS APPLICABLE)	(PRINT SELLER'S CORPORATE OR INDIVIDUAL NAME AS APPLICABLE)
BY X______________________________	BY X______________________________
(PRINT NAME OF SIGNATORY)	(PRINT NAME OF SIGNATORY)

FARO Technologies Inc.

Approved by x __________________________________

____
(PRINT NAME OF SIGNATORY)

Appendix D: Industrial Service Policy

This Service Plan (hereafter, the "Plan") is part of the Operating Manual for the FARO manufactured product purchased from FARO TECHNOLOGIES INC. (hereafter, "FARO"). The Plan and all of the optional additions, are subject to the conditions in Appendices A, B, & C, and are subject to change. This appendix refers to FARO's service plans as written in the sales advertising literature, and is meant to provide additional details that the literature does not permit.

1.00 The purchase of the Plan shall occur with the purchase of the FARO products.

1.01 The plan shall apply to systems exclusively created or authored by FARO.

1.02 The plan shall include FARO product hardware only, and can not be extended or transferred through the sale of any part of the system to a third party unless the entire system has been sold or transferred.

1.03 The plan shall not cover Hardware or Software which has been subjected to misuse or intentional damage. FARO reserves the right to determine the condition of all returned Hardware and/or Software.

1.04 FARO shall determine the service method and contractor to service/ repair all hardware which is not directly manufactured by FARO. All outside contractor terms and conditions are available from FARO and are incorporated herein by reference.

1.05 FARO shall not be responsible for any non-FARO authored software which inhibits the operation of the system. Furthermore the plan will not cover the re-installation of any software.

1.06 The Hardware and Software are subject to changes in design, manufacture, and programming. All updates are as follows:

a) Hardware - The FARO Laser Tracker and all of the associated optional parts, and the Computer are not subject to updates.

b) Software - All computer programs, authored by FARO, which are used in conjunction with the FARO provided Hardware, will be updated (maintenance upgrades) for the life of the Purchaser's current version. All enhancement and functionality upgrades must be purchased.

c) 3rd Party Software - All computer programs not authored by FARO will not be updated under the Plan. The purchaser is responsible for the acquisition of all 3rd party software updates and warranty service or claims.

1.07In the event that FARO replaces any product or replacement product, FARO retains all right, title, and interest in and to all products or portions of products that were replaced by FARO.

2.00 Definitions

2.01"FARO" means FARO Technologies, Inc.

2.02"Purchaser" means the party buying the Product and who is legally obligated hereunder.

2.03"Software" means all computer programs, disk drive directory organization and content, including the diskettes containing such computer programs and disk drive directory organization and content, sold pursuant to the Order.

2.04"Product" means the FARO Laser Tracker, the Software, operating manuals and any other product or merchandise sold pursuant to the Order. If the Purchaser is buying only a FARO Laser Tracker, or the Software, Product will mean the product being purchased by the Purchaser pursuant to the Order.

2.05"System" means a combination of the FARO Laser Tracker, the Software, the Computer, and optional parts associated with the FARO Laser Tracker.

2.06"Hardware" means the FARO Laser Tracker and all of the associated optional parts, and the Computer if provided by FARO.

2.07"Software" means all computer programs, authored by FARO, which are used in conjunction with the FARO provided Hardware.

The following is a layman's definition of the coverage.

Standard Service Plans

All shipping times below are to destinations within the Continental United States. Outside the Continental U.S., FARO will ship equipment directly to the customs broker.

- Standard Service Plans are contracted at time of purchase or at any time while a unit is covered by a FARO hardware service plan (as described in more detail later).

- The Standard Service Plan covers the FARO Laser Tracker and controller box.
- Shipping costs, including insurance from the Purchaser to FARO are the responsibility of the Purchaser. FARO will be responsible for all return shipping costs including insurance.
- All reasonable efforts will be made to keep the service repair time within 7 (FaroArm) or 14 (FARO Laser Tracker and Laser Scanner) working days. The equipment will be returned via 2-Day air service, therefore, total service repair time will vary due to return shipping location.
- Since the FARO Laser Tracker is designed to be used with many other software packages not authored by FARO, this service plan can be purchased in its entirety to cover only FARO produced or authored products. For items not produced or authored by FARO, the customer is responsible for securing their own separate warranty or service plan coverage.

Hardware Coverage

FARO Laser Tracker

Covered

- All parts and labor for FARO Laser Trackers failing under normal use as described in Appendix B.
- Annual calibration and re-certification of the FARO Laser Tracker.

Not Covered

- Misuse
- Intentional damage
- Wear and tear of probes, ball bars, auxiliary hardware products such as cables, wrenches, hex keys, screwdrivers, etc.

Computer

Covered

- FARO contracts with 3rd party service providers for this service for up to 3 years. The terms and conditions of FARO's contract with the provider apply herein and are incorporated herein by reference.
- Typically, these services include repair of the computer, memory cards, and video monitors.

Not Covered

- All exclusions contained in the 3rd party service providers policy which is incorporated herein by reference.
- Software operating system installation.
- User intentional or unintentional removal of key software property or files.

Software Coverage

Covered

- Periodically, FARO Technologies may release maintenance updates of its proprietary software. This will be supported through the life of the product version. All enhancement and functionality upgrades will be available in the next full version for a fee.

Not Covered

- End users are responsible for the procurement and installation of 3rd party authored or S/W updates as required to use with FARO authored software products, unless FARO Technologies resold these packages to the end user as an authorized reseller. Examples of 3rd party authored S/W are: DOS, Windows, AutoCAD, AutoSurf, SurfCAM and others.

Premium Service Plans

The Premium Service Plans additionally provide loaner FARO Laser Trackers and Computers when service is required. All equipment shipping costs are paid for by FARO (both ways). FARO will make its best effort to ship all loaner FARO Laser Trackers within 24 hours of the receipt of the purchasers request. Once the need for a service has been verified by FARO, FARO will make its best effort to ship all loaner computers within 72 hours of the receipt of the purchaser’s request.

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FARO. THE MEASURE OF SUCCESS.

APPENDIX G-2.8

ATLAS RAILCAR AMSTED RAIL SPECIFIC TRUCK FABRICATION PROCESSES

Appendix G-2.8.1 Amsted Rail ASF-K Swing Motion™ Truck for 290 Ton Flat Car Assembly Procedure, Product Bulletin No. N544, Rev C

SWING MOTION™ TRUCK FOR 290 TON FLAT CAR

ASSEMBLY PROCEDURE

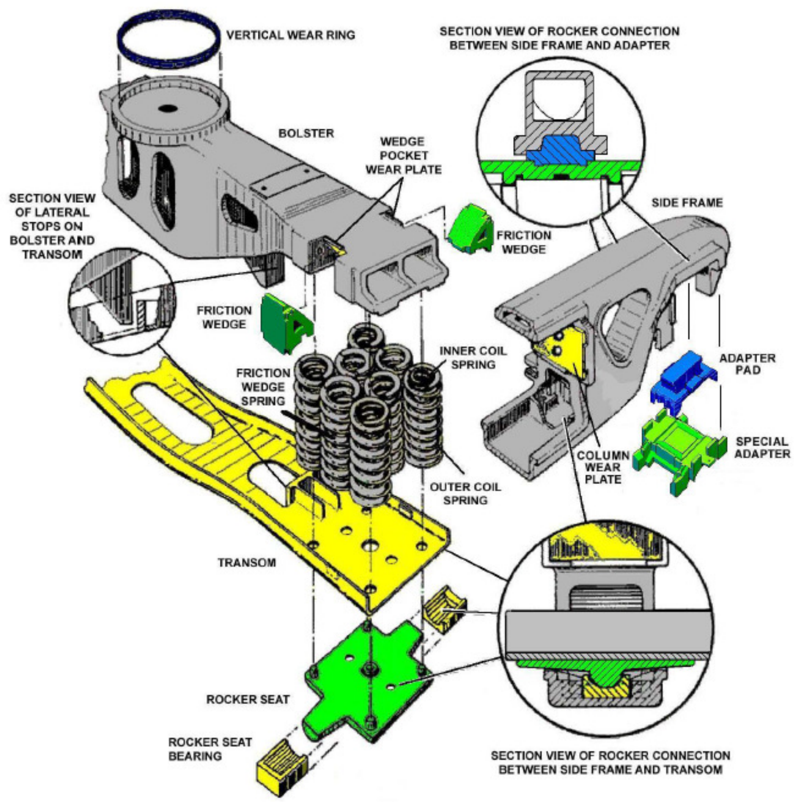
PRODUCT BULLETIN NO. N544

AMSTED RAIL
1700 WALNUT STREET
GRANITE CITY, IL 62040 USA

TELEPHONE: (800) 621-8442

Issue	Date Issued
Original	August 6, 2010
Rev. A	July 24, 2012
Rev. B	July 30, 2012
Rev. C	July 27, 2017

Swing Motion Truck
Exploded View of Assembly



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Product Bulletin –N544

Swing Motion Truck
Basic Assembly Procedure

The following procedure should be used to assemble the Swing Motion truck. These trucks are designed to be used on a car in two sets of three trucks each. There are different configurations for middle trucks in the set and end trucks in the set. The middle and end trucks must be marked to ensure that they do not get installed in the wrong position on the car, or the performance of the car will be significantly reduced. The Bills of Material are included here to help ensure correct parts are being used in the correct configuration. Assembly problems or questions should be addressed to the Amsted Rail engineering department for resolution.

6 1/2 x 9 Prototype End Truck Parts 4 5/16" Spring Travel (Drawing AS-517)

Part Description	Part No.	Qty. Per Truck
Side Frame (w/column wear plates installed)	517A	2
Side Frame Column Wear Plate	50268	4
Side Frame Column Bolt	98-1-10444	8
Side Frame Column Locknut	98-1-10445	8
Pedestal Roof Spacer Shim	98-1-10654	4
Bolster (w/center plate vertical wear liner and wedge pocket wear liners installed)	519A3	1
Center Plate Vertical Ring Wear Liner	98-1-10028	1
Bolster Wedge Pocket Wear Plate	51285-1	4
Transom	48493-4	1
Rocker Seat	52764	2
Rocker Seat Bearing	49538	4
Wedge	48446	4
Control Coil Spring Group:		4
Outer Control Spring	1-94	4
Inner Control Spring	1-95	4
Load Coil Center Spring Group:		4
Outer Load Spring (Empty)	1-96	4
Load Coil Corner Spring Group:		8
Outer Load Spring (Loaded)	1-92	8
Inner Load Spring (Empty)	1-97	8
Inner-Inner Load Spring	1-99	8
Center Plate Horizontal Wear Liner	50112-2	1
Frame Key	43135	4
Adapter Pad	10522A	4
Special Adapter	10523A	4
Grounding Strap	10562	4
Hex Head Bolt	10563	8
Hex Elastic Stop Nut	10564	4
Helical Spring Lock Washer	10565	4
Hardened Washer	10566	4

6 1/2 x 9 Prototype Middle Truck Parts 6 5/16" Spring Travel (Drawing AS-518)

Part Description	Part No.	Qty. Per Truck
Side Frame (w/column wear plates installed)	517A	2
Side Frame Column Wear Plate	50268	4
Side Frame Column Bolt	98-1-10444	8
Side Frame Column Locknut	98-1-10445	8
Pedestal Roof Spacer Shim	98-1-10654	4
Bolster (w/center plate vertical wear liner and wedge pocket wear liners installed)	519A2	1
Center Plate Vertical Ring Wear Liner	98-1-10028	1
Bolster Wedge Pocket Wear Plate	51285-1	4
Transom	48493-4	1
Rocker Seat	52764	2
Rocker Seat Bearing	49538	4
Wedge	48446	4
Control Coil Spring Group:		4
Outer Control Spring	1-88	4
Inner Control Spring	1-89	4
Load Coil Corner Spring Group:		8
Outer Load Spring (Loaded)	1-92	8
Inner Load Spring (Empty)	1-91	8
Inner-Inner Load Spring	1-99	8
Load Coil Center Spring Group:		4
Outer Load Spring (Empty)	1-90	4
Inner Load Spring (Loaded)	1-93	4
Center Plate Horizontal Wear Liner	50112-2	1
Frame Key	43135	4
Bolster Wedge Pocket Wear Plate	51285-1	4
Adapter Pad	10522A	4
Special Adapter	10523A	4
Grounding Strap	10562	4
Hex Head Bolt	10563	8
Hex Elastic Stop Nut	10564	4
Helical Spring Lock Washer	10565	4
Hardened Washer	10566	4

6 1/2 x 9 End Truck Parts 4 5/16" Spring Travel (Drawing AS-517-1)

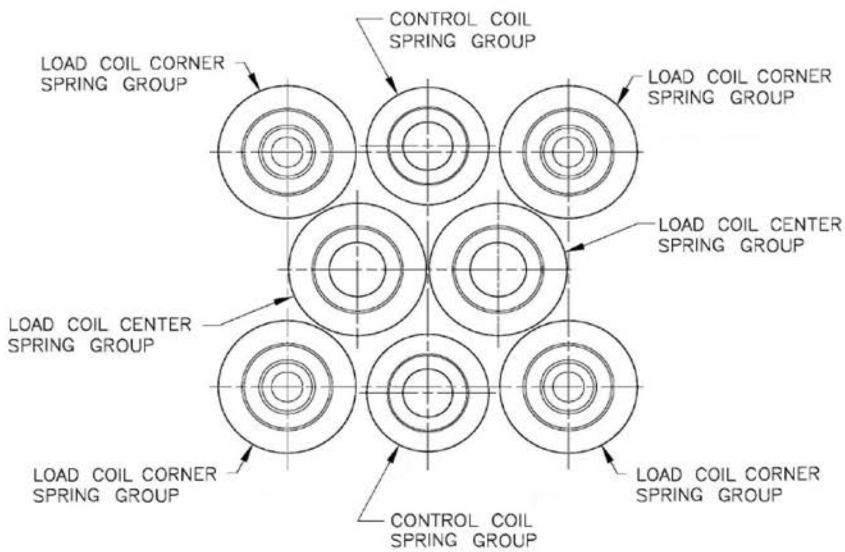
Part Description	Part No.	Qty. Per Truck
Side Frame (w/column wear plates installed)	517C	2
Side Frame Column Wear Plate	50268	4
Side Frame Column Bolt	98-1-10444	8
Side Frame Column Locknut	98-1-10445	8
Bolster (w/center plate vertical wear liner and wedge pocket wear liners installed)	519A3	1
Center Plate Vertical Ring Wear Liner	98-1-10028	1
Bolster Wedge Pocket Wear Plate	51285-1	4
Transom	48493-4	1
Rocker Seat	52764-1	2
Rocker Seat Bearing	49538	4
Wedge	48446	4
Control Coil Spring Group:		4
Outer Control Spring	1-94	4
Inner Control Spring	1-95	4
Load Coil Center Spring Group:		8
Outer Load Spring (Empty)	1-96	4
Load Coil Corner Spring Group:		4
Outer Load Spring (Loaded)	1-92	8
Inner Load Spring (Empty)	1-97	8
Inner-Inner Load Spring	1-99	8
Center Plate Horizontal Wear Liner	50112-2	1
Frame Key	43135	4
Adapter Pad	10522A	4
Special Adapter	10523A	4
Grounding Strap	10562	4
Hex Head Bolt	10563	8
Hex Elastic Stop Nut	10564	8
Helical Spring Lock Washer	10565	8
Hardened Washer	10566	8

6 1/2 x 9 Middle Truck Parts 6 5/16" Spring Travel (Drawing AS-518-1)

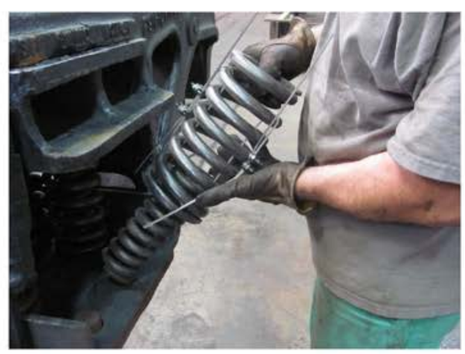
Part Description	Part No.	Qty. Per Truck
Side Frame (w/column wear plates installed)	517C	2
Side Frame Column Wear Plate	50268	4
Side Frame Column Bolt	98-1-10444	8
Side Frame Column Locknut	98-1-10445	8
Bolster (w/center plate vertical wear liner and wedge pocket wear liners installed)	519A2	1
Center Plate Vertical Ring Wear Liner	98-1-10028	1
Bolster Wedge Pocket Wear Plate	51285-1	4
Transom	48493-4	1
Rocker Seat	52764-1	2
Rocker Seat Bearing	49538	4
Wedge	48446	4
Control Coil Spring Group:		4
Outer Control Spring	1-88	4
Inner Control Spring	1-89	4
Load Coil Corner Spring Group:		8
Outer Load Spring (Loaded)	1-92	8
Inner Load Spring (Empty)	1-91	8
Inner-Inner Load Spring	1-99	8
Load Coil Center Spring Group:		4
Outer Load Spring (Empty)	1-90	4
Inner Load Spring (Loaded)	1-93	4
Center Plate Horizontal Wear Liner	50112-2	1
Frame Key	43135	4
Adapter Pad	10522A	4
Special Adapter	10523A	4
Grounding Strap	10562	4
Hex Head Bolt	10563	8
Hex Elastic Stop Nut	10564	8
Helical Spring Lock Washer	10565	8
Hardened Washer	10566	8

Assembly Procedure:

1. Assemble the spring groups as indicated in the appropriate truck BOM, and mark each group for truck position (end or middle truck) and spring group position in the spring nest (Control, Load Coil Corner, and Load Coil Center group). Note: The load coil spring groups for the middle truck are very difficult to install, the preferred method of installation is by compressing and gagging each group. (corner group: outer & inner springs together)(center group: only outer spring). Optional method is to use prybar and sledge for installation however caution must be taken not to damage springs.

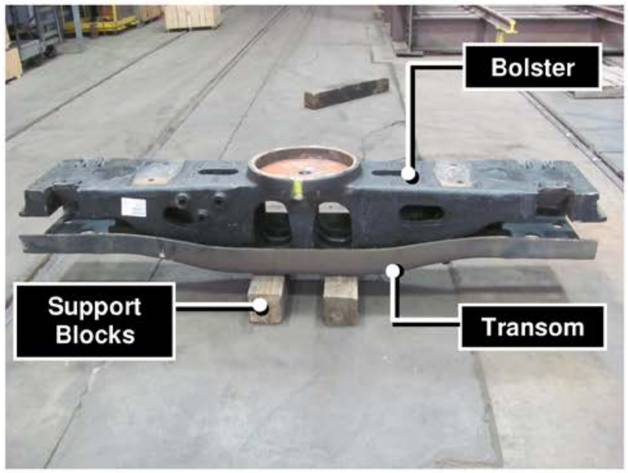


Middle truck corner springs compressed



Middle truck center spring compressed

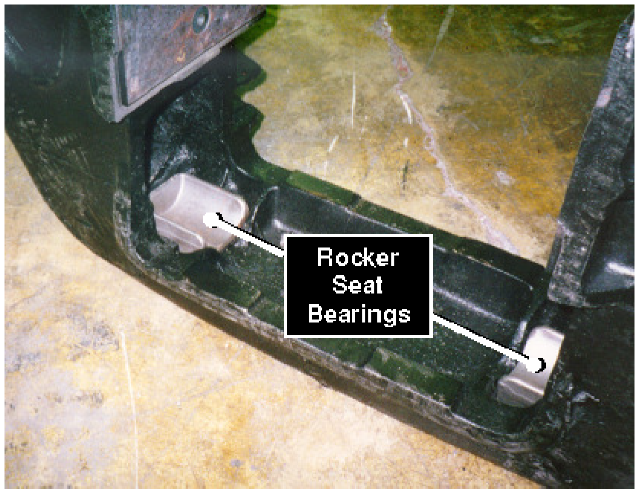
2. Place the transom on support blocks, raising it several inches off the floor. Blocks should be placed close together under the belly of the transom. Place the bolster on the transom. Transom to bolster alignment is produced by setting the lateral stops of the bolster into the stop openings in the transom.



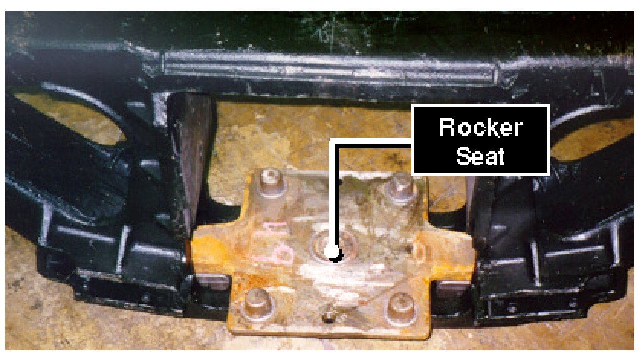
3. Observe the number of "buttons" that have been cast onto the sides of the sideframes above one pedestal jaw. These refer to the wheelbase of the sideframe. When possible, the number of buttons on each sideframe should be the same. AAR regulations permit the use of trucks where the number of buttons differs by one (i.e., left sideframe has 3 buttons, right sideframe has 2 buttons).

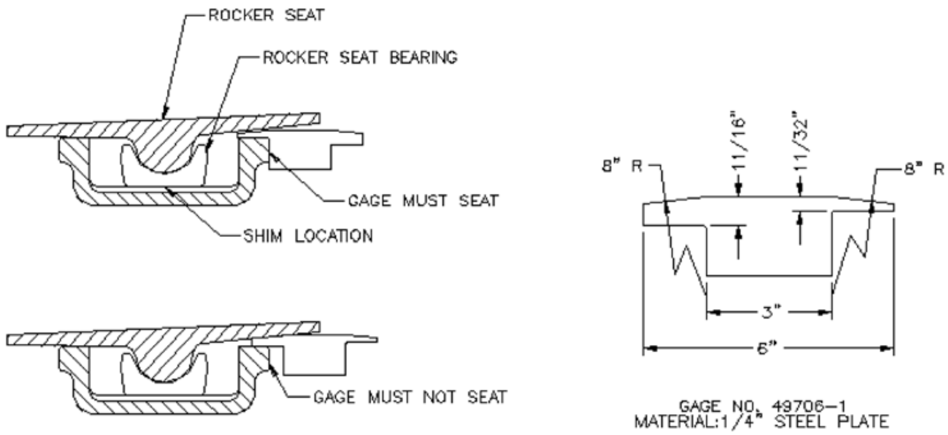
4. Install brake beam unit device wear plates into unit device guides on the sideframe. Do not use self centering type wear plates.

5. Check that the rocker seat bearing pockets in the lower portion of the side frames are free of positives, shot blast, or other debris and clean-up if necessary. Place the rocker seat bearings into the pockets with the closed end facing the sideframe pedestal as shown. The rocker seat bearings must seat firmly in the pocket without rocking.

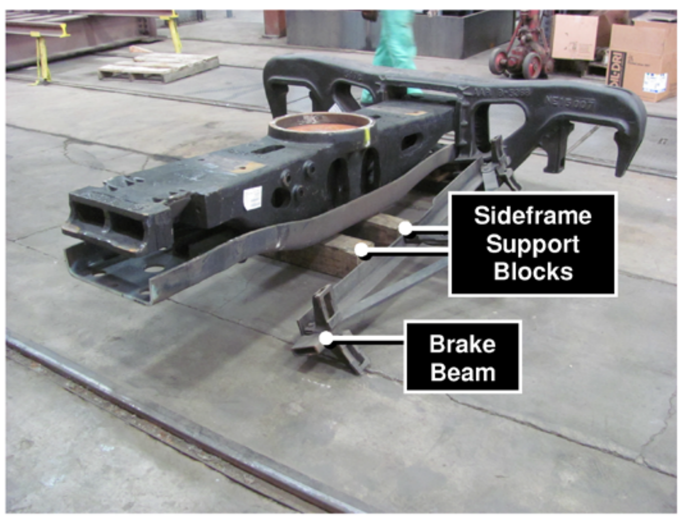


6. Place the rocker seat into the sideframe and align the seat ends into the rocker seat bearing concave surfaces. Tilt the rocker seat to one side of the sideframe until it stops. Use gage No. 49706-1 to verify the correct amount of clearance is present. The gage should bottom out against the sideframe wall using the thin side (GO) and not bottom out using the thick side (NO-GO).

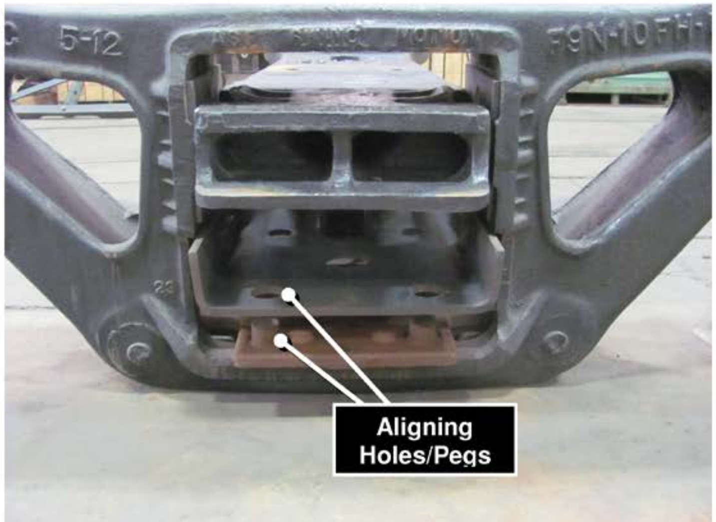




7. Using an appropriate hoist, lift and slide the sideframe over the ends of the bolster/transom assembly. The bolster will fit in through the spring window and the transom will fit through the lower part of the spring window. Align the holes in the transom with the pegs cast into the rocker seat. Support the sideframe on blocks so that the transom stays in contact with the rocker seat.

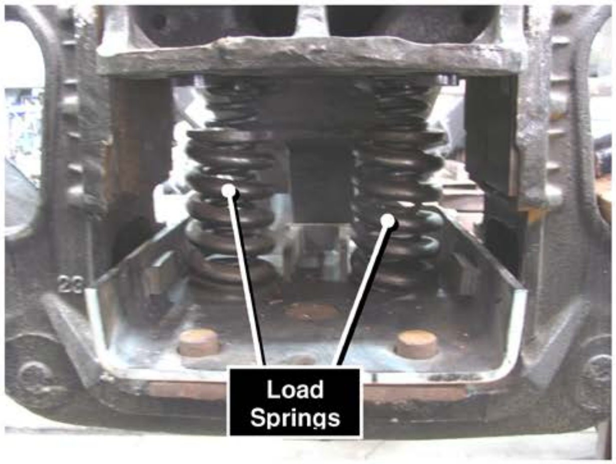


8. Repeat with the other sideframe. The transom should be resting on the two rocker seats, with the bolster lined up in the sideframes.

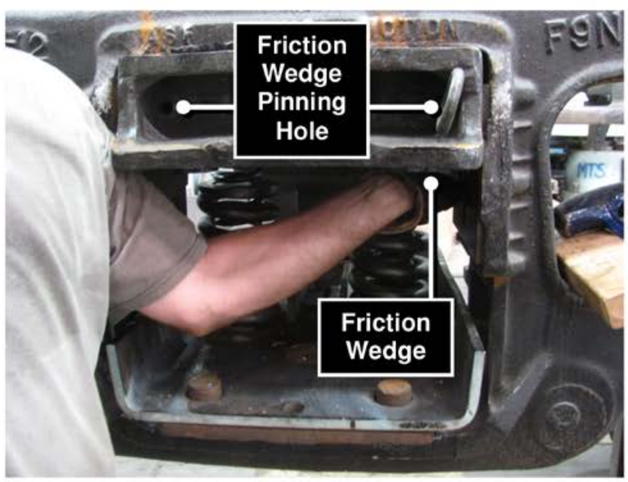


9. Using an appropriate hoist, raise the bolster to the top of the sideframe spring window.

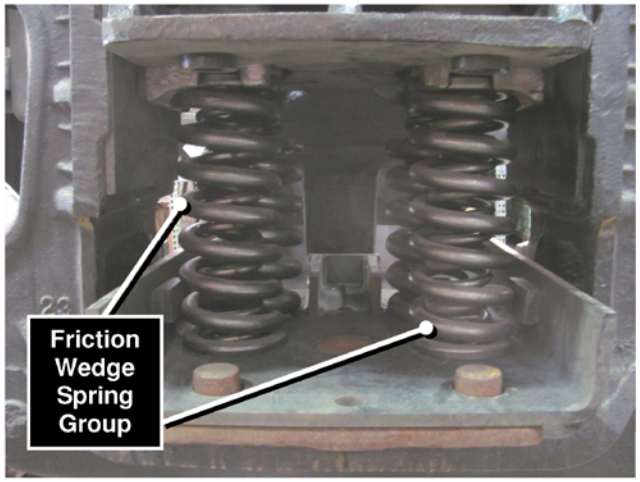
10. With the bolster still in the raised position, insert the inner load coil corner spring groups. The spring base should fit over the peg emerging from the rocker seat through the transom and the top of the inner spring should fit over the bolster spring retainer ring. Then install the inner load coil center spring group.



11. Lift the friction wedges into position and pin them in place using a long screwdriver or steel pin (5/8" diameter or less). Insert the control coil spring group assemblies under the boss on the bottom of the friction wedge. The base of the spring may need to be forced into place with a wooden lever. Once the springs are in place, the pin must be removed to allow free wedge movement.



12. Install the remaining load springs. The load coil center spring group must be placed in the center of the spring seat, prior to placing the outer load coil corner spring groups.



13. Lower the bolster onto the springs.

14. Visually check to ensure that all the springs are seated properly within the bolster and sideframe locating pegs. Note that these trucks have dual rate springs and some of the load coils will not be in contact with the bolster.

15. The above assembly procedure will produce a complete subassembly ready for placement on the wheelset. These trucks require special adapters that work with the polymer adapter pads. The correct parts are 10522A adapter pad and 10523A adapter. AAR standard adapters may not be used. Grounding straps must be installed with these adapters as the pads are electrically insulating.

16. Brake beams, brake shoes, Ellcon Brake cylinders, side bearing cages should be installed the same as any conventional three piece truck.

Post Assembly:

Side bearing height should be measured after trucks are installed underneath the car structure. Measurement should occur on level track measuring from the prepared surface of the bolster at the center of the side bearing to the surface of the wear plate attached to the car body bolster. Incorrect setting of the side bearing can result in reduced performance.

Appendix G-2.8.2 Amsted Rail Kasgro S-2043 Swing Motion Truck Break In Procedure Specification Spec 459, Rev C

AmstedRail	BlueWave	ASF-Keystone Specification	Spec 459
Date	Rev	KASGRO S-2043 SWING MOTION TRUCK BREAK IN PROCEDURE	Page 1 of 2
31, July 2017	C		OWNER Product Engineering

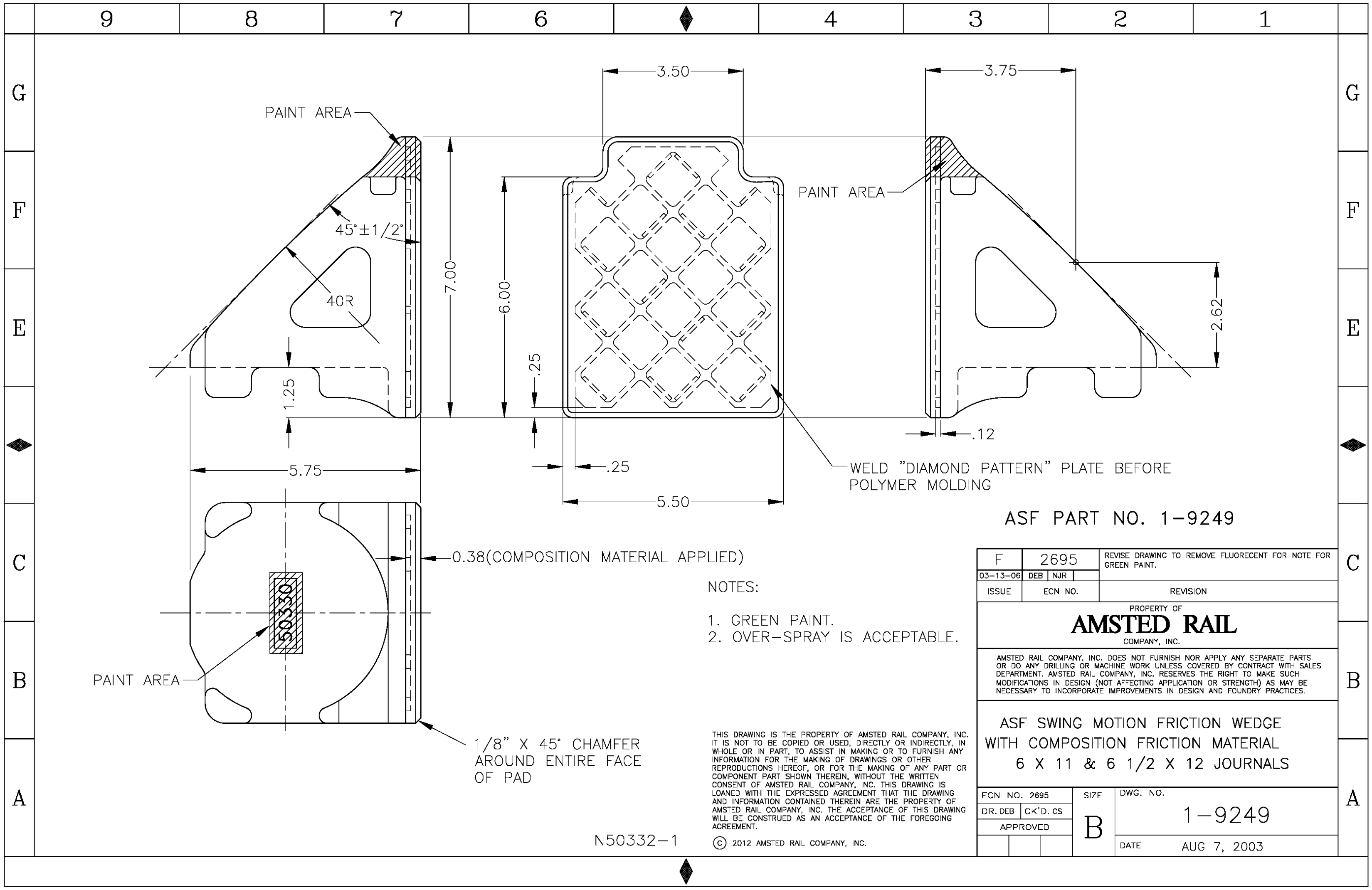
1. **PURPOSE –** To document a standard procedure for breaking in trucks prior to shipping to the customer.
2. **SCOPE –** Swing Motion Trucks with 12A adapter plus for 290 ton flatcar.
3. **REFERENCES:**
   - 3.1. TEC Test Plan 096
   - 3.2. Product Bulletin N544 - Basic Assembly Procedure
4. **TOOLS AND EQUIPMENT REQUIRED:**
   - 4.1. Multi-axis Load Frame
5. **PROCEDURE:**
   - 5.1. Set-up Multi-axis load frame to apply vertical load to the centerplate (position Q in AAR M-202).
   - 5.2. Assemble a truck per Basic Assembly Procedure Product Bulletin N544 except:
     - 5.2.1. The load coil set is not installed. In place of the specified set of load coils, 4 shop coils are used in the corners of each spring nest.
     - 5.2.2. 12A adapter plus pads and adapters are not installed. In their place, shop pedestal rocker seats (part No. 51606) and reverse crown swing motion adapters (part No. 51032) are used.
   - 5.3. Run the break in program for 10,000 cycles. The break in program cycle consists of a Q bounce of +/-1.5” from a mean spring height of 8.5”.
   - 5.4. Once the machine has completed its 10,000 cycles, remove the truck from the machine.
   - 5.5. Pin the Friction wedges.
   - 5.6. Remove the shop load springs from the truck, and install correct spring group. Using a paint marker, write “end” (AS-517-1) or “middle” (AS-518-1) on the side frame above the bolster opening.
   - 5.7. Install blocks between the top of the bolster ends and the side frames to secure the truck for shipment.
   - 5.8. Lift truck off shop wheelsets. Store shop bearing adapters and pedestal rocker seats.

ASF-Keystone Specification No. 459	Page 2 of 2

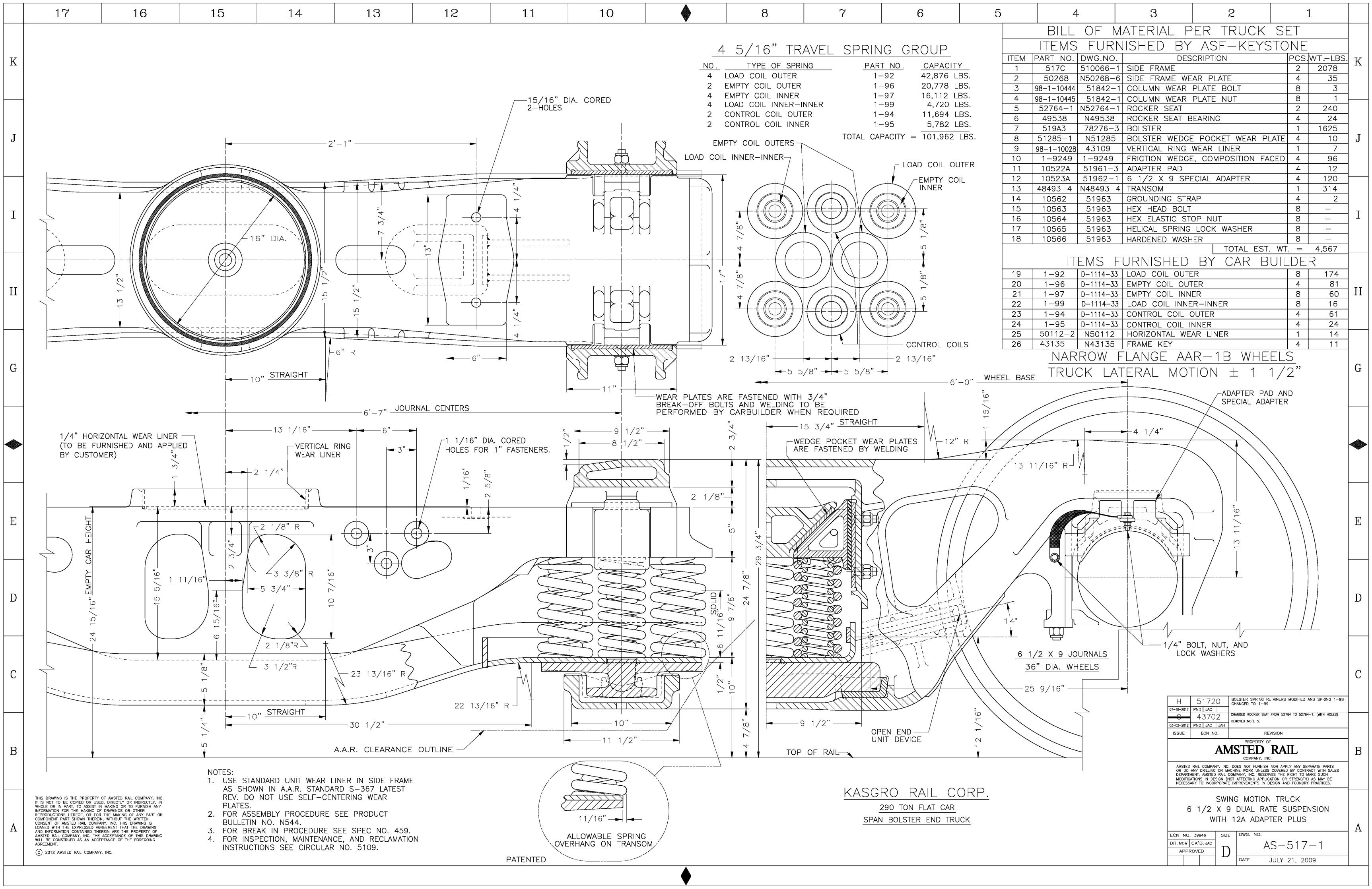
Revision History

Revision	Revision Date	Description	Author
-	09/03/2009	Specification created.	JAC
A	04/12/2010	Revised procedure to take out rock motion	JAC
B	08/06/2010	CHANGED 300TON TO 290 TON	JAC
C	7/31/2017	Title changed	JAH

Appendix G-2.8.3 Amsted Rail ASF Swing Motion Friction Wedge with Composition Friction Material Drawing No. 1-9249, Rev B



Appendix G-2.8.4 Amsted Rail ASF Swing Motion Truck 6 ½ X 9 Dual Rate Suspension with 12A Adapter Plus Drawing No. AS-517-1, Rev D



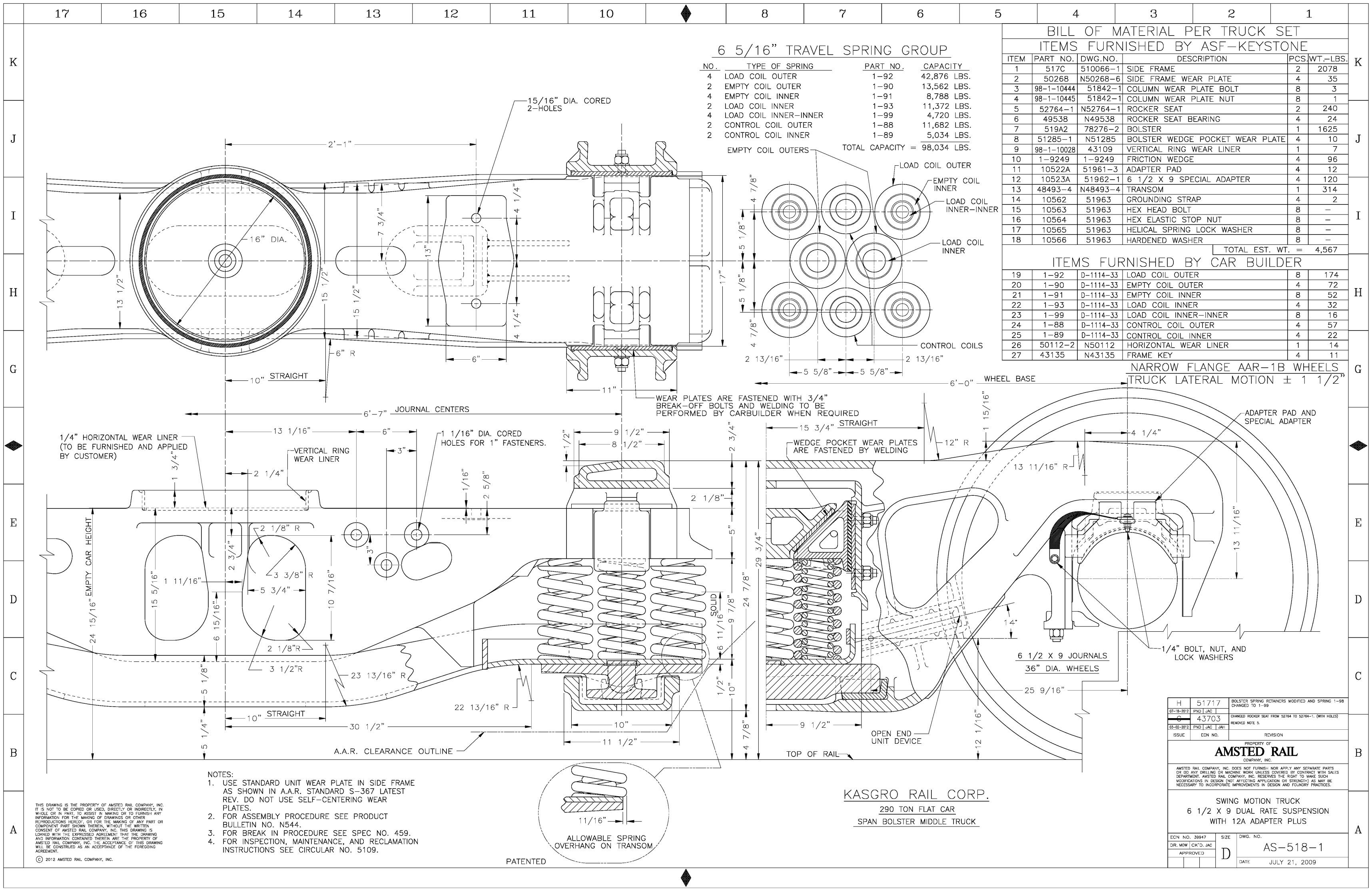
4 5/16" TRAVEL SPRING GROUP

NO.	TYPE OF SPRING	PART NO.	CAPACITY
4	LOAD COIL OUTER	1–92	42,876 LBS.
2	EMPTY COIL OUTER	1–96	20,778 LBS.
4	EMPTY COIL INNER	1–97	16,112 LBS.
4	LOAD COIL INNER–INNER	1–99	4,720 LBS.
2	CONTROL COIL OUTER	1–94	11,694 LBS.
2	CONTROL COIL INNER	1–95	5,782 LBS.
		TOTAL CAPACITY =	101,962 LBS.

