Appendix J
Final Family 1 Conceptual Cradle Design

TABLE OF CONTENTS

APPENDIX J.1: FS-18-0269, TITLED "ATLAS PROJECT CORRECTION OF FAMILY 1 CONCEPTUAL CRADLE CALCULATION CALC-3015276 & DYNAMIC MODELING INPUT CALCULATION CALC-3015834"

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Document # FS-18-0269
Delivery via email

Patrick R. Schwab, Contracting Officer Representative
U.S. Department of Energy
Office of Nuclear Energy
1000 Independence Ave., SW
Washington, D.C. 20585

October 23, 2018

Subject: **Atlas Project: Correction of Family 1 Conceptual Cradle Calculation CALC-3015276 & Dynamic Modeling Input Calculation CALC-3015834**
Reference: **Contract DE-NE0008390**

Orano Federal Services LLC

10101 David Taylor Drive
Suite 200
Charlotte NC 28262

Tel: 704-805-2990

Dear Mr. Schwab;

As we previously discussed mid-September, during the design of the test loads an error was discovered in the end stop weight calculation for the Family 1 HI-STAR 60 conceptual cradle/end stop design. This error resulted in the end stop weight used in modeling of the HI-STAR 60 cast being too high.

The weight of the HI-STAR 60 conceptual cradle was incorrectly calculated in a worksheet supporting CALC-3015133-002, *Atlas Railcar Family 1 Conceptual Cradle Structural Calculation*. This revision over predicts the nominal weight of the HI-STAR 60 conceptual cradle end stop by approximately 5000 lbs each, or 20,000 lbs for the conceptual cradle design. Specifically, the Outer Vertical Plate is identified as the value contributing to the over estimation. A difference of 4614 lbs is calculated between the Outer Vertical Plate weight in Revision 2 as 8248 lbs and the corrected calculation value of 3634 lbs. As a result of the incorrectly calculated value, the calculation was revised as reflected in CALC-3015133-004 enclosed with this letter.

Additional weight of approximately 1,000 lbs was added to the HI-STAR 60 conceptual cradle design in DWG-3015137, *Atlas Railcar Cradle Family 1 Conceptual Drawing*, revised in order to ensure that the HI-STAR 60 conceptual cradle remained within the overall bounding conditions. The central cradle doubler plates (DWG-3015137-002 Item 3) at the pin locations were lengthened 5 inches to achieve the required weight. Revised DWG-3015137-002 is enclosed with this letter.

Finally, CALC-3015133 Rev 2 reported an incorrect HI-STAR 60 end stop weight which was used as input for CALC-3015934-001, *Atlas Railcar Cask and Cradle Dynamic Modeling Inputs*, and CALC-3015276-003, *Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation*. These calculations were also corrected resulting in changes to the conceptual cradle weight, center of gravity and mass moment of inertia; however the corrected values remain within the bounding conditions of dynamic modeling inputs evaluated by TTCI. Revised CALC-3015934-002 and CALC-3015276-004 are included for your reference in enclosed letter FS-18-0257, *Atlas Railcar CALC-3015133-002, HI-STAR 60 conceptual cradle weight.*

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Document # FS-18-0269
Patrick R. Schwab
October 18, 2018
Page 1 of 3

TTCI has since evaluated the corrected modeling inputs for the HI-STAR 60 conceptual cradle design dynamic curving regimes and determined that the revised modeling results remain within the previous prediction range and that the original dynamic modeling results are still valid for acceptance to S-2043 requirements. A letter confirming this is enclosed as CR-18-006, *Response Atlas Railcar HI-STAR 60 Conceptual Cradle Weight.*

This error will be explained in the project's Phase 3 report with the revised calculations and drawing transmitted at that time. Please note that enclosed calculations and drawings are for information only at this time.

As a result of this needed corrective action, Orano Federal Services (FS) has processed an internal Corrective Action Report (CAR) to internally identify the error, determine corrective actions and make assignments for those corrective actions, and track the corrective actions until closure; this notification letter officially closes the related CAR. However, please feel free to contact me with any questions or comments regarding this issue. I can be reached at 704-805-2994 or at mark.denton@orano.group.

Best Regards,

Mark A. Denton
Sr. Project Manager
Used Fuel and Waste Management

Copies (delivery via email):
Trevor Bluth, U.S. DOE, Idaho Operations Office
Todd Heavner, Orano
Donald Hillstrom, Orano
Slade Klein, Orano
Michael Masterson, Orano

Enclosures:

- Letter FS-18-0257, *Atlas Railcar CALC-3015133-002, HI-STAR 60 conceptual cradle weight*
- DWG-3015137-002, *Atlas Railcar Cradle Family 1 Conceptual Drawing,*
- CALC-3015133, Rev 004, *Atlas Railcar Family 1 Conceptual Cradle Structural Calculation*
- Letter CR-18-006, *Response Atlas Railcar HI-STAR 60 Conceptual Cradle Weight*

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2

APPENDIX J.2 : LETTER FS-18-0257, ATLAS RAILCAR CALC-