BILL OF MATERIAL PER TRUCK SET

ITEM	PART NO.	DWG.NO.	DESCRIPTION	PCS.	WT.–LBS.
ITEMS FURNISHED BY ASF–KEYSTONE					
1	517C	510066–1	SIDE FRAME	2	2078
2	50268	N50268–6	SIDE FRAME WEAR PLATE	4	35
3	98–1–10444	51842–1	COLUMN WEAR PLATE BOLT	8	3
4	98–1–10445	51842–1	COLUMN WEAR PLATE NUT	8	1
5	52764–1	N52764–1	ROCKER SEAT	2	240
6	49538	N49538	ROCKER SEAT BEARING	4	24
7	519A3	78276–3	BOLSTER	1	1625
8	51285–1	N51285	BOLSTER WEDGE POCKET WEAR PLATE	4	10
9	98–1–10028	43109	VERTICAL RING WEAR LINER	1	7
10	1–9249	1–9249	FRICTION WEDGE, COMPOSITION FACED	4	96
11	10522A	51961–3	ADAPTER PAD	4	12
12	10523A	51962–1	6 1/2 X 9 SPECIAL ADAPTER	4	120
13	48493–4	N48493–4	TRANSOM	1	314
14	10562	51963	GROUNDING STRAP	4	2
15	10563	51963	HEX HEAD BOLT	8	–
16	10564	51963	HEX ELASTIC STOP NUT	8	–
17	10565	51963	HELICAL SPRING LOCK WASHER	8	–
18	10566	51963	HARDENED WASHER	8	–
			TOTAL EST. WT. =		4,567
ITEMS FURNISHED BY CAR BUILDER					
19	1–92	D–1114–33	LOAD COIL OUTER	8	174
20	1–96	D–1114–33	EMPTY COIL OUTER	4	81
21	1–97	D–1114–33	EMPTY COIL INNER	8	60
22	1–99	D–1114–33	LOAD COIL INNER–INNER	8	16
23	1–94	D–1114–33	CONTROL COIL OUTER	4	61
24	1–95	D–1114–33	CONTROL COIL INNER	4	24
25	50112–2	N50112	HORIZONTAL WEAR LINER	1	14
26	43135	N43135	FRAME KEY	4	11

Appendix G-2.8.5 Amsted Rail ASF Swing Motion Truck 6 ½ X 9 Low Profile Assembly Dual Rate Suspension Drawing No. AS-518, Rev D



6 5/16" TRAVEL SPRING GROUP

NO.	TYPE OF SPRING	PART NO.	CAPACITY
4	LOAD COIL OUTER	1–92	42,876 LBS.
2	EMPTY COIL OUTER	1–90	13,562 LBS.
4	EMPTY COIL INNER	1–91	8,788 LBS.
2	LOAD COIL INNER	1–93	11,372 LBS.
4	LOAD COIL INNER–INNER	1–99	4,720 LBS.
2	CONTROL COIL OUTER	1–88	11,682 LBS.
2	CONTROL COIL INNER	1–89	5,034 LBS.
		TOTAL CAPACITY =	98,034 LBS.

BILL OF MATERIAL PER TRUCK SET

ITEM	PART NO.	DWG.NO.	DESCRIPTION	PCS.	WT.–LBS.
ITEMS FURNISHED BY ASF–KEYSTONE					
1	517C	510066–1	SIDE FRAME	2	2078
2	50268	N50268–6	SIDE FRAME WEAR PLATE	4	35
3	98–1–10444	51842–1	COLUMN WEAR PLATE BOLT	8	3
4	98–1–10445	51842–1	COLUMN WEAR PLATE NUT	8	1
5	52764–1	N52764–1	ROCKER SEAT	2	240
6	49538	N49538	ROCKER SEAT BEARING	4	24
7	519A2	78276–2	BOLSTER	1	1625
8	51285–1	N51285	BOLSTER WEDGE POCKET WEAR PLATE	4	10
9	98–1–10028	43109	VERTICAL RING WEAR LINER	1	7
10	1–9249	1–9249	FRICTION WEDGE	4	96
11	10522A	51961–3	ADAPTER PAD	4	12
12	10523A	51962–1	6 1/2 X 9 SPECIAL ADAPTER	4	120
13	48493–4	N48493–4	TRANSOM	1	314
14	10562	51963	GROUNDING STRAP	4	2
15	10563	51963	HEX HEAD BOLT	8	–
16	10564	51963	HEX ELASTIC STOP NUT	8	–
17	10565	51963	HELICAL SPRING LOCK WASHER	8	–
18	10566	51963	HARDENED WASHER	8	–
			TOTAL EST. WT. =		4,567
ITEMS FURNISHED BY CAR BUILDER					
19	1–92	D–1114–33	LOAD COIL OUTER	8	174
20	1–90	D–1114–33	EMPTY COIL OUTER	4	72
21	1–91	D–1114–33	EMPTY COIL INNER	8	52
22	1–93	D–1114–33	LOAD COIL INNER	4	32
23	1–99	D–1114–33	LOAD COIL INNER–INNER	8	16
24	1–88	D–1114–33	CONTROL COIL OUTER	4	57
25	1–89	D–1114–33	CONTROL COIL INNER	4	22
26	50112–2	N50112	HORIZONTAL WEAR LINER	1	14
27	43135	N43135	FRAME KEY	4	11

Appendix G-2.8.6 Amsted Rail Kasgro – End Truck – Assembly Check List TEC-300, Rev C

AmstedRail	BlueWave	Form	TEC-300
Date	Rev.	Kasgro - End Truck - Assembly Check List	Page 1 of 1
9/14/2015	C		Owner: Test Engineering

Truck No:_______________ Date:_______________

Item	Part No.	Description	Qty.	Serial No.	Operator Initials	Supervisor Initials
1	517C	Side Frame	2			
	-	-	-			
2	52764-1	Rocker Seat	2			
	-	-	-			
3	49538	Rocker Seat Bearing	4	NA		
4	519A3	Bolster	1			
5	1-9249	Friction Wedge	4	NA		
6	10522A	Adapter Pad	4	NA		
7	10523A	6-1/2 x 9 Special Adapter	4	NA		
8	48493-4	Transom	1	NA		
9	10562	Grounding Strap	4	NA		
10	10563	Hex Head Bolt	8	NA		
11	10564	Hex Elastic Stop Nut	8	NA		
12	10565	Helical Spring Lock Washer	8	NA		
13	10566	Hardened Washer	8	NA		
14	1-92	Load Coil Outer	8	NA		
15	1-96	Empty Coil Outer	4	NA		
16	1-97	Empty Coil Inner	8	NA		
17	1-99	Load Coil Inner-Inner	8	NA		
18	1-94	Control Coil Outer	4	NA		
19	1-95	Control Coil Inner	4	NA		

Signature of Completion

TEC Operator:_______________________ **Date:**_______________

TEC Supervisor:_____________________ **Date:**_______________

TEC Director:_______________________ **Date:**_______________

Comments:____

Appendix G.2.8.7 Amsted Rail Kasgro – Middle Truck – Assembly Check List TEC-301, Rev C

AmstedRail	BlueWave	Form	TEC-301
Date: 9/14/2015	Rev.: C	Kasgro - Middle Truck - Assembly Check List	Page 1 of 1; Owner: Test Engineering

Truck No:________________ **Date:**_______________

Item	Part No.	Description	Qty.	Serial No.	Operator Initials	Supervisor Initials
1	517C	Side Frame	2			
	-	-	-			
2	52764-1	Rocker Seat	2			
	-	-	-			
3	49538	Rocker Seat Bearing	4	NA		
4	519A2	Bolster	1			
5	1-9249	Friction Wedge	4	NA		
6	10522A	Adapter Pad	4	NA		
7	10523A	6-1/2 x 9 Special Adapter	4	NA		
8	48493-4	Transom	1	NA		
9	10562	Grounding Strap	4	NA		
10	10563	Hex Head Bolt	8	NA		
11	10564	Hex Elastic Stop Nut	8	NA		
12	10565	Helical Spring Lock Washer	8	NA		
13	10566	Hardened Washer	8	NA		
14	1-92	Load Coil Outer	8	NA		
15	1-90	Empty Coil Outer	4	NA		
16	1-91	Empty Coil Inner	8	NA		
17	1-93	Load Coil Inner	4	NA		
18	1-99	Load Coil Inner-Inner	8	NA		
19	1-88	Control Coil Outer	4	NA		
20	1-89	Control Coil Inner	4	NA		

Signature of Completion

TEC Operator:______________________ **Date:**_______________

TEC Supervisor:______________________ **Date:**_______________

TEC Director:______________________ **Date:**_______________

Comments:____

APPENDIX G-2.9

ATLAS RAILCAR SAFETY MONITORING SYSTEM

Appendix G-2.9.1 System Safety Monitoring Procurement Specifications for use with AAR Standard S-2043 HLRW Railcars
Procurement Specification SSM Procurement Spec RF

SYSTEM SAFETY MONTORING PROCUREMENT SPECIFICATION FOR USE WITH AAR STANDARD S-2043 HLRW RAILCARS

Rick Ford

Kasgro Rail Corp., Inc.
121 Rundle Road
New Castle, PA 16102
Tel: 724-658-9061

System Safety Monitoring Procurement Specification for AAR S-2043 HLRW Trains

1.0 Scope of Work

1.1 S-2043 System Safety Monitoring (SSM) Equipment for use with railcars to be used for transport of High Level Radioactive Materials (HLRM) by rail. The system supplied must be 100% compatible with current SSM equipment currently being utilized on DODX railcars for transport of HLRM. Supply of SSM equipment for use with one (1) 12-axle cask flat car and two (2) 4-axle buffer flat cars to meet the requirements of American Association of American Railroads (AAR) Standards S-2043 and S-2045, unless otherwise specified, herein.

"Note: SSM communication utilizing CDMA 1XRTT technology is not acceptable as it planned for sunsetting at the end of December 2019."

2.0 Applicable Documents and Drawings

2.1 The documents identified herein a part of this specification and revision dates shall be the date of Request for Proposals.
2.2 Commercial documents listed herein (i.e. AAR. ASTM, AWS), the latest revision is acceptable.
2.3 Should a conflict occur between this procurement specification and the references listed herein, the text of this procurement specification shall take precedence. Any conflicts shall be identified to the Buyer for information.
2.4 Association of American Railroads (AAR) Specifications, Standards and Recommended Practices.
2.2 S-2043 Performance Standard for Trains Used to Carry High-Level Radioactive Material, Effective 2003, Revised 2009, or latest version.
2.4 S-2045 Standard Operating Procedure for Installation of Remote Monitoring Equipment.
2.5 S-5700 Railroad Electronics Standards Configuration Management.
2.6 S-5702 Railroad Electronics Environmental Requirements
2.7 American Welding Society (AWS)
2.7.1 D1.1 Structural Welding Code – Steel
2.7.2 D15.1 Railroad Welding Specification, Cars and Locomotives
2.8 Railcar General Arrangement Drawings for cask and buffer cars.

3.0 Quality Assurance Provisions

3.1 Unless otherwise approved by the Buyer, the Seller shall maintain a quality management and inspection system with a nationally recognized quality standard during the term of the contract. The Seller's quality manual shall be available for Buyer review, upon request.

4.0 Buyer Supplied Equipment

4.1 The Buyer will provide one (1) 12-axle cask Flat car and two (2) 4-axle buffer cars. Buyer shall perform testing as required by Sections 6.2 and 6.3 to AAR standard S-2043 (reference paragraph 5.21 below).

5.0 Requirements

5.1 The Seller shall design and provide all of the software, materials, equipment, resources, and documentation necessary to satisfy the requirements in AAR Standard S-2043 for system safety monitoring. The monitoring system shall satisfy all of the requirements for real-time and remote monitoring including, data collection, data storage, data download, data transmission, operating displays, train stop alarms, warning signals, internal self-test circuitry, report generation, etc. Sensors may be wireless, hardwired, or a combination of both at the option of the Seller. All requirements in S-2043 shall apply (reference Sections 4.5, 4.7.8, 6.2, Appendix A Section 4.6, and Appendix B Sections 5.4 and 5.5) with the following exceptions

(1) The system is not required to monitor the braking performance parameters monitored by the Electronically Controlled Pneumatic (ECP) brake system.

(2) The monitoring system is not required to function over the ECP braking system, but the design shall not preclude the ability to develop and incorporate communication via the ECP braking system in the future as required by Paragraph 4.4.1 of S-2043.

5.2 In lieu of real-time ECP brake system communication per Paragraph 4.5.4.2.1 of S-2043, the monitoring equipment shall communicate real-time with the locomotive, buffer cask, and escort vehicles via other direct connection such as radio frequency. Remote communication per Paragraph 4.5.4.2.2 of S-2043 may be via cellular, satellite, or combinations thereof. The system shall:

(1) Monitor and record all required parameters simultaneously at a sampling rate acceptable to the AAR/EEC (i.e., a polling refresh rate no slower than once per second and a maximum notification dwell time of 10 seconds).

(2) Save all data/variances at times when communication coverage (cellular or satellite), is temporarily unavailable, and transmit the data when coverage is re-established.

(3) Save all data collected in the event of a power failure or railcar derailment. The system shall exhibit the same robust capabilities of modern locomotive event recorders (reference: 49 CFR, Part 229 Appendix D).

(4) Provide secure encrypted data transmission that is Federal Information Processing Standard (FIPS) PUB 140-2 compliant or greater. The Security Level applied per FIPS PUB 140-2 shall be at the option of the Seller.

(5) Provide secure password protected access to the data, both real-time and remotely.

(6) Immediately provide remote notification of alarms via cell phone or E-mail to pre-established personnel designated by the Buyer.

(7) Conform to technology that utilizes the equivalent of Long-term Evolution (LTE, 4G or latest technology).

5.3 The monitoring system shall be designed for use on the cask and buffer flat cars as shown on Kasgro drawings XXXXX, in both the loaded and empty conditions. The loaded conditions are shown on drawing XXXXX. The number of railcars to be equipped with the monitoring system shall be defined in the purchase order.

5.4 The monitoring system shall be capable of operating with multiple SSM equipped flatcars in a train, and shall differentiate the data being collected, recorded, and reported for each specific railcar.

5.5 The railcar monitoring equipment and system shall be designed for operation and storage under the range of environmental conditions and requirements specified in Section 3.0 of AAR Standard S-5702; for the appropriate class/category of the equipment as delineated in Table 3.1 of S-5702 except at follows:

5.6 The railcar monitoring equipment and system shall satisfy the requirements in Section 4.0 of S- 5702 relating to electromagnetic interference and compatibility as clarified below:

(1) The Radiated Limits per Paragraph 4.2.1 of S-5702 shall apply only to equipment that utilizes train line or other railcar supplied power, or resides in the locomotive. In addition, supplied equipment shall not operate on any frequency used by railroad communications (150, 220, 450 and 900 MHz) and any cellular frequencies.

(2) The requirements for Conducted Emissions, Conducted Susceptibility, and ESD Susceptibility per Paragraphs 4.2.2.1, 4.2.2.2 and 4.2.3 of S-5702, respectively, shall only apply to equipment that utilizes train line or other railcar supplied power, or resides in the locomotive.

The Seller shall provide evidence in writing that the equipment has met the applicable electromagnetic interference (EMI) acceptance tests required by S-5702.

5.7 The Safety System Monitoring Equipment shall:

(1) Be capable of substantial down-time (3 to 4 years) in outside storage between uses without degradation to the instrumentation or power supply.

(2) Be designed to allow for easily integrating future sensor types/models with minimal or no redesign.

5.8 If required by the AAR, the railcar monitoring equipment and system shall:

(1) Comply with the Vendors configuration management guidelines of AAR Standard S-5700.
(2) Comply with the standards established by the Railway Electronics Task Force (RETF). The Seller's configuration management processes shall be compatible with the configuration management plan used by the RETF so that the Seller's products clearly indicate the version of the standard(s) with which they are compliant.

5.9 The Seller shall provide a complete parts list and an assembly drawing to show the arrangement of the monitoring system as it will be installed on the 12-axle cask and 4-axle buffer flatcars (i.e., sensor locations, mounting and wiring arrangements, location of power supplies and data processing equipment, etc.). Enlarged views or supplemental drawings shall be provided, as necessary, to show the details for sensor and equipment mounting. The drawings and subsequent revisions shall be subject to Buyer approval.

5.10 The Seller shall provide an assembly, operating, maintenance, and troubleshooting manual for the monitoring system specific to both the cask and buffer flat car application. The manual shall be subject to Buyer approval and shall include:

(1) A complete description of the monitoring system, including a detailed description of the method of sampling/collecting, storing, and reporting information for both the real-time and remote systems.
(2) A system schematic and high level block diagram.
(3) A copy of the assembly drawing(s) and parts list.
(4) A copy of the manufacturer's specification sheets for each sensor and component.
(5) Assembly and equipment checkout instructions.
(6) Operating instructions including methods to confirm proper system/equipment calibration, sensor response, and communication.
(7) Maintenance instructions including a list of required spare parts.
(8) A fault tree analysis per Section 4.5.5 of S-2043.
(9) Any custom software developed by the Seller.

5.11 The Seller shall obtain or confirm AAR/EEC acceptance of the System Safety Monitoring design in accordance with Section 4. 7 .8 of S-2043 and Section 3 of S-2045, prior to installation of the lead monitoring system on a cask and buffer flatcar test vehicles. The design package shall be provided for Buyer review and information at least 30-days prior to submittal to the AAR/EEC. AAR acceptance of the monitoring system (in writing) shall be provided to the Buyer as evidence of compliance with this requirement.

5.12 The real-time limits/situations requiring a train stop signal shall be as specified in Paragraph 4.5.4.2.1 of S-2043. The real-time limits requiring a warning for train inspection at the next scheduled stop shall be as specified in paragraph 4.5.4.2.2 of S-2043. In addition, the real-time and remote systems shall specifically identify and notify of any detected variances to: (1) the overheated roller bearing criteria specified in Rule 36 of the Field Manual of the AAR Interchange Rules (IR), and (2) the wheel out of round (flats) impact criterion specified in Rule 41 of the AAR IR and AAR Report No. R-829 (Wheel Impact Load Detector Tests and Development of Wheel Flat Specification).

5.13 Unless otherwise accepted by the Buyer, instrumentation for measuring lateral acceleration and hunting shall be mounted near the lateral centerline of one of the car-body bolsters and on each span bolster in line with the lateral centerline of Truck-A and Truck-B. Alternate sensor mounting locations as recommended by the Seller are acceptable subject to Buyer approval.

5.14 The power supply for the monitoring system shall be capable of continuous operation and monitoring of all required parameters for a period of no less than 1 year without the need to replace any portion of the power supply (e.g., batteries).

All sensors with an independent power supply (i.e. sensors that do not rely on the source that powers the central processing unit) shall be equipped with a feature that minimizes (e.g. nanoamps) or precludes the draw of power until activated for use.

5.15 The system shall include self-test circuitry to internally check power levels and to assess the performance status of the equipment/sensors installed to monitor all of the parameters required by paragraph 4.5.4.1 of S-2043, except as excluded in paragraph 5.1 above.

5.16 The system shall be capable of preparing reports showing the measured conditions and system response while monitoring all of the parameters listed in Section 4.5.4 of S-2043, except as excluded in paragraph 5.1 above. The data shall be collected and recorded in such a manner to identify specific railcar location and train speed for all other parameters monitored. Report generation shall be available in both tabular and graphical formats (e.g., .xls, .csv) to facilitate trend analyses.

5.17 The monitoring system shall be designed to provide the flexibility to:

(1) Only transmit and archive the exception data, including the raw data for 60 minutes prior to the exception.
(2) Delete the remotely stored data at the end of each trip.

(3) Limit or exclude either the real-time or remote data transmissions at the operating option of the Buyer.

(4) Exclude the locomotive warning or stop-train display lights at the operating option of the Buyer for each individual trip (i.e. portable).

(5) Relocate the readout display panel between escort vehicles and trains (i.e., portable).

(6) Remotely delete the data stored on the system's removable media (i.e., without physical work on the railcar-mounted equipment.)

All sensors of the same type shall be interchangeable with one another. The Seller shall ensure any programming required to activate or incorporate replacement sensors into the monitoring system can be performed remotely.

Portable display units shall include an audio alarm that sounds when a warning/exception occurs. The alarm shall have the ability to be turned off once the warning/exception has been acknowledged. The Seller shall provide protective carrying cases (e.g., hard plastic outer shell with internal padding) for the portable display units to facilitate handling and to minimize the potential for handling damage. One case shall be provided per display or per set of displays.

5.18 All welds used for assembly of the monitoring equipment to the cask and buffer flatcars shall be made and subjected to a 1X visual inspection in accordance with AWS D1 .1 or AWS D15.1.

5.19 Equipment and sensors located on the car body or end platforms shall be protected from potential inadvertent damage due to personnel walking or working on the railcar.

5.20 Unless otherwise approved by the Buyer, central onboard power/monitoring units shall be stenciled or decaled per S-2045 to identify the unit function and the applicable contact phone number for information related to the device. The stencil/decal shall be highly visible and shall be a minimum of 2" x 3" in size. Stencil/decal color shall be as agreed between the Buyer and Seller, but shall not be bright yellow.

5.21 Prior to full system production, the Seller shall provide and install lead monitoring systems on cask and buffer test vehicles. The test cars and the monitoring systems shall be tested and operated by the Buyer in accordance with Sections 6.2 (System Monitoring Tests) and 6.3 (Revenue Service Tests) of AAR Standard S-2043. Seller personnel shall be on location at the test facility (Transportation Technology Center) to provide technical support during the testing performed per Section 6.2 of S-2043, and shall be responsible to resolve any system design/hardware issues. Lessons learned or necessary equipment improvements determined from lead unit testing shall be implemented on all subsequent production units.

5.22 When required by the purchase order, the Seller's personnel shall install the monitoring systems on the production cask and buffer flat cars, and confirm that each system is fully functional and is operating in compliance with the technical requirements specified herein and by the applicable AAR standards and specifications. Seller installations shall be field service operations at the locations of the flatcars at the time of system installation. If third party installation is performed, Seller shall package, pack, and ship all equipment to the required destinations. Packaging and packing shall be per good commercial practice and shall ensure the equipment arrives at destination without damage during handling or shipment.

5.23 Over the course of the development, testing, and production of the monitoring system various meetings/conferences shall be conducted between the Buyer and Seller including:

(1) A kickoff meeting (within 1 month after order placement) to review the overall development plan and schedule.
(2) Periodic meetings (approximately every 6 weeks) at the Sellers facility to review overall status and emergent issues.
(3) Weekly status calls.
(4) A meeting at the Sellers facility to review the design package prepared for submittal to the AAR/EEC per paragraph 5.11 above.

5.24 The Seller shall install tamper-indicating security seals around the outermost enclosures that contain the removable data storage media. The Seller shall provide all tools and materials necessary for seal installation, and one set of seal equipment (wire spool, package of security seals, seal press) shall be provided for each railcar to be equipped with monitoring equipment, with the total quantity identified by the purchase order.

It is recommended that the same type of security seals currently used on DODX railcar SSM equipment be used to maintain consistency.

Appendix G-2.9.2 Lat-Lon AAR Approved S-2043 System Procurement Specification SSM Procurement Spec RF

Lat-Lon, LLC
2300 S. Jason St.
Denver, CO 80223
303-937-7406

LAT-LON AAR APPROVED S-2043 SYSTEM

[redacted] awarded Lat-Lon, LLC a contract [redacted] with a monitoring system to meet AAR S-2043 requirements with the following exceptions:

(1) The system is not required to monitor the braking performance parameters monitored by the Electronically Controlled Pneumatic (ECP) brake system.
(2) The monitoring system is not required to function over the ECP braking system.

This is consistent with the implementation plan for multiple-car testing of the 290 ton flatcar, as submitted [redacted] and accepted by the AAR/EEC.

Railcar Drawing

[redacted]

Page 1

SYSTEM DESCRIPTION

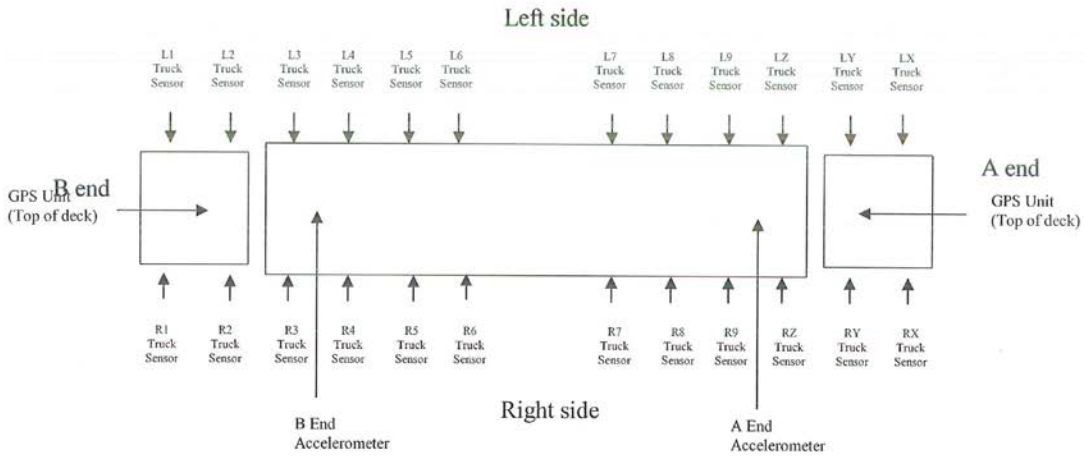
Design Overview

Two monitoring systems are installed on each car. One system is positioned at the A end platform and is responsible for the A end readings and the other system is mounted on the B end platform and responsible for the B end readings. This creates redundant car body measurements on each car while making the system more failsafe and cost effective.

Orientation

The general layout for the 12 axle flat car monitoring system is shown on the diagram below.

Flat Car Diagram - Top View



Page 2

System Components

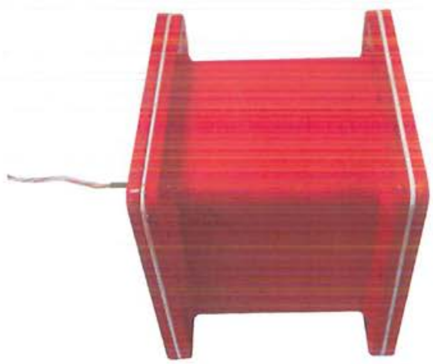
The monitoring system is broken down into nine component groups. Each component group has a number of sub assemblies. The system is maintained on a component basis. These components are designated as follows:

Mounting Pedestal
A End
B End

Pedestal Cover (qty 2 per pedestal)
A End
B End

GPS Base Unit
A End GPS Base Unit
B End GPS Base Unit

Memory Module
A End
B End

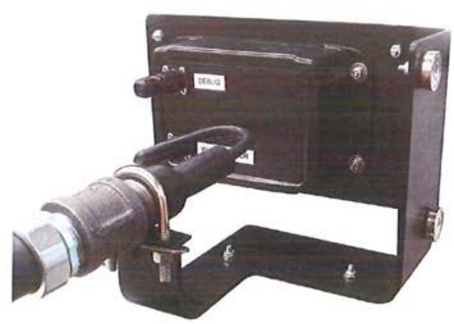


Battery Module
A End
B End

Page 4

Solar/Antenna Cap
- A End
  - Cellular Antenna
  - VHF Antenna
  - Wireless Sensor Antenna
  - Solar Panels
- B End
  - Cellular Antenna
  - VHF Antenna
  - Wireless Sensor Antenna
  - Solar Panels

Wired Sensor & Wire Harness
- A End
- B End

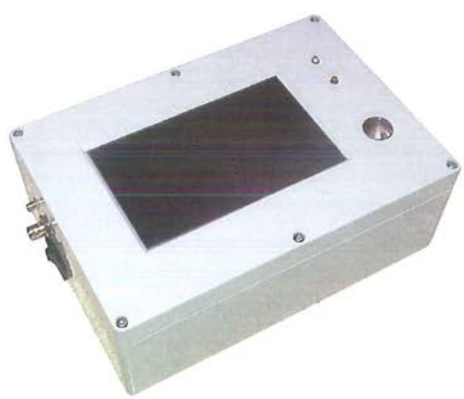


Wireless Truck Mounted Sensors – Each of these sensors are identical but its position is designated into the unit's database.

R1 Sensor
R2 Sensor
R3 Sensor
R4 Sensor
R5 Sensor
R6 Sensor Associated with B end
L1 Sensor
L2 Sensor
L3 Sensor
L4 Sensor
L5 Sensor
L6 Sensor

R7 Sensor
R8 Sensor
R9 Sensor
RZ Sensor
RY Sensor
RX Sensor Associated with A end
L7 Sensor
L8 Sensor
L9 Sensor
LZ Sensor
LY Sensor
LX Sensor

Portable Display Units (set)
Two units provided per set



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APPENDIX G-3
ATLAS RAILCAR BILL OF MATERIAL

DATE:	4/17
LISTED BY;	NH
CHECKED BY:	JO

RAIL KASGRO CORP
121 RUNDLE RD. NEW CASTLE, PA

CUSTOMER:

Issue Date: Jan-2018

TYPE OF CAR: 12 AXLE FLAT ATLAS CASK CAR

ITEM	DWG. NO. OR	REL'D		DESCRIPTION	QUAN.		P.O.	VENDOR
NO.	MFG. PART NO.	PUR	FAB		CAR	TOT	NO.	
1-1	S4D-6512 LINE 30			GRAB IRON	8			ARI
1-2	TCC-III-60LT			TRUCK SIDE BEARING	12			MINER ENT.
1-3	SM110			SWING MOTION TRUCK ASSEMBLY	6			AMSTED RAIL
1-4	343-L			TRUCK MOUNTED BRAKE SYSTEM	6			AMSTED RAIL
1-5	SE67			COUPLER	2			McCONWAY &
1-6	11865			E15G CUSHIONING UNIT	2			AMSTED RAIL
1-7	D-1155-33			TRUCK SPRING SETS	6			WABTEC
1-8	DB60II			PNEUMATIC AIR BRAKE	2			NEW YORK AIR BR
1-9	18094			E-YOKE ASSEMBLY	2			AMSTED RAIL
1-10	61936			WHEEL SET ASSEMBLIES	12			PROGRESS RAIL
1-11	V-674			BRAKE SHOE	24			AIRTEK
1-12	TTEF-15W			UNCOUPLING LEVER ASSEMBLY	2			ROLLFORM
1-13	BB624-RH			#24 BRAKE BEAM RH	6			MINER ENT.
1-14	BB624-LH			#24 BRAKE BEAM LH	6			MINER ENT.
1-15	MSF-289-K2			CENTER PLATE	4			MARITIME STEEL
1-16	MSF-289-K2X			CENTER PLATE	2			MARITIME STEEL
1-17				1/4" PROOF COIL CHAIN X 24"	2			HUSTON GROUP
1-18				1/4" S-HOOK	2			STRATO
1-19	EHS			HOSE SUPPORT	2			STRATO
1-20	AAR 300			1 1/4 X 45 DEG STREET ELBOW	2			B.M. KRAMER
1-21	AAR-300			1 1/4 COUPLING	2			B.M.KRAMER
1-22	FTF20-20G			1 1/4 SWIVEL FITTING	4			STRATO
1-23	1-B-3280			HOSE CLAMP	4			STRATO
1-27	93840			1/2" GASKET	6			WABTEC
1-28	565252			3/8 SOCKET WELD FITTING	8			WABTEC
1-29	93839			3/8 GASKET	12			WABTEC
1-30	565256			3/4 SOCKET WELD FITTING	14			WABTEC
1-31	93841			3/4" GASKET	18			WABTEC
1-32	578321			3/4 90 DEG SOCKET WELD FITTING	4			WABTEC
1-33	98903			3/4 X 3/4 X 3/4 TEE BODY	4			WABTEC
1-34	517865			3/4 X 3/4 X 3/8 TEE BODY	2			WABTEC
1-35	565259			1" SOCKET WELD FITTING	4			WABTEC
1-36	93986			1" GASKET	6			WABTEC
1-37	565262			1 1/4 SOCKET WELD FITTING	7			WABTEC
1-38	94790			1 1/4 GASKET	7			WABTEC
1-39	2457			3/4 PIPE ANCHOR	4			IRECO
1-40	2356			3/4 WEDGE	4			IRECO
1-41	30191			1 1/4 PIPE ANCHOR	18			IRECO
1-42	3594X			1 1/4 WEDGE	18			IRECO
1-45	1026			JAW FOR 3/4" ROD	6			WABTEC
1-46	1078			EYE FOR 3/4" ROD	14			WABTEC
1-47	33000-2			INT POWER HANDBRAKE	2			AMSTED RAIL
1-48	1749			8" DIA SHEAVE WHEEL	10			AMSTED RAIL
1-49	600			5 1/2 DIA SHEAVE	4			AMSTED RAIL
1-50	458			CLEVIS	16			AMSTED RAIL
1-51	240			RIVET	16			AMSTED RAIL
1-52	1091-A			JOINER	18			AMSTED RAIL
1-53	18			END LINK	2			AMSTED RAIL
1-54	8028			1 3/32" DIA X 3" BRAKE PIN	6			GENERAL
1-56	8031			1 3/32" DIA X 4 1/2"" BRAKE PIN	16			GENERAL
1-57				5/16" LOCKTITE COTTER	22			GENERAL
1-58				1/2" ALLOY CHAIN X 7'-0"	2			HUSTON GROUP
1-59				1/2" ALLOY CHAIN X 3'-3"	4			HUSTON GROUP
1-60				1/2" ALLOY CHAIN X 2'-5"	2			HUSTON GROUP
1-61				1/2" ALLOY CHAIN X 2'-3"	2			HUSTON GROUP
1-62	SRD-6512 LINE 55			GRAB IRON	2			ARI

Page 1 1155-BOM ATLAS CASK CAR

DATE:	4/17
LISTED BY;	NH
CHECKED BY:	JO

RAIL KASGRO CORP
121 RUNDLE RD. NEW CASTLE, PA

Issue Date: June 2017

CUSTOMER:
TYPE OF CAR: 12 AXLE FLAT ATLAS CASK CAR

ITEM NO.	DWG. NO. OR MFG. PART NO.	REL'D PUR	REL'D FAB	DESCRIPTION	QUAN. CAR	TOT	P.O. NO.	VENDOR
1-63	S1-F-0048			ROUTE CARD BOARD	1			ARI
1-64	539547			3/8 X 3/4 X 3/4 TEE	2			WABTEC
1-68	578321			3/4 SOCK WELD FITTING 90 DEG	2			WABTEC
1-69	578319			3/8 90 DEG SOCKET WELD FITTING	2			WABTEC
1-70	579687			1 1/4 SOCKET WELD NO GASKET	7			WABTEC
1-83	AAR 300			1 1/4" X 1" REDUCER	2			B.M. KRAMER
1-84	SCH 80			1" PIPE NIPPLE X 6" LG	2			B.M. KRAMER
1-85				1" PIPE COUPLING	4			B.M. KRAMER
1-86				3/8" PIPE ANCHOR	2			IRECO
1-87				3/8" WEDGE	2			IRECO
2-1				5/8"-11 NC BOLT X 2 1/4" LG	28			AAR Vendor List
2-2				5/8"-11 NC NYL INS LOCKNUT	70			AAR Vendor List
2-3				5/8" DIA BEVEL WASHER	8			AAR Vendor List
2-4				7/8"-9 NC BOLT X 3" LG	24			AAR Vendor List
2-5				7/8"-9 NC NYL INS LOCKNUT	24			AAR Vendor List
2-6				1/2"-13 NC NYL INS LOCKNUT	56			AAR Vendor List
2-7				3/8"-13 NC NYL INS LOCKNUT	36			AAR Vendor List
2-8				5/8"-11 NC BOLT X 12 1/2" LG	8			AAR Vendor List
2-9				5/8"-11 NC BOLT X 2 1/2" LG	12			AAR Vendor List
2-10				5/8"-11 NC BOLT X 3" LG	2			AAR Vendor List
2-11				5/8"-11 NC BOLT X 4 1/2" LG	4			AAR Vendor List
2-12				1/2"-13 NC BOLT X 2" LG	32			AAR Vendor List
2-13				1/2"-13 NC BOLT X 4" LG	12			AAR Vendor List
2-14				1"-8 NC BOLT X 7" LG	6			AAR Vendor List
2-15				1"-8 NC NYL INS LOCKNUT	6			AAR Vendor List
2-16				3/8"-16 NC SLCS X 1"	16			AAR Vendor List
2-17				1/2" 13 NC SLCS X 1 1/4" LG	16			AAR Vendor List
2-18				1/2" 13 NC SLCS X 1 1/2" LG	4			AAR Vendor List
2-19				1/2"-13 NC X 1 7/8" LG TEE HEAD BOLT	2			AAR Vendor List
2-20				3/8"-16 NC BOLT X 1 1/2" LG	36			AAR Vendor List
2-21				5/16" X 1 1/2" LG COTTER	2			AAR Vendor List
2-22				5/8"-11 NC BOLT X 1 1/2" LG	4			AAR Vendor List
2-23				1/2"-13 NC BOLT X 2 1/2"LG	8			AAR Vendor List
2-24				1/2"-13 NC SLCS X 2 3/4" LG	4			AAR Vendor List
2-25				7/8"-9 NC BOLT X 2" LG	2			AAR Vendor List
2-26				7/8"-9 NC NYL INS LOCKNUT	2			AAR Vendor List
	S-2043 SYSTEM			SYSTEM SAFETY MONITORING	2			LAT-LON, LLC

APPENDIX G-4
ATLAS RAILCAR FABRICATION INSPECTION PLAN

Appendix G-4.1 KASGRO Rail Receiving Inspection Report

KASGRO RAIL CORP

FORM 9Z-1
RECEIVING INSPECTION REPORT

Date 7/21/10

P.O.# ____________________ CAR/JOB #____________

MATERIAL DESCRIPTION ____

DRAWING #_________________ PART #____________________________

(IF FABRICATED PART) DRAWING # ___________________________

MILL REPORTS RECEIVED YES___ NO___ N/A___ REPORTS CORRECT YES__NO__ N/A__

ACCEPTANCE PER SAMPLE SIZE WHEN SAMPLING LOTS OF MATERIAL

LOT SIZE	SAMPLE SIZE	REJECTION CRITERIA
1-10	1	1
11-20	2	1
21-50	3	1
51-100	4	1
101-200	5	1
201-500	6	1
501-UP	7 PER 500 LOT	1 PER 500 LOT

DATE RECEIVED	QUANTITY	QUANTITY REMAINING	REMARKS

To the best of my knowledge all information contained in this document is accurate.

Signed: ____ Kasgro Rail

Appendix G-4.2 Railcar Dimensional Inspection and Sampling Plan Forms 9B and 9C

PURCHASE ORDER: RAILCAR DIMENSIONAL INSPECTION AND SAMPLING PLAN 1

DRAWING NO.		REV LEVEL	

FORM 9B 3/17/10

ITEM NO.	NO. PER CAR	SAMPLING PLAN		
3-14	8	1 OF	8	LIMITED DIMENSIONS (SEE DATA SHEET)
3-15	8	1 OF	8	LIMITED DIMENSIONS (SEE DATA SHEET)
3-16	8	1 OF	8	LIMITED DIMENSIONS (SEE DATA SHEET)

INSPECTION ACCEPTANCE PER SAMPLE SIZE

LOT SIZE	SAMPLE SIZE	REJECTION CRITERIA
1-10	1	1
11-20	2	1
21-50	3	1
51-100	4	1
101-200	5	1
501-UP	6	1

To the best of my knowledge all information contained in this document is accurate.

Signed: ______________________________ Kasgro Rail

The recording of false, fictitious or fraudulent statements or entires on this doucment may be punishable as a felony under federal law statutes.

PURCHASE ORDER: RAILCAR DIMENSIONAL INSPECTION AND SAMPLING PLAN 2

DRAWING NO.	0	REV LEVEL	0
Item no.	3-14	Qty	8

FORM 9C 3/17/10

Inspected By: ______________________ Date: __________

Dimension/ Tolerance	Frequency of Inspection	Method of Inspection	Tool No.	Record Actual Dimension	Results Piece 1
22'-8"	1 OF 8	A	NA	OK/UNSAT	
3' 6"	1 OF 8	A	NA	OK/UNSAT	
2" Thickness	1 OF 8	A	NA	OK/UNSAT	

Inspection Method Legend
A-TAPE MEASURE
B-VARIABLE GAGE
C-FIXED GAGE

Inspection Symbol
Check Mark = OK
x = UNSAT
Yes = Record Actual Dimension
NA = No Inspection Required

The recording of false, fictitious or fraudulent statements or entires on this doucment may be punishable as a felony under federal law statutes.

PURCHASE ORDER: RAILCAR DIMENSIONAL INSPECTION AND SAMPLING PLAN 3

FORM 9C 3/17/10

DRAWING NO.	0	REV LEVEL	0
Item no.	3-15	Qty	8

Inspected By: ______________________ Date: ______________

Dimension/ Tolerance	Frequency of Inspection	Method of Inspection	Tool No.	Record Actual Dimension	Results Piece 1
22'-11 3/16"	1 OF 8	A	NA	OK/UNSAT	
3' 1"	1 OF 8	A	NA	OK/UNSAT	
2" Thickness	1 OF 8	A	NA	OK/UNSAT	

Inspection Method Legend
A-TAPE MEASURE
B-VARIABLE GAGE
C-FIXED GAGE

Inspection Symbol
Check Mark = OK
x = UNSAT
Yes = Record Actual Dimension
NA = No Inspection Required

The recording of false, fictitious or fraudulent statements or entires on this doucment may be punishable as a felony under federal law statutes.

PURCHASE ORDER: RAILCAR DIMENSIONAL INSPECTION AND SAMPLING PLAN 4

DRAWING NO.	0	REV LEVEL	0
Item no.	3-16	Qty	8

FORM 9C 3/17/10

Inspected By: ____________________ Date: ____________

Dimension/ Tolerance	Frequency of Inspection	Method of Inspection	Tool No.	Record Actual Dimension	Results Piece 1
22'-11 3/16"	1 OF 8	A	NA	OK/UNSAT	
4"	1 OF 8	A	NA	OK/UNSAT	
2" Thickness	1 OF 8	A	NA	OK/UNSAT	

Inspection Method Legend
A-TAPE MEASURE
B-VARIABLE GAGE
C-FIXED GAGE

Inspection Symbol
Check Mark = OK
x = UNSAT
Yes = Record Actual Dimension
NA = No Inspection Required

The recording of false, fictitious or fraudulent statements or entires on this doucment may be punishable as a felony under federal law statutes.

Appendix G-4.3 KASGRO Rail Burning Table Inspection Report Form 9Z-A-1

KASGRO RAIL CORP

FORM 9Z-A-1
BURNING TABLE INSPECTION REPORT

DATE 7/21/10

P.O.# ____________________ CAR/JOB #____________

MATERIAL DESCRIPTION ____

DRAWING #_________________ PART #____________________________

MILL REPORTS RECEIVED YES___ NO___ N/A___ REPORTS CORRECT YES__NO__ N/A__

ACCEPTANCE PER SAMPLE SIZE WHEN SAMPLING LOTS OF MATERIAL

LOT SIZE	SAMPLE SIZE	REJECTION CRITERIA
1-10	1	1
11-20	2	1
21-50	3	1
51-100	4	1
101-200	5	1
201-500	6	1
501-UP	7 PER 500 LOT	1 PER 500 LOT

DATE CUT	QUANTITY	QUANTITY REMAINING	REMARKS

To the best of my knowledge all information contained in this document is accurate.

Signed: ____ Kasgro Rail

Appendix G-4.4 Car Body – Heat Identification Form
Form 44B, Rev 3/12/2010

CAR BODY - HEAT IDENTIFCATION
FORM 44B - 3/12/2010

DATE : BODY NUMBER:

TO THE BEST OF MY KNOWLEDGE ALL INFORMATION CONTAINED IS ACCURATE

SIGNED: ______________________________ KASGRO RAIL

* Use of ASTM 572 grade 50 material is acceptable for grade 60 mat'l provided the mechanical properties for grade 60 material are satisfied

Charpy impact testing, when required, will be in accordance with ASTM A673. The minimum average absorbed energy shall be 20 ft-lbs at zero degrees F. Tranverse impact test is required for plate widths over 24 inches

PART NO.	PRINT NO.	HEAT NUMBER	MELTER	QTY/CAR	MATERIAL	special testing
3-11	D-1114-09			2	A-36	hardness
3-11	D-1114-09			2	A-36	hardness
3-15	D-1114-10			1	A-572 GR50	
3-16	D-1114-10			4	A-572 GR60*	charpy
3-16	D-1114-10			4	A-572 GR60*	charpy
3-16	D-1114-10			4	A-572 GR60*	charpy
3-16	D-1114-10			4	A-572 GR60*	charpy
3-17	D-1114-10			2	A-572 GR50	
3-17	D-1114-10			2	A-572 GR50	
3-18	D-1114-10			2	A-572 GR50	
3-18	D-1114-10			2	A-572 GR50	
3-26	D-1114-12			2	A-572 GR60*	charpy
3-26	D-1114-12			2	A-572 GR60*	charpy
3-27	D-1114-13			2	A-572 GR50	
3-27	D-1114-13			2	A-572 GR50	
3-28	D-1114-13			2	A-572 GR50	
3-28	D-1114-13			2	A-572 GR50	
3-31	D-1114-14			2	A-572 GR50	
3-31	D-1114-14			2	A-572 GR50	
3-32	D-1114-14			2	A-572 GR50	
3-32	D-1114-14			2	A-572 GR50	
3-34	D-1114-15			2	A-572 GR60*	charpy
3-34	D-1114-15			2	A-572 GR60*	charpy
3-35	D-1114-16			1	A-572 GR60*	charpy
3-36	D-1114-16			1	A-572 GR50	
3-37	D-1114-16			2	A-572 GR50	
3-37	D-1114-16			2	A-572 GR50	
3-139	D-1114-39			2	A-572 GR42	
3-139	D-1114-39			2	A-572 GR42	

Bolster Assembly Applied A end______________ B end__________________

Welding Wire Hobart:

Note: The recording of false, factitious or fraudulent statements or entries on this document may be punishable as a felony under federal statutes.

1

CAR BODY - HEAT IDENTIFCATION
FORM 44B - 3/12/2010

DATE : BODY NUMBER:

TO THE BEST OF MY KNOWLEDGE ALL INFORMATION CONTAINED IS ACCURATE

SIGNED: ______________________________ KASGRO RAIL

* Use of ASTM 572 grade 50 material is acceptable for grade 60 mat'l provided the mechanical properties for grade 60 material are satisified

Charpy impact testing, when required, will be in accordance with ASTM A673. The minimum average absorbed energy shall be 20 ft-lbs at zero degrees F. Tranverse impact test is required for plate widths over 24 inches

PART NO.	PRINT NO.	Control Number	Melter	QTY/CAR	MATERIAL	special testing
3-120	D-1114-8			4	A-514 GR B	
3-120	D-1114-8			4	A-514 GR B	
3-120	D-1114-8			4	A-514 GR B	
3-120	D-1114-8			4	A-514 GR B	
3-19	D-1114-11			2	A-572 GR50	
3-19	D-1114-11			2	A-572 GR50	
3-20	D-1114-11			2	A-572 GR50	
3-20	D-1114-11			2	A-572 GR50	
3-22	D-1114-11			2	A-572 GR50	
3-22	D-1114-11			2	A-572 GR50	
3-24	D-1114-11			4	A-572 GR50	
3-24	D-1114-11			4	A-572 GR50	
3-24	D-1114-11			4	A-572 GR50	
3-24	D-1114-11			4	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-33	D-1114-11			14	A-572 GR50	
3-76	D-1114-11			2	A-572 GR50	
3-76	D-1114-11			2	A-572 GR50	
3-107	D-1114-11			2	A-572 GR50	
3-107	D-1114-11			2	A-572 GR50	

Note: The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal statutes.

CAR BODY - HEAT IDENTIFCATION
FORM 44B - 3/12/2010

DATE : BODY NUMBER:

TO THE BEST OF MY KNOWLEDGE ALL INFORMATION CONTAINED IS ACCURATE

SIGNED: ______________________________ KASGRO RAIL

* Use of ASTM 572 grade 50 material is acceptable for grade 60 mat'l provided the mechanical properties for grade 60 material are satisfied

Charpy impact testing, when required, will be in accordance with ASTM A673. The minimum average absorbed energy shall be 20 ft-lbs at zero degrees F. Tranverse impact test is required for plate widths over 24 inches

PART NO.	PRINT NO.	Control Number	Melter	QTY/CAR	MATERIAL	special testing
3-109	D-1114-11			2	A-572 GR50	
3-109	D-1114-11			2	A-572 GR50	
3-29	D-1114-14			2	A-572 GR50	
3-29	D-1114-14			2	A-572 GR50	
3-30	D-1114-14			2	A-572 GR50	
3-30	D-1114-14			2	A-572 GR50	
3-38	D-1114-16			4	A-36	
3-38	D-1114-16			4	A-36	
3-38	D-1114-16			4	A-36	
3-38	D-1114-16			4	A-36	
3-39	D-1114-17			4	A-572 GR50	
3-39	D-1114-17			4	A-572 GR50	
3-39	D-1114-17			4	A-572 GR50	
3-39	D-1114-17			4	A-572 GR50	
3-40	D-1114-17			2	A-572 GR50	
3-40	D-1114-17			2	A-572 GR50	
3-41	D-1114-17			4	A-572 GR50	
3-41	D-1114-17			4	A-572 GR50	
3-41	D-1114-17			4	A-572 GR50	
3-41	D-1114-17			4	A-572 GR50	
3-42	D-1114-17			2	A-572 GR50	
3-42	D-1114-17			2	A-572 GR50	
3-75	D-1114-17			2	A-500 B	
3-75	D-1114-17			2	A-500 B	
3-150	D-1114-17			2	A-572 GR50	
3-150	D-1114-17			2	A-572 GR50	
3-151	D-1114-17			2	A-572 GR50	
3-151	D-1114-17			2	A-572 GR50	
3-153	D-1114-17			2	A-572 GR50	
3-153	D-1114-17			2	A-572 GR50	
3-154	D-1114-17			2	A-572 GR50	
3-154	D-1114-17			2	A-572 GR50	

Note: The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal statutes.

CAR BODY - HEAT IDENTIFCATION
FORM 44B - 3/12/2010

DATE : BODY NUMBER:

TO THE BEST OF MY KNOWLEDGE ALL INFORMATION CONTAINED IS ACCURATE

SIGNED: ______________________ KASGRO RAIL

* Use of ASTM 572 grade 50 material is acceptable for grade 60 mat'l provided the mechanical properties for grade 60 material are satisified

Charpy impact testing, when required, will be in accordance with ASTM A673. The minimum average absorbed energy shall be 20 ft-lbs at zero degrees F. Tranverse impact test is required for plate widths over 24 inches

PART NO.	PRINT NO.	Control Number	Melter	QTY/CAR	MATERIAL	special testing
3-45	D-1114-18			4	A-572 GR50	
3-45	D-1114-18			4	A-572 GR50	
3-45	D-1114-18			4	A-572 GR50	
3-45	D-1114-18			4	A-572 GR50	
3-70	D-1114-18			4	A-572 GR50	
3-70	D-1114-18			4	A-572 GR50	
3-70	D-1114-18			4	A-572 GR50	
3-70	D-1114-18			4	A-572 GR50	
3-71	D-1114-18			4	A-572 GR50	
3-71	D-1114-18			4	A-572 GR50	
3-71	D-1114-18			4	A-572 GR50	
3-71	D-1114-18			4	A-572 GR50	
3-72	D-1114-18			4	A-572 GR50	
3-72	D-1114-18			4	A-572 GR50	
3-72	D-1114-18			4	A-572 GR50	
3-72	D-1114-18			4	A-572 GR50	
3-74	D-1114-18			7	A-572 GR50	
3-74	D-1114-18			7	A-572 GR50	
3-74	D-1114-18			7	A-572 GR50	
3-74	D-1114-18			7	A-572 GR50	
3-74	D-1114-18			7	A-572 GR50	
3-74	D-1114-18			7	A-572 GR50	
3-74	D-1114-18			7	A-572 GR50	
3-21	D-1114-25			4	A-656 GR80	charpy
3-21	D-1114-25			4	A-656 GR80	charpy
3-21	D-1114-25			4	A-656 GR80	charpy
3-21	D-1114-25			4	A-656 GR80	charpy
3-67	D-1114-25			2	A-572 GR50	
3-67	D-1114-25			2	A-572 GR50	
3-68	D-1114-25			2	A-572 GR50	
3-68	D-1114-25			2	A-572 GR50	
3-69	D-1114-25			2	A-572 GR50	

Note: The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal statutes.

CAR BODY - HEAT IDENTIFCATION
FORM 44B - 3/12/2010

DATE : BODY NUMBER:

TO THE BEST OF MY KNOWLEDGE ALL INFORMATION CONTAINED IS ACCURATE

SIGNED: ______________________________ KASGRO RAIL

* Use of ASTM 572 grade 50 material is acceptable for grade 60 mat'l provided the mechanical properties for grade 60 material are satisified

Charpy impact testing, when required, will be in accordance with ASTM A673. The minimum average absorbed energy shall be 20 ft-lbs at zero degrees F. Tranverse impact test is required for plate widths over 24 inches

PART NO.	PRINT NO.	Control Number	Melter	QTY/CAR	MATERIAL	special testing
3-69	D-1114-25			2	A-572 GR50	
3-131	D-1114-37			2	A-572 GR50	
3-131	D-1114-37			2	A-572 GR50	
3-133	D-1114-37			2	A-572 GR50	
3-133	D-1114-37			2	A-572 GR50	
3-134	D-1114-37			2	A-572 GR50	
3-134	D-1114-37			2	A-572 GR50	
3-136	D-1114-37			1	A-572 GR50	
3-138	D-1114-37			4	A-572 GR50	
3-138	D-1114-37			4	A-572 GR50	
3-138	D-1114-37			4	A-572 GR50	
3-138	D-1114-37			4	A-572 GR50	
3-141	D-1114-37			2	A-572 GR50	
3-141	D-1114-37			2	A-572 GR50	
3-119	D-1114-38			4	A-572 GR50	charpy
3-119	D-1114-38			4	A-572 GR50	charpy
3-119	D-1114-38			4	A-572 GR50	charpy
3-119	D-1114-38			4	A-572 GR50	charpy
3-135	D-1114-38			2	A-572 GR50	
3-135	D-1114-38			2	A-572 GR50	
3-137	D-1114-38			2	A-572 GR50	charpy
3-137	D-1114-38			2	A-572 GR50	charpy
3-143	D-1114-41			1	A-572 GR50	
3-144	D-1114-41			2	A-572 GR50	
3-144	D-1114-41			2	A-572 GR50	
3-145	D-1114-41			2	A-572 GR50	
3-145	D-1114-41			2	A-572 GR50	

Note: The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal statutes.

CAR BODY - HEAT IDENTIFCATION
FORM 44B - 3/12/2010

DATE :		Bolster Number:				
TO THE BEST OF MY KNOWLEDGE ALL INFORMATION CONTAINED IS ACCURATE						
SIGNED:_____					KASGRO RAIL	
PART NO.	PRINT NO.	HEAT NUMBER	MELTER	QTY/ CAR	MATERIAL	special testing
3-10	D-1114-08			1	A-572-50	NO
3-12	D-1114-08			2	A-572-50	NO
3-12	D-1114-08			2	A-572-50	NO
3-13	D-1114-08			2	A-572-50	NO
3-13	D-1114-08			2	A-572-50	NO
3-14	D-1114-08			2	A-572-50	NO
3-14	D-1114-08			2	A-572-50	NO

CAR BODY - HEAT IDENTIFCATION
FORM 44B - 3/12/2010

DATE :		Bolster Number:				
TO THE BEST OF MY KNOWLEDGE ALL INFORMATION CONTAINED IS ACCURATE						
SIGNED:_____					KASGRO RAIL	
PART NO.	PRINT NO.	HEAT NUMBER	MELTER	QTY/ CAR	MATERIAL	special testing
3-10	D-1114-08			1	A-572-50	NO
3-12	D-1114-08			2	A-572-50	NO
3-12	D-1114-08			2	A-572-50	NO
3-13	D-1114-08			2	A-572-50	NO
3-13	D-1114-08			2	A-572-50	NO
3-14	D-1114-08			2	A-572-50	NO
3-14	D-1114-08			2	A-572-50	NO

Appendix G-4.5 Span Bolster Heat Identification Form
Form 42, Rev 2/11/2010

FORM 42 2/11/2010

SPAN BOLSTER HEAT IDENTIFICATION FORM

SPAN BOLSTER NUMBER_______________

LEFT SIDE PART #	HEAT # KMC-	RIGHT SIDE PART #	HEAT # KMC-
3-2		3-8	
3-8		3-9	
3-9		3-11	
3-11		3-12	
3-11		3-3	
3-12		3-3	
3-1		3-23	
3-1		3-5	
3-22		3-5	
3-7		3-5	
3-7		3-25	
3-7		3-26	
3-24		3-4	
3-26		3-4	
3-6		3-4	
3-6		3-23	
3-6		3-21	
3-22			
3-21			

INSPECTOR_______________ DATE_______________

Appendix G-4.6 Kasgro Rail New Car Inspection Form Form 5-12-B, Rev 2

Page 1 of 6

KASGRO RAIL CORP

FORM 5-12-B

NEW CAR INSPECTION

Rev 2

Date: 12/07/16

Car Number ______________________ Job Number ________

Wheel / Axle ______________________

Part Number			
Wheel pressure on file		Bearing pressure on file	

MANU/MOD/C/DA/SR#	Axle	MANU/MOD/C/DA/SR#
Left		Right
	1	
	2	
	3	
	4	
	5	
	6	
	7	
	8	
	9	
	10	
	11	
	12	

HANDBRAKE - Model No.

DRAFT SYSTEM

	Part Number
A End	
B End	

TRUCKS

Part Number			
No.	Left side frame (buttons)	Bolster	Right side frame (buttons)
1			
2			
3			
4			
5			
6			

Span Bolster	Part Number

INSPECTOR: DATE:

Note: The recording of false, fictitious, or fraudulent statements on this document may be punishable as a felony under federal statues

KASGRO RAIL CORP
FORM 5-12-B

NEW CAR INSPECTION

Rev 2

Date: 12/07/16

Car Number ____________ Job Number ____________

SPRINGS - PATTERN / TYPE

Outer Coil	
Inner Coil	
Inner Inner Coil	
STABILITY DEVICE (if used)	Model Number

CLEARANCE OF SAFETY APPLIANCES - 2" Minimum --- 1/2" Perferred

AIR BRAKES

Brake Valve	
EP 60 Serial # A-End	
EP 60 Serial # B-End	

SLACK ADJUSTER

Model Number

BRAKE CYLINDER - TRUCK MOUNTED

Travel No. 1 Cylinder	Part #	
Travel No. 2 Cylinder	Part #	
Travel No. 3 Cylinder	Part #	
Travel No. 4 Cylinder	Part #	
Travel No. 5 Cylinder	Part #	
Travel No. 6 Cylinder	Part #	

Brake Pins & Cotter Keys	
Brake Rigging Free & Clear	
Brake Shoe 1 1/2" - **2"**	

CENTER WEAR PLATE LINERS

No. 1	
No. 2	
No. 3	
No. 4	
No. 5	
No. 6	

INSPECTOR: **Date:**

Note: The recording of false, fictitious, or fraudulent statements on this document may be punishable as a felor under federal statues

KASGRO RAIL CORP
FORM 5-12-B

NEW CAR INSPECTION

Rev 2 **Date: 12/07/16**

Car Number ____________ **Job Number** ____________

SIDE BEARING CLEARANCE

BR		BL		
CR		CL		
DR		DL		
Span BR	1/8 - 3/16"	Span BL		1/8 - 3/16"
ER		EL		
FR		FL		
AR		AL		
Span AR	1/8 - 3/16"	Span AL		1/8 - 3/16"

UNDER CAR CLEARANCE - 2 3/4" Minimum ____

DIMEMSIONS

Maximum Width	
Working Deck Length	

At "A" End Right Side		At "A" End Left Side	
At Center Right Side		At Center Left Side	
At "B" End Right Side		At "B" End Left Side	

TESTING

Single Car Test		Golden Shoe Test	
Brake Pipe Restriction Test		Truck Curve Test	
Slack Adjuster Test		Load Test	

Couplers	Type	Height
A-End		
B-End		

INSPECTOR: **Date:**

Note: The recording of false, fictitious, or fraudulent statements on this document may be punishable as a felony under federal statues

KASGRO RAIL CORP
FORM 5-12-B

NEW CAR INSPECTION

Rev 2

Date: 12/07/16

LOCKNUT SECURED AGAINST CONTROL ARM NUT ON SLACK ADJUSTER TRIGGER

TRUCK LOCATION			INSPECTOR	DATE
B	YES ______	NO ______		
C	YES ______	NO ______		
D	YES ______	NO ______		
E	YES ______	NO ______		
F	YES ______	NO ______		
A	YES ______	NO ______		

CROSS KEY RETAINER BOLT TORQUED TO 25 FOOT LBS.			INSPECTOR	DATE
A	YES ______	NO ______		
B	YES ______	NO ______		

3 TABS BENT OVER FLAT AGAINST BOLT HEAD			INSPECTOR	DATE
A	YES ______	NO ______		
B	YES ______	NO ______		

CHECK AND RECORD LOCKING CENTER PIN TRAVEL

TRUCK LOCATION		INSPECTOR	DATE
A-OUTBOARD	______		
A-INBOARD	______		
B-OUTBOARD	______		
B-INBOARD	______		

CENTER PIN AT CAR BODY		INSPECTOR	DATE
A	______		
B	______		

CHECK AND RECORD LT. WT. STENCILED ON RAILCAR. MAKE SURE IT MATCHES LIGHTWEIGHT ON FORM 46

L______________INSPECTOR________________________DATE____________

R______________INSPECTOR________________________DATE____________

CHECK RAILCAR FOR 6 JACKING PADS 4 PCS. 3-42 2 PCS. 3-109

INSPECTOR________________________________DATE____________

Note: The recording of false, fictitious, or fraudulent statements on this document may be punishable as a felony under federal statues

KASGRO RAIL CORP
FORM 5-12-B

NEW CAR INSPECTION

Rev 2 Date: 12/07/16

MIDDLE TRUCK COVER PLATES LOCATED IN THE CORRECT POSITION-BOLTS SHOULD BE TOWARD THE OUTBOARD END OF CAR

			INSPECTOR	DATE
A	YES ______	NO ______		
B	YES ______	NO ______		

TRUCK BOWLS LUBRICATED

			INSPECTOR	DATE
B	YES ______	NO ______		
C	YES ______	NO ______		
D	YES ______	NO ______		
E	YES ______	NO ______		
F	YES ______	NO ______		
A	YES ______	NO ______		

SPAN BOLSTER BOWLS LUBRICATED

			INSPECTOR	DATE
A	YES ______	NO ______		
B	YES ______	NO ______		

PROTECTING COVERS INSTALLED OVER ECP PIGTAIL CONNECTION PINS

			INSPECTOR	DATE
A	YES ______	NO ______		
B	YES ______	NO ______		

COMPLETE AND PROPER MARKING APPLIED TO RAILCAR AND END PLATFORMS PER STENCIL DRAWING E-1114-3 REV. I

INSPECTOR DATE

______________________ ____________

AFTER ALL AIRBRAKE TESTING IS DONE FINAL INSPECTION OF ALL SPRING SETS WHEN RAILCARS ARE FULLY ASSEMBLED, AND WITH THE RAILCAR JACKED TO REMOVE THE WEIGHT OF THE CARBODY FROM THE SPAN BOLSTER/TRUCK ASSEMBLIES

INSPECTOR DATE

______________________ ____________

Note: The recording of false, fictitious, or fraudulent statements on this document may be punishable as a felony under federal statues

Page 6 of 6

KASGRO RAIL CORP
FORM 5-12-B

NEW CAR INSPECTION

Rev 2

Date: 12/07/16

CHECK SHEVE WHEEL CARRIER ASSEMBLY GAP ON SLIDING SHEVE WHEEL ASSEMBLY TO SPAN BOLSTER
GAP SET TO 1/8" TO -1/16" BL AND AR

PROPER INSTALLATION OF CCSB WEAR PLATES

Truck Location		Truck Location	
BR	YES__ NO__	BL	YES__ NO__
CR	YES__ NO__	CL	YES__ NO__
DR	YES__ NO__	DL	YES__ NO__
ER	YES__ NO__	EL	YES__ NO__
FR	YES__ NO__	FL	YES__ NO__
AR	YES__ NO__	AL	YES__ NO__

INSPECTOR ____________________

DATE ____________________

Note: The recording of false, fictitious, or fraudulent statements on this document may be punishable as a felony under federal statutes

Appendix G-4.7 Kasgro Rail Certificate of Order Conformance Example

Kasgro Rail Corporation
121 Rundle Rd. • New Castle, PA 16102
724-658-9061 • 724-658-7639 Fax • www.kasgro.com

KASGRO

CERTIFICATE OF ORDER CONFORMANCE

Date: January 24, 2017

SUPPLIER:
Kasgro Rail Corp
121 Rundle Rd
New Castle PA 16102

Rail Car Number [redacted]

BPMI STANDARD INDENTIFIER NUMBER: [redacted]

WE HEARBY CERTIFY THAT WE HAVE COMPLIED WITH AAR REQUIREMENTS AND ALL THE REQUIREMENTS OF YOUR PURCHASE ORDER NO. K104609 THRU AMENDMENT NO. 12

[redacted]

[redacted]
TITLE

NOTE: The Recording of False, Fictitious or Fraudulent Statements or Entries on the Document may be Punishable as Felony Under Federal Statutes.

Specialty Rail Car Solutions

APPENDIX G-5
ATLAS RAILCAR FABRICATION TRAVELERS

Appendix G-5.1 Kasgro Specialty Railcar Solutions, Form 84, Flat Car Assembly Form, QA Form 84, Rev April 11, 2017

Kasgro Specialty Railcar Solutions

Form 84

Flat Car Assembly

Quality Assurance
Car Body Bolster Reporting Form
Fit and Weld Car Body Bolster

Car #:________________________________

Inspect fit-up: __________________________________

Weld

Inspect all welds:_____________________________

Welders Clock #____________
____
____
____

All repairs to be made and forms completed before moving assembly

Group leader or foreman’s Signature: __________________________
Date____________

Inspector’s signature: ______________________________________Date____________

1

Form #84 April 11, 2017

Kasgro Specialty Railcar Solutions
Form 84

Flat Car Assembly

Quality Assurance
Railcar Car Body Reporting Form

Fit – Side sills, Center sill, Center plates, End sills, Body bolsters and Cross bearers to railcar deck plate

Check fit-up for proper application to drawings___________________________________

Weld

Inspect all welds:________________________________

Welders Clock #_________________
____
____
____

All repairs to be made and forms completed before moving assembly

Group leader or foreman's signature: ___________________________Date______________

Inspector's signature: ____Date______________

Kasgro Specialty Railcar Solutions

Form 84

Flat Car Assembly

Quality Assurance
Railcar Reporting Form

Fit – Bottom Cover Plate and Side Sill Gussets

Check fit-up for proper application to drawings____________________________________

Weld

Inspect all welds:____

Welders Clock #_______________
____
____
____

All repairs to be made and forms completed before moving assembly

Group leader or foreman's signature: _____________________________Date_____________

Inspector's signature: ____Date_____________

Kasgro Specialty Railcar Solutions

Form 84

Flat Car Assembly

Quality Assurance
Reporting form

Position #7
Apply Airbrake, Piping

Inspection
Inspect all parts/sub-assemblies for proper application to drawings

Inspect all welds and fastenings: ____

Welders Clock #________________
____
____
____

All repairs to be made and forms completed before moving assembly

Group leader or foreman's signature: ______________________________Date_____________

Inspector's signature: ____Date_____________

Appendix G-5.2 Kasgro Specialty Railcar Solutions, Form 85, Span Bolster Assembly Form, QA Form 85, Rev April 11, 2017

Kasgro Specialty Railcar Solutions

Form 85

Tri-Span Bolster Assembly

Car Number:____

Tri-Span Bolster Number:______________________

Quality Assurance
Draft Sill Arrangement Reporting Form

Draft Sill Arrangement

Inspection
Inspect all parts/sub-assemblies for proper application to drawings
Steel Stamp Number

Inspect Fit-up: ________________________

Check Draft Pocket Dimensions: ________________________

Weld Draft Sill: ___________________________

Inspect all welds:_________________________________

Welders Clock #__________________
____
____
____

All repairs to be made and forms completed before moving assembly

Group leader or foreman's signature: ____________________________Date__________________

Inspector's signature: ____Date__________________

QA Form 85 1 April 11, 2017

Kasgro Specialty Railcar Solutions

Form 85

Tri-Span Bolster Assembly

Quality Assurance
Fit Tri-Span Bolster
Check Fit-up for proper application to drawings

Inspect Fit-up____

Weld

Inspect all welds:______________________________

Welders Clock #______________
____
____
____

All repairs to be made and forms completed before moving assembly

Group leader or Foreman's signature: __________________________Date_______________

Inspector's signature: _______________________________________Date_______________

Kasgro Specialty Railcar Solutions

Form 85

Tri-Span Bolster Assembly

Quality Assurance
Fit and weld End Platform
Check fit-up for proper application to drawing

Inspect fit-up____

Weld

Inspect all welds:________________________________

Welders Clock #____________
____
____
____

All repairs to be made and forms completed before moving assembly

Group leader or foreman's signature: ___________________________Date_____________

Inspector's signature: ____Date_____________

Kasgro Specialty Railcar Solutions
Form 85

Tri-Span Bolster Assembly

Quality Assurance
Apply safety appliances, cushion unit, coupler, airbrake and hand brake equipment

Cushion Unit Serial Number: ______________________________

Check Safety Appliance locations for proper application to drawings

Inspector: ____

Welders Clock #_________________
____
____
____

All repairs to be made and forms completed before moving assembly

Group leader or foreman's signature; ______________________________Date_____________

Inspector's signature:____Date_____________

APPENDIX G-6

ATLAS RAILCAR OPERATION AND MAINTENANCE INFORMATION

(See Enclosed Appendix G-6 Document)

APPENDIX G-7
AAR EEC SUBMITTAL
FOR ATLAS RAILCAR

EXPERIENCE • INNOVATION • SOLUTIONS

S-2043 CERTIFICATION: PRELIMINARY SIMULATIONS OF KASGRO-ATLAS 12-AXLE CASK CAR

REPORT P-17-021

for Kasgro Rail Corporation

Revised December 14, 2017

TTCI®
Transportation Technology Center, Inc.

S-2043 CERTIFICATION: PRELIMINARY SIMULATIONS OF KASGRO-ATLAS 12-AXLE CASK CAR

P-17-021

for Kasgro Rail Corporation

Prepared by
Russell Walker and Shawn Trevithick

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

Revised December 14, 2017

EXECUTIVE SUMMARY

Kasgro Rail Corporation contracted with Transportation Technology Center, Inc. (TTCI) to perform vehicle dynamics modelling of their cask car design 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 (HLRM)."[1] Kasgro designed the cask car as part of a project with AREVA Federal Services LLC (AFS). The United States Department of Energy contracted with AFS to design the Atlas cask car and buffer cars for transportation of high level radioactive material.

The cask car is a 12-axle, flat deck car. The car deck is supported on two span bolsters. Each span bolster rests on three 2-axle trucks. The car is fitted with Swing Motion® trucks. The secondary suspension uses custom secondary springs with different spring groups in the end trucks of the span bolster than are used in the middle truck of each span bolster to better equalize weight. Primary suspension pads connect the side frames to the axles and allow the axles to steer in curves. The car is designed to use narrow flange wheel profiles that, together with 0.75-inch lateral secondary suspension clearance, allows the three trucks to negotiate a curve. The car is 78 feet, 1 1/4 inches over pulling faces, and has a middle truck center spacing of 38 feet, 6 inches. The span bolster center plate spacing is 38 feet. The truck side bearings are long travel constant contact with a nominal preload of 6,000 pounds.

Kasgro designed the Atlas cask car to carry 17 different spent nuclear fuel casks. AFS created conceptual cradle designs for each cask that can be attached to the railcar through standardized attachment components. The cradle is attached to the railcar deck at the four pin blocks in the center of the railcar deck. Some of the casks use end stops for longitudinal restraint, and AFS created conceptual designs for end stops to suit the cradles that require them. The end stops attach to the railcar at the eight pin blocks at each end of the deck. The pin blocks for the end stops may also be used to attach ballast load if the car is moved in an S-2043 train without a cask loaded onto it.

The full set of S-2043 simulations were performed with the ballast load and with the HI-Star 190 XL, the heaviest, highest center of gravity cask. Dynamic curving simulations were performed with every cask.

The following three tables summarize simulation predictions for S-2043 preliminary analysis regimes.

1 Association of American Railroads. Last Revised: 20–09. *Manual of Standards and Recommended Practices*. Section C, Car Construction Fundamentals and Details. Standard S-2043 "Performance Specification for Trains Used to Carry High-Level Radioactive Material." Washington, DC.

Summary Table (1/3)

Description	S-2043 Paragraph	Subsection	Empty		Loaded		Worst Example that Does Not Meet
			Meets	Does Not Meet	Meets	Does Not Meet	
Truck Twist Equalization	4.2.1		X		X		
Carbody Twist Equalization	4.2.2		X		X		
Static Curve Stability	4.2.3	Base Car	X		X		
		Like Car	X		X		
		Long Car	X		X		
		Buffer Car	X		X		
		Long-Base Car Combination	X		X		
Curve Negotiation	4.2.4	Uncoupled 125-foot radius curve	X		X		
		Coupled 250-foot radius curve	X		X		
		No. 7 crossover	X		X		
Twist and Roll	4.3.9.6	39-foot inputs	X		X		
		38-ft	X		X		
Pitch and Bounce	4.3.9.7	39-foot inputs	X		X		
		38-ft inputs	X		X		
Yaw and Sway	4.3.9.8	39-foot inputs	X		X		
		38-ft inputs	X		X		
Dynamic Curving	4.3.9.9	39-foot inputs	X			X	Wheel L/V 0.88, Limit=0.8, A-end and B-end lead, Loaded[a]
		38-ft inputs	X			X	Wheel L/V 0.90, Limit=0.8, A-end Lead, Loaded
Single Bump	4.3.10.1		X		X		
Curving with Single Rail Perturbation	4.3.10.2	1-inch bump	X		X		
		2-inch bump	X		X		
		3-inch bump		X		X	Wheel L/V 0.91, Limit=0.8, Empty 5 degree roll angle, Limit=4.0, A and B-end lead, Loaded[a]
		1-inch dip	X		X		
		2-inch dip		X	X		Wheel L/V 0.81, Limit=0.8. Empty
		3-inch dip		X		X	Wheel L/V 0.96, Limit=0.8, Empty Truck Side L/V 0.52, Limit=0.5, Empty 4.5 degree roll angle, Limit=4.0, A and B-end lead, Loaded[a]
Hunting	4.3.11.3		X		X		
Constant Curving	4.3.11.4		X		X		

[a] The section for this regime describes this condition and shows a comparison to results with an AAR conditionally approved S-2043 12-axle car

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Summary Table (2/3)

Description	S-2043 Paragraph	Subsection	Empty		Loaded		Worst example that does not meet
			Meets	Does Not Meet	Meets	Does Not Meet	
Curving with Various Lubrication Conditions	4.3.11.5	Case 1 New	X		X		
		Case 2 New		X	X		95% Wheel L/V Ratio=0.62, Limit = 0.60, Empty
		Case 3 New	X		X		
		Case 4 New		X	X		95% Wheel L/V Ratio=0.66, Limit = 0.60, Empty
		Case 1 Worn		X		X	Truck Side L/V 0.56, Empty
		Case 2 Worn		X		X	Truck side L/V Ratio=0.62, Limit=0.5, Loaded[a] 95% Wheel L/V Ratio =0.68, Limit=0.60, Empty
		Case 3 Worn	X		X		
		Case 4 Worn		X		X	Truck side L/V Ratio=0.61, Limit=0.5, Empty, Loaded[a] 95% Wheel L/V Ratio =0.61, Limit=0.60, Empty
Limiting Spiral Negotiation	4.3.11.6	Entry A-end	X		X		
		Exit A-end	X		X		
Turnouts and Crossovers	4.3.11.7	RH Turnout	X		X		
		LH Turnout	X		X		
		Crossover	X			X	Truck side L/V Ratio=0.52, Limit=0.5, Loaded
Ride Quality	4.3.12	Class 2	X		X		
		Class 3	X		X		
		Class 4	X		X		
		Class 5	X		X		
		Class 6	X		X		
Buff and Draft Curving	4.3.13	Base-Buff	X		X		
		Long-Buff	X		X		
		Like-Buff		X	X		Truck side L/V Ratio=0.51, Limit=0.50, Empty
		Buffer Car-Buff	X		X		
		Base-Draft	X		X		
		Long-Draft	X		X		
		Like-Draft	X		X		
		Buffer Car-Draft	X		X		
Braking Effects on Steering	4.3.14		X		X		

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Summary Table (3/3)

Description	S-2043 Paragraph	Subsection	Loaded: Meets	Loaded: Does Not Meet	Worst example that does not meet
Worn Component Simulations	4.3.15				
Constant Contact Side Bearings	4.3.15	Constant Curving	X		
		Dynamic Curving		X	Maximum Wheel L/V Ratio=1.16, Limit=0.8
		Hunting		X	Minimum Vertical Wheel Load=22%, Limit≥25%
		Hunting – Empty Car Ballast Load	X		
		Twist and Roll	X		
Center Plates	4.3.15	Constant Curving	X		
		Dynamic Curving		X	Maximum Wheel L/V Ratio=0.95, Limit=0.8
		Hunting		X	Minimum Vertical Wheel Load=24%, Limit≥25%
Primary Pad	4.3.15	Constant Curving – Soft	X		
		Dynamic Curving – Soft		X	Maximum Wheel L/V Ratio=0.83, Limit=0.80, but better than baseline of 0.88.
		Hunting – Soft		X	Minimum Vertical Wheel Load=24%, Limit≥25%
		Hunting – Empty Car Ballast Load	X		
		Constant Curving – Stiff	X		
		Dynamic Curving – Stiff		X	Maximum Wheel L/V Ratio=0.96, Limit=0.8
		Hunting – Stiff		X	Minimum Vertical Wheel Load=24%, Limit≥25%
Friction Wedges	4.3.15	Limiting Spiral	X		
		Dynamic Curving		X	Maximum Wheel L/V Ratio=0.87, Limit=0.80, but better than baseline of 0.88.
		Pitch and Bounce	X		
		Twist and Roll	X		
Broken Springs	4.3.15	Limiting Spiral	X		
		Dynamic Curving		X	Maximum Wheel L/V Ratio = 0.90, Limit=0.80
		Pitch and Bounce	X		
		Twist and Roll	X		

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1.0 INTRODUCTION

Kasgro Rail Corporation contracted with Transportation Technology Center, Inc. (TTCI) to perform vehicle dynamics modelling of their cask car design 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 (HLRM)." Kasgro designed the cask car as part of a project with AREVA Federal Services LLC (AFS). The United States Department of Energy contracted with AFS to design the Atlas cask car and buffer cars for transportation of HLRM.

2.0 OBJECTIVE

The objective of this work is to estimate the performance of the Atlas cask car in analysis regimes specified in S-2043.

3.0 PROCEDURES

3.1 Car Description

Figure 1 shows the Atlas cask car arrangement drawing. Figure 2 shows a wireframe model of the NUCARS®[2] system file. The wireframe model shows a loaded car. The boxes on the deck represent the 190 XL cask and the two end stops.

Kasgro designed the Atlas cask car to carry 17 different spent nuclear fuel casks. AFS created conceptual cradle designs for each cask that can be attached to the railcar through standardized attachment components. The cradle attached to the railcar deck at the four pin blocks in the center of the railcar deck as can be seen in Figure 1. Some of the casks used end stops for longitudinal restraint, and AFS created conceptual designs for end stops to suit the cradles that require them. The end stops attached to the railcar at the eight pin blocks at each end of the deck.

The full set of S-2043 simulations were performed with the ballast load and with the HI-STAR 190 XL, the heaviest, highest center of gravity (CG) cask. Dynamic Curving Simulations were performed with every cask, to help identify which cask would represent the load conditions that were most likely to provide the most extreme performance. The most extreme case would then be chosen to perform the full set of S-2043 simulations.

[2] NUCARS® is a registered trademark of Transportation Technology Center, Inc.

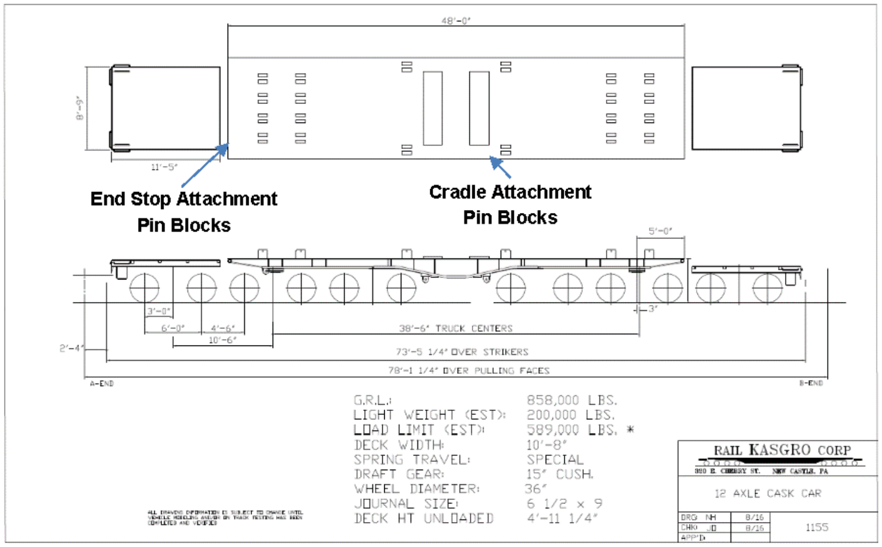

Figure 1. Atlas Cask Car

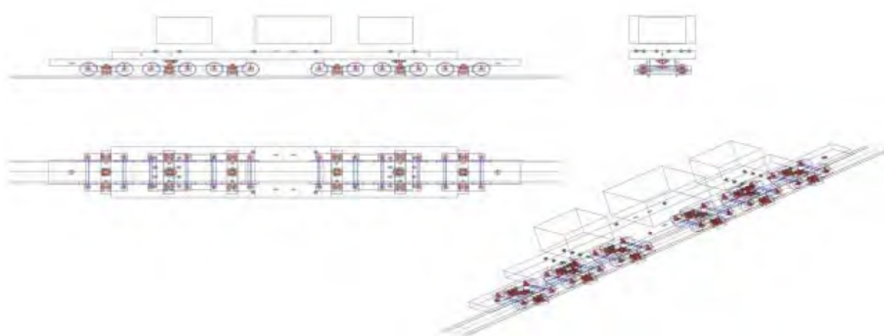

Figure 2. Top, Side, End, and ISO Views of the Wireframe Atlas Cask Car Model

Table 1 shows the geometric properties of the railcar.

Initial modeling showed that the empty cask car (at a gross weight of 200,000 pounds) had high truck side L/V ratios in the buff and draft curving regime. To alleviate this, additional weight was added in the model. The model nearly met buff and draft curving requirements at a gross rail load of 428,915 pounds. This required a ballast weight of 200,500 pounds. The additional weight consisted of two ballast assemblies, each weighing 100,250 pounds. Each ballast assembly consisted of two main assemblies, weighing approximately 40,000 pounds each; and one top assembly that weighed approximately 20,000 pounds. The main assemblies were constructed using seven steel plates, 48 inches wide, 106 inches long, and 3.5 inches thick; and a top plate 2.25 inches thick. Two steel rails, each 2.5 inches thick, were attached to

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the bottom of each main assembly so that the ballast load could be mounted to the deck of the of the cask car using the outer pin blocks of the end stop mounting hardware. The top assemblies were made using four steel plates, 48 inches wide, 106 inches long, and 3.5 inches thick.

Table 2 shows the mass properties of the carbody, ballast weights, end stops, and combined cask and cradle used for the models run in all of the S-2043 regimes. AFS supplied mass properties of all 17 casks, cradles, and end stops for the casks that use end stops. The document containing this data is supplied in the Appendix.

Table 1. Geometric Parameters

Parameter	Dimensions	Units
Length over Pulling Faces (in Draft)	937.25	inch
Truck Center Spacing	462	inch
Axle Spacing	72	inch
Coupler Length (Pin to coupling line)	43	inch
Cushion Unit Travel	15	inch

Table 2. Mass Parameters

Component	Center of Gravity (inches from Top of Rail, Centerline of Track, Lead Axle)			Weight (lbs.)	Mass (lb.-s2/in.)	Mass Moment of inertia about Center of Gravity (lb.-s2-in.)		
	X	Y	Z			X	Y	Z
Carbody with Attachment Hardware	-393	0	54.9	83,500	289.89	396,000	8,920,000	8,710,000
Lead Ballast Weight	-158	0	58.1	100,250	259.7	216,000	271,000	418,000
Trail Ballast Weight	-628	0	58.1	100,250	259.7	216,000	271,000	418,000
HI-STAR 190 XL Cask and Cradle	-375.9	0	121.0	434,405	1,125.1	1,690,000	6,400,000	6,360,000
Lead End Stop for HI-STAR 190 XL	-191.5	0	119.5	20,000	51.8	95,100	76,300	77,500
Trail End Stop for HI-STAR 190 XL	-594.5	0	119.5	20,000	51.8	95,100	76,300	77,500

The ballasted car is symmetrical. Empty (ballasted) simulations were done with the car in one orientation only. Simulations of the car loaded with the HI-STAR 190 XL cask were performed A- and B-end leading.

The Atlas cask car is a very similar design to the 290-ton, AAR EEC conditionally approved S-2043 12-axle car (hereafter referred to as the "CA S-2043 12-Axle Car"). The trucks are identical and the carbody is very similar. Kasgro modified the Atlas car deck to reduce the deck height compared to the CA S-2043 12-Axle Car. The major difference is that the Atlas car uses attachment pin blocks to mount a variety of cradles and end stops rather than using one style of permanently attached cradle like the CA S-2043 12-Axle Car.

The ATLAS car model uses separate rigid bodies to model the carbody, the combined cradle and cask, and the two end stops for casks that require them. The pinned joints that connect the cask and end stops to the carbody are modeled with line friction elements that support the vertical load and model the sliding friction if the load moves laterally within the connection clearance. Separate connections are used to simulate the stops when the clearance is taken up.

3.2 Truck Description

Kasgro plans to use Amsted 100-ton Swing Motion® trucks in the cask car. The truck model — including the geometry, mass properties, and pad stiffness values — is based on the model TTCI created of the Kasgro CA S-2043 12-Axle Car. The 12-axle railcar model predictions were compared to test results to develop confidence in the model inputs (TTCI proprietary report number P-10-044). This section contains a brief description of the trucks.

Table 3 shows the weight of the trucks components in the NUCARS® model. The weights of smaller components like the rocker seats and the bearing adapters are not included in the model individually, but are lumped together with the side frames, bolster, and transom.

Table 3. Weights of Truck Components.

Truck Component	Modeled Weight	Units
Two side frames	2831	lbs.
Bolster	1750	lbs.
Transom	539	lbs.
Total truck weight including hardware and springs	5120	lbs.

Except for the transom, all of the bodies that make up the truck are modeled as rigid. The first torsional mode along the Y-axis is modeled for the transom in order to more correctly predict the truck twist equalization performance.

Table 4 shows the truck configuration modeled.

Table 4. Truck Configuration

Part	Description
Secondary suspension end trucks	(2) 1-94, (2) 1-95, (2) 1-96, (4) 1-97, (4) 1-92, (4) 1-99
Secondary suspension middle trucks	(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 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 10532A
Center bowl liner	Metal horizontal liner

Table 5 shows the primary suspension characteristics as modeled for the cask car.

Table 5. Primary Suspension

Part	Description
Longitudinal Stiffness	22,500 lbs./in.
Longitudinal Clearance	0.625 in.
Lateral Stiffness	48,000 lbs./in.
Lateral Clearance	0.25 in.
Vertical Stiffness	500,000 lbs./in.

The friction wedges used in this truck have a 45-degree wedge angle, a composition vertical face, and a steel slope face.

3.3 Preliminary Simulations with Every Cask

The 17 different loads modeled represent a range of weight, mass properties, and CG height. Figure 3 shows the overall CG height of the car plotted against the gross rail load for the 17 casks, the empty ballasted car, and two load cases for the CA S-2043 12-axle car. Figure 4 shows the combined roll inertia, and Figure 5 shows the combined yaw inertia of the carbody and load for the same cases. The graphs show that the ballasted car and the HI-STAR 190 XL represent the minimum and maximum CG and roll inertia of all the loads the ATLAS car will carry. The CA S-2043 12-axle car results are also effectively additional load cases because the two cars are dimensionally very close and use almost identical suspension parameters.

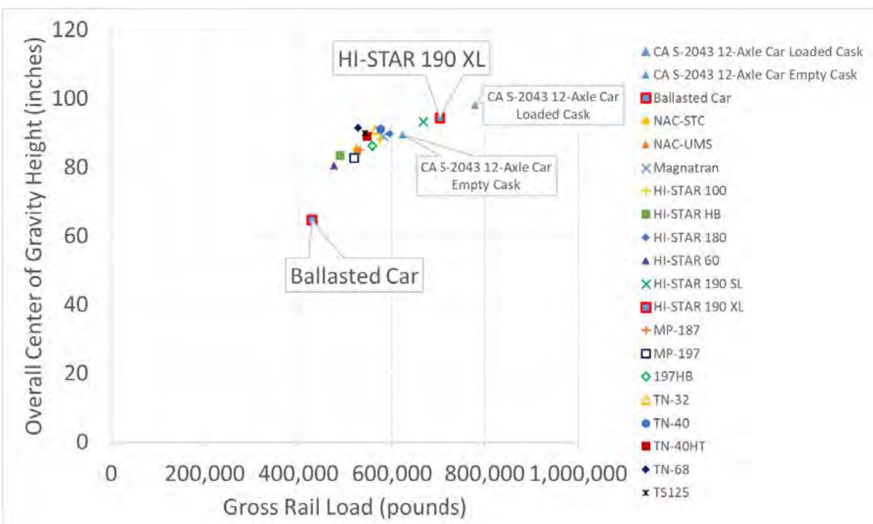

Figure 3. Overall Center of Gravity Height Plotted against Gross Rail Load for the 17 Casks, Ballast load, and Two Loaded Cases for the 290-ton, AAR EEC Conditionally Approved S-2043 12-Axle Car (CA S-2043 12-Axle Car) in Two Load Conditions

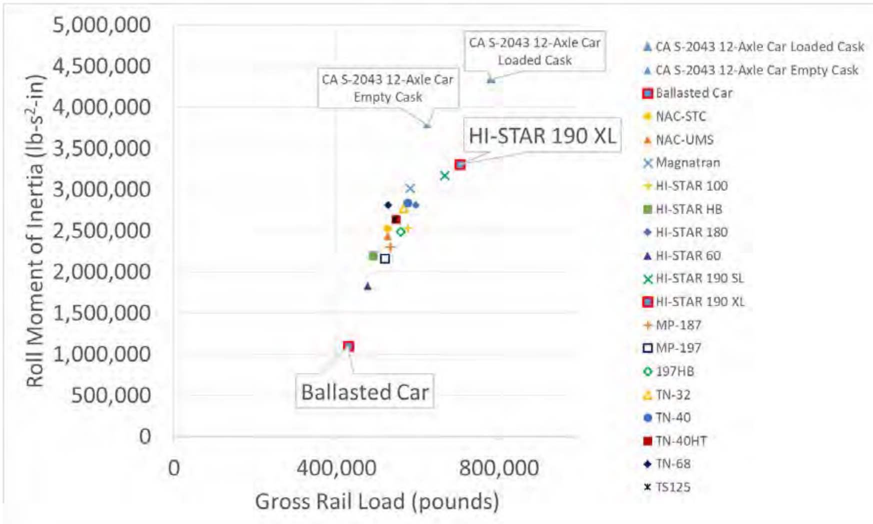

Figure 4. Roll Moment of Inertia of Car Body and Load Plotted against Gross Rail Load for the 17 Casks, Ballast Load, and Two Loaded Cases for the 290-ton, AAR EEC Conditionally Approved S-2043 12-Axle Car (CA S-2043 12-Axle Car) in Two load Conditions

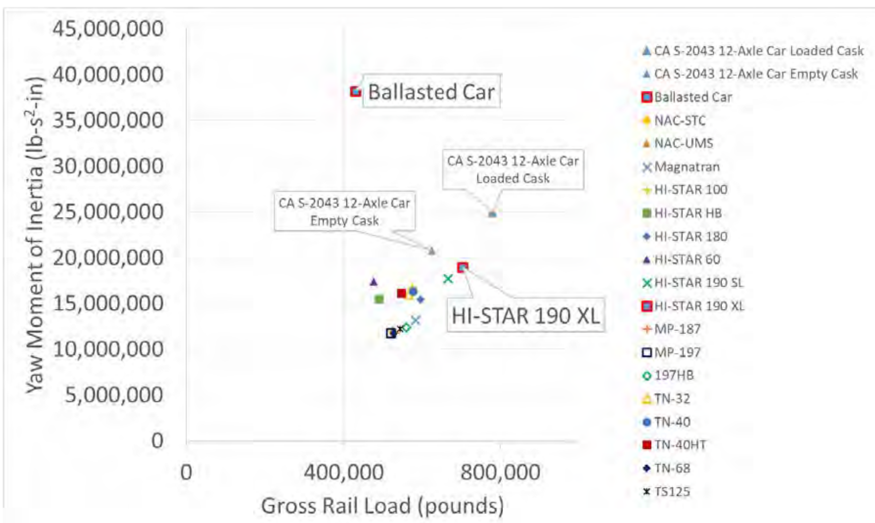

Figure 5. Yaw Moment of Inertia of Car Body and Load Plotted against Gross Rail Load for the 17 Casks, Ballast Load, and Two Loaded Cases for the 290-ton, AAR EEC Conditionally Approved S-2043 12-Axle Car (CA S-2043 12-Axle Car) in Two load Conditions

TTCI simulated the car loaded with each cask in the Dynamic Curving regime to show the range of performance with the different loads. The car was simulated traveling over the dynamic curve zone in clockwise (CW) and counter-clockwise (CCW) directions, and also with the A-end leading and B-end leading. Some physical properties of the car and load and the worst-case performance of those four conditions are compared to the performance criteria for each load case in Table 6 through 8.

The worst performance in Dynamic Curving is seen when the car is loaded with the HI-STAR 190 XL cask. This cask is the heaviest, producing a gross rail load of 703,000 pounds as modeled, and the highest center of gravity case with an overall CG of about 94 inches. These values are based on nominal weights and include the effects of spring deflection, so it is less than the worst-case value of 95-96 inches reported by AFS in "Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation." This load case was therefore chosen for performing all the required S-2043 simulations.

Table 6. Dynamic Curving with Various Loads (Part 1 of 3)

Criterion	Limiting Value	Ballasted Car	NAC-Intl.			Holtec Intl.	
			NAC-STC	NAC-UMS	Magnatran	HI-STAR 100	HI-STAR HB
Gross Rail Load (pound)		429,000	525,000	525,000	582,000	575,000	489,000
Combined CG height (inch)		65	85	85	89	88	83
CGx Carbody and Load from C/L (inch)		0.0	2.2	1.8	5.3	0.5	1.4
CGy Carbody and Load from C/L (inch)		0.0	0.0	0.0	0.0	0.0	0.0
CGz Carbody and Load from TOR (inch)		79.4	102.2	102.2	104.9	104	101.7
Mass Carbody and Load (pound-s^2/inch)		809.2	1057.9	1059.0	1206.6	1188.4	964.1
Ixx Carbody and Load (pound-s^2-inch)		1,099,705	2,524,665	2,432,181	3,012,867	2,531,502	2,202,180
Iyy Carbody and Load (pound-s^2-inch)		38,414,690	12,889,523	13,303,637	14,344,366	17,909,548	16,670,366
Izz Carbody and Load (pound-s^2-inch)		38,220,731	11,778,542	12,192,680	13,164,706	16,677,300	15,508,245
Maximum carbody roll angle (degree)	4.0	0.9	1.0	1.0	1.0	0.9	1.0
Maximum wheel L/V	0.80	0.71	0.70	0.71	0.69	0.69	0.72
Maximum truck side L/V	0.50	0.36	0.36	0.36	0.36	0.36	0.37
Minimum vertical wheel load (%)	25	54	55	55	55	55	55
Peak-to-peak carbody lateral acceleration (g)	1.30	0.19	0.19	0.19	0.20	0.17	0.19
Maximum carbody lateral acceleration (g)	0.75	0.16	0.15	0.16	0.15	0.14	0.15
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.06	0.08	0.08	0.08	0.08	0.07
Maximum vertical suspension deflection (%)	95	43	55	54	61	59	50

Table 7. Dynamic Curving with Various Loads (Part 2 of 3)

Criterion	Limiting Value	Holtec Intl.				TN Americas LLC	
		HI-STAR 180	HI-STAR 60	HI-STAR 190 SL	HI-STAR 190 XL	MP-187	MP-197
Gross Rail Load (pound)		595,000	476,000	667,000	703,000	532,000	519,000
Combined CG height (inch)		90	81	93	94	85	83
CGx Carbody and Load from C/L (inch)		11.7	5.4	12.4	12.7	0.0	0.7
CGy Carbody and Load from C/L (inch)		0.0	0.0	0.0	0.0	0.0	0.0
CGz Carbody and Load from TOR (inch)		105.4	98.5	108	108	102	99
Mass Carbody and Load (pound-s^2/inch)		1240.0	931.3	1425.8	1518.4	1076.6	1043.7
Ixx Carbody and Load (pound-s^2-inch)		2,814,615	1,830,703	3,169,456	3,310,523	2,305,463	2,160,704
Iyy Carbody and Load (pound-s^2-inch)		16,630,979	18,468,965	18,974,927	20,271,816	12,907,293	12,812,028
Izz Carbody and Load (pound-s^2-inch)		15,406,882	17,415,528	17,674,433	18,962,033	11,771,996	11,735,082
Maximum carbody roll angle (degree)	4.0	1.0	1.0	1.2	1.2	1.0	0.9
Maximum wheel L/V	0.80	0.70	0.72	0.71	**0.88**[a]	0.70	0.70
Maximum truck side L/V	0.50	0.36	0.37	0.35	0.37	0.36	0.36
Minimum vertical wheel load (%)	25	53	56	54	49	57	56
Peak-to-peak carbody lateral acceleration (g)	1.30	0.18	0.18	0.17	0.16	0.20	0.20
Maximum carbody lateral acceleration (g)	0.75	0.14	0.15	0.14	0.13	0.15	0.16
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.07	0.06	0.07	0.06	0.08	0.08
Maximum vertical suspension deflection (%)	95	63	49	71	78	54	53

[a] Section 5.4.2 describes this condition and shows a comparison to results with the CA S-2043 12-Axle Car

Table 8. Dynamic Curving with Various Loads (Part 3 of 3)

Criterion	Limiting Value	TN Americas LLC					Energy-Solutions
		197HB	TN-32	TN-40	TN-40HT	TN-68	TS125
Gross Rail Load (pound)		558,000	565,000	575,000	546,000	527,000	543,000
Combined CG height (inch)		86	91	91	89	92	90
CGx Carbody and Load from C/L (inch)		1.1	0.4	0.2	0.2	4.6	3.3
CGy Carbody and Load from C/L (inch)		0.0	0.0	0.0	0.0	0.0	0.0
CGz Carbody and Load from TOR (inch)		102.3	107.8	107.9	106.5	110.3	107.6
Mass Carbody and Load (pound-s^2/inch)		1143.4	1162.5	1187.4	1111.9	1064.1	1105.6
Ixx Carbody and Load (pound-s^2-inch)		2,491,487	2,772,216	2,843,756	2,638,715	2,814,484	2,635,791
Iyy Carbody and Load (pound-s^2-inch)		13,539,652	17,379,564	17,807,581	17,518,709	13,252,727	13,679,951
Izz Carbody and Load (pound-s^2-inch)		12,362,768	15,941,945	16,351,895	16,104,611	11,718,988	12,255,198
Maximum carbody roll angle (degree)	4.0	1.0	1.2	1.2	1.0	1.3	1.1
Maximum wheel L/V	0.80	0.69	0.70	0.70	0.70	0.72	0.70
Maximum truck side L/V	0.50	0.36	0.37	0.37	0.37	0.38	0.37
Minimum vertical wheel load (%)	25	57	55	55	55	54	54
Peak-to-peak carbody lateral acceleration (g)	1.30	0.19	0.18	0.18	0.17	0.21	0.21
Maximum carbody lateral acceleration (g)	0.75	0.14	0.15	0.14	0.15	0.16	0.16
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.08	0.07	0.07	0.07	0.08	0.07
Maximum vertical suspension deflection (%)	95	57	58	59	56	55	57

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3.4 Track Geometry Input Data

The regimes of Twist and Roll, Pitch and Bounce, Yaw and Sway, and Dynamic Curving were modeled using measured track geometry of the actual test zones at the Transportation Technology Center in Pueblo, Colorado. TTCI's experience has shown that simulations using measured track geometry as inputs generally produce more realistic results than simulations using mathematically generated inputs. In this section measured track geometry inputs are compared to the track geometry standards listed in AAR MSRP Section C-II, Standard M-1001 Chapter 11, paragraph 11.5.2.5 for Twist and Roll, Pitch and Bounce, Yaw and Sway, and Dynamic Curving. Each relevant geometry measurement is shown on the plot and the tolerances specified in Chapter 11 table 11.2 are shown in red.

The wavelength of the inputs for each of the actual test zones at TTC is 39 feet. The inputs were scaled to perform additional simulations with wavelength equal to the Atlas car's truck center spacing of 38 feet.

The twist and roll regime consists of a series of 10 3/4-inch vertical track deviations offset on each rail to input roll motions to the car. Figure 6 shows the cross level and gage measurements from the inputs used for the Twist and Roll simulations. The cross level and gage measurements are within tolerances.

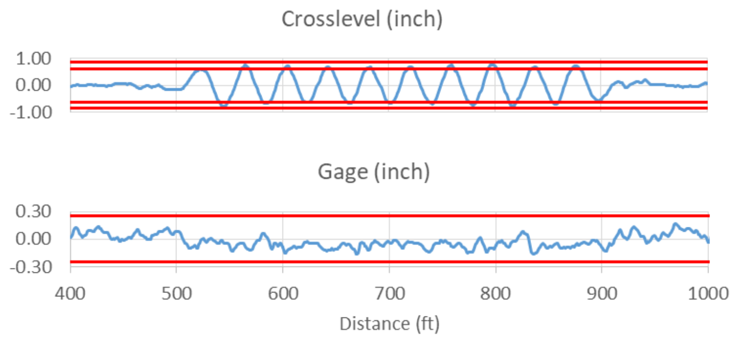

Figure 6. Twist and Roll Track Geometry Measurements and Tolerances

The pitch and bounce regime consists of a series of 10 3/4-inch vertical track deviations on each rail to input vertical motions to the car. Figure 7 shows profile, cross level and gage measurements from the inputs used for Pitch and Bounce simulations. One-half inch was added to the profile measurement so the bottom of the perturbations were about zero and the peak amplitude tolerance of 0.75-inch ±0.125 inch could be easily marked on the plot. The actual shape of the profile of the track at the ends of the zone is somewhat distorted by the measurement system filters. The cross level is slightly higher than the tolerance about 50-feet beyond the end of the zone, but is other-wise within tolerance. The gage is within tolerance.

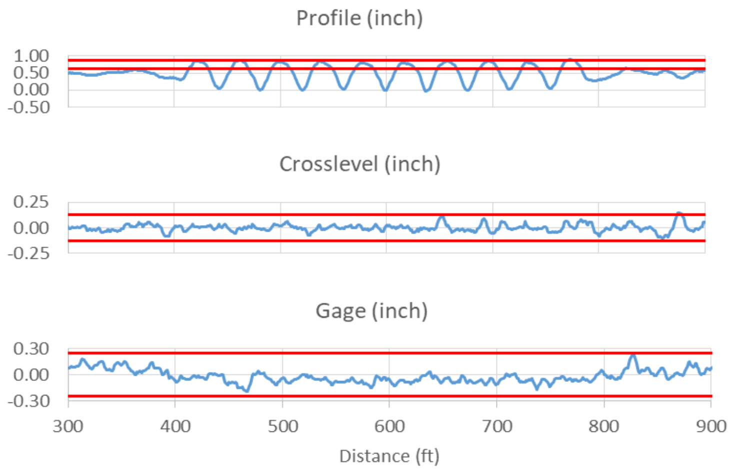

Figure 7. Pitch and Bounce Track Geometry Measurements and Tolerances

The dynamic curve section is on a 10-degree curve with 4 inches superelevation. The dynamic curving regime consists of a series of 0.5-inch vertical track deviations offset on each rail to input roll motions to the car. At the same time, the gage of the track changes from 56.5 inches to 57.5 inches to input lateral motions to the car. Figure 8 shows the gage, cross level, and superelevation measurements and tolerances for the inputs used for Dynamic Curving simulations. The gage and cross level are within the tolerance. The superelevation is consistently higher than the tolerance through most of the test zone. The effect of this will be to make the simulation regime more severe for the lower speed condition.

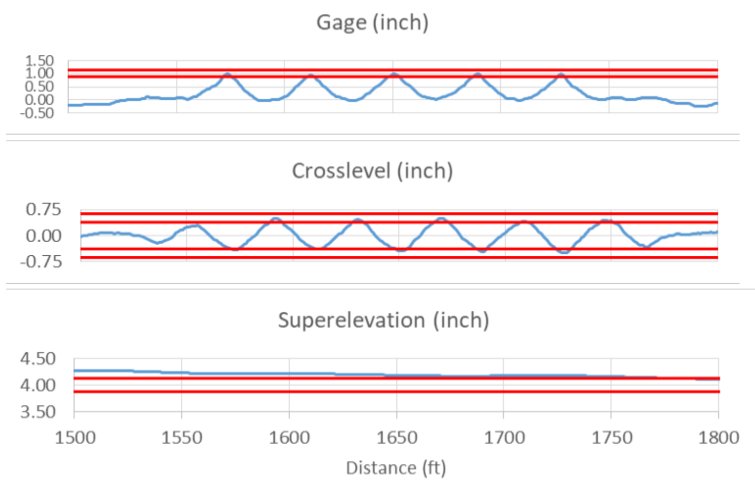

Figure 8. Dynamic Curving Track Geometry Measurements and Tolerances

The yaw and sway regime consists of a series of 1.25-inch lateral track deviations on a section with 1-inch wide gage to input lateral and yaw motions to the car. Figure 9 shows the gage, cross level, and alignment measurements and tolerance for the inputs used for Yaw and Sway simulations. The gage varies more than the tolerance allows, dropping below 0.875 and rising higher than 1.125 in a few locations. The cross level is within tolerance. The alignment has one perturbation at the beginning of the zone with amplitude slightly higher than the tolerance.

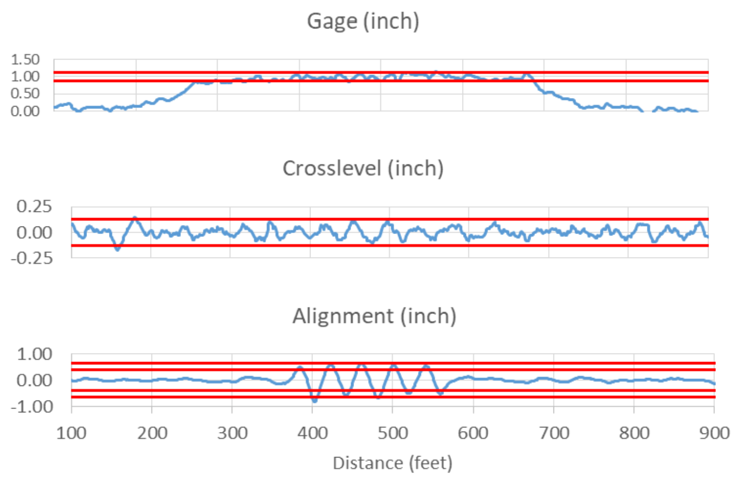

Figure 9. Yaw and Sway Track Geometry Measurements and Tolerances

4.0 NONSTRUCTURAL STATIC ANALYSIS RESULTS

Dynamic analysis simulations were conducted according to Paragraph 4.2 of S-2043. The nonstructural static analysis regimes are designed to demonstrate truck and car performance under static conditions of track twist or curve negotiation.

In this section, each analysis regime is briefly described, followed by the simulation predictions for that analysis regime. Predicted values are compared to criteria levels for each regime. Plots showing data trends are provided where appropriate.

4.1 Truck Twist Equalization (S-2043 Paragraph 4.2.1)

S-2043 requires the truck twist equalization regime to verify the design has adequate truck load equalization performance. Truck load equalization performance is the ability of a truck to distribute vertical load to all the wheels in a truck when negotiating a short wavelength track twist deviation. The analysis is performed by simulating raising and lowering one wheel in a truck from 0 to 3 inches in 0.5-inch increments. This analysis was performed for each wheel in the car. The requirement is that all wheel loads must remain above 60 percent of the nominal static wheel load when displaced 2 inches, and above 40 percent of the nominal static wheel load when displaced 3 inches.

4.1.1 Empty Car with Ballast Load – Truck Twist

TTCI simulated raising and lowering each wheel and predicted the worst performance in the interior trucks, axles 5-8.

Figure 10 shows a plot of the simulation predictions for the interior trucks. The worst-case predictions are 62.2 percent wheel load when a wheel is displaced 2 inches, and 56.3 percent wheel load when a wheel is displaced 3 inches. The simulation predictions meet the requirements of the truck twist equalization regime.

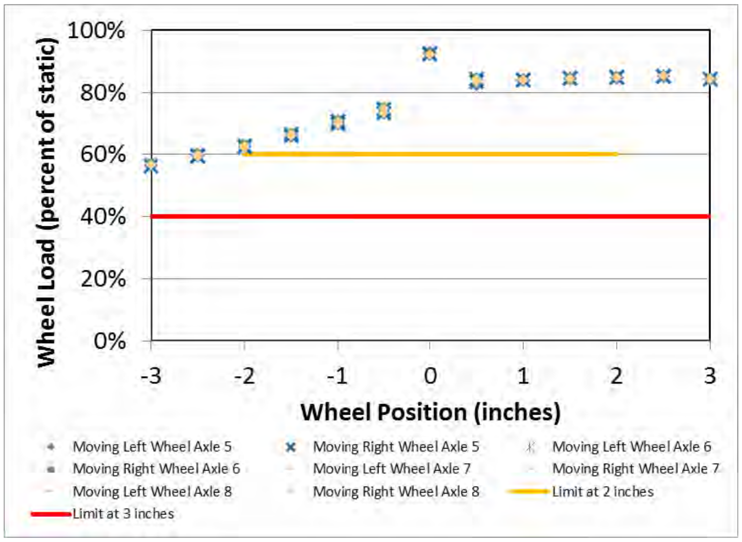

Figure 10. Truck Twist Equalization Simulation Predictions for Axles 5-8 of the Empty Car

4.1.2 HI-STAR 190 XL Cask – Truck Twist

TTCI simulated raising and lowering each wheel and predicted the worst performance in the interior trucks, axles 5-8. Figure 11 shows a plot of the simulation predictions for the interior trucks. The worst-case predictions are 64.7 percent wheel load when a wheel is displaced 2 inches, and 59.0 percent wheel load when a wheel is displaced 3 inches. The simulation predictions meet the requirements of the truck twist equalization regime.

Figure 11. Truck Twist Equalization Simulation Predictions for Axles 5-8 of the Car Loaded with the HI-STAR 190 XL Cask

4.2 Carbody Twist Equalization (S-2043 Paragraph 4.2.2)

S-2043 requires the carbody twist equalization regime to simulate wheel unloading during carbody twist. Carbody twist occurs when the car is negotiating a spiral or a long wavelength track-twist deviation. The analysis is performed by simulating the raising and lowering of all the wheels on one side of the span bolster from 0 to 3 inches in 0.5-inch increments. This analysis was performed for each side of each span bolster. The requirement is that all wheel loads must remain above 60 percent of the nominal static wheel load when displaced 2 inches, and above 40 percent of the nominal static wheel load when displaced 3 inches.

4.2.1 Empty Car with Ballast Load – Carbody Twist Equalization

Figure 12 shows a plot of carbody twist performance for the empty car with ballast load. The worst-case simulation predictions are 68 percent minimum vertical wheel load when displaced 2 inches, and 62 percent minimum vertical wheel load when displaced 3 inches. The simulation predictions meet the requirements of the carbody twist regime.

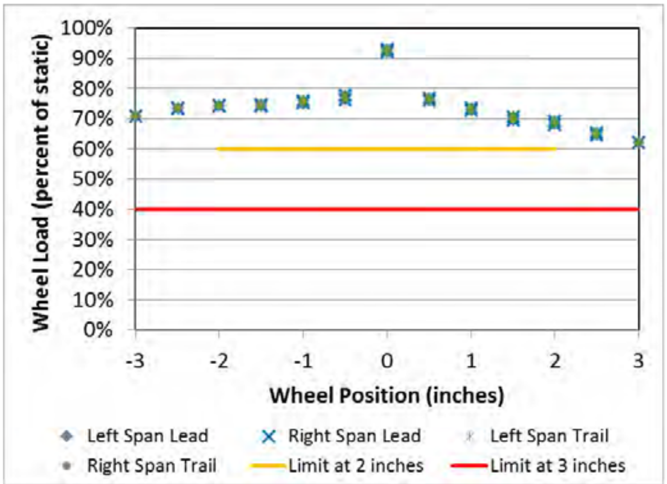

Figure 12. Carbody Twist Simulation Predictions for the Empty Car with Ballast Load

4.2.2 HI-STAR 190 XL Cask – Carbody Twist Equalization

Figure 12 shows a plot of carbody twist performance for the car loaded with the HI-STAR 190 XL cask. The worst-case simulation predictions are 68 percent minimum vertical wheel load when displaced 2 inches, and 64 percent minimum vertical wheel load when displaced 3 inches. The simulation predictions meet the requirements of the carbody twist regime.

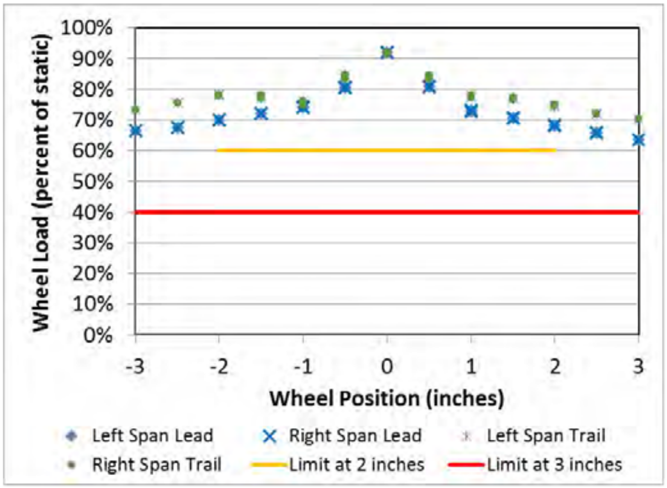

Figure 13. Carbody Twist Simulation Predictions for the
Car Loaded with the HI-STAR 190 XL Cask

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4.3 Static Curve Stability (S-2043 Paragraph 4.2.3)

The static curve stability analysis regime in S-2043 refers to the curve stability test in AAR Chapter 11, Paragraph 11.3.3.3. The curve stability regime requires the car be subjected to a 200,000-pound buff load and a 200,000-pound draft load while placed on a curve of no less than 10 degrees. The curve may have no more than 0.5 inch superelevation. The test car will be coupled to a base car or a like car, whichever is more severe, and a long car with 90-foot over strikers, 66-foot truck centers, 60-inch couplers, and conventional draft gear. The combination of the long car and base car is typically tested, and was included in the simulations. In addition, S-2043 requires that the analysis be performed with the car coupled to cars it will be coupled to in HLRM train operation. In HLRM train operation the Atlas cask car may be coupled to a buffer car that is 66 feet, 4 5/8 inches over pulling faces, has 44-foot 6-inch truck centers, 43-inch couplers, and is equipped with 15-inch cushion units. The requirement is that no wheel lift and no suspension separation may occur for this analysis.

4.3.1 Empty Car with Ballast Load - Static Curve Stability

Figure 14 shows simulation predictions of minimum vertical wheel loads for the five cases of coupled cars analyzed. No wheel lift occurred. The simulations predictions were checked for suspension separation at the centerplate, constant contact side bearings, coil springs, transom to side frame connection, and primary pads by verifying that all of those connections were carrying vertical load. No suspension separation was found. The simulation predictions meet the requirements of the curve stability regime.

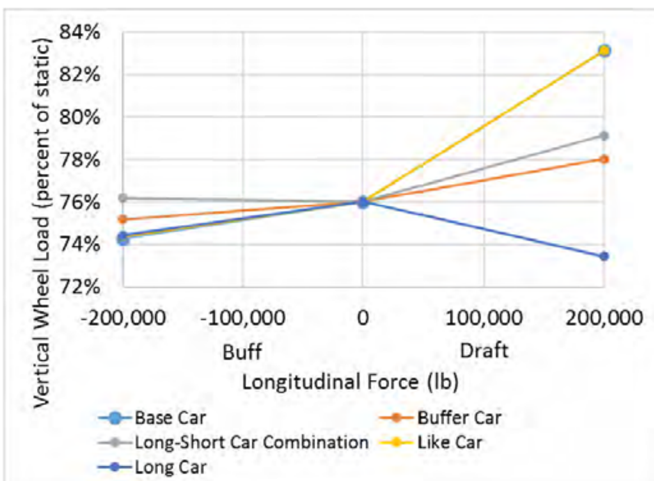

Figure 14. Simulation Predictions of Minimum Vertical Wheel Loads in the Static Curve Stability Regime

4.3.2 HI-STAR 190 XL Cask - Static Curve Stability

Figure 15 shows simulation predictions of minimum vertical wheel loads for the five cases of coupled cars analyzed. No wheel lift occurred. The simulations predictions were checked for suspension separation at the centerplate, constant contact side bearings, coil springs, transom to side frame connection, and primary pads by verifying that all of those connections were carrying vertical load. No suspension separation was found. The simulation predictions meet the requirements of the curve stability regime.

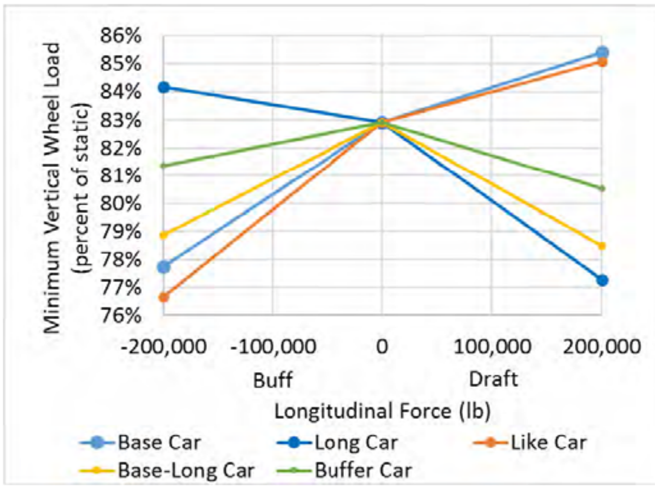

Figure 15. Simulation Predictions of Minimum Vertical Wheel Loads in the Static Curve Stability Regime

4.4 Curve Negotiation (S-2043 Paragraph 4.2.4)

Curve negotiation calculations were performed with NUCARS® simulations. The cask car had a truck center spacing of 38 feet 6 inches and a length over pulling faces of couplers of 78 feet 1 1/4 inches. For these dimensions, the AAR MSRP Section C-II, Standard M-1001, Chapter 2 paragraph 2.1.4.2[3] requires the car be designed to negotiate a 350-foot radius curve when coupled and a 150-foot radius curve when uncoupled.

TTCI simulated the uncoupled car negotiating a 150-foot radius curve using NUCARS®. No wheel lift occurred. The simulations predictions were checked for suspension separation at the centerplate, constant contact side bearings, the coil springs, the transom-to-side frame connection, and the primary pads by verifying that all of those connections were carrying vertical load. No suspension separation was found.

TTCI simulated the car negotiating a 350-foot radius curve while coupled to a base car, a like car, and a buffer car that the Atlas cask car may be coupled to in HLRM service. No

[3] Association of American Railroads. 2011. *Manual of Standards of Recommended Practices*. Section C-II Design, Fabrication, and Construction of Freight Cars, Standard M-1001, Chapter 2, General Data, Paragraph 2.1.4.2 "Horizontal Curve and Tangent." Washington, DC.

wheel lift occurred. The simulations predictions were checked for suspension separation at the centerplate, side bearings, the coil springs, the transom-to-side frame connection, and the primary pads by verifying that all of those connections were carrying vertical load. No suspension separation was found.

TTCI simulated the car negotiating a No. 7 crossover on 13-foot centers while coupled to a base car, a like car, and a buffer car that the cask car may be coupled to in HLRM service. No wheel lift occurred. The simulations predictions were checked for suspension separation at the centerplate, side bearings, the coil springs, the transom-to-side frame connection, and the primary pads by verifying that all of those connections were carrying vertical load. No suspension separation was found.

The simulation predictions meet the requirements of the curve negotiation regime.

5.0 DYNAMIC ANALYSIS RESULTS

Dynamic analysis simulations were conducted according to Paragraph 4.3 of S-2043.

In this section, each analysis regime is briefly described, followed by the simulation predictions for that analysis regime. Tables show predicted values for each regime compared to the criteria presented in Table 4.1 of AAR Standard S-2043. Predicted values that do not meet the criteria are shown in red bold font. Predicted values that are at the criteria level are shown in black bold font. Plots showing data trends are provided. Where criteria differ between S-2043 and AAR MSRP Section C-II, Standard M-1001, Chapter 11, "Service-worthiness Tests and Analyses for New Freight Cars" (AAR Chapter 11), criteria for both standards are shown on the plots.

In cases where the Atlas cask car did not meet S-2043 criteria, data is compared to results from the CA S-2043 12-Axle Car to show the difference in performance between the two. Comparison data is taken from the test data or final modeling, as appropriate for the specific comparison.

Lateral carbody acceleration standard deviation is calculated over a 1,000-foot section. In many cases the simulation regime is less than 1000-feet. In those cases that metric and criterion are not applicable and are marked with "NA."

Simulations were performed using a coefficient of friction between the wheel and rail of 0.5. AAR 1B narrow flange wheel profiles were used for all cases except those where specific worn profiles were called for in the specification.

Measured rail profiles from the actual test zones at TTC were used where applicable. Where no actual test zone exists, new 136-pound rail with 10-inch crown radius was used.

Simulation predictions were made using inputs created with measured track geometry. TTCI's experience has shown that simulations with measured track geometry produce better predictions of car performance than are obtained with analytic track inputs created with mathematical functions. Because the measured track geometry inputs contain short wavelengths that cause spurious peaks in the data, the 50-millisecond and 3-foot analysis windows described in AAR Chapter 11 and S-2043 are used when analyzing data to produce the most realistic results.

5.1 Twist and Roll (S-2043 Paragraph 4.3.9.6)

Simulations of the twist and roll regime were conducted according to Paragraph 4.3.9.6 of S-2043. The twist and roll regime consists of a series of 3/4-inch vertical track deviations offset on each rail to input roll motions to the car. Simulations of 39-foot and 38-foot wavelengths were performed.

5.1.1 Empty Car with Ballast Load – Twist and Roll

Table 9 shows the worst-case simulation predictions for empty car twist and roll. Figure 16 shows the peak-to-peak roll angle plotted against speed to show the trend in performance. Simulation predictions meet S-2043 criteria for twist and roll.

Table 9. Twist and Roll Simulation Predictions for the Ballast Load

Criterion	Limiting Value	39-foot inputs	38-foot inputs
Maximum carbody roll angle (degree)	4.0	1.8	1.6
Maximum wheel L/V	0.80	0.21	0.19
Maximum truck side L/V	0.50	0.13	0.14
Minimum vertical wheel load (%)	25	63	64
Peak-to-peak carbody lateral acceleration (g)	1.30	0.19	0.19
Maximum carbody lateral acceleration (g)	0.75	0.10	0.11
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.09	0.09
Maximum vertical suspension deflection (%)	95	45	45

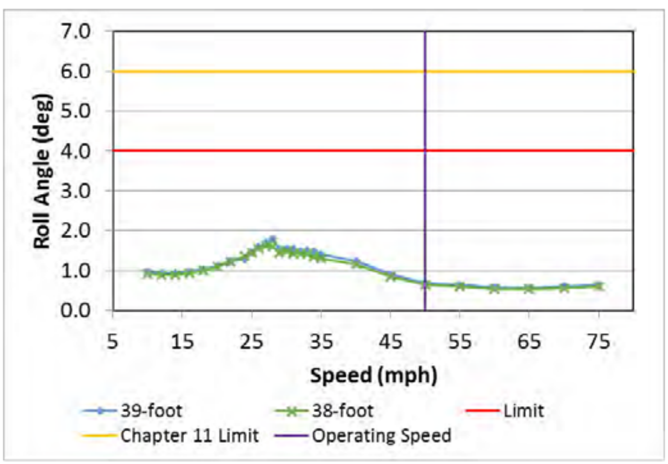

Figure 16. Predicted Roll Angle for the Ballast Load in the Twist and Roll Regime

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5.1.2 HI-STAR 190 XL Cask – Twist and Roll

Table 10 shows the worst-case simulation predictions for the car loaded with the HI-STAR 190 XL. Figure 16 shows the peak-to-peak roll angle plotted against speed to show the trend in performance. Simulation predictions meet S-2043 criteria for twist and roll.

Table 10. Twist and Roll Simulation Predictions for the HI-STAR 190 XL Load

Criterion	Limiting Value	39-foot inputs A-Lead	39-foot inputs B-Lead	38-foot inputs A-Lead	38-foot inputs B-Lead
Maximum carbody roll angle (degree)	4.0	2.0	2.1	1.8	1.8
Maximum wheel L/V	0.80	0.14	0.14	0.14	0.13
Maximum truck side L/V	0.50	0.11	0.10	0.09	0.09
Minimum vertical wheel load (%)	25	68	66	69	67
Peak-to-peak carbody lateral acceleration (g)	1.30	0.22	0.24	0.21	0.22
Maximum carbody lateral acceleration (g)	0.75	0.12	0.13	0.12	0.12
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.11	0.11	0.11	0.13
Maximum vertical suspension deflection (%)	95	74	74	74	74

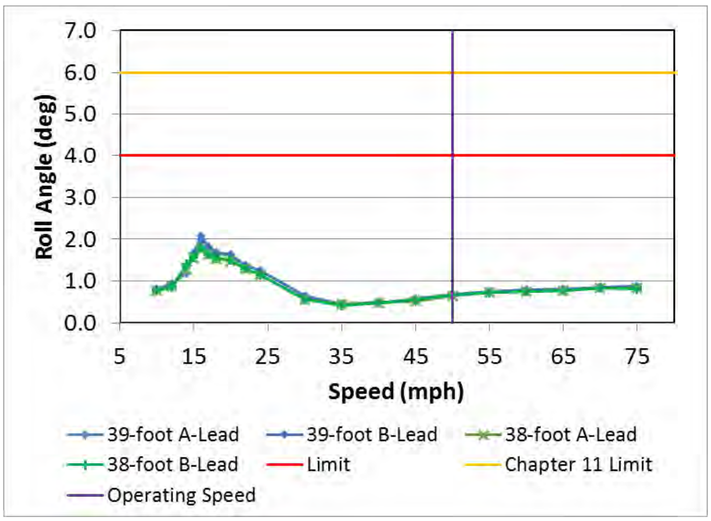

Figure 17. Predicted Roll Angle for the HI-STAR 190 XL Load in the Twist and Roll Regime

5.2 Pitch and Bounce (S-2043 Paragraph 4.3.9.7)

Simulations of the pitch and bounce regime were conducted according to Paragraph 4.3.9.7 of S-2043. The pitch and bounce regime consists of a series of 3/4-inch vertical track deviations in parallel on each rail to input vertical motions to the car. Simulations of 39-foot and 38-foot wavelengths were performed.

5.2.1 Empty Car with Ballast Load – Pitch and Bounce

Table 11 shows the worst-case simulation predictions for pitch and bounce for the ballast load condition. Figure 18 shows the maximum vertical acceleration plotted against speed to show the trend in performance. Ballast load simulation predictions meet S-2043 criteria for pitch and bounce.

Table 11. Pitch and Bounce Simulation Predictions for the Ballast Load

Criterion	Limiting Value	39-foot inputs A-end	38-foot inputs A-end
Maximum carbody roll angle (degree)	4.0	0.1	0.1
Maximum wheel L/V	0.80	0.08	0.09
Maximum truck side L/V	0.50	0.07	0.07
Minimum vertical wheel load (%)	25	61	62
Peak-to-peak carbody lateral acceleration (g)	1.30	0.13	0.11
Maximum carbody lateral acceleration (g)	0.75	0.07	0.06
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.34	0.35
Maximum vertical suspension deflection (%)	95	48	50

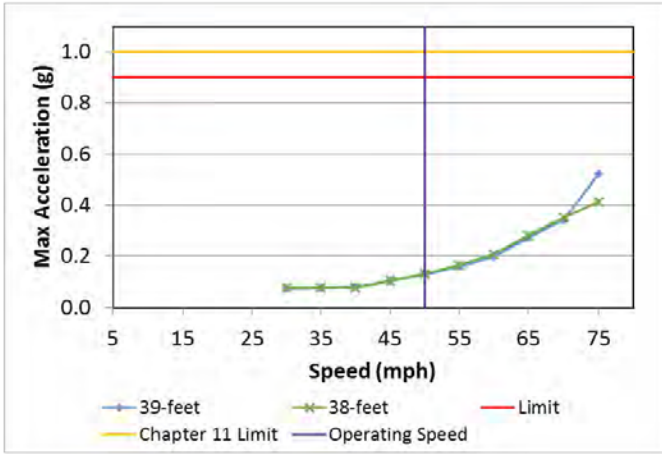

Figure 18. Predicted Vertical Acceleration for the Ballast Load in the Pitch and Bounce Regime

5.2.2 HI-STAR 190 XL Cask – Pitch and Bounce

Table 12 shows the worst-case simulation predictions for pitch and bounce. Figure 19 shows the minimum vertical wheel load plotted against speed to show the trend in performance. Simulation predictions meet S-2043 criteria for pitch and bounce.

Table 12. Pitch and Bounce Simulation Predictions for the HI-STAR 190 XL Cask

Criterion	Limiting Value	39-foot inputs A-Lead	39-foot inputs B-Lead	38-foot inputs A-Lead	38-foot inputs B-Lead
Maximum carbody roll angle (degree)	4.0	0.1	0.1	0.2	0.2
Maximum wheel L/V	0.80	0.06	0.05	0.06	0.06
Maximum truck side L/V	0.50	0.04	0.04	0.04	0.04
Minimum vertical wheel load (%)	25	68	73	70	74
Peak-to-peak carbody lateral acceleration (g)	1.30	0.14	0.16	0.13	0.14
Maximum carbody lateral acceleration (g)	0.75	0.07	0.08	0.07	0.07
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.21	0.22	0.20	0.22
Maximum vertical suspension deflection (%)	95	72	76	71	76

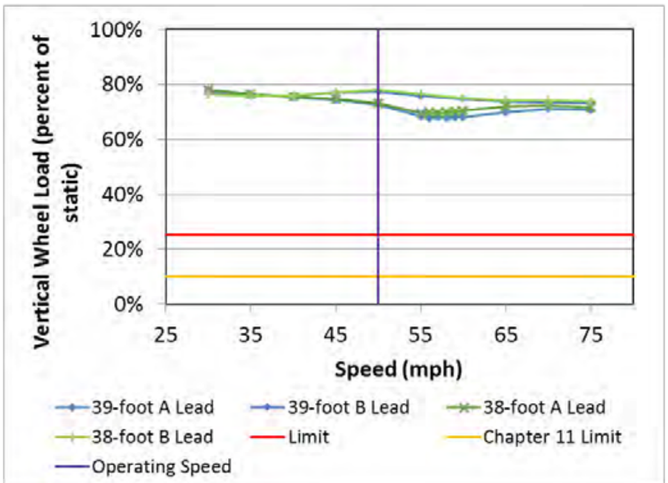

Figure 19. Predicted Minimum Vertical Wheel Load for the HI-STAR 190 XL Cask in the Pitch and Bounce Regime

5.3 Yaw and Sway (S-2043 Paragraph 4.3.9.8)

Simulations of the yaw and sway regime were conducted according to Paragraph 4.3.9.8 of S-2043. The yaw and sway regime consists of a series of 1.25-inch lateral track deviations on a section with 1-inch wide gage to input lateral and yaw motions to the car. Simulations of 39-foot and 38-foot wavelengths were performed.

5.3.1 Empty Car with Ballast Load – Yaw and Sway

Table 13 shows the worst-case simulation predictions for yaw and sway with the ballast load. Figure 20 shows the maximum wheel L/V ratio plotted against speed to show the trend in performance. Simulation predictions meet S-2043 criteria for yaw and sway.

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Table 13. Yaw and Sway Simulation Predictions for the Ballast Load

Criterion	Limiting Value	39-foot inputs	38-foot inputs
Maximum carbody roll angle (degree)	4.0	1.4	1.0
Maximum wheel L/V	0.80	0.76	0.72
Maximum truck side L/V	0.50	0.42	0.40
Minimum vertical wheel load (%)	25	46	49
Peak-to-peak carbody lateral acceleration (g)	1.30	0.50	0.42
Maximum carbody lateral acceleration (g)	0.75	0.28	0.24
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.13	0.11
Maximum vertical suspension deflection (%)	95	46	44

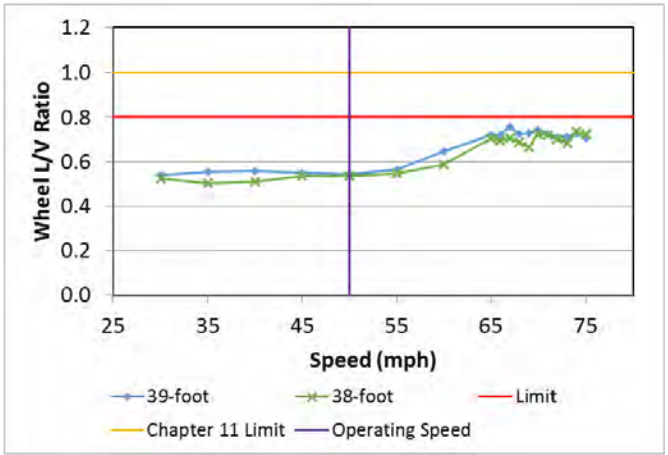

Figure 20. Predicted Maximum Wheel L/V Ratio for the Ballast Load in the Yaw and Sway Regime

5.3.2 HI-STAR 190 XL Cask – Yaw and Sway

Table 14 shows the worst-case simulation predictions for yaw and sway. Figure 21 shows the maximum wheel L/V ratio plotted against speed to show the trend in performance. Simulation predictions meet S-2043 criteria for yaw and sway.

Table 14. Yaw and Sway Simulation Predictions for the HI-STAR 190 XL Cask

Criterion	Limiting Value	39-foot inputs A-Lead	39-foot inputs B-Lead	38-foot inputs A-Lead	38-foot inputs B-Lead
Maximum carbody roll angle (degree)	4.0	0.8	0.8	0.6	0.6
Maximum wheel L/V	0.80	0.59	0.57	0.57	0.57
Maximum truck side L/V	0.50	0.29	0.30	0.30	0.30
Minimum vertical wheel load (%)	25	56	60	57	59
Peak-to-peak carbody lateral acceleration (g)	1.30	0.64	0.67	0.64	0.63
Maximum carbody lateral acceleration (g)	0.75	0.34	0.36	0.34	0.34
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.11	0.11	0.12	0.12
Maximum vertical suspension deflection (%)	95	70	68	68	67

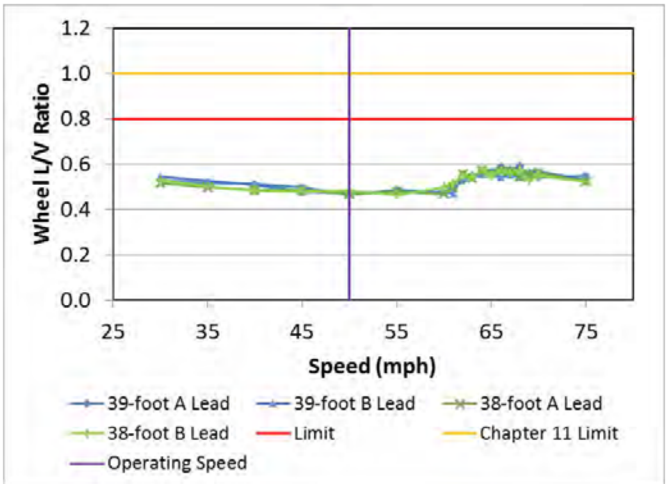

Figure 21. Predicted Maximum Wheel L/V Ratio for the HI-STAR 190 XL in the Yaw and Sway Regime

5.4 Dynamic Curving (S-2043 Paragraph 4.3.9.9)

Simulations of the dynamic curving regime were conducted according to Paragraph 4.3.9.9 of S-2043. The dynamic curve section is on a 10-degree curve with 4 inches superelevation. The dynamic curving regime consists of a series of 0.5-inch vertical track deviations offset on each rail to input roll motions to the car. At the same time, the gage of the track changes from 56.5 inches to 57.5 inches to input lateral motions to the car. Simulations of 39-foot and 38-foot wavelengths were performed. Speeds ranging from 3 inches underbalance to 3 inches overbalance are simulated.

5.4.1 Empty Car with Ballast Load – Dynamic Curving

Table 15 shows the worst-case simulation predictions for dynamic curving. Figure 22 shows the wheel L/V ratio plotted against speed to show the trend in performance. Simulation predictions meet S-2043 criteria for dynamic curving.

Table 15. Dynamic Curving Simulation Predictions for the Empty Car with Ballast Load

Criterion	Limiting Value	39-foot inputs CW	39-foot inputs CCW	38-foot inputs CW	38-foot inputs CCW
Maximum carbody roll angle (degree)	4.0	0.8	0.9	0.7	0.8
Maximum wheel L/V	0.80	0.71	0.70	0.70	0.71
Maximum truck side L/V	0.50	0.35	0.36	0.35	0.36
Minimum vertical wheel load (%)	25	54	55	55	55
Peak-to-peak carbody lateral acceleration (g)	1.30	0.17	0.19	0.17	0.16
Maximum carbody lateral acceleration (g)	0.75	0.13	0.16	0.14	0.15
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.05	0.06	0.05	0.05
Maximum vertical suspension deflection (%)	95	43	43	43	43

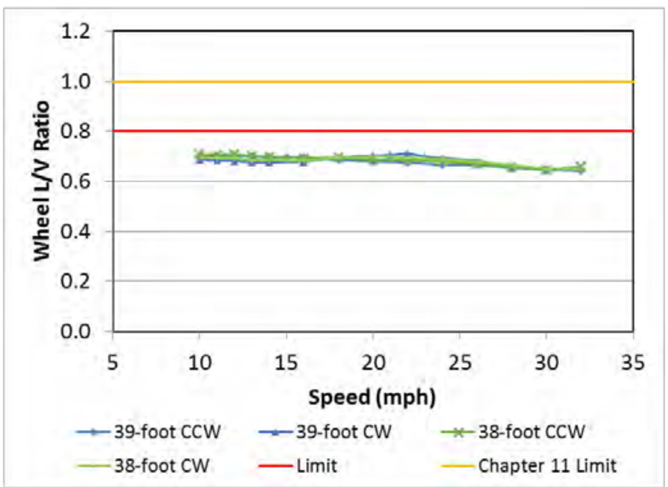

Figure 22. Predicted Maximum Wheel L/V Ratio in the Dynamic Curving Regime for the Empty Car with Ballast Load

5.4.2 HI-STAR 190 XL Cask – Dynamic Curving

Table 16 shows the worst-case simulation predictions for dynamic curving with 39-foot wavelength perturbations. Table 17 shows the same data with 38-foot wavelength perturbations. Figure 23 shows the wheel L/V ratio plotted against speed for the 39-foot wavelength input to show the trend in performance. Figure 25 shows corresponding data for 38-foot wavelength input. Data for A-end leading and B-end leading are shown, but for the 39-foot wavelength input the 17-inch longitudinal CG offset of the cask did not make a difference in performance. Simulation predictions did not meet S-2043 criteria for maximum wheel L/V ratio in CW dynamic curving. Figure 24 shows the distance plot of the highest wheel L/V ratio for the 39-foot wavelength cases and Figure 26 shows the same data for 38-foot wavelength cases.

Predicted wheel L/V ratios for the Atlas cask car were lower than those for the CA S-2043 12-Axle Car in the loaded cask condition. Maximum Wheel L/V ratios of 0.98 were measured in the test and simulations predicted a maximum of 1.07 in Dynamic Curving for the CA S-2043 12-Axle Car with the loaded cask.

Table 16. 39-foot Wavelength Dynamic Curving Simulation Predictions for the HI-STAR 190 XL Cask

Criterion	Limiting Value	A-Lead CW	A-Lead CCW	B-Lead CW	B-Lead CCW
Maximum carbody roll angle (degree)	4.0	1.2	1.2	1.2	1.2
Maximum wheel L/V	0.80	**0.88**	0.68	**0.88**	0.68
Maximum truck side L/V	0.50	0.37	0.34	0.37	0.34
Minimum vertical wheel load (%)	25	49	54	49	54
Peak-to-peak carbody lateral acceleration (g)	1.30	0.16	0.16	0.16	0.16
Maximum carbody lateral acceleration (g)	0.75	0.13	0.13	0.13	0.13
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.06	0.06	0.06	0.06
Maximum vertical suspension deflection (%)	95	78	75	78	75

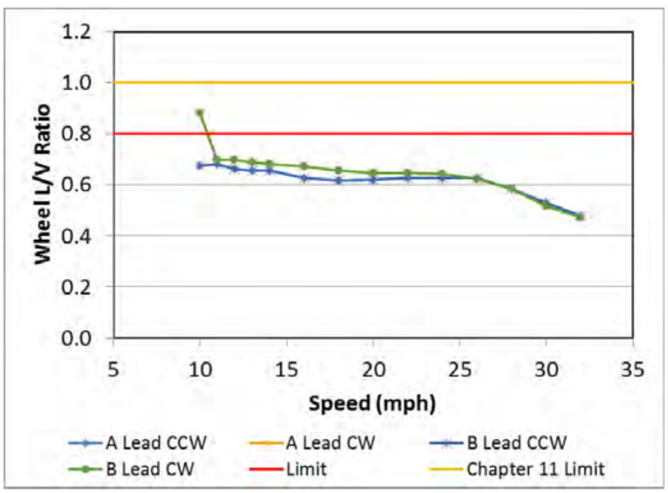

Figure 23. Predicted Maximum Wheel L/V Ratio in the 39-foot Wavelength Dynamic Curving Regime for the HI-STAR 190 XL Cask

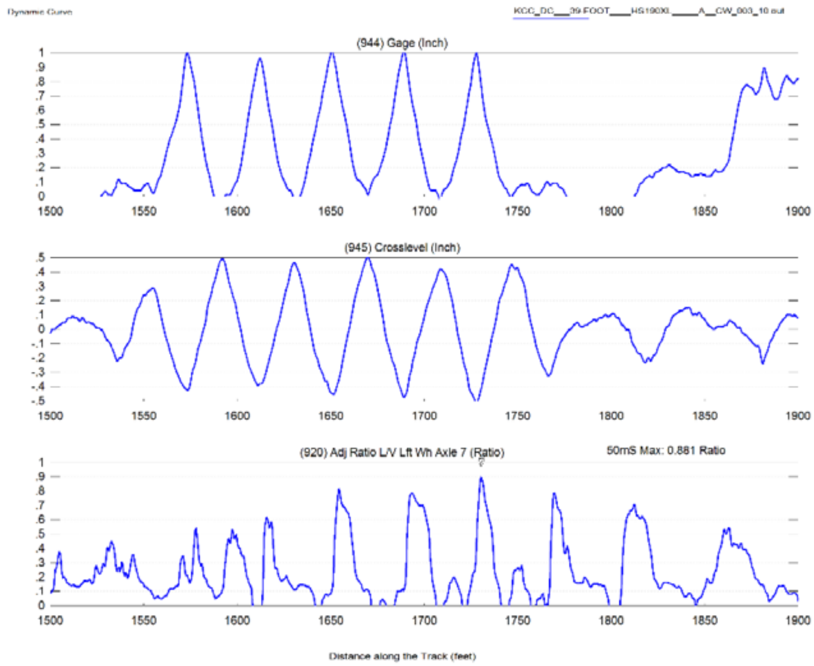

Figure 24. Gage, Cross level, and Wheel L/V Ratio on the Leading Axle of the Trailing Span Bolster in 39-Foot Dynamic Curving Regime with A-end Lead, CW
*Note that the Gage and Cross level are at Axle 1, so should be Shifted 38 Feet to Match the L/V Data for Axle 7

Table 17. 38-foot Wavelength Dynamic Curving Simulation Predictions for the HI-STAR 190 XL Cask

Criterion	Limiting Value	A-Lead CW	A-Lead CCW	B-Lead CW	B-Lead CCW
Maximum carbody roll angle (degree)	4.0	1.4	1.1	1.5	1.0
Maximum wheel L/V	0.80	**0.90**	0.69	**0.88**	0.68
Maximum truck side L/V	0.50	0.38	0.34	0.38	0.33
Minimum vertical wheel load (%)	25	48	54	49	55
Peak-to-peak carbody lateral acceleration (g)	1.30	0.15	0.16	0.15	0.15
Maximum carbody lateral acceleration (g)	0.75	0.13	0.13	0.13	0.14
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.06	0.08	0.07	0.08
Maximum vertical suspension deflection (%)	95	78	75	78	75

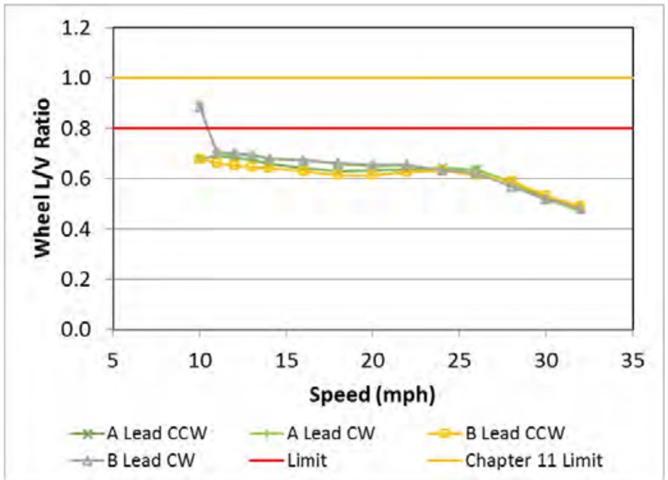

Figure 25. Predicted Maximum Wheel L/V Ratio in the 38-foot Wavelength Dynamic Curving Regime for the HI-STAR 190 XL Cask

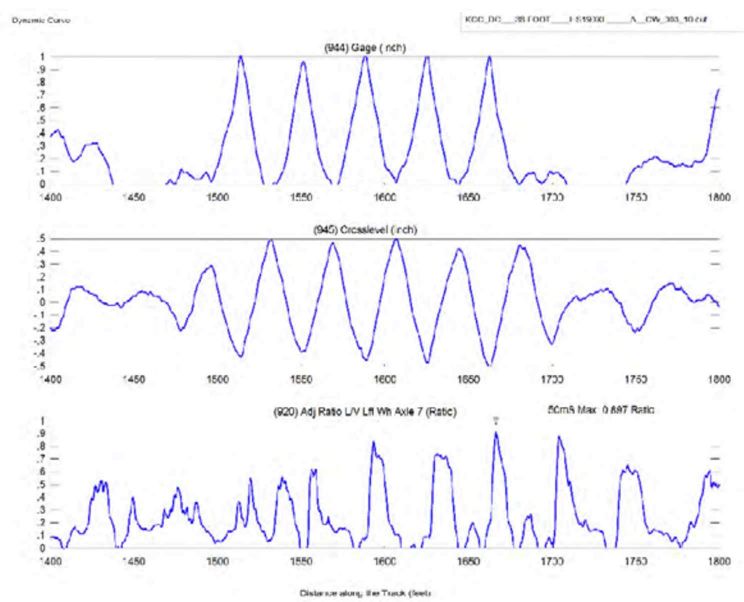

Figure 26. Gage, Cross level, and Wheel L/V Ratio on the Leading Axle of the Trailing Span Bolster in 38-Foot Dynamic Curving Regime with A-end Lead, CW
Note that the Gage and Cross level are at Axle 1, so should be shifted 38 Feet to Match the L/V Data for Axle 7

5.5 Single Bump (S-2043 Paragraph 4.3.10.1)

Simulations of the single bump regime were conducted according to Paragraph 4.3.10.1 of S-2043. The single bump regime consists of a flat topped vertical profile deviation with 1-inch amplitude. The initial change is 1 inch in 7 feet, followed by a steady elevation of 1 inch for 20 feet, and finishing with a ramp back to normal elevation over 7 feet. No standard test zone exists for the single bump regime, but measured track geometry from a test performed in 2009 was used as input for the simulation.

5.5.1 Empty Car with Ballast Load – Single Bump

Table 18 shows the worst-case simulation predictions for the single bump for the empty car with ballast load. Figure 27 shows the minimum vertical wheel load plotted against speed to show the trend in performance. Simulation predictions meet S-2043 criteria for the single bump.

Table 18. Single Bump Simulation Predictions for the Empty Car with Ballast Load

Criterion	Limiting Value	Single Bump
Maximum carbody roll angle (degree)	4.0	0.1
Maximum wheel L/V	0.80	0.03
Maximum truck side L/V	0.50	0.03
Minimum vertical wheel load (%)	25	65
Peak-to-peak carbody lateral acceleration (g)	1.30	0.03
Maximum carbody lateral acceleration (g)	0.75	0.02
Lateral carbody acceleration standard deviation (g)	0.13	NA
Maximum carbody vertical acceleration (g)	0.90	0.20
Maximum vertical suspension deflection (%)	95	44

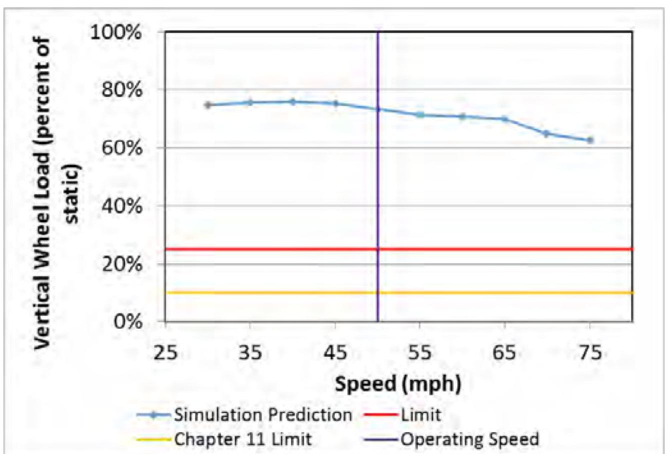

Figure 27. Simulation Predictions of Minimum Vertical Wheel Load for the Single Bump Regime for the Empty Car with Ballast Load

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5.5.2 HI-STAR 190 XL Cask - Single Bump

Table 19 shows the worst-case simulation predictions for the single bump for the loaded car with HI-STAR 190 XL cask. Figure 28 shows the minimum vertical wheel load plotted against speed to show the trend in performance. Simulation predictions meet S-2043 criteria for the single bump.

Table 19. Single Bump Simulation Predictions for the HI-STAR 190 XL Cask

Criterion	Limiting Value	Single Bump A-Lead	Single Bump B-Lead
Maximum carbody roll angle (degree)	4.0	0.1	0.1
Maximum wheel L/V	0.80	0.02	0.02
Maximum truck side L/V	0.50	0.02	0.02
Minimum vertical wheel load (%)	25	73	71
Peak-to-peak carbody lateral acceleration (g)	1.30	0.04	0.05
Maximum carbody lateral acceleration (g)	0.75	0.02	0.03
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.22	0.21
Maximum vertical suspension deflection (%)	95	69	72

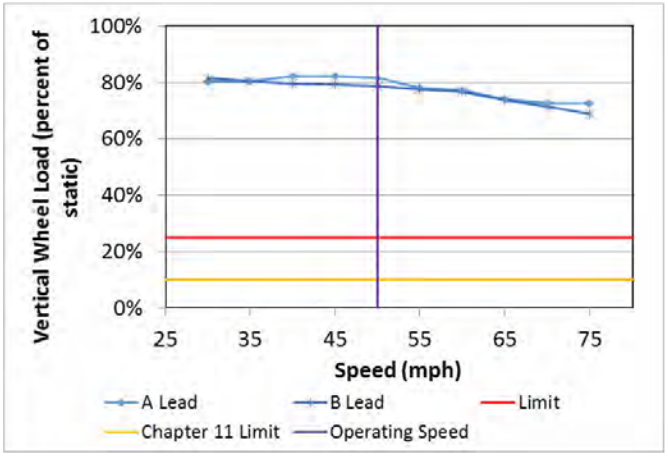

Figure 28. Simulation Predictions of Minimum Vertical Wheel Load for the Single Bump Regime for the HI-STAR 190 XL Cask

5.6 Curving with Single Rail Perturbation (S-2043 Paragraph 4.3.10.2)

Simulations of the curving with single rail perturbation regime were conducted according to Paragraph 4.3.10.2 of S-2043. The curving with single rail perturbation regime is located on a 12-degree curve with no superelevation. Simulations were made for 1-, 2-, and 3-inch outside rail dips and for 1-, 2-, and 3-inch inside rail bumps. The perturbation is a flat topped ramp with an elevation change over 6 feet, a steady elevation over 12 feet, ramping to the original elevation over 6 feet. The inputs for this simulation regime were mathematically generated because no actual test zone exists. Tests of a 2-inch bump and dip were performed in 2009, but inputs from measurements of those perturbations were less severe than the analytic inputs and were not used for the simulations reported here. S-2043 prescribes that the simulations be made in 2-mph increments from 4 mph to 14 mph for the 1- and 2-inch amplitude perturbations. The maximum speed over the 3-inch perturbations shall be 10 mph.

5.6.1 Empty Car with Ballast Load – Curve with Single Perturbation

Table 20 shows the worst-case simulation predictions for the curving with single bump regime. Figure 29 shows the maximum wheel L/V ratio plotted against speed to show the trend in performance. Table 21 and Figure 30 show the corresponding information for the curving with single dip simulations. Simulation predictions do not meet S-2043 criteria for single wheel L/V ratio in the 3-inch bump case or the 2- and 3-inch dip cases. Simulation predictions do not meet S-2043 criteria for truck side L/V ratio in the 3-inch dip case. Figure 31 shows a plot of the worst single wheel L/V ratio and the worst truck side L/V ratio over the 3 inch dip at 4 mph.

Table 20. Curving with Single Bump Simulation Predictions for the Empty Car with Ballast Load

Criterion	Limiting Value	1-inch	2-inch	3-inch
Maximum carbody roll angle (degree)	4.0	0.4	1.4	2.2
Maximum wheel L/V	0.80	0.71	0.78	**0.91**
Maximum truck side L/V	0.50	0.41	0.44	0.49
Minimum vertical wheel load (%)	25	58	51	45
Peak-to-peak carbody lateral acceleration (g)	1.30	0.06	0.12	0.16
Maximum carbody lateral acceleration (g)	0.75	0.04	0.08	0.09
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.05	0.07	0.07
Maximum vertical suspension deflection (%)	95	50	59	67

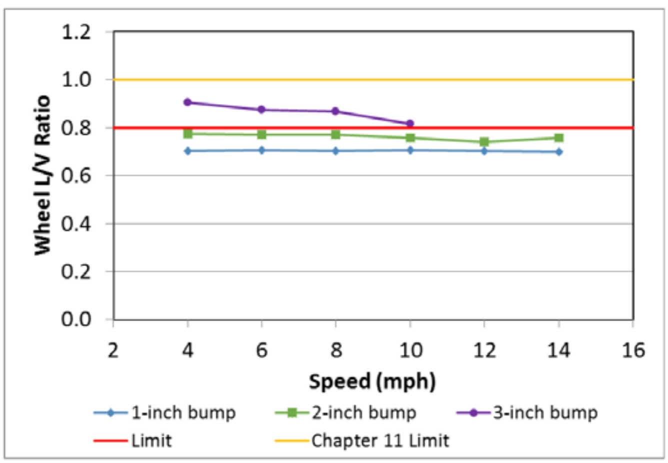

Figure 29. Curving with Single Bump Simulation Predictions for Empty Car with Ballast Load

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Table 21. Curving with Single Dip Simulation Predictions for the Empty Car with Ballast Load

Criterion	Limiting Value	1-inch	2-inch	3-inch
Maximum carbody roll angle (degree)	4.0	0.3	0.9	1.3
Maximum wheel L/V	0.80	0.72	**0.81**	**0.96**
Maximum truck side L/V	0.50	0.42	0.46	**0.52**
Minimum vertical wheel load (%)	25	65	54	44
Peak-to-peak carbody lateral acceleration (g)	1.30	0.05	0.13	0.11
Maximum carbody lateral acceleration (g)	0.75	0.04	0.08	0.07
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.04	0.06	0.06
Maximum vertical suspension deflection (%)	95	43	50	50

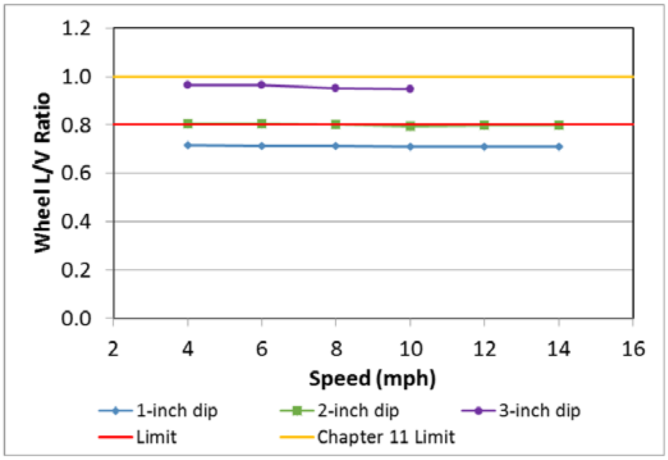

Figure 30. Curving with Single Dip Simulation Predictions for the Empty Car with Ballast Load

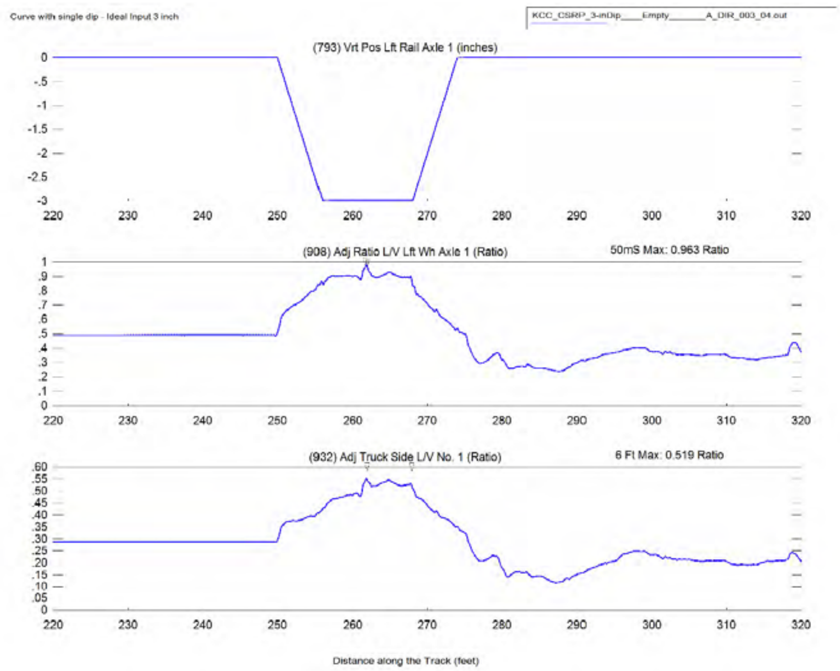

Figure 31. Left Rail Position, Lead Axle Left Wheel L/V Ratio, and Lead Left Truck Side L/V Ratio Plotted Against Distance over the 3-Inch Dip at 4 mph for the Empty Car with Ballast Load

5.6.2 HI-STAR 190 XL Cask – Curve with Single Perturbation

Table 22 shows the worst-case simulation predictions for the curving with single bump regime with the HI-STAR 190 XL cask with A-end leading. Figure 32 shows the peak to peak roll angle plotted against speed to show the trend in performance. Table 23 and Figure 33 show the corresponding information for the curving with single-dip simulations. Tables 24 and 25 and Figures 34 and 35 show the corresponding data for B-end leading cases. Simulation predictions do not meet S-2043 criteria for the maximum carbody roll angle in the 3-inch bump and 3-inch dip cases for both the A and B-end leading. Figure 36 shows a plot of carbody roll angle versus distance for the 3-inch dip at 10 mph with the A-end leading. Simulation predictions meet S-2043 criteria for the maximum vertical suspension deflection in the 3-inch bump case with B-end leading with a value equal to the criterion of 95 percent.

Predicted carbody roll angles for the Atlas cask car were lower than those for the CA S-2043 12-Axle Car in the loaded cask condition. A maximum peak to peak carbody roll angle of 5.4 degrees was predicted on the 3-inch bump for the CA S-2043 12-Axle Car compared to 5.0 degrees for the Atlas car.

Table 22. Curving with Single Bump A-end Lead Simulation Predictions for the Car Loaded with the HI-STAR 190 XL Cask

Criterion	Limiting Value	1-inch	2-inch	3-inch
Maximum carbody roll angle (degree)	4.0	0.5	3.0	**5.0**
Maximum wheel L/V	0.80	0.53	0.59	0.64
Maximum truck side L/V	0.50	0.29	0.33	0.33
Minimum vertical wheel load (%)	25	58	53	38
Peak-to-peak carbody lateral acceleration (g)	1.30	0.05	0.14	0.21
Maximum carbody lateral acceleration (g)	0.75	0.05	0.08	0.12
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.04	0.08	0.07
Maximum vertical suspension deflection (%)	95	77	86	94

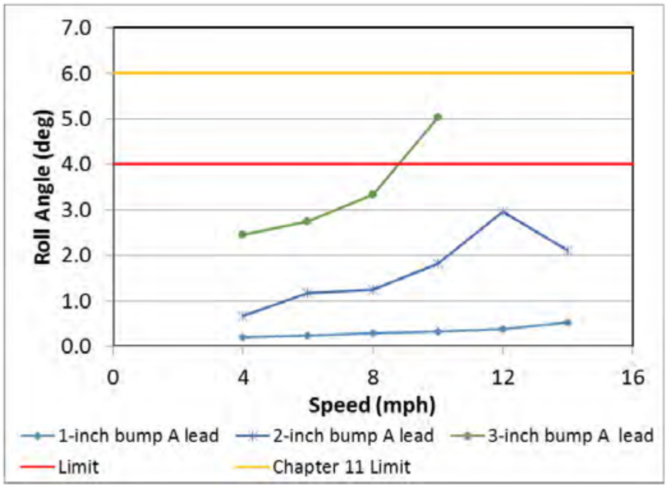

Figure 32. Curving with Single Bump A-end Lead Simulation Predictions with the HI-STAR 190 XL Cask

Table 23. Curving with Single Dip A-end Lead Simulation Predictions for the Car Loaded with the HI-STAR 190 XL Cask

Criterion	Limiting Value	1-inch	2-inch	3-inch
Maximum carbody roll angle (degree)	4.0	0.5	2.6	4.5
Maximum wheel L/V	0.80	0.57	0.68	0.79
Maximum truck side L/V	0.50	0.32	0.35	0.38
Minimum vertical wheel load (%)	25	64	56	44
Peak-to-peak carbody lateral acceleration (g)	1.30	0.06	0.11	0.19
Maximum carbody lateral acceleration (g)	0.75	0.05	0.07	0.10
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.04	0.07	0.06
Maximum vertical suspension deflection (%)	95	73	82	88

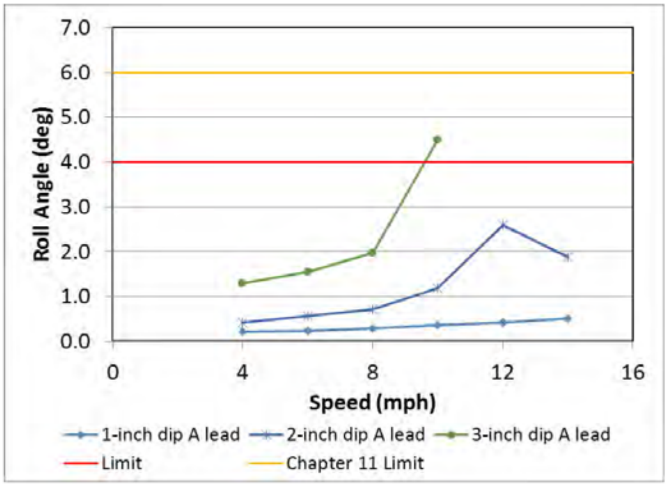

Figure 33. Curving with Single Dip A-end Lead Simulation Predictions with the HI-STAR 190 XL Cask

Table 24. Curving with Single Bump B-end Lead Simulation Predictions for the Car Loaded with the HI-STAR 190 XL Cask

Criterion	Limiting Value	1-inch	2-inch	3-inch
Maximum carbody roll angle (degree)	4.0	0.6	3.0	**5.0**
Maximum wheel L/V	0.80	0.53	0.54	0.57
Maximum truck side L/V	0.50	0.29	0.30	0.31
Minimum vertical wheel load (%)	25	58	51	45
Peak-to-peak carbody lateral acceleration (g)	1.30	0.06	0.14	0.21
Maximum carbody lateral acceleration (g)	0.75	0.05	0.07	0.11
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.05	0.07	0.07
Maximum vertical suspension deflection (%)	95	77	88	**95**

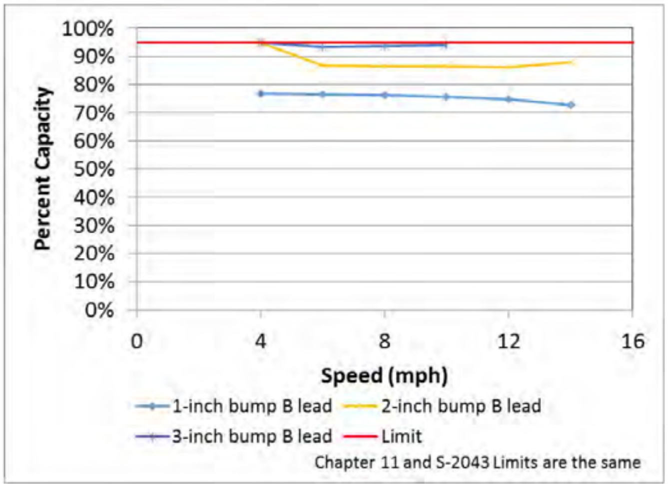

Figure 34. Curving with Single Bump B-end Lead Simulation Predictions with the HI-STAR 190 XL Cask

Table 25. Curving with Single Dip B-end Lead Simulation Predictions for the Car Loaded with the HI-STAR 190 XL Cask

Criterion	Limiting Value	1-inch	2-inch	3-inch
Maximum carbody roll angle (degree)	4.0	0.4	2.5	**4.2**
Maximum wheel L/V	0.80	0.57	0.63	0.73
Maximum truck side L/V	0.50	0.32	0.34	0.36
Minimum vertical wheel load (%)	25	64	56	48
Peak-to-peak carbody lateral acceleration (g)	1.30	0.07	0.11	0.19
Maximum carbody lateral acceleration (g)	0.75	0.05	0.06	0.10
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.05	0.10	0.07
Maximum vertical suspension deflection (%)	95	71	84	91

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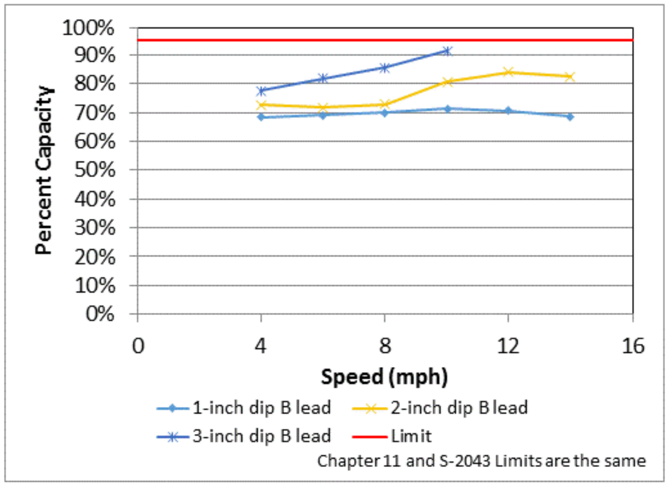

Figure 35. Curving with Single Dip B-end Lead Simulation Predictions with the HI-STAR 190 XL Cask

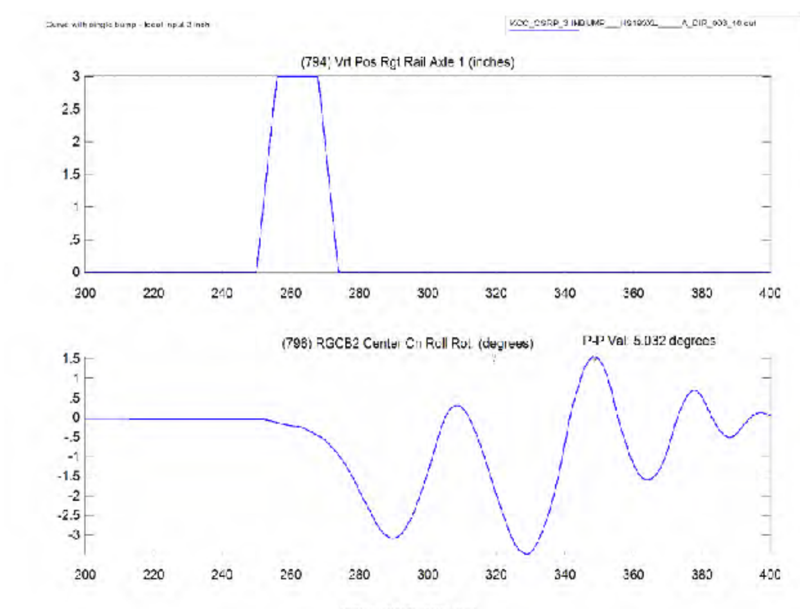

Figure 36. Right Rail Position and Carbody Roll Angle Plotted Against Distance over the 3-Inch Dip at 10 mph for the Car Loaded with HI-STAR 190 XL Cask

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5.7 Hunting (S-2043 Paragraph 4.3.11.3)

Simulations of the hunting regime were conducted according to Paragraph 4.3.11.3 of S-2043. The hunting regime was modeled using a 7,900-foot section of measured track geometry from the Railroad Test Track (RTT) at TTC. The inputs include 5,500 feet of tangent track followed by a 2,400-foot section with a spiral, and a portion of a 50-minute curve with 6 inches of superelevation. These simulations were performed with KR wheel profiles as specified by AAR Chapter 11, Paragraph 11.7.2.

5.7.1 Empty Car with Ballast Load - Hunting

Table 26 shows the worst-case simulation predictions of the empty car with ballast load for the hunting regime. Figure 37 shows the maximum lateral carbody acceleration standard deviation over 1,000 feet plotted against speed to show the trend in performance. Simulation predictions meet S-2043 criteria for the hunting regime.

Table 26. Hunting Simulation Predictions for the Empty Car with Ballast Load

Criterion	Limiting Value	Simulation Predictions
Maximum carbody roll angle (degree)	4.0	0.3
Maximum wheel L/V	0.80	0.22
Maximum truck side L/V	0.50	0.19
Minimum vertical wheel load (%)	25	60
Peak-to-peak carbody lateral acceleration (g)	1.30	0.21
Maximum carbody lateral acceleration (g)	0.75	0.18
Lateral carbody acceleration standard deviation (g)	0.13	0.05
Maximum carbody vertical acceleration (g)	0.90	0.09
Maximum vertical suspension deflection (%)	95	44

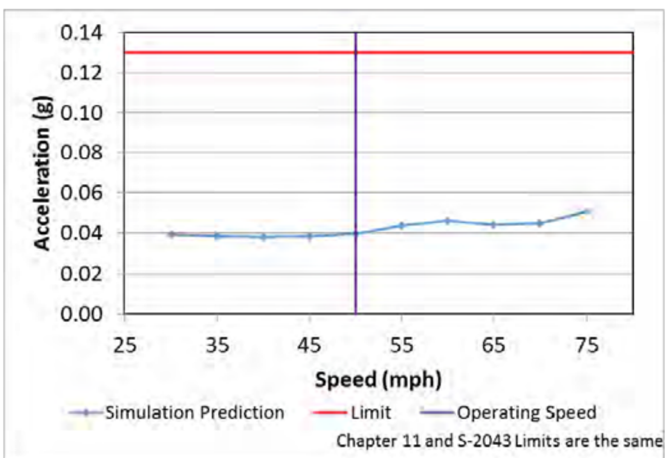

Figure 37. Predicted Maximum Lateral Acceleration Standard Deviation for the Empty Car with Ballast Load in the Hunting Regime

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5.7.2 HI-STAR 190 XL Cask - Hunting

Table 27 shows the worst-case simulation predictions of the car loaded with the HI-STAR 190 XL cask for the hunting regime.

Figure 38 shows the maximum lateral carbody acceleration standard deviation over 1,000 feet plotted against speed to show the trend in performance. The minimum vertical wheel load was just at the S-2043 limit of 25 percent of the static wheel load. Simulation predictions meet S-2043 criteria for the hunting regime.

Figure 39 shows the minimum vertical wheel load plotted against speed for the car loaded with the HI-STAR 190 XL cask in the hunting regime. The trend shows that the vertical wheel loads are lower at the lower speeds. The hunting simulation inputs are measured track geometry from the RTT at TTC. This track is designed for test speeds up to 165 mph and has shallow, 50-minute curves with 6-inches superelevation. The curves at each end of the 5000-foot tangent test zone are included in the simulation input. The minimum vertical wheel loads reported are from the curve at the end of the zone. The low vertical wheel load is due to the extreme underbalance conditions at low speed rather than a hunting behavior. Figure 40 shows the curvature, superelevation, cross level, carbody roll angle, and the worst-case vertical wheel load for the car loaded with the HI-STAR 190 XL cask for the 35 mph hunting regime simulation. There is very little cross level variation at the location where the low vertical wheel load occurs, but the carbody rolls toward the low rail as it enters the curve, tipping on the centerplate and causing the side bearings to go solid. This results in a short carbody roll response that exacerbates the low vertical wheel load.

Table 27. Hunting Simulation Predictions for the Car Loaded with the HI-STAR 190 XL Cask

Criterion	Limiting Value	A-end Lead	B-end Lead
Maximum carbody roll angle (degree)	4.0	3.7	3.6
Maximum wheel L/V	0.80	0.19	0.20
Maximum truck side L/V	0.50	0.17	0.17
Minimum vertical wheel load (%)	25	**25**	29
Peak-to-peak carbody lateral acceleration (g)	1.30	0.35	0.37
Maximum carbody lateral acceleration (g)	0.75	0.23	0.25
Lateral carbody acceleration standard deviation (g)	0.13	0.09	0.09
Maximum carbody vertical acceleration (g)	0.90	0.12	0.13
Maximum vertical suspension deflection (%)	95	86	86

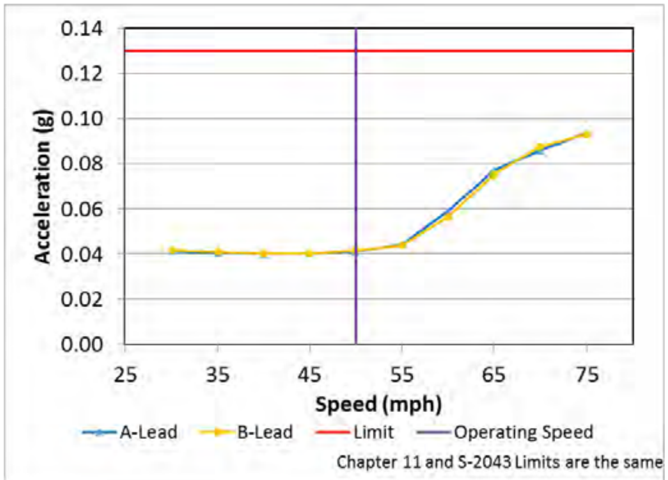

Figure 38. Standard Deviation of Lateral Acceleration for the Car Loaded with HI-STAR 190 XL in the Hunting Regime

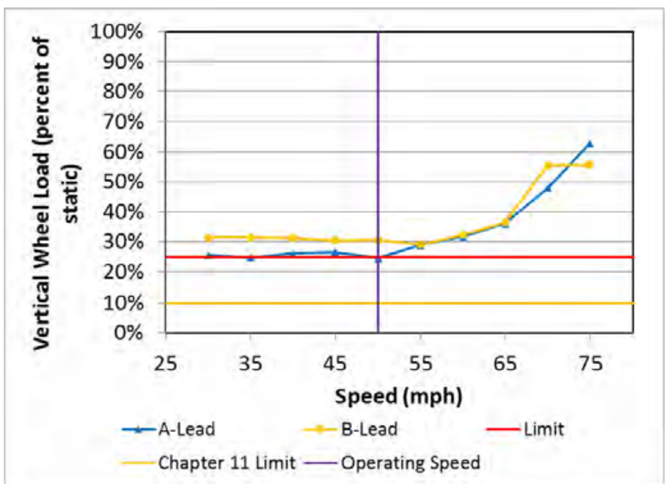

Figure 39. Minimum Vertical Wheel Load for the Car Loaded with HI-STAR 190 XL in the Hunting Regime

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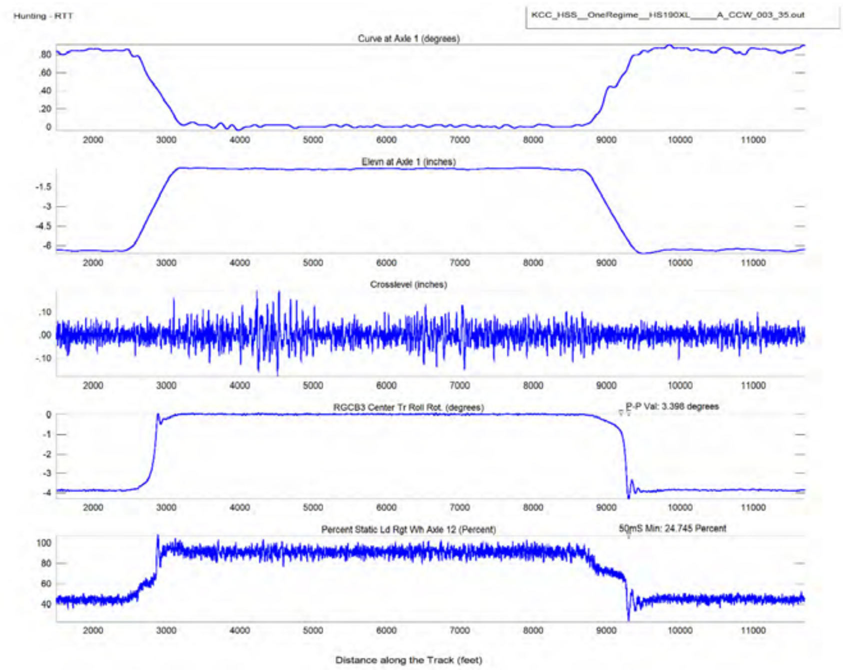

Figure 40. Curvature, Superelevation, Cross level, Roll Angle, and the Worst-case Vertical Wheel Load for the Hunting Regime Simulations with the Car Loaded with the HI-STAR 190 XL Cask at 35 mph

5.8 Constant Curving (S-2043 Paragraph 4.3.11.4)

Simulations of the constant curving regime were conducted according to Paragraph 4.3.11.4 of S-2043. The constant curving test regime was modeled using measured track geometry from the 7.5-, 10-, and 12-degree curves of the Wheel-Rail Mechanisms (WRM) loop at TTC.

Simulation predictions presented for constant curving include the 95th percentile wheel L/V ratio for the steady curve portion of the inputs. This criterion is not listed in Table 4.1 of the S-2043 design paragraph, but is listed in Table 5.1 of the S-2043 single car test paragraph. The 95th percentile wheel L/V ratio is relevant to these simulations, because the simulations are performed with measured track geometry inputs rather than ideal track geometry.

5.8.1 Empty Car with Ballast Load – Constant Curving

Table 28 shows the worst-case simulation predictions for the constant curving regime. Figure 41 shows the 95th percentile wheel L/V ratio plotted against speed to show the trend in performance. The simulation predictions meet S-2043 criteria.

Table 28. Constant Curving Simulation Predictions for Empty Car with Ballast Load

Criterion	Limiting Value	CW	CCW
Maximum carbody roll angle (degree)	4.0	0.5	0.6
Maximum wheel L/V	0.80	0.64	0.68
Maximum truck side L/V	0.50	0.38	0.38
Minimum vertical wheel load (%)	25	58	57
Peak-to-peak carbody lateral acceleration (g)	1.30	0.13	0.10
Maximum carbody lateral acceleration (g)	0.75	0.13	0.12
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.06	0.07
Maximum vertical suspension deflection (%)	95	47	47
95% Wheel L/V Ratio	0.60	0.57	0.58

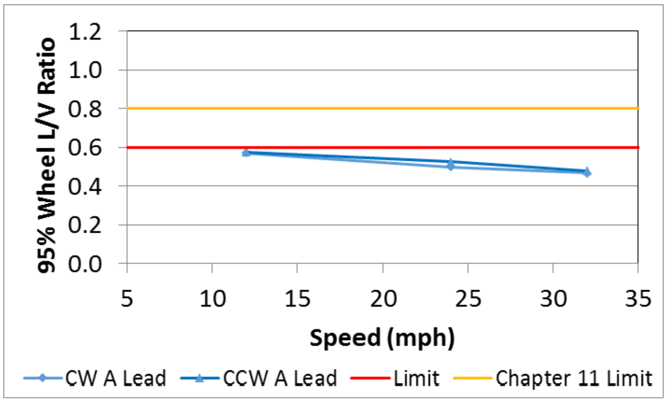

Figure 41. 95th Percentile Wheel L/V Ratio for the Empty Car with Ballast Load in the 12-Degree Curve

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5.8.2 HI-STAR 190 XL Cask – Constant Curving

Table 29 shows the worst-case simulation predictions for the constant curving regime with the HI-STAR 190 XL cask car. Figure 42 shows the 95th percentile wheel L/V ratio plotted against speed to show the trend in performance. The simulation predictions meet S-2043 criteria.

Table 29. Simulation Predictions for Constant Curving for the HI-STAR 190 XL Cask

Criterion	Limiting Value	A-end Lead CW	A-end Lead CCW	B-end Lead CW	B-end Lead CCW
Maximum carbody roll angle (degree)	4.0	1.4	1.7	1.0	1.0
Maximum wheel L/V	0.80	0.63	0.64	0.62	0.63
Maximum truck side L/V	0.50	0.36	0.34	0.34	0.34
Minimum vertical wheel load (%)	25	53	52	56	54
Peak-to-peak carbody lateral acceleration (g)	1.30	0.18	0.16	0.19	0.15
Maximum carbody lateral acceleration (g)	0.75	0.16	0.14	0.16	0.15
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.09	0.10	0.10	0.12
Maximum vertical suspension deflection (%)	95	76	75	74	75
95% Wheel L/V Ratio	0.60	0.54	0.54	0.47	0.52

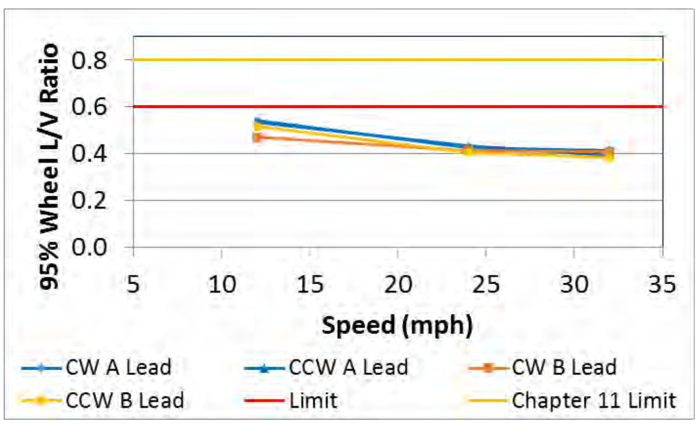

Figure 42. 95th Percentile Wheel L/V Ratio for the HI-STAR 190 XL in the 12-Degree Curve

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5.9 Curving with Various Lubrication Conditions (S-2043 Paragraph 4.3.11.5)

Simulation of curving with various lubrication conditions were performed according to S-2043 paragraph 4.3.11.5. Constant curving simulations were repeated in a 10-degree curve with coefficient of friction conditions shown in Table 30. Simulations were performed using a new wheel profile on a new rail profile and with a hollow wheel profile on a ground rail profile. Figure 43 shows the worn wheel and rail profiles used for the simulations. The right side is the high rail in this plot. The gap between the rail profile in red and the wheel profile in blue on the gage corner of the rail represents a distinctive two point contact condition. The lubrication and profile conditions are designed to show performance when the wheelset cannot provide normal steering forces. The metrics presented in this section were computed over the entire curve including the entry and exit spiral, except for the 95 percentile L/V ratio, which was computed in the steady curve section.

Table 30. Wheel/rail Coefficients of Friction for the Curving with Various Lubrication Conditions Regime

Friction Coefficient	High Rail Crown	High Rail Gage Face	Low Rail Crown
Case 1	0.5	0.5	0.5
Case 2	0.5	0.2	0.5
Case 3	0.5	0.2	0.2
Case 4	0.2	0.2	0.5

Figure 43. Worn Wheel Profiles on the Ground Rail Profiles (The Wheelset is Shifted to the High Rail in the Position it would be in a Left Hand Curve)

5.9.1 Empty Car with Ballast Load - Curving with Various Lubrication Conditions

Table 31 shows empty car with ballast load simulation predictions for the four friction cases with new wheel profiles. Simulations of Cases 1 and 3 meet S-2043 criteria. The Case 2 and 4 simulations do not meet the S-2043 Paragraph 5 criterion for 95th percentile wheel L/V ratios, although they do meet the corresponding AAR Chapter 11 criterion. The AAR Chapter 11 criterion is 0.8 for 95th percentile single wheel L/V ratio.

Table 31. Simulation Predictions for Curving with Rail Lubrication Cases 1-4 and New Wheels and Rails, Empty Car with Ballast Load

Criterion	Limiting Value	Case 1 New	Case 2 New	Case 3 New	Case 4 New
Maximum carbody roll angle (degree)	4.0	0.5	0.5	0.5	0.5
Maximum wheel L/V	0.80	0.69	0.73	0.43	0.75
Maximum truck side L/V	0.50	0.36	0.37	0.27	0.47
Minimum vertical wheel load (%)	25	56	56	56	57
Peak-to-peak carbody lateral acceleration (g)	1.30	0.10	0.11	0.12	0.12
Maximum carbody lateral acceleration (g)	0.75	0.12	0.12	0.12	0.13
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.06	0.06	0.06	0.06
Maximum vertical suspension deflection (%)	95	44	44	44	44
95% Wheel L/V Ratio	0.60	0.57	**0.62**	0.37	**0.66**

Table 32 shows simulation predictions for the four friction cases with hollow worn wheel profiles and ground rail profiles. Simulations of Case 3 meet S-2043 criteria. Simulations of Cases 1, 2, and 4 do not meet S-2043 criteria for truck side L/V ratios. Simulations of Cases 2 and 4 do not meet S-2043 criteria for 95th percentile wheel L/V ratios. The Case 1 simulations do meet the corresponding AAR Chapter 11 criterion for truck side L/V ratio. The AAR Chapter 11 criterion for truck side L/V ratio is 0.6. The Case 2 and 4 simulations meet the AAR Chapter 11 criterion for the 95th percentile wheel L/V ratio, which is 0.8.

Table 32. Simulation Predictions for Curving with Rail Lubrication Cases 1-4 and Hollow Worn Wheels and Ground Rails, Empty Car with Ballast Load

Criterion	Limiting Value	Case 1 Worn	Case 2 Worn	Case 3 Worn	Case 4 Worn
Maximum carbody roll angle (degree)	4.0	0.5	0.5	0.5	0.5
Maximum wheel L/V	0.80	0.70	0.78	0.47	0.71
Maximum truck side L/V	0.50	**0.56**	**0.61**	0.30	**0.61**
Minimum vertical wheel load (%)	25	54	52	53	54
Peak-to-peak carbody lateral acceleration (g)	1.30	0.16	0.16	0.15	0.16
Maximum carbody lateral acceleration (g)	0.75	0.14	0.14	0.13	0.14
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.06	0.06	0.06	0.06
Maximum vertical suspension deflection (%)	95	44	44	44	44
95% Wheel L/V Ratio	0.60	0.59	**0.68**	0.40	**0.61**

Figure 44 shows a plot of 95th percentile wheel L/V ratio versus speed for the Case 2 lubrication condition with the worn wheel profile. Figure 45 shows a plot of truck side L/V ratio versus speed for the Case 2 lubrication condition with the worn wheel profile. Figure 46 shows a plot of wheel L/V ratio versus distance for the worst worn case simulation, the underbalance speed for the Case 2 lubrication condition with worn wheel profiles. Figure 47 shows a plot of truck side L/V ratio versus distance for the worst-case simulation, the underbalance speed for Case 4 lubrication with worn wheel profiles.

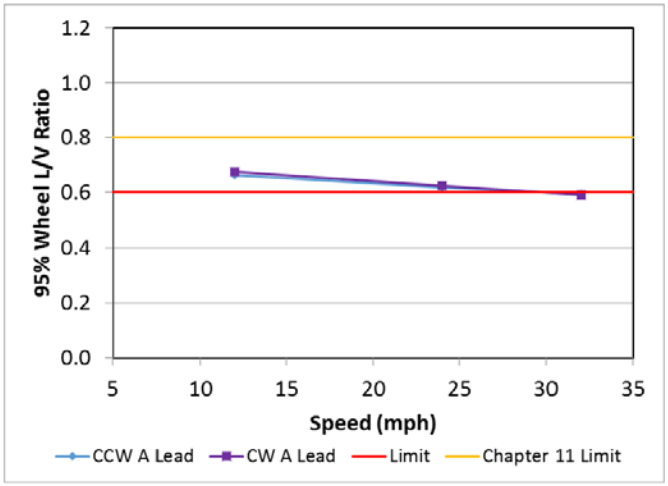

Figure 44. Empty Car with Ballast Load 95-Percent Wheel L/V Ratio for Curving with Case 2 Lubrication and Worn Wheel Profile

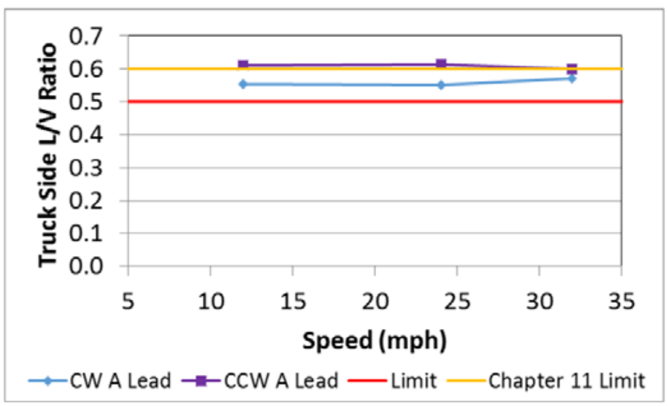

Figure 45. Empty Car with Ballast Load Truck side L/V Ratio for Curving with Case 2 Lubrication and Worn Wheel Profile

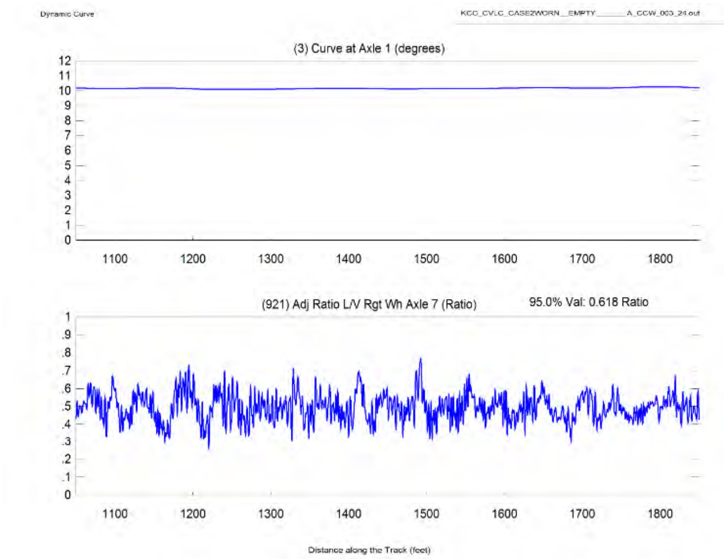

Figure 46. Plot of Wheel L/V Ratio versus Distance for Case 2 Friction with Worn Profiles - Plot Shows Data for the Lead Axle of the Trailing Span Bolster

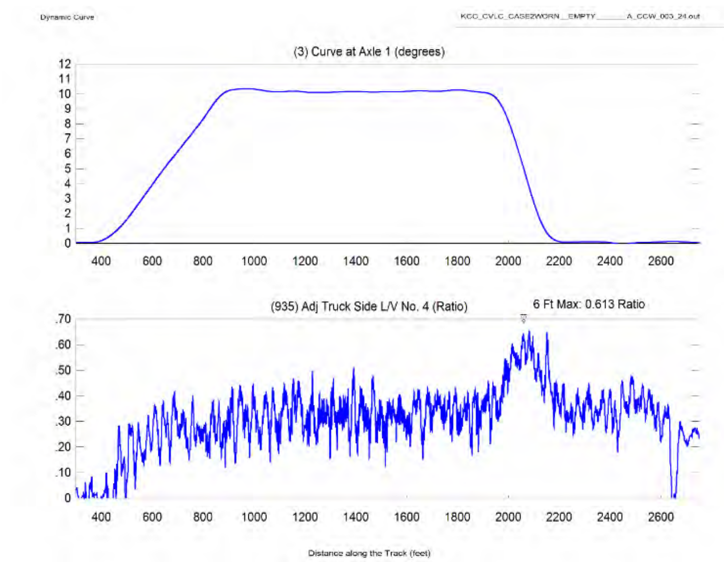

Figure 47. Plot of Truck Side L/V Ratio versus Distance for Case 4 Friction with Worn Profiles- Plot Shows Data for the High Rail of the Middle Truck on the Lead Span Bolster

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5.9.2 HI-STAR 190 XL Cask - Curving with Various Lubrication Conditions

Table 33 shows simulation predictions for the four friction cases with new wheel and rail profiles. The table shows the worst-case results for runs in CW and CCW directions with A-end and B-end leading. Figure 48 shows a plot of maximum wheel L/V ratio against speed for case four lubrication conditions with new wheel profiles to demonstrate the trend in performance. Simulations predictions of the car loaded with the HI-STAR 190 XL cask meet S-2043 criteria for curving with various lubrication conditions using new wheel and rail profiles.

Table 33. Simulation predictions for Curving with Rail Lubrication Cases 1-4 and New Wheels and Rails, Car Loaded with HI-STAR 190 XL Cask

Criterion	Limiting Value	Case 1 New	Case 2 New	Case 3 New	Case 4 New
Maximum carbody roll angle (degree)	4.0	0.7	0.7	0.7	0.7
Maximum wheel L/V	0.80	0.68	0.70	0.39	0.76
Maximum truck side L/V	0.50	0.33	0.39	0.22	0.45
Minimum vertical wheel load (%)	25	55	55	56	55
Peak-to-peak carbody lateral acceleration (g)	1.30	0.19	0.19	0.19	0.19
Maximum carbody lateral acceleration (g)	0.75	0.16	0.16	0.15	0.16
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.09	0.09	0.09	0.09
Maximum vertical suspension deflection (%)	95	73	73	73	73
95% Wheel L/V Ratio	0.60	0.47	0.48	0.44	0.46

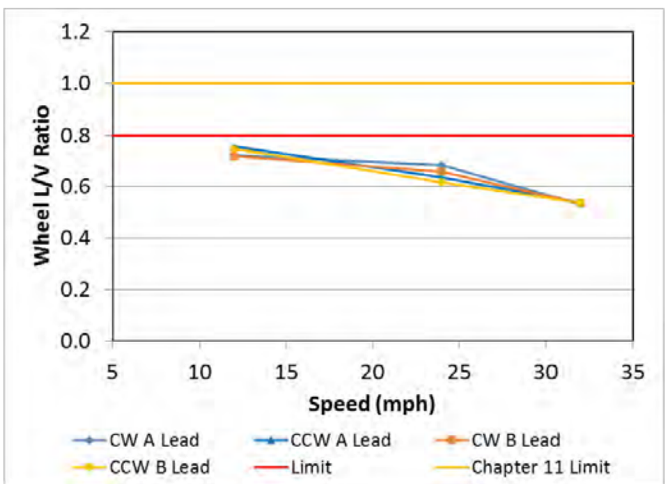

Figure 48. Predictions of Wheel L/V Ratio for Case 4 Lubrication with New Wheel and Rail Profiles - the Plot Shows Simulations of Both Directions of Travel and Both Car Orientations

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Table 34 shows simulation predictions of the car loaded with the HI-STAR 190 XL cask for the four friction cases with hollow worn wheel profiles and ground rail profiles. The table shows the worst-case results for runs in CW and CCW directions with A-end and B-end leading. Simulations of Case 3 meet S-2043 criteria. Simulations of Cases 1, 2, and 4 do not meet S-2043 criteria for truck side L/V ratios, although Case 1 predictions do meet the corresponding AAR Chapter 11 criteria. The AAR Chapter 11 criterion for truck side L/V ratio is 0.6. Case 2 and Case 4 simulations predictions are equal to the S-2043 limit for 95 percent wheel L/V ratio.

Table 34. Simulation predictions for Curving with Rail Lubrication Cases 1-4 and Hollow Worn Wheels and Ground Rails, Car Loaded with HI-STAR 190 XL Cask

Criterion	Limiting Value	Case 1 Worn	Case 2 Worn	Case 3 Worn	Case 4 Worn
Maximum carbody roll angle (degree)	4.0	0.8	0.8	0.8	0.8
Maximum wheel L/V	0.80	0.69	0.76	0.43	0.70
Maximum truck side L/V	0.50	**0.55**	**0.62**	0.25	**0.61**
Minimum vertical wheel load (%)	25	51	50	52	52
Peak-to-peak carbody lateral acceleration (g)	1.30	0.25	0.26	0.25	0.25
Maximum carbody lateral acceleration (g)	0.75	0.19	0.19	0.18	0.19
Lateral carbody acceleration standard deviation (g)	0.13	0.04	0.04	0.04	0.04
Maximum carbody vertical acceleration (g)	0.90	0.09	0.09	0.09	0.09
Maximum vertical suspension deflection (%)	95	74	74	74	74
95% Wheel L/V Ratio	0.60	0.58	**0.60**	0.59	**0.60**

Figure 49 shows a plot of maximum truck side L/V versus speed for CW and CCW with A and B-end leading. Figure 50 shows a plot of truck side L/V versus distance for the 12 mph CCW run with the B-end leading. The plot shows data for the middle truck of the lead span bolster. The peak value occurs in the exit spiral of the curve.

Predicted truck side L/V ratios for the Atlas cask car were higher than those for the CA S-2043 12-Axle Car in the loaded cask condition. A maximum 6-foot truck side L/V ratio of 0.54 was predicted for lubrication Case 4 with worn wheels for the CA S-2043 12-Axle Car compared to 0.61 for the Atlas car.

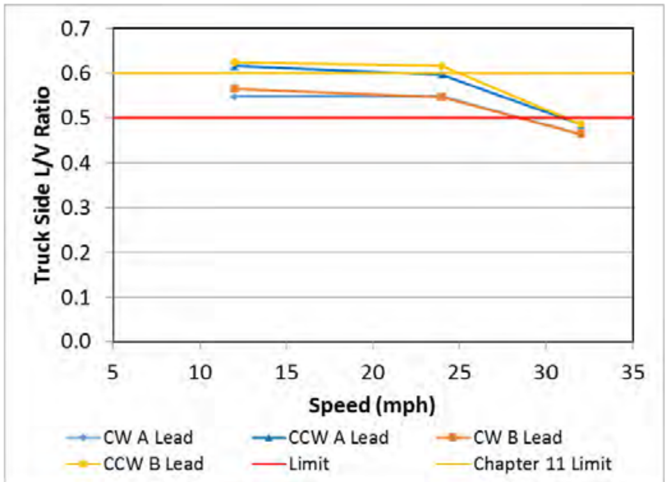

Figure 49. Predictions of Truck Side L/V Ratio for Case 2 Lubrication with Worn Wheel and Rail Profiles - the Plot Shows Simulations of Both Directions of Travel and Both Car Orientations, Car Loaded with HI-STAR 190 XL Cask

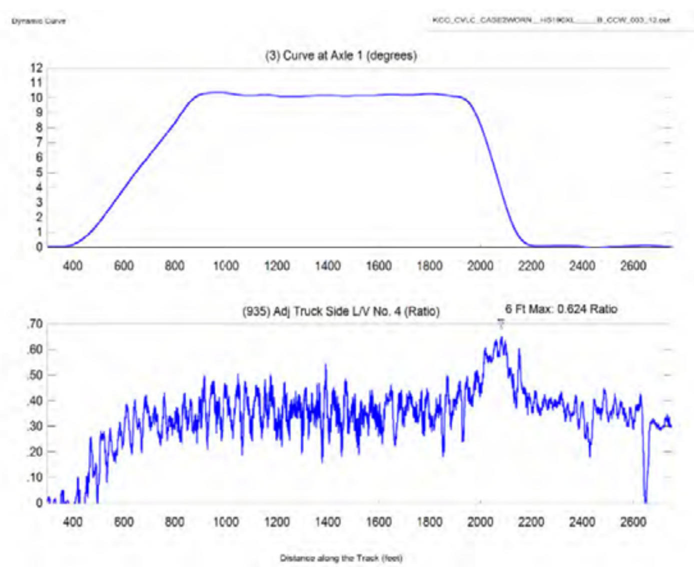

Figure 50. Plot of Truck Side L/V Ratio versus Distance for Case 2 Friction with Worn Wheel and Rail Profiles - the Plot Shows Data for the High Rail of the Middle Truck on the Lead Span Bolster

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5.10 Limiting Spiral Negotiation (S-2043 Paragraph 4.3.11.6)

Simulations of the limiting spiral regime were conducted according to Paragraph 4.3.11.6 of S-2043. The limiting spiral has a steady curvature change from 0 to 10 degrees and a steady superelevation change from 0 inch to 4 3/8 inches in 89 feet.

5.10.1 Empty Car with Ballast Load - Limiting Spiral Negotiation

Table 35 shows the worst-case simulation predictions for the car with ballast load in the limiting spiral regime. Figure 51 shows the maximum wheel L/V plotted against speed to show the trend in performance. Simulation predictions meet S-2043 criteria for the limiting spiral regime.

Table 35. Empty Car with Ballast Load Limiting Spiral Simulation Predictions

Criterion	Limiting Value	Spiral Entry	Spiral Exit
Maximum carbody roll angle (degree)	4.0	0.6	0.6
Maximum wheel L/V	0.80	0.59	0.66
Maximum truck side L/V	0.50	0.30	0.39
Minimum vertical wheel load (%)	25	60	59
Peak-to-peak carbody lateral acceleration (g)	1.30	0.11	0.12
Maximum carbody lateral acceleration (g)	0.75	0.09	0.12
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.05	0.07
Maximum vertical suspension deflection (%)	95	44	44

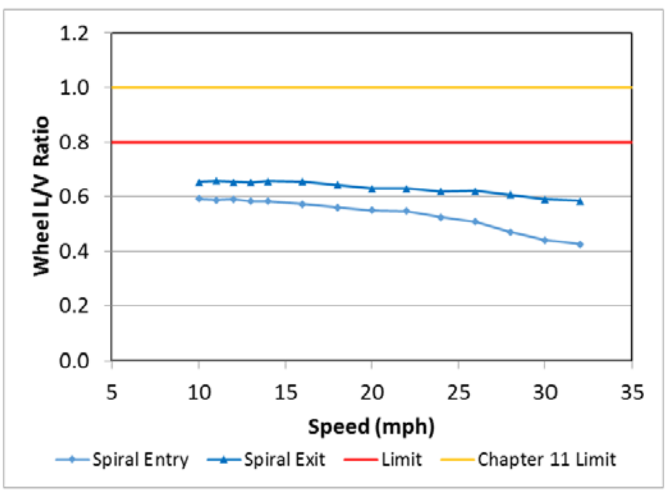

Figure 51. Predicted Maximum Wheel L/V for the Limiting Spiral Regime, Empty Car with Ballast Load

5.10.2 HI-STAR 190 XL Cask - Limiting Spiral Negotiation

Table 36 shows the worst-case simulation predictions for the car with the HI-STAR 190 XL cask in the limiting spiral regime. Figure 52 shows the maximum wheel L/V plotted against speed to show the trend in performance. Simulation predictions meet S-2043 criteria for the limiting spiral regime.

Table 36. Simulation Predictions for Car Loaded with HI-STAR 190 XL Cask in Limiting Spiral Regime

Criterion	Limiting Value	Spiral Entry A-Lead	Spiral Entry B-Lead	Spiral Exit A-Lead	Spiral Exit B-Lead
Maximum carbody roll angle (degree)	4.0	0.9	0.9	2.3	2.3
Maximum wheel L/V	0.80	0.49	0.49	0.48	0.48
Maximum truck side L/V	0.50	0.24	0.24	0.43	0.31
Minimum vertical wheel load (%)	25	60	60	45	54
Peak-to-peak carbody lateral acceleration (g)	1.30	0.13	0.13	0.18	0.09
Maximum carbody lateral acceleration (g)	0.75	0.11	0.11	0.15	0.09
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.07	0.07	0.08	0.06
Maximum vertical suspension deflection (%)	95	73	73	78	78

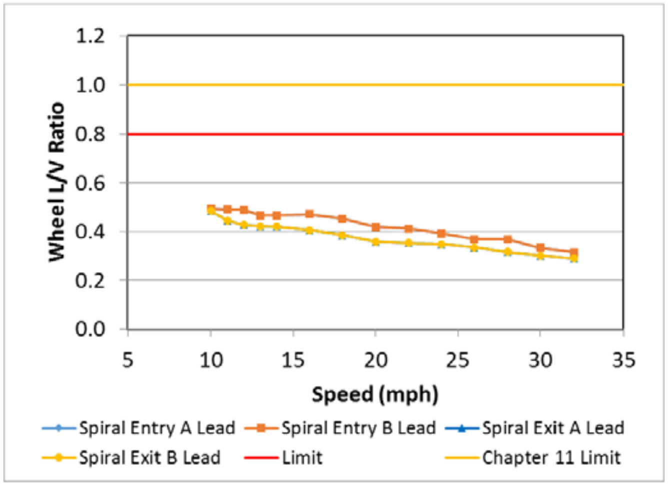

Figure 52. Single Wheel L/V Ratio for Car Loaded with HI-STAR 190 XL Cask in Limiting Spiral Regime

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5.11 Turnouts and Crossovers (S-2043 Paragraph 4.3.11.7)

Simulations of the turnout and crossover regime were conducted according to Paragraph 4.3.11.7 of S-2043. Simulations were performed through a No. 7 AREMA straight point turnout and a No. 7 crossover on 13-foot track centers at speeds up to 15 mph. The inputs for this simulation regime were mathematically generated because no actual test zone exists.

5.11.1 Empty Car with Ballast Load – Turnouts and Crossovers

Table 37 shows the worst-case simulation predictions for the turnout regime. Figure 53 shows a plot of wheel L/V ratio in a No. 7 turnout. Simulation predictions meet S-2043 criteria for the turnout regime.

Table 37. Turnout Simulation Predictions for Empty Car with Ballast Load

Criterion	Limiting Value	No. 7 Turnout Left Hand	No. 7 Turnout Right Hand
Maximum carbody roll angle (degree)	4.0	0.1	0.1
Maximum wheel L/V	0.80	0.66	0.66
Maximum truck side L/V	0.50	0.47	0.47
Minimum vertical wheel load (%)	25	60	60
Peak-to-peak carbody lateral acceleration (g)	1.30	0.13	0.13
Maximum carbody lateral acceleration (g)	0.75	0.07	0.07
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.05	0.05
Maximum vertical suspension deflection (%)	95	44	44

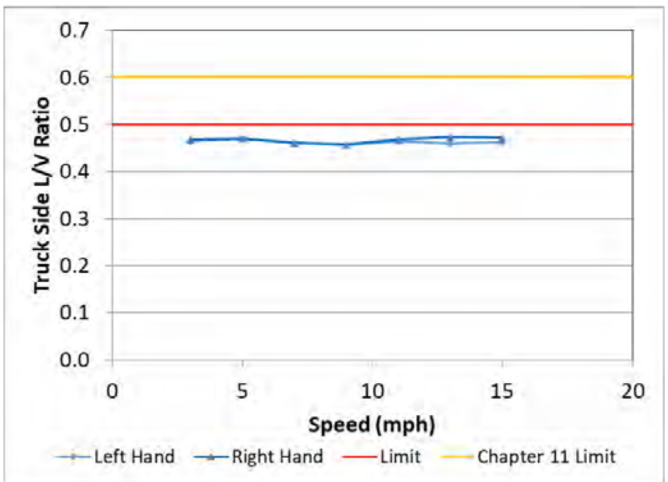

Figure 53. Simulation Predictions Truck Side L/V Ratio for Empty Car with Ballast Load in No. 7 Turnout

Table 38 shows the worst-case simulation predictions for the crossover regime. Figure 54 shows a plot of truck side L/V ratio in the crossover. Simulation predictions of truck side L/V ratio are equal to the S-2043 criterion for that metric, all other metrics meet S-2043 criteria for the No. 7 crossover.

Table 38. Crossover Simulation Predictions for Empty Car with Ballast Load

Criterion	Limiting Value	No. 7 Crossover
Maximum carbody roll angle (degree)	4.0	0.1
Maximum wheel L/V	0.80	0.74
Maximum truck side L/V	0.50	**0.50**
Minimum vertical wheel load (%)	25	61
Peak-to-peak carbody lateral acceleration (g)	1.30	0.14
Maximum carbody lateral acceleration (g)	0.75	0.12
Lateral carbody acceleration standard deviation (g)	0.13	NA
Maximum carbody vertical acceleration (g)	0.90	0.07
Maximum vertical suspension deflection (%)	95	46

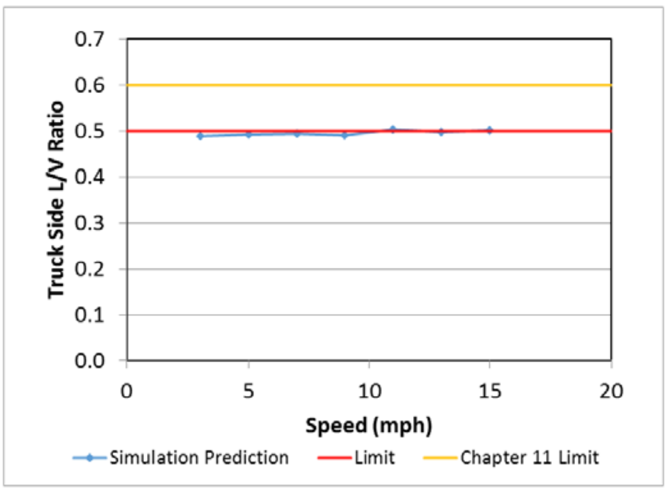

Figure 54. Simulation Predictions of Truck side L/V Ratio on Crossovers for Empty Car with Ballast Load

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5.11.2 HI-STAR 190 XL Cask – Turnouts and Crossovers

Table 39 shows the worst-case simulation predictions for the turnout regime. Figure 55 shows a plot of wheel L/V ratio in a No. 7 turnout. Simulation predictions meet S-2043 criteria for the turnout portion of the turnouts and crossovers regime.

Table 39. Turnout Simulation Predictions, Car Loaded with HI-STAR 190 XL Cask

Criterion	Limiting Value	Left Hand A-Lead	Right Hand A-Lead	Left Hand B-Lead	Right Hand B-Lead
Maximum carbody roll angle (degree)	4.0	0.2	0.2	0.2	0.2
Maximum wheel L/V	0.80	0.60	0.60	0.60	0.62
Maximum truck side L/V	0.50	0.45	0.46	0.46	0.46
Minimum vertical wheel load (%)	25	64	64	67	67
Peak-to-peak carbody lateral acceleration (g)	1.30	0.21	0.23	0.23	0.22
Maximum carbody lateral acceleration (g)	0.75	0.11	0.13	0.12	0.12
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.18	0.14	0.09	0.09
Maximum vertical suspension deflection (%)	95	68	68	70	70

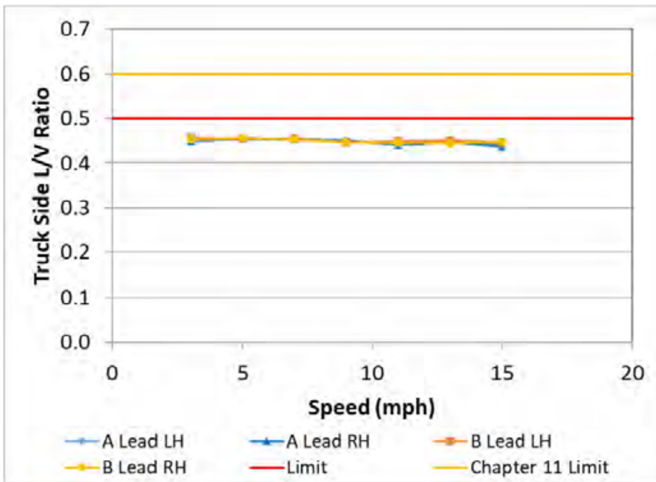

Figure 55. Simulation Predictions of Truck Side L/V Ratio for No. 7 Turnout, Car Loaded with HI-STAR 190 XL Cask

Table 40 shows the worst-case simulation predictions for the crossover regime. Figure 56 shows a plot of the maximum truck side L/V versus speed to show the trend in performance. Figure 57 shows a plot of the worst-case truck side L/V ratio versus distance in the crossovers. Simulation predictions do not meet S-2043 criteria for truck side L/V ratio in the No. 7 crossover. Other performance metrics meet S-2043 criteria.

Predicted truck side L/V ratios for the Atlas cask car were higher than those for the CA S-2043 12-Axle Car in the loaded cask condition. A maximum 6-foot truck side L/V ratio of 0.51 was predicted on the crossover for the CA S-2043 12-Axle Car compared to 0.52 for the Atlas car.

Table 40. Crossover Simulation Predictions, Car Loaded with HI-STAR 190 XL Cask

Criterion	Limiting Value	No. 7 Crossover A-Lead	No. 7 Crossover B-Lead
Maximum carbody roll angle (degree)	4.0	0.3	0.3
Maximum wheel L/V	0.80	0.65	0.67
Maximum truck side L/V	0.50	**0.51**	**0.52**
Minimum vertical wheel load (%)	25	64	65
Peak-to-peak carbody lateral acceleration (g)	1.30	0.22	0.24
Maximum carbody lateral acceleration (g)	0.75	0.13	0.13
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.10	0.09
Maximum vertical suspension deflection (%)	95	73	75

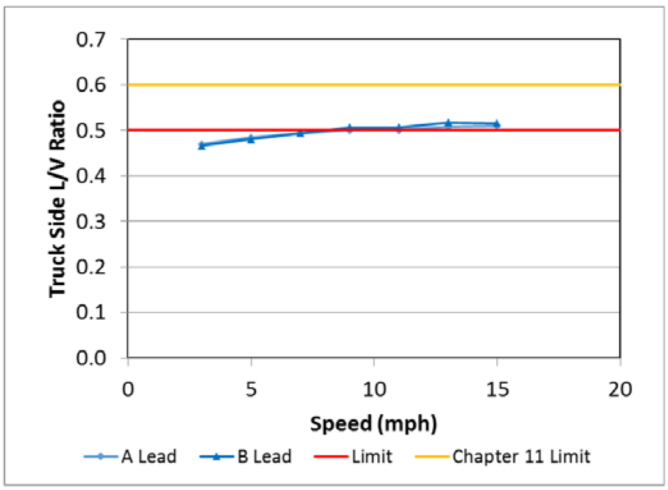

Figure 56. Simulation Predictions of Truck Side L/V Ratio on Crossovers, Car Loaded with HI-STAR 190 XL Cask

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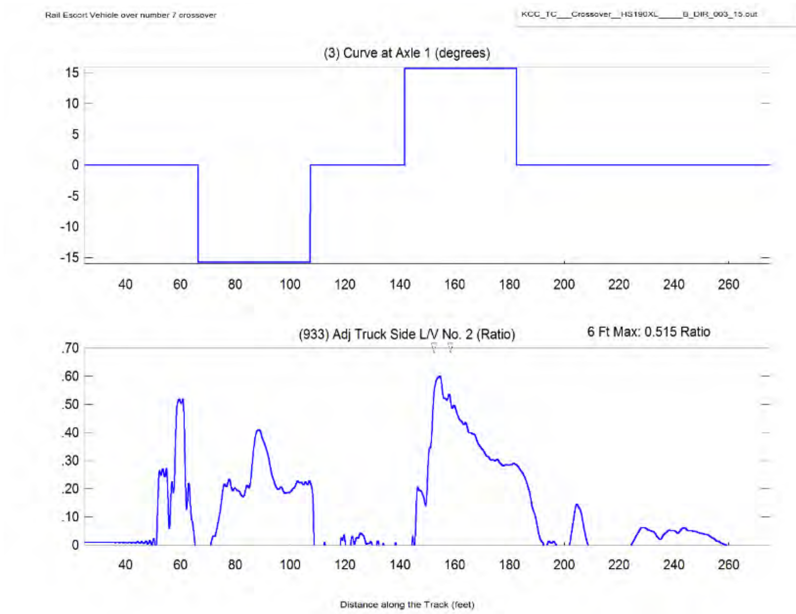

Figure 57. Truck side L/V Ratio on the Leading Truck in the No. 7 Crossover, B-end Leading, 15 mph, Car Loaded with HI-STAR 190 XL Cask

5.12 Ride Quality (S-2043 Paragraph 4.3.12)

Simulations of the ride quality regime were conducted according to Paragraph 4.3.12 of S-2043. Simulations were performed over standardized track geometry files representing track allowed under FRA designations of Class 2 through Class 6. These track geometry files are provided by the AAR. Simulation speeds were from 10 mph to the FRA freight speed limit for each track class. The track geometry files are described briefly below:

- Class 2 Inputs. 74,000 feet of track including curves up to 10 degrees
- Class 3 Inputs. 28,000 feet of track including curves up to 3 degrees
- Class 4 Inputs. 22,000 feet of tangent track
- Class 5 Inputs. 6,700 feet of tangent track
- Class 6 Inputs. 16,000 feet of tangent track

S-2043 Paragraph 4.3.12.4 requires simulation of non-passenger carrying railcars on these track classes. The predictions are compared to the performance criteria in Table 4.1 of S-2043.

5.12.1 Empty Car with Ballast Load – Ride Quality

Table 41 shows the worst-case simulation predictions for the ride quality simulations with the empty car with ballast load. Figure 58 shows a plot of the predicted maximum wheel L/V ratio in the ride quality regime. Simulation predictions meet S-2043 criteria for the ride quality simulations.

Table 41. Ride Quality Simulation Predictions, Empty Car with Ballast Load

Criterion	Limiting Value	Class 2	Class 3	Class 4	Class 5	Class 6
Maximum carbody roll angle (degree)	4.0	1.1	0.7	0.5	0.8	1.0
Maximum wheel L/V	0.80	0.73	0.62	0.70	0.54	0.31
Maximum truck side L/V	0.50	0.36	0.18	0.20	0.16	0.17
Minimum vertical wheel load (%)	25	57	55	59	55	51
Peak-to-peak carbody lateral acceleration (g)	1.30	0.15	0.24	0.27	0.40	0.32
Maximum carbody lateral acceleration (g)	0.75	0.09	0.12	0.15	0.20	0.21
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03	0.05	0.07	0.07
Maximum carbody vertical acceleration (g)	0.90	0.09	0.31	0.27	0.27	0.28
Maximum vertical suspension deflection (%)	95	55	60	51	51	51

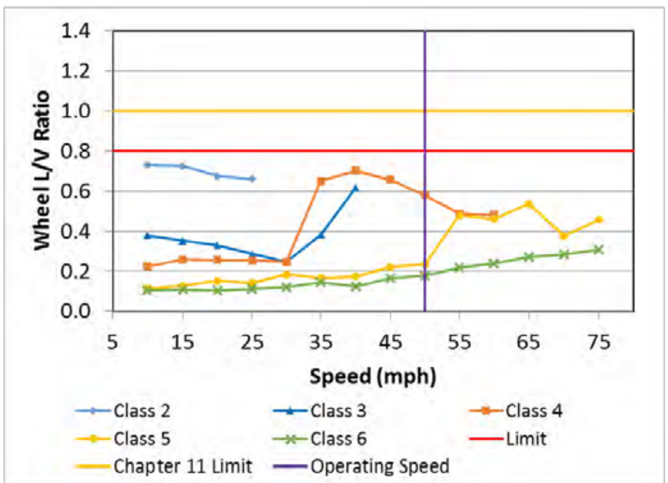

Figure 58. Predicted Maximum Wheel L/V Ratio for the Empty Car with Ballast Load in the Ride Quality Regime

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5.12.2 HI-STAR 190 XL Cask – Ride Quality

Table 42 shows the worst-case simulation predictions for the ride quality simulations with the car loaded with a HI-STAR 190 XL cask. Figure 59 shows a plot of the predicted maximum wheel L/V ratio in the ride quality regime. Simulation predictions meet S-2043 criteria for the ride quality simulations.

Table 42. Ride Quality Simulation Predictions, Car Loaded with HI-STAR 190 XL Cask

Criterion	Limiting Value	Class 2	Class 3	Class 4	Class 5	Class 6
Maximum carbody roll angle (degree)	4.0	1.4	0.9	2.0	3.1	3.5
Maximum wheel L/V	0.80	0.63	0.29	0.38	0.18	0.17
Maximum truck side L/V	0.50	0.33	0.11	0.11	0.13	0.12
Minimum vertical wheel load (%)	25	60	56	58	58	60
Peak-to-peak carbody lateral acceleration (g)	1.30	0.17	0.23	0.34	0.45	0.45
Maximum carbody lateral acceleration (g)	0.75	0.14	0.13	0.17	0.24	0.28
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.02	0.05	0.07	0.08
Maximum carbody vertical acceleration (g)	0.90	0.12	0.32	0.33	0.23	0.23
Maximum vertical suspension deflection (%)	95	80	84	77	79	79

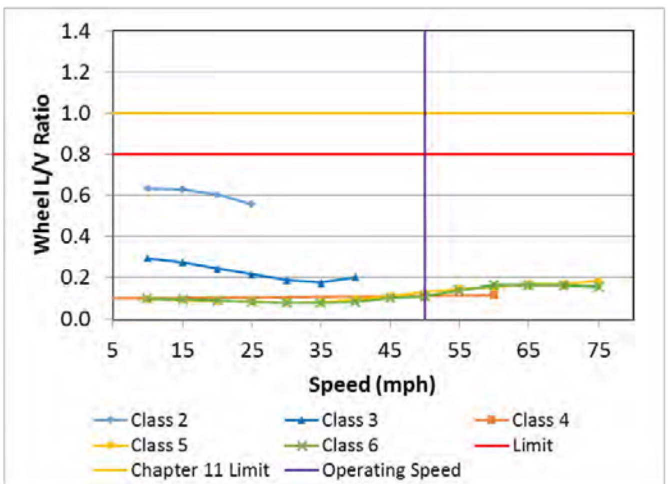

Figure 59. Predicted Maximum Wheel L/V Ratio for the Loaded Car with HI-STAR 190 XL cask in the Ride Quality Regime

5.13 Buff and Draft Curving (S-2043 Paragraph 4.3.13)

Simulations of the buff and draft curving regime were conducted according to Paragraph 4.3.13 of S-2043. Simulations were performed using measured track geometry of the 12-degree curve of the WRM loop at TTC. Simulations were designed to simulate the cask car coupled to:

- A base car as described in the AAR MSRP Section C-II, Standard M-1001 Chapter 2, Paragraph 2.1.4.2.3.[4]
- A long car with 90-foot over strikers, 66-foot truck centers, 60-inch couplers, and conventional draft gear.
- Like Car.
- Buffer Car - the car the cask car will be coupled to in HLRM service.

The longitudinal forces of 250,000-pounds buff and 250,000-pounds draft were applied to the car in the simulation. The lateral component of the force was calculated using the method presented in AAR MSRP Section C-II, Standard M-1001 Chapter 2, Paragraph 2.1.6.4 and 2.1.6.5. The longitudinal and lateral forces were applied in the model using external force connection elements.

5.13.1 Empty Car with Ballast Load – Buff and Draft Curving

Table 43 shows the worst-case simulation predictions for draft force cases and Table 44 shows the worst-case simulation predictions for the buff force cases. The column headings in the tables show the car that the Atlas cask car was coupled to at each end. Figure 60 shows a plot of the maximum truck side L/V ratio for the four draft force cases modeled. Figure 61 shows a plot of the maximum truck side L/V ratio for the four buff force cases modeled. Simulation predictions do not meet S-2043 criteria for truck side L/V under buff force when coupled to another cask car. The truckside L/V of 0.51 occurred on the high rail on the leading truck in the body of the curve at 32 mph. Figure 62 shows a plot of truck side L/V for this case. Simulation predictions meet S-2043 criteria for the other buff and draft curving cases.

[4] Association of American Railroads. 2011. *Manual of Standards of Recommended Practices*. Section C-II Design, Fabrication, and Construction of Freight Cars, Standard M-1001, Chapter 2. General Data, Paragraph 2.1.4.2.3 "Base Car." Washington, DC.

Table 43. Simulation Predictions for 250,000 Draft Force, Empty Car with Ballast Load

Criterion	Limiting Value	Base	Long	Like	Buffer Car
Maximum carbody roll angle (degree)	4.0	0.6	0.6	0.6	0.6
Maximum wheel L/V	0.80	0.65	0.63	0.64	0.64
Maximum truck side L/V	0.50	0.45	0.42	0.45	0.39
Minimum vertical wheel load (%)	25	48	48	49	57
Peak-to-peak carbody lateral acceleration (g)	1.30	0.09	0.10	0.09	0.09
Maximum carbody lateral acceleration (g)	0.75	0.11	0.11	0.11	0.11
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.06	0.06	0.06	0.06
Maximum vertical suspension deflection (%)	95	47	46	47	47

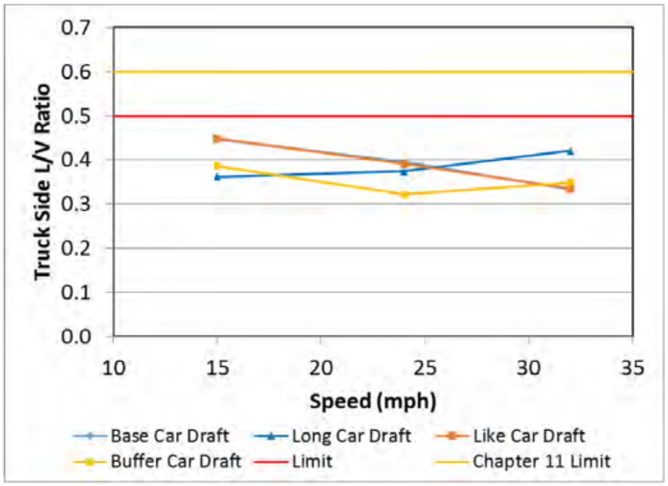

Figure 60. Truck Side L/V Ratio for the Empty Car with Ballast Load for Curving Simulations under 250,000 Pounds Draft Force

Table 44. Simulation Predictions for 250,000 Buff Force, Empty Car with Ballast Load

Criterion	Limiting Value	Base	Long	Like	Buffer Car
Maximum carbody roll angle (degree)	4.0	0.6	0.7	0.6	0.6
Maximum wheel L/V	0.80	0.63	0.65	0.65	0.58
Maximum truck side L/V	0.50	0.48	0.44	**0.51**	0.43
Minimum vertical wheel load (%)	25	48	53	46	51
Peak-to-peak carbody lateral acceleration (g)	1.30	0.09	0.09	0.09	0.09
Maximum carbody lateral acceleration (g)	0.75	0.11	0.11	0.11	0.12
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.05	0.05	0.05	0.05
Maximum vertical suspension deflection (%)	95	48	47	48	46

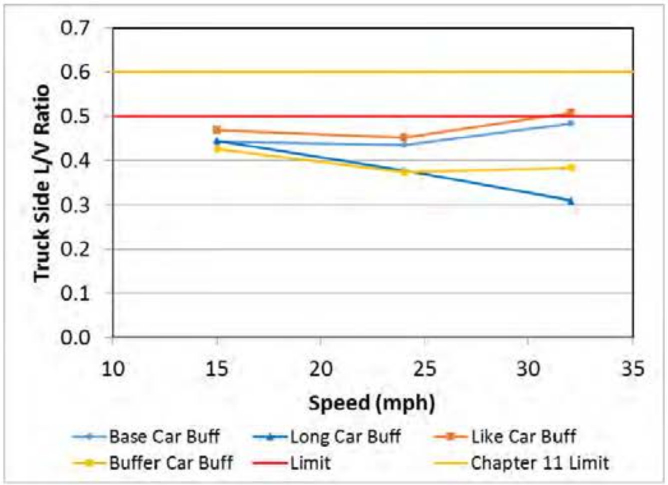

Figure 61. Truck Side L/V Ratio for the Empty Car with Ballast Load for Curving Simulations under 250,000 Pounds Buff Force

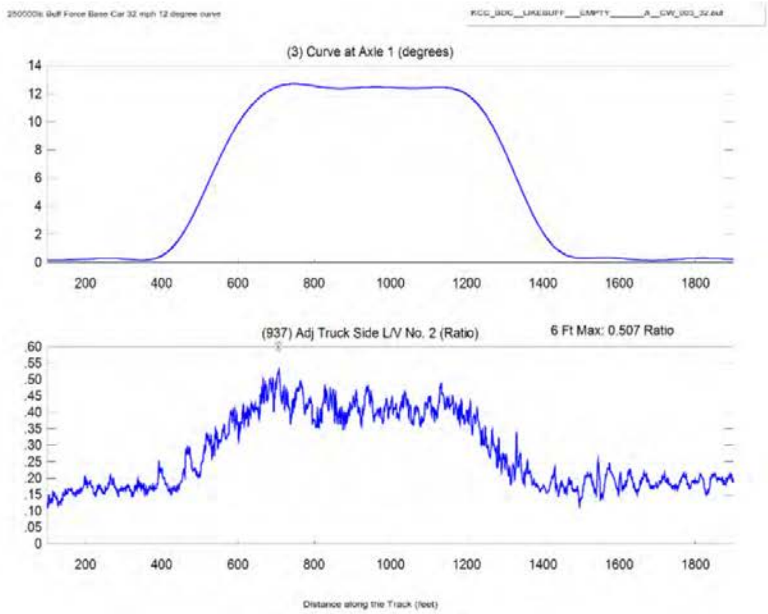

Figure 62. Truck side L/V Ratio for the Empty Car with Ballast Load Coupled to a Like Car under 250,000 Pounds Buff Load at 32 mph

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5.13.2 HI-STAR 190 XL Cask – Buff and Draft Curving

Table 45 shows the worst-case simulation predictions for draft force cases and Table 46 shows the worst-case simulation predictions for the buff force cases. Simulation predictions meet S-2043 criteria. Figure 63 shows a plot of the minimum vertical wheel load versus speed for the four cases modeled in draft and Figure 64shows the same data for buff cases.

Table 45. Simulation Predictions for 250,000 Draft Force, Loaded Car with the HI-STAR 190 XL

Criterion	Limiting Value	Base	Long	Like	Buffer Car
Maximum carbody roll angle (degree)	4.0	1.2	3.6	1.2	2.7
Maximum wheel L/V	0.80	0.60	0.56	0.60	0.59
Maximum truck side L/V	0.50	0.39	0.32	0.39	0.34
Minimum vertical wheel load (%)	25	52	33	52	47
Peak-to-peak carbody lateral acceleration (g)	1.30	0.12	0.14	0.12	0.12
Maximum carbody lateral acceleration (g)	0.75	0.12	0.13	0.12	0.12
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.08	0.09	0.08	0.07
Maximum vertical suspension deflection (%)	95	75	79	75	76

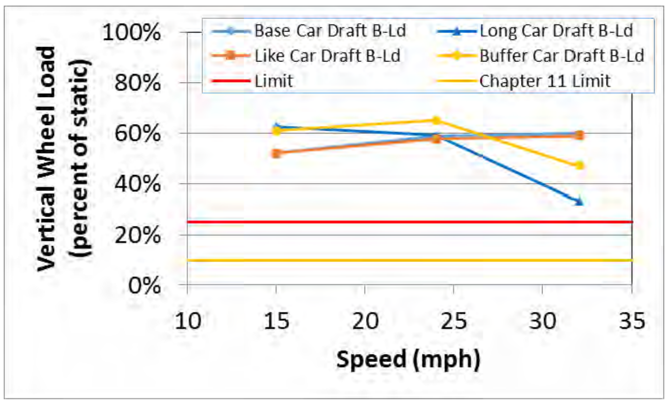

Figure 63. Minimum Vertical Wheel Loads for the Car Loaded with the HI-STAR 190 XL Cask with B-end Leading for Curving Simulations under 250,000 Pounds Draft Force

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Table 46. Simulation Predictions for 250,000 Buff Force, Loaded Car with the HI-STAR 190 XL

Criterion	Limiting Value	Base	Long	Like	Buffer Car
Maximum carbody roll angle (degree)	4.0	3.5	3.6	1.2	2.7
Maximum wheel L/V	0.80	0.54	0.56	0.60	0.59
Maximum truck side L/V	0.50	0.35	0.32	0.39	0.34
Minimum vertical wheel load (%)	25	31	33	52	47
Peak-to-peak carbody lateral acceleration (g)	1.30	0.13	0.14	0.12	0.12
Maximum carbody lateral acceleration (g)	0.75	0.12	0.13	0.12	0.12
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.07	0.09	0.08	0.07
Maximum vertical suspension deflection (%)	95	86	78	87	83

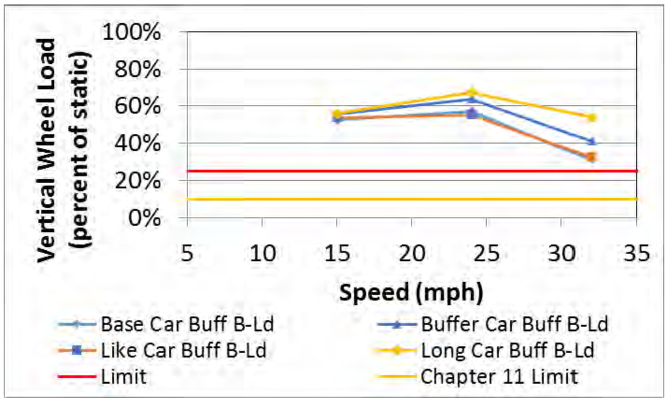

Figure 64. Minimum Vertical Wheel Loads for the Car Loaded with the HI-STAR 190 XL Cask with B-end Leading for Curving Simulations under 250,000 Pounds Buff Force

5.14 Braking Effects on Steering (S-2043 Paragraph 4.3.14)

Simulations of the braking effects on steering regime were conducted according to Paragraph 4.3.14 of S-2043. Simulations were performed using measured track geometry of the 12-degree curve of the WRM loop at TTC.

The brake shoe could apply a 5,342-pound force to the wheel based on the gross rail load of 789,000 pounds and the maximum brake ratio of 16.25 percent as specified in S-2043 Paragraph 4.4.2.3 “Loaded Brake Ratio.” The brake beam guide is inclined 14 degrees from horizontal on the Swing Motion® truck used on the cask car. The longitudinal and vertical forces applied to the wheels were resolved from this data and applied to the axles using external force inputs in the NUCARS® model. The braking torque was calculated assuming a coefficient of friction of 0.33 between the brake shoe and wheel. This torque was applied to the axles for these simulations.

5.14.1 Empty Car with Ballast Load – Braking Effects on Steering

Table 47 shows the worst-case results from the braking in curves simulation. Simulation predictions meet S-2043 criteria for the braking in curves regime. Braking appears to have only a small effect on steering, with the largest detrimental change being a drop of the minimum vertical wheel load from 41percent to 29 percent of static wheel load for simulations when braking forces are simulated.

Table 47. Simulation Predictions for the Braking in Curves Simulation, Empty Car with Ballast Load

Criterion	Limiting Value	No Braking	With Braking
Maximum carbody roll angle (degree)	4.0	0.5	0.5
Maximum wheel L/V	0.80	0.58	0.55
Maximum truck side L/V	0.50	0.34	0.36
Minimum vertical wheel load (%)	25	41	29
Peak-to-peak carbody lateral acceleration (g)	1.30	0.08	0.06
Maximum carbody lateral acceleration (g)	0.75	0.06	0.05
Lateral carbody acceleration standard deviation (g)	0.13	0.02	0.01
Maximum carbody vertical acceleration (g)	0.90	0.05	0.05
Maximum vertical suspension deflection (%)	95	46	46

5.14.2 HI-STAR 190 XL Cask – Braking Effects on Steering

Table 48 shows the worst-case results from the braking in curves simulation. Simulation predictions meet S-2043 criteria for the braking in curves regime. Braking appears to have only a small effect on steering, with the largest detrimental change being a drop of the minimum vertical wheel load from 70 percent to 58 percent of static wheel load for A-end leading simulations when braking forces are simulated. A similar, but slightly smaller drop in minimum vertical wheel load occurs for B-end leading simulations.

Table 48. Simulation Predictions for the Braking in Curves Simulation, Loaded Car with the HI-STAR 190 XL

Criterion	Limiting Value	A-Lead No Braking	A-Lead Braking	B-Lead No Braking	B-Lead Braking
Maximum carbody roll angle (degree)	4.0	0.6	0.6	0.7	0.7
Maximum wheel L/V	0.80	0.51	0.50	0.51	0.50
Maximum truck side L/V	0.50	0.31	0.32	0.31	0.32
Minimum vertical wheel load (%)	25	70	58	66	57
Peak-to-peak carbody lateral acceleration (g)	1.30	0.08	0.07	0.08	0.07
Maximum carbody lateral acceleration (g)	0.75	0.06	0.05	0.06	0.06
Lateral carbody acceleration standard deviation (g)	0.13	0.02	0.02	0.02	0.02
Maximum carbody vertical acceleration (g)	0.90	0.06	0.06	0.06	0.07
Maximum vertical suspension deflection (%)	95	74	74	70	70

6.0 WORN COMPONENT SIMULATIONS (S-2043 PARAGRAPH 4.3.15)

Worn component simulations were conducted according to Paragraph 4.3.15 of S-2043. Wear of the following components was simulated:

- Constant Contact Side Bearings (CCSB).
- Center plates.
- Primary pad.
- Friction wedges.
- Broken springs.

Most worn component simulations were performed with the HI-STAR 190 XL cask because this configuration generally produced the worst performance. Hunting simulations were performed with the empty car with ballast load for low preload CCSB conditions and soft primary pad conditions. All simulations were performed with the A-end leading.

In this section, worst-case simulation predictions for the worn components are summarized in tables together with the criteria and base line predictions for the new condition car. In cases where the component wear causes the performance to degrade such that the car does not meet criteria, plots are shown to demonstrate the trend in performance and show the worst-case condition.

The regimes chosen for each worn component case are not expected to identify every regime where the worn component may affect results, but rather, represent a set of cases that check the modes of performance that might be affected. The regimes used in worn component simulations were selected from those required by Chapter 11. For example, simulations of the effects of truck component wear in turnouts, crossovers, spiral entry/exit and curves with bumps/dips were not performed because these effects would also be evident in the regimes of curving and dynamic curving.

6.1 Constant Contact Side Bearing (CCSB)

Wear in a CCSB may result in a loss of side bearing preload. Wear of the carbody centerplate or the truck center bowl may result in a reduction of the CCSB setup height. To examine the effect of these types of CCSB wear, simulations were performed with:

- The CCSB having half the stiffness and half the preload of new CCSB (3,000-pound nominal preload). This condition will reduce the turning moment between the truck bolster and the span bolster. It will also reduce the roll stiffness between the truck bolster and span bolster.
- The setup height of the new CCSB reduced to 4 7/8 inch. This condition will increase the turning moment between the truck bolster and span bolster. It will also increase the roll stiffness and reduce the roll clearance between the truck bolster and span bolster.

The performance of the car with worn CCSB was checked in constant curving, dynamic curving, hunting, and twist and roll with the HI-STAR 190 XL cask. The performance of the car with low preload CCSB was checked with the empty car with ballast load in hunting.

Constant curving simulations were performed in both directions using track geometry measurements for a section of track that includes a 7.5-, 12-, and 10-degree curve and their entry and exit spirals. The spiral on the north end of the 12-degree curve is an old test zone known as the bunched spiral. The curvature changes linearly from 0 to 12 degrees over the 200-foot length of the bunched spiral and the superelevation changes from 0 to 5 inches in the center 100 feet. The bunched spiral is no longer a required AAR test regime, but serves in this case to check car performance under severe track twist conditions.

Table 49 shows a comparison of constant curving simulation predictions for baseline and worn CCSB simulations. Simulation predictions for worn CCSB meet S-2043 criteria for constant curving.

Table 49. Simulation Predictions of the Atlas Cask Car with Worn CCSB in Constant Curving

Criterion	Limiting Value	Baseline	Low Preload CCSB	Low Setup Height CCSB
Maximum carbody roll angle (degree)	4.0	1.7	0.9	1.9
Maximum wheel L/V	0.80	0.64	0.65	0.63
Maximum truck side L/V	0.50	0.36	0.36	0.37
Minimum vertical wheel load (%)	25	52	53	51
Peak-to-peak carbody lateral acceleration (g)	1.30	0.18	0.19	0.18
Maximum carbody lateral acceleration (g)	0.75	0.16	0.18	0.16
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.10	0.10	0.10
Maximum vertical suspension deflection (%)	95	76	76	76

Table 50 shows a comparison of dynamic curving simulation predictions for baseline and worn CCSB simulations. Simulation predictions for worn CCSB do not meet the S-2043 single wheel L/V ratio criteria for dynamic curving in the low preload, reduced stiffness case. The L/V ratios increased from 0.88 for the baseline case to 1.16 for the low preload, reduced stiffness case. In contrast, the L/V ratios reduced to 0.71 with the reduced setup height case. All other criteria were met for dynamic curving with worn CCSB.

Figure 65 shows a plot of maximum wheel L/V ratio versus speed for the baseline case and the two worn CCSB cases to show the trend in performance. The performance is identical at higher speeds, but diverges at low speed where the side bearing condition affects how the span bolster centerplate tips on the truck bolster in the underbalance curving condition. Figure 66 shows a plot of the worst-case single wheel L/V ratio versus distance for the low preload CCSB case.

Table 50. Simulation Predictions of the Atlas Cask Car with Worn CCSB in Dynamic Curving

Criterion	Limiting Value	Baseline	Low Preload CCSB	Low Setup Height CCSB
Maximum carbody roll angle (degree)	4.0	1.2	1.6	1.2
Maximum wheel L/V	0.80	**0.88**	**1.16**	0.71
Maximum truck side L/V	0.50	0.37	0.45	0.34
Minimum vertical wheel load (%)	25	49	41	54
Peak-to-peak carbody lateral acceleration (g)	1.30	0.16	0.16	0.17
Maximum carbody lateral acceleration (g)	0.75	0.13	0.13	0.14
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.06	0.06	0.06
Maximum vertical suspension deflection (%)	95	78	79	75

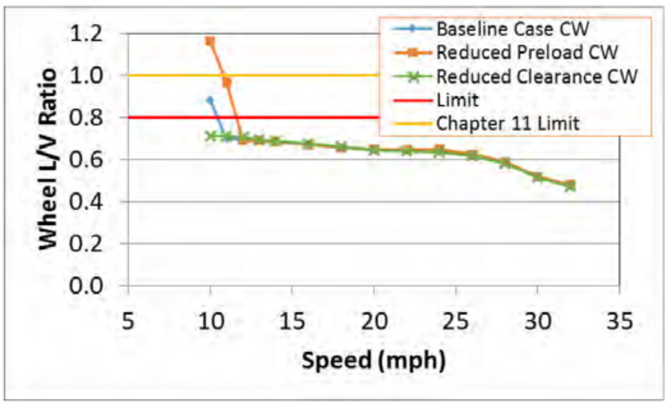

Figure 65. Single Wheel L/V Ratio for Worn CCSB Cases, A-end Leading CW Runs

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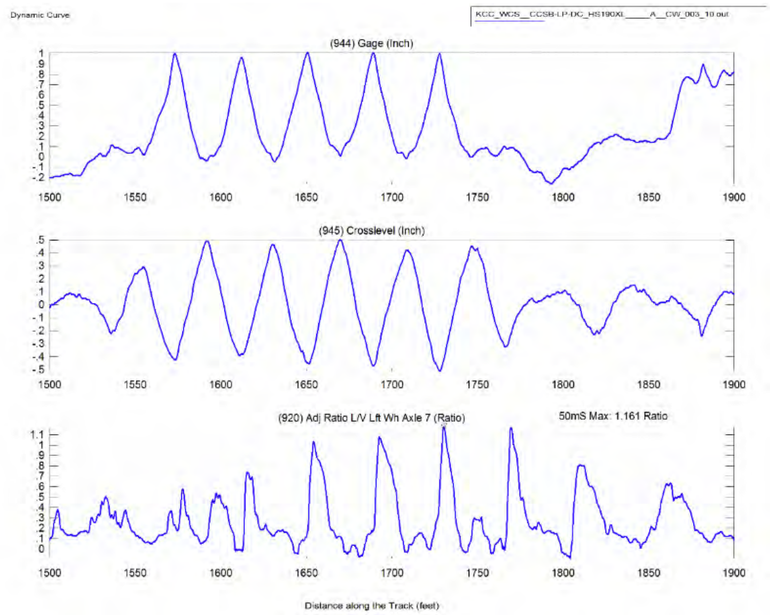

Figure 66. Distance Plot of Single Wheel L/V Ratio for the Leading Axle of the Trailing Span Bolster with Low Preload CCSB at 10 mph for CW Dynamic Curving with A-end Leading

Table 51 shows a comparison of hunting simulation predictions for baseline and worn CCSB simulations. Simulation predictions for low preload CCSB do not meet the S-2043 criterion for minimum vertical wheel load in hunting. In contrast, the low setup height case shows improved performance over the baseline case. Simulation predictions meet the S-2043 criteria for the other metrics.

Figure 67 shows the minimum vertical wheel load plotted against speed for the baseline case and two worn side bearing cases in the hunting regime. The trend shows that the vertical wheel loads are lower at the lower speeds. The hunting simulation inputs are measured track geometry from the RTT at TTC. This track has shallow, 50-minute curves with 6-inches superelevation. The curves at each end of the 5,000-foot tangent test zone are included in the simulation input. The minimum vertical wheel loads reported are from the curve at the end of the zone. The extreme underbalance conditions at low speed contribute greatly to the low vertical wheel loads.

Figure 68 shows vertical wheel load as the percent of static wheel load plotted against distance for the low preload CCSB case at 40 mph in the hunting regime. The plot shows that the exception occurs as the car enters the curve at the end of the zone and is likely the result of the extreme underbalance condition rather than a hunting behavior, as previously discussed in Section 5.7.2.

Table 51. Simulation Predictions of the Atlas Cask Car with Worn CCSB in Hunting

Criterion	Limiting Value	Baseline	Low Preload CCSB	Low Setup Height CCSB
Maximum carbody roll angle (degree)	4.0	3.7	3.7	2.7
Maximum wheel L/V	0.80	0.19	0.19	0.19
Maximum truck side L/V	0.50	0.17	0.17	0.17
Minimum vertical wheel load (%)	25	**25**	**22**	33
Peak-to-peak carbody lateral acceleration (g)	1.30	0.35	0.43	0.41
Maximum carbody lateral acceleration (g)	0.75	0.23	0.26	0.27
Lateral carbody acceleration standard deviation (g)	0.13	0.09	0.10	0.09
Maximum carbody vertical acceleration (g)	0.90	0.12	0.12	0.13
Maximum vertical suspension deflection (%)	95	86	86	82

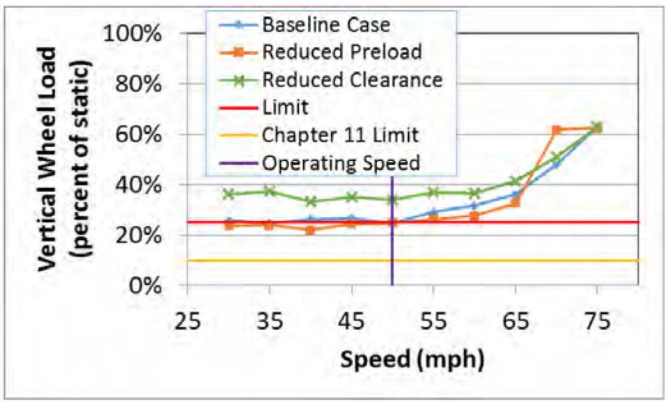

Figure 67. Minimum Vertical Wheel Load for CCSB Wear Cases Plotted Against Speed.

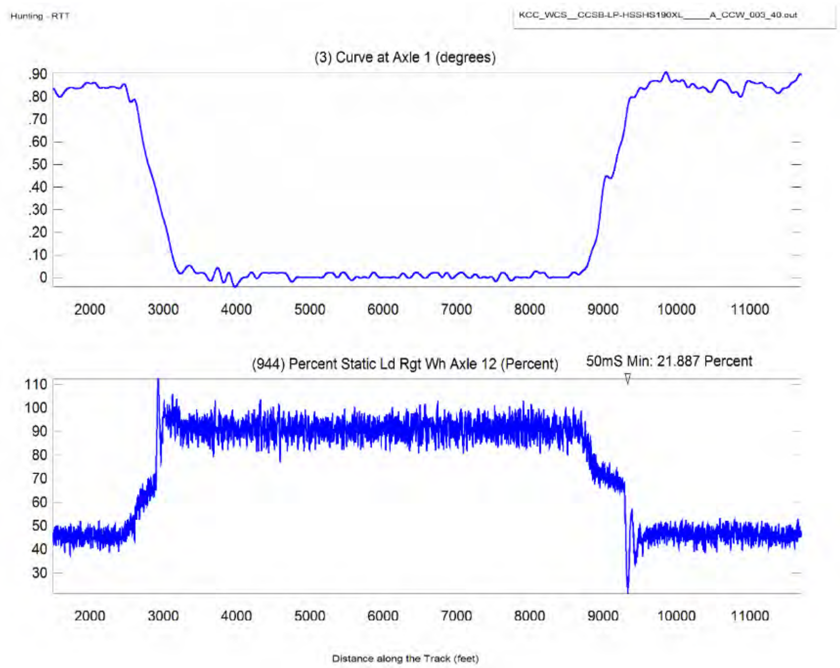

Figure 68. Vertical Wheel Load Plotted Against Distance for the Low Preload CCSB Case at 40 mph in the Hunting Regime - the Plot Shows that the Exception Occurred as the Car Enters the Curve at the End of the Zone and is Likely Due to the Extreme Underbalance Condition Rather than a Hunting Behavior

Table 52 shows a comparison of hunting simulation predictions for baseline and low preload CCSB simulations with the empty car with ballast load. Simulation predictions for low preload CCSB meet the S-2043 criterion for hunting.

Table 52. Hunting Simulation Predictions for the Empty Car with Ballast Load and Worn CCSB

Criterion	Limiting Value	Baseline	Low Preload CCSB
Maximum carbody roll angle (degree)	4.0	0.3	0.3
Maximum wheel L/V	0.80	0.22	0.23
Maximum truck side L/V	0.50	0.19	0.20
Minimum vertical wheel load (%)	25	60	58
Peak-to-peak carbody lateral acceleration (g)	1.30	0.21	0.23
Maximum carbody lateral acceleration (g)	0.75	0.18	0.20
Lateral carbody acceleration standard deviation (g)	0.13	0.05	0.05
Maximum carbody vertical acceleration (g)	0.90	0.09	0.10
Maximum vertical suspension deflection (%)	95	44	66

Table 53 shows a comparison of twist and roll simulation predictions for baseline and worn CCSB simulations. Simulation predictions for worn CCSB meet S-2043 criteria for twist and roll.

Table 53. Simulation Predictions of the Atlas Cask Car with Worn CCSB in Twist and Roll

Criterion	Limiting Value	Baseline	Low Preload CCSB	Low Setup Height CCSB
Maximum carbody roll angle (degree)	4.0	2.0	1.9	2.0
Maximum wheel L/V	0.80	0.14	0.17	0.14
Maximum truck side L/V	0.50	0.11	0.11	0.10
Minimum vertical wheel load (%)	25	68	68	68
Peak-to-peak carbody lateral acceleration (g)	1.30	0.22	0.22	0.21
Maximum carbody lateral acceleration (g)	0.75	0.12	0.11	0.12
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.11	0.11	0.11
Maximum vertical suspension deflection (%)	95	74	74	74

6.2 Centerplate

To examine the effect of centerplate wear, simulations were performed with centerplate friction increased from 0.3 for the baseline case to 0.5 for the worn case. The performance of the car with worn centerplates was checked in constant curving, dynamic curving, and hunting with the HI-STAR 190 XL cask.

Constant curving simulations were performed in both directions using track geometry measurements for a section of track that includes a 7.5-, 12-, and 10-degree curve and their entry and exit spirals. The bunched spiral, as described in a previous section, was used to check a severe track twist condition.

Table 54 shows a comparison of constant curving simulation predictions for baseline and worn centerplate simulations. Simulation predictions for worn centerplate meet S-2043 criteria for constant curving.

Table 54. Simulation Predictions of the Atlas Cask Car with Worn Centerplate in Constant Curving

Criterion	Limiting Value	Baseline	Worn Centerplate
Maximum carbody roll angle (degree)	4.0	1.7	1.6
Maximum wheel L/V	0.80	0.64	0.66
Maximum truck side L/V	0.50	0.36	0.37
Minimum vertical wheel load (%)	25	52	52
Peak-to-peak carbody lateral acceleration (g)	1.30	0.18	0.20
Maximum carbody lateral acceleration (g)	0.75	0.16	0.17
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.10	0.10
Maximum vertical suspension deflection (%)	95	75	75

Table 55 shows a comparison of dynamic curving simulation predictions for baseline and worn centerplate simulations. Simulation predictions for both the baseline and the worn centerplate do not meet S-2043 criteria for wheel L/V ratio for dynamic curving, with the worn condition providing slightly worse performance. Figure 69 shows the maximum single wheel L/V ratio plotted against speed for the worn centerplate and baseline cases. Figure 70 shows a plot of wheel L/V Ratio for the leading Axle of the trailing span bolster at 10 mph for the worn centerplate in CW dynamic curving.

Table 55. Simulation Predictions of the Atlas Cask Car with Worn Centerplate in Dynamic Curving

Criterion	Limiting Value	Baseline	Worn Centerplate
Maximum carbody roll angle (degree)	4.0	1.2	1.2
Maximum wheel L/V	0.80	**0.88**	**0.95**
Maximum truck side L/V	0.50	0.37	0.37
Minimum vertical wheel load (%)	25	49	47
Peak-to-peak carbody lateral acceleration (g)	1.30	0.16	0.16
Maximum carbody lateral acceleration (g)	0.75	0.13	0.12
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.06	0.06
Maximum vertical suspension deflection (%)	95	78	78

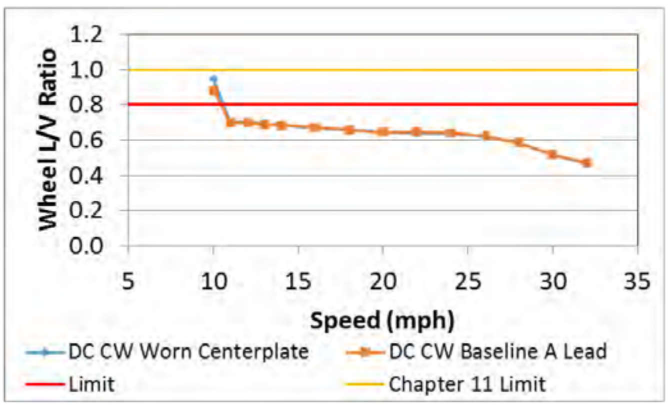

Figure 69. Maximum Single Wheel L/V Ratio for the Worn Centerplate in Clockwise Dynamic Curving Plotted Against Speed

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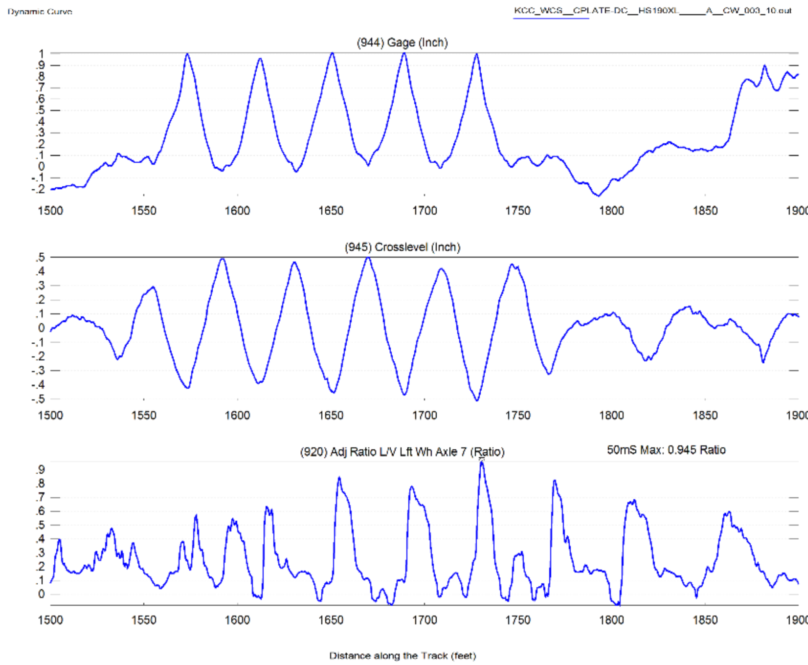

Figure 70. Single Wheel L/V Ratio plotted Against Distance for the Worn Centerplate during CW Dynamic Curving at 10 mph

Table 56 shows a comparison of hunting simulation predictions for baseline and worn centerplate simulations. Simulation predictions for these conditions do not meet S-2043 criteria for minimum vertical wheel load for hunting. The mechanism of the performance issue is similar to that described in Sections 5.7.2 and 6.1; thus, the trend and distance plots are not shown here.

All other criteria were met for hunting with worn centerplates, including the ones normally associated with hunting behavior; peak-to-peak carbody lateral acceleration, maximum carbody lateral acceleration, and lateral carbody acceleration standard deviation over 1,000 feet.

Table 56. Simulation Predictions of the Atlas Cask Car with Worn Centerplate in Hunting

Criterion	Limiting Value	Baseline (μ=0.3)	Worn Centerplate (μ=0.5)
Maximum carbody roll angle (degree)	4.0	3.7	3.7
Maximum wheel L/V	0.80	0.19	0.19
Maximum truck side L/V	0.50	0.17	0.17
Minimum vertical wheel load (%)	25	**25**	**24**
Peak-to-peak carbody lateral acceleration (g)	1.30	0.35	0.40
Maximum carbody lateral acceleration (g)	0.75	0.23	0.29
Lateral carbody acceleration standard deviation (g)	0.13	0.09	0.09
Maximum carbody vertical acceleration (g)	0.90	0.12	0.12
Maximum vertical suspension deflection (%)	95	86	86

6.3 Primary Pad

It is not clear how the primary pads of the Swing Motion® trucks will wear over time. To examine the possible impact of different changes, the primary pads were simulated with both lower and higher longitudinal and lateral stiffness. For lower stiffness runs the stiffness was reduced by a factor of 2. For higher stiffness runs the stiffness was increased by a factor of 20.

The performance of the car with worn primary pads was checked in constant curving, dynamic curving, and hunting with the HI-STAR 190 XL cask. The performance of the car with soft primary pads was checking in hunting with the empty car with ballast load.

Constant curving simulations were performed in both directions using track geometry measurements for a section of track that includes a 7.5-, 12-, and 10-degree curve and their entry and exit spirals. The bunched spiral, as described in a previous section, was used to check a severe track twist condition. Table 57 shows a comparison of constant curving simulation predictions for baseline and worn primary pad simulations. Simulation predictions for worn primary pads meet S-2043 criteria for constant curving.

Table 57. Simulation Predictions of the Atlas Cask Car with Worn Primary Pads in Constant Curving

Criterion	Limiting Value	Baseline	Soft Primary Pad	Stiff Primary Pad
Maximum carbody roll angle (degree)	4.0	1.7	1.8	1.4
Maximum wheel L/V	0.80	0.64	0.59	0.73
Maximum truck side L/V	0.50	0.36	0.32	0.40
Minimum vertical wheel load (%)	25	52	53	52
Peak-to-peak carbody lateral acceleration (g)	1.30	0.18	0.17	0.26
Maximum carbody lateral acceleration (g)	0.75	0.16	0.16	0.21
Lateral carbody acceleration standard deviation (g)	0.13	0.03	0.03	0.04
Maximum carbody vertical acceleration (g)	0.90	0.10	0.10	0.10
Maximum vertical suspension deflection (%)	95	76	75	76

Table 58 shows a comparison of dynamic curving simulation predictions for baseline and worn primary pad simulations. Simulation predictions for both the baseline car and the worn primary pads do not meet S-2043 criteria for wheel L/V ratio for dynamic curving, with the stiff pad configuration generally providing the worst performance. Figure 71 shows the trend in performance with speed, and Figure 72 shows a distance plot of the 10 mph simulation of the stiff pad condition. Simulation predictions for worn primary pads meet all other S-2043 criteria in dynamic curving.

Table 58. Simulation Predictions of the Atlas Cask Car with Worn Primary Pads in Dynamic Curving

Criterion	Limiting Value	Baseline	Soft Primary Pad	Stiff Primary Pad
Maximum carbody roll angle (degree)	4.0	1.2	1.3	1.2
Maximum wheel L/V	0.80	**0.88**	**0.83**	**0.96**
Maximum truck side L/V	0.50	0.37	0.29	0.49
Minimum vertical wheel load (%)	25	49	49	48
Peak-to-peak carbody lateral acceleration (g)	1.30	0.16	0.16	0.22
Maximum carbody lateral acceleration (g)	0.75	0.13	0.13	0.18
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.06	0.07	0.07
Maximum vertical suspension deflection (%)	95	78	78	78

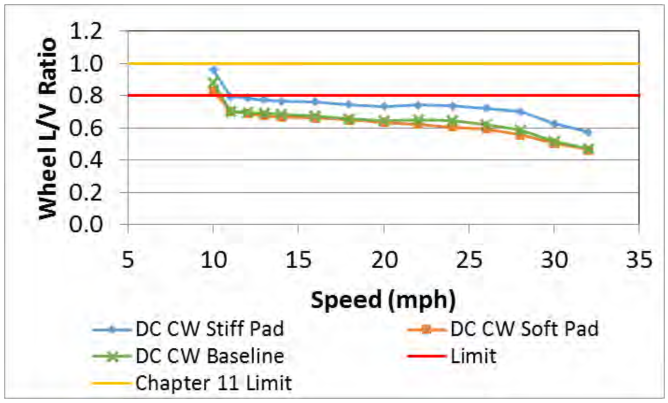

Figure 71. Maximum Single Wheel L/V Ratio for the Worn Pad Conditions in CW Dynamic Curving Plotted Against Speed.

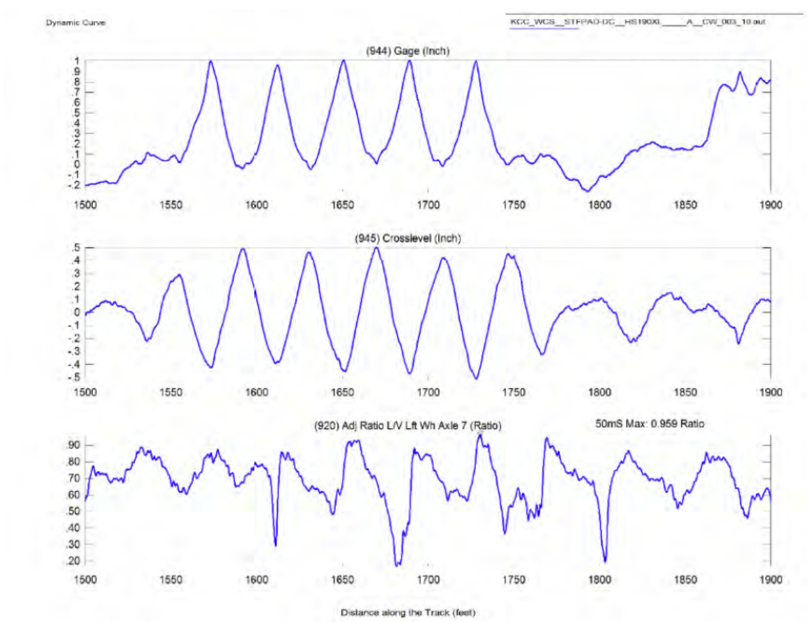

Figure 72. Single Wheel L/V Ratio Plotted Against Distance for the Stiff Worn Pad Condition during CW Dynamic Curving at 10 mph

Table 59 shows a comparison of hunting simulation predictions for baseline and worn primary pad simulations with the HI-STAR 190 XL cask. Simulation predictions for both of the worn conditions do not meet S-2043 criteria for minimum vertical wheel load for hunting. The mechanism of the performance issue is similar to that described in Section 5.7.2 and 6.1; thus, the trend and distance plots are not shown here.

All other criteria were met for hunting with worn primary pads, including the ones normally associated with hunting behavior; peak-to-peak carbody lateral acceleration, maximum carbody lateral acceleration, and lateral carbody acceleration standard deviation over 1,000 feet.

Table 59. Simulation Predictions of the Atlas Cask Car with Worn Primary Pads in Hunting

Criterion	Limiting Value	Baseline	Soft Primary Pad	Stiff Primary Pad
Maximum carbody roll angle (degree)	4.0	3.7	3.6	3.6
Maximum wheel L/V	0.80	0.19	0.18	0.41
Maximum truck side L/V	0.50	0.17	0.16	0.17
Minimum vertical wheel load (%)	25	**25**	**24**	**24**
Peak-to-peak carbody lateral acceleration (g)	1.30	0.35	0.43	0.33
Maximum carbody lateral acceleration (g)	0.75	0.23	0.27	0.24
Lateral carbody acceleration standard deviation (g)	0.13	0.09	0.10	0.06
Maximum carbody vertical acceleration (g)	0.90	0.12	0.12	0.13
Maximum vertical suspension deflection (%)	95	86	86	86

Table 60 shows a comparison of hunting simulation predictions for baseline and soft primary pad simulations with the empty car with ballast load. Simulation predictions meet S-2043 criteria for hunting.

Table 60. Hunting Simulation Predictions for the Empty Car with Ballast Load and Soft Primary Pads

Criterion	Limiting Value	Baseline	Soft Primary Pad
Maximum carbody roll angle (degree)	4.0	0.3	0.4
Maximum wheel L/V	0.80	0.22	0.22
Maximum truck side L/V	0.50	0.19	0.18
Minimum vertical wheel load (%)	25	60	59
Peak-to-peak carbody lateral acceleration (g)	1.30	0.21	0.25
Maximum carbody lateral acceleration (g)	0.75	0.18	0.19
Lateral carbody acceleration standard deviation (g)	0.13	0.05	0.06
Maximum carbody vertical acceleration (g)	0.90	0.09	0.11
Maximum vertical suspension deflection (%)	95	44	44

6.4 Friction Wedges

The wedge rise limit for the Swing Motion® trucks used in the cask car is 11/16 inch. Worn wedge simulations were performed with the wedges at this state of wear in all locations. The worn wedge condition was checked for limiting spiral, dynamic curving, pitch and bounce, and twist and roll regimes with the HI-STAR 190 XL Cask.

Table 61 shows a comparison of limiting spiral simulation predictions for baseline and worn friction wedge simulations. Simulation predictions for worn friction wedges meet S-2043 criteria.

Table 61. Simulation Predictions of the Atlas Cask Car with Worn Friction Wedges in Limiting Spiral

Criterion	Limiting Value	Spiral Entry Baseline	Spiral Exit Baseline	Spiral Entry Worn Wedge	Spiral Exit Worn Wedge
Maximum carbody roll angle (degree)	4.0	0.9	2.3	0.9	2.3
Maximum wheel L/V	0.80	0.49	0.48	0.50	0.47
Maximum truck side L/V	0.50	0.24	0.31	0.24	0.30
Minimum vertical wheel load (%)	25	60	54	60	55
Peak-to-peak carbody lateral acceleration (g)	1.30	0.13	0.09	0.12	0.09
Maximum carbody lateral acceleration (g)	0.75	0.11	0.09	0.10	0.09
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.07	0.06	0.06	0.05
Maximum vertical suspension deflection (%)	95	73	78	73	77

Table 62 shows a comparison of dynamic curving simulation predictions for baseline and worn friction wedge simulations. Simulation predictions for both the baseline car and the worn friction wedges do not meet S-2043 criteria for wheel L/V ratio for dynamic curving, although the L/V ratio is actually slightly lower with the worn friction wedges. Simulation predictions for worn friction wedges meet all other S-2043 criteria.

Table 62. Simulation Predictions of the Atlas Cask Car with Worn Friction Wedges in Dynamic Curving

Criterion	Limiting Value	Baseline	Worn Friction Wedges
Maximum carbody roll angle (degree)	4.0	1.2	1.4
Maximum wheel L/V	0.80	**0.88**	**0.87**
Maximum truck side L/V	0.50	0.37	0.36
Minimum vertical wheel load (%)	25	49	49
Peak-to-peak carbody lateral acceleration (g)	1.30	0.16	0.15
Maximum carbody lateral acceleration (g)	0.75	0.13	0.13
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.06	0.06
Maximum vertical suspension deflection (%)	95	78	78

Table 63 shows a comparison of pitch and bounce simulation predictions for baseline and worn friction wedge simulations. Simulation predictions for worn friction wedges meet S-2043 criteria for pitch and bounce.

Table 63. Simulation Predictions of the Atlas Cask Car with Worn Friction Wedges in Pitch and Bounce

Criterion	Limiting Value	Baseline	Worn Friction Wedges
Maximum carbody roll angle (degree)	4.0	0.1	0.2
Maximum wheel L/V	0.80	0.06	0.05
Maximum truck side L/V	0.50	0.04	0.04
Minimum vertical wheel load (%)	25	68	66
Peak-to-peak carbody lateral acceleration (g)	1.30	0.14	0.15
Maximum carbody lateral acceleration (g)	0.75	0.07	0.08
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.21	0.29
Maximum vertical suspension deflection (%)	95	72	73

Table 64 shows a comparison of twist and roll simulation predictions for baseline and worn friction wedges. Simulation predictions for worn friction wedges meet S-2043 criteria for twist and roll.

Table 64. Simulation Predictions of the Atlas Cask Car with Worn Friction Wedges in Twist and Roll

Criterion	Limiting Value	Baseline	Worn Friction Wedges
Maximum carbody roll angle (degree)	4.0	2.0	2.2
Maximum wheel L/V	0.80	0.14	0.14
Maximum truck side L/V	0.50	0.11	0.09
Minimum vertical wheel load (%)	25	68	67
Peak-to-peak carbody lateral acceleration (g)	1.30	0.22	0.21
Maximum carbody lateral acceleration (g)	0.75	0.12	0.12
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.11	0.10
Maximum vertical suspension deflection (%)	95	74	74

6.5 Broken Spring

The cask car uses different springs in the end trucks than in the center trucks of a span bolster. Table 4 shows the spring configuration of the two trucks. The broken spring simulations were done with one 1-96 spring removed from the spring nest of the leading truck of the trailing span bolster to represent a broken or missing spring. This location was chosen because modeling of this vehicle and testing of the CA S-2043 12-Axle Car showed that this area is critical for the dynamic curving regime. The broken spring condition was checked for limiting spiral, dynamic curving, pitch and bounce, and twist and roll with the HI-STAR 190 XL Cask.

Table 65 shows a comparison of limiting spiral simulation predictions for baseline and broken spring simulations. Simulation predictions for broken springs meet S-2043 criteria in the limiting spiral regime.

Table 65. Simulation Predictions of the Atlas Cask Car with a Broken Spring in Limiting Spiral

Criterion	Limiting Value	Spiral Entry Baseline	Spiral Exit Baseline	Spiral Entry Broken Spring	Spiral Exit Broken Spring
Maximum carbody roll angle (degree)	4.0	0.9	2.3	0.9	2.2
Maximum wheel L/V	0.80	0.49	0.48	0.50	0.50
Maximum truck side L/V	0.50	0.24	0.31	0.24	0.30
Minimum vertical wheel load (%)	25	60	54	60	54
Peak-to-peak carbody lateral acceleration (g)	1.30	0.13	0.09	0.13	0.09
Maximum carbody lateral acceleration (g)	0.75	0.11	0.09	0.10	0.09
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.07	0.06	0.07	0.06
Maximum vertical suspension deflection (%)	95	73	78	74	78

Table 66 shows a comparison of dynamic curving simulation predictions for baseline and broken spring simulations. Simulation predictions for both the baseline car and the broken springs do not meet S-2043 criterion for single wheel L/V ratio. Figure 73 shows the maximum single wheel L/V ratio plotted against speed to show the trend in performance. Figure 74 shows the single wheel L/V ratio plotted against distance for the 10 mph CW run. Broken spring simulations met other S-2043 criteria.

Table 66. Simulation Predictions of the Atlas Cask Car with a Broken Spring in Dynamic Curving

Criterion	Limiting Value	Baseline	Broken spring
Maximum carbody roll angle (degree)	4.0	1.2	1.3
Maximum wheel L/V	0.80	**0.88**	**0.90**
Maximum truck side L/V	0.50	0.37	0.38
Minimum vertical wheel load (%)	25	49	50
Peak-to-peak carbody lateral acceleration (g)	1.30	0.16	0.16
Maximum carbody lateral acceleration (g)	0.75	0.13	0.13
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.06	0.06
Maximum vertical suspension deflection (%)	95	78	78

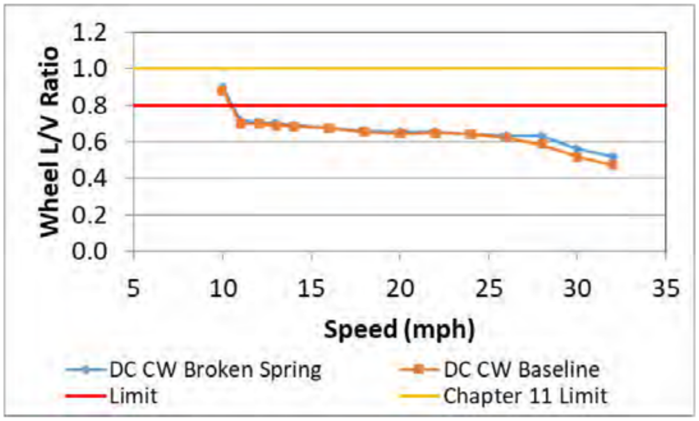

Figure 73. Maximum Single Wheel L/V Ratio for the Broken Spring in CW Dynamic Curving Plotted Against Speed

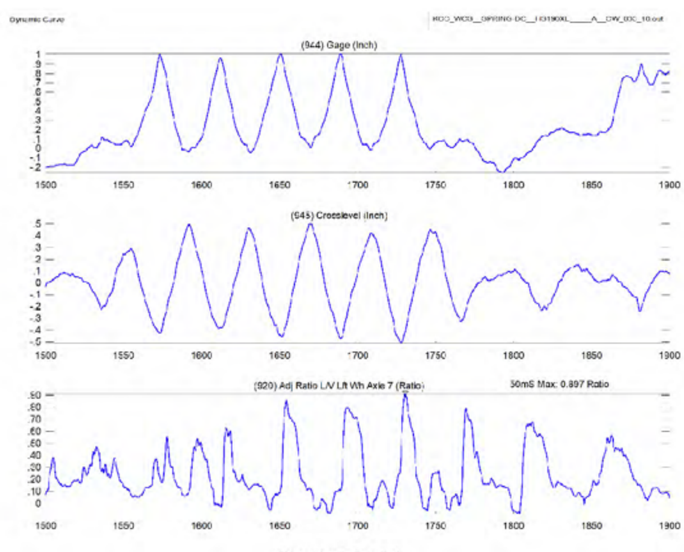

Figure 74. Single Wheel L/V Ratio Plotted Against Distance for Dynamic Curving with a Broken Spring

Table 67 shows a comparison of pitch and bounce simulation predictions for baseline and broken spring simulations. Simulation predictions for broken springs meet S-2043 criteria in the pitch and bounce regime.

Table 67. Simulation Predictions of the Atlas Cask Car with a Broken Spring in Pitch and Bounce

Criterion	Limiting Value	Baseline	Broken spring
Maximum carbody roll angle (degree)	4.0	0.1	0.2
Maximum wheel L/V	0.80	0.06	0.06
Maximum truck side L/V	0.50	0.04	0.04
Minimum vertical wheel load (%)	25	68	63
Peak-to-peak carbody lateral acceleration (g)	1.30	0.14	0.14
Maximum carbody lateral acceleration (g)	0.75	0.07	0.07
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.21	0.21
Maximum vertical suspension deflection (%)	95	72	71

Table 68 shows a comparison of twist and roll simulation predictions for baseline and broken spring. Simulation predictions for broken springs meet S-2043 criteria for the twist and roll regime.

Table 68. Simulation Predictions of the Atlas Cask car with a Broken Spring in Twist and Roll

Criterion	Limiting Value	Baseline	Broken spring
Maximum carbody roll angle (degree)	4.0	2.0	2.1
Maximum wheel L/V	0.80	0.14	0.15
Maximum truck side L/V	0.50	0.11	0.11
Minimum vertical wheel load (%)	25	68	67
Peak-to-peak carbody lateral acceleration (g)	1.30	0.22	0.23
Maximum carbody lateral acceleration (g)	0.75	0.12	0.12
Lateral carbody acceleration standard deviation (g)	0.13	NA	NA
Maximum carbody vertical acceleration (g)	0.90	0.11	0.11
Maximum vertical suspension deflection (%)	95	74	74

7.0 OBSERVATIONS AND CONCLUSIONS

The car met S-2043 criteria for:

- Truck Twist Equalization
- Carbody Twist Equalization
- Static Curve Stability
- Curve Negotiation
- Twist and Roll
- Pitch and Bounce
- Single Bump
- Hunting
- Constant Curving
- Limiting Spiral Negotiation
- Ride Quality
- Braking Effects on Steering

The car did not meet all of the criteria for:

- Dynamic Curving
- Curving with Single Rail Perturbation

- Curving with Various Lubrication Conditions
- Turnouts and Crossovers
- Buff and Draft Curving
- Worn Component Cases

Tables 69-71 summarize the results from all of the regimes.

Table 72 shows a comparison of Atlas cask car performance to the CA S-2043 12-Axle Car design it was based on regimes where the Atlas car did not meet performance requirements. The CA S-2043 12-Axle Car simulation cases included Empty and Loaded Cask conditions. Load conditions for which the worst case condition was predicted for the Atlas car and the CA S-2043 12-Axle Car are noted. Both test and modeling data are available for the CA S-2043 12-Axle Car in the dynamic curving regime, so both are noted in the table. No attempt is made to compare worn condition cases because there are very few conditions where meaningful comparisons can be made.

Table 69. Summary Table (1/3)

Description	S-2043 Paragraph	Subsection	Empty		Loaded		Worst example that does not meet
			Meets	Does Not Meet	Meets	Does Not Meet	
Truck Twist Equalization	4.2.1		X		X		
Carbody Twist Equalization	4.2.2		X		X		
Static Curve Stability	4.2.3	Base Car	X		X		
		Like Car	X		X		
		Long Car	X		X		
		Buffer Car	X		X		
		Long-Base Car Combination	X		X		
Curve Negotiation	4.2.4	Uncoupled 125-foot radius curve	X		X		
		Coupled 250-foot radius curve	X		X		
		No. 7 crossover	X		X		
Twist and Roll	4.3.9.6	39-foot inputs	X		X		
		38-foot inputs	X		X		
Pitch and Bounce	4.3.9.7	39-foot inputs	X		X		
		38-foot inputs	X		X		
Yaw and Sway	4.3.9.8	39-foot inputs	X		X		
		38-foot inputs	X		X		
Dynamic Curving	4.3.9.9	39-foot inputs	X			X	Wheel L/V 0.88, Limit=0.8, A-end and B-end lead, Loaded[a]
		38-foot inputs	X			X	Wheel L/V 0.90, Limit=0.8, A-end Lead, Loaded
Single Bump	4.3.10.1		X		X		
Curving with Single Rail Perturbation	4.3.10.2	1-inch bump	X		X		
		2-inch bump	X		X		
		3-inch bump		X		X	Wheel L/V 0.91, Limit=0.8, Empty 5 degree roll angle, Limit=4.0, A and B-end lead, Loaded[a]
		1-inch dip	X		X		
		2-inch dip		X	X		Wheel L/V 0.81, Limit=0.8. Empty
		3-inch dip		X		X	Wheel L/V 0.96, Limit=0.8, Empty Truck Side L/V 0.52, Limit=0.5, Empty 4.5 degree roll angle, Limit=4.0, A and B-end lead, Loaded[a]
Hunting	4.3.11.3		X		X		
Constant Curving	4.3.11.4		X		X		

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Table 70. Summary Table (2/3)

Description	S-2043 Paragraph	Subsection	Empty		Loaded		Worst example that does not meet
			Meets	Does Not Meet	Meets	Does Not Meet	
Curving with Various Lubrication Conditions	4.3.11.5	Case 1 New	X		X		
		Case 2 New		X	X		95% Wheel L/V Ratio=0.62, Limit = 0.60
		Case 3 New	X		X		
		Case 4 New		X	X		95% Wheel L/V Ratio=0.66, Limit = 0.60
		Case 1 Worn		X		X	Truck Side L/V 0.56, Limit=0.5, Empty
		Case 2 Worn		X		X	Truck side L/V Ratio=0.62, Limit=0.5, Loaded 95% Wheel L/V Ratio =0.68, Limit=0.60, Empty
		Case 3 Worn	X		X		
		Case 4 Worn		X		X	Truck side L/V Ratio=0.61, Limit=0.5, Empty, Loaded 95% Wheel L/V Ratio =0.61, Limit=0.60, Empty
Limiting Spiral Negotiation	4.3.11.6	Entry A-end	X		X		
		Exit A-end	X		X		
Turnouts and Crossovers	4.3.11.7	RH Turnout	X		X		
		LH Turnout	X		X		
		Crossover	X			X	Truck side L/V Ratio=0.52, Limit=0.5, Loaded
Ride Quality	4.3.12	Class 2	X		X		
		Class 3	X		X		
		Class 4	X		X		
		Class 5	X		X		
		Class 6	X		X		
Buff and Draft Curving	4.3.13	Base-Buff	X		X		
		Long-Buff	X		X		
		Like-Buff		X	X		Truck side L/V Ratio=0.51, Limit=0.50, Empty
		Buffer Car-Buff	X		X		
		Base-Draft	X		X		
		Long-Draft	X		X		
		Like-Draft	X		X		
		Buffer Car-Draft	X		X		
Braking Effects on Steering	4.3.14		X		X		

Table 71. Summary Table (3/3)

Description	S-2043 Paragraph	Subsection	Loaded: Meets	Loaded: Does Not Meet	Worst example that does not meet
Worn Component Simulations	4.3.15				
Constant Contact Side Bearings	4.3.15	Constant Curving	X		
		Dynamic Curving		X	Maximum Wheel L/V Ratio=1.16, Limit=0.8
		Hunting		X	Minimum Vertical Wheel Load=22%, Limit≥25%
		Hunting Empty Car Ballast Load	X		
		Twist and Roll	X		
Center Plates	4.3.15	Constant Curving	X		
		Dynamic Curving		X	Maximum Wheel L/V Ratio=0.95, Limit=0.8
		Hunting		X	Minimum Vertical Wheel Load=24%, Limit≥25%
Primary Pad	4.3.15	Constant Curving– Soft	X		
		Dynamic Curving – Soft		X	Maximum Wheel L/V Ratio=0.83, Limit=0.80, but better than baseline of 0.88.
		Hunting – Soft		X	Minimum Vertical Wheel Load=24%, Limit≥25%
		Hunting Empty Car Ballast Load	X		
		Constant Curving – Stiff	X		
		Dynamic Curving – Stiff		X	Maximum Wheel L/V Ratio=0.96, Limit=0.8
		Hunting – Stiff		X	Minimum Vertical Wheel Load=24%, Limit≥25%
Friction Wedges	4.3.15	Limiting Spiral	X		
		Dynamic Curving		X	Maximum Wheel L/V Ratio=0.87, Limit=0.80, but better than baseline of 0.88.
		Pitch and Bounce	X		
		Twist and Roll	X		
oken Springs	4.3.15	Limiting Spiral	X		
		Dynamic Curving		X	Maximum Wheel L/V Ratio = 0.90, Limit=0.80
		Pitch and Bounce	X		
		Twist and Roll	X		

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Table 72. Comparison of Atlas to CA S-2043 12-Axle Car - Performance Regimes Not Met

Description	S-2043 Paragraph	Sub.	Empty Does Not Meet	Loaded Does Not Meet	Worst example that does not meet
Dynamic Curving	4.3.9.9	39-foot inputs		X	**ATLAS:** Wheel L/V 0.88, Limit=0.8, A-end and B-end lead, Loaded. **CA S-2043 12-Axle Car:** Wheel L/V 0.98 test, 1.07 simulation, Loaded Cask
		38-ft inputs		X	**ATLAS:** Wheel L/V 0.90, Limit=0.8, A-end Lead, Loaded **CA S-2043 12-Axle Car:** No comparison available, see 39-foot
Curving with Single Rail Perturbation	4.3.10.2	3-inch bump	X	X	**ATLAS:** 5 degree roll angle, Limit=4.0, A and B-end lead, Loaded. Wheel L/V 0.91, Limit=0.80, Empty **CA S-2043 12-Axle Car:** 5.4 degree roll angle, Empty Cask. Wheel L/V 0.64 Empty Cask
		2-inch dip	X		**ATLAS:** Wheel L/V 0.81, Limit=0.8, Empty. **CA S-2043 12-Axle Car:** Wheel L/V 0.63, Empty Cask
		3-inch dip	X	X	**ATLAS:** Roll angle=4.2 degrees, Limit=4.0, Loaded. Wheel L/V=0.96, Limit=0.8, Empty. Truck Side L/V=0.52, Limit=0.5, Empty. **CA S-2043 12-Axle Car:** Roll angle=4.7 degrees, Loaded Cask. Wheel L/V 0.77, Empty Cask. Truck Side L/V=0.36, Empty Cask.
Curving with Various Lubrication Conditions	4.3.11.5	Case 2 New	X		**ATLAS:** 95% Wheel L/V Ratio=0.62, Limit = 0.60, Empty **CA S-2043 12-Axle Car:** 95% Wheel L/V 0.56 simulation. Empty Cask
		Case 4 New	X		**ATLAS:** 95% Wheel L/V Ratio=0.66, Limit = 0.60, Empty **CA S-2043 12-Axle Car:** 95% Wheel L/V 0.65, Empty Cask
		Case 1 Worn	X	X	**ATLAS:** Truck Side L/V 0.56, Limit=0.5, Empty **CA S-2043 12-Axle Car:** Truck Side L/V 0.52, Empty & Loaded Cask
		Case 2 Worn	X	X	**ATLAS:** Truck side L/V Ratio=0.62, Limit=0.5, Loaded, 95% Wheel L/V Ratio =0.68, Limit=0.60, Empty **CA S-2043 12-Axle Car:** Truck Side L/V 0.54, 95% Wheel L/V 0.67, Empty Cask
		Case 4 Worn	X	X	**ATLAS:** Truck side L/V Ratio=0.61, Limit=0.5, Empty, Loaded **CA S-2043 12-Axle Car:** Truck Side L/V 0.54, Empty & Loaded Cask
Turnouts and Crossovers	4.3.11.7	Cross-over		X	**ATLAS:** Truck side L/V Ratio=0.52, Limit=0.5, Loaded **CA S-2043 12-Axle Car:** Truck Side L/V 0.506, Loaded Cask
Buff and Draft Curving	4.3.13	Like-Buff	X		**ATLAS:** Truck side L/V Ratio=0.51, Limit=0.50, Empty **CA S-2043 12-Axle Car:** Truck Side L/V 0.40, Empty Cask, Draft Condition

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APPENDIX:
ATLAS RAILCAR CASK AND CRADLE DYNAMIC MODELING INPUTS
AREVA FEDERAL SERVICES LLC

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Attachment 37

AREVA	AREVA Federal Services LLC
	CALCULATION

Document No.:	CALC-3015934	**Rev. No.**	000	**Page 1 of 53**
Project No.:	00225.03.0050	**Project Name:**	DOE Atlas Railcar	
Title:	Atlas Railcar Cask and Cradle Dynamic Modeling Inputs			

Summary:

The Department of Energy (DOE) has contracted AREVA Federal Services (AFS) to design the Atlas railcar. This contract includes designing conceptual transport package cradles for 17 spent nuclear fuel transportation casks. AFS has partnered with Transportation Technology Center, Inc. (TTCI) to perform dynamic modeling of the 17 railcar cask and cradle designs. This calculation generates the Atlas Railcar cask and cradle inputs required for the dynamic modeling to be performed by the TTCI. Additional requested dynamic modeling inputs are generated in Appendix B.

This document is not safety related.

Note: See Appendix L for latest revision containing only an editorial change.

Contains Unverified Input / Assumptions: Yes: ☐ No: ☒

Software Utilized: SolidWorks, Microsoft Excel ① **Software Active in AFS EASI: Yes: ☒ No: ☐** **Error Reports & Associated Corrective Actions Reviewed: Yes: ☒ No: ☐** ① AFS-EN-PRC-013 does not require Excel to be listed on the EASI.	**Version:** **- 2014 x64 Edition, SP 5.0** **- 2010**	**Storage Media: Yes: ☒ No: ☐** **Location:** COLDStor

	Printed Name	Signature	Date
Preparer:	E. Gonsiorowski	Erik Gonsiorowski	4/13/17
Checker:	D. Wick	[signature]	4/13/17
Approver:	D. Hillstrom	Donald Hillstrom	4/14/17
Other:	S. Klein	[signature]	4/14/17

AFS-EN-FRM-002 Rev. 07 (Effective April 21, 2015)
Reference: AFS-EN-PRC-002

AREVA Federal Services
APR 19 2017
Records Management

TRANSPORTATION TECHNOLOGY CENTER, INC.
A SUBSIDIARY OF THE ASSOCIATION OF AMERICAN RAILROADS

P.O. Box 11130
55500 DOT Road
Pueblo, CO 81001

APPENDIX G-8

AAR EEC NOTICE TO PROCEED

TO TEST PHASE FOR ATLAS RAILCAR

Ron Hynes
Assistant Vice President
Technical Services

Nichole Fimple
Executive Director
Rules and Standards

ASSOCIATION OF AMERICAN RAILROADS
Transmitted via email

February 2, 2018
File 209.240

Subject: AAR Standard S-2043 Initial Design Approval of the Kasgro/AREVA Department of Energy (DOE) "Atlas" High Level Radioactive Material (HLRM) Cask Car

Mr. Rick Ford
AVP Mechanical & Utilization
Kasgro Rail Corporation
121 Rundle Road
New Castle, PA 16102

Dear Mr. Ford:

The AAR Equipment Engineering Committee (EEC) has completed the S-2043 Initial Review of the DOE Atlas HLRM Cask Car. The initial design is hereby approved, and all parties involved are notified to proceed with the test requirements of S-2043. Approval was based on completion of the following requirements:

Structural Analysis
Nonstructural Static Analysis
Dynamic Analysis
Brake System Design
Railcar Clearance and Weight

There was no mention of System Safety Monitoring in the submission, but EEC understands that this item will be addressed as the Multiple Car Test phase approaches.

If you have any questions or need additional information, please contact Mr. Jon Hannafious of our Transportation Technology Center, Inc., subsidiary at jon_hannafious@aar.com or (719) 584-0682.

Sincerely,

Nichole Fimple

Nichole Fimple

NF/jsh
cc: David Cackovic
Mark Denton, AREVA
Equipment Engineering Committee

Association of American Railroads
425 Third Street, SW, Suite 1000, Washington D. C. 20024, (202) 639-2139 FAX No. (202) 639-2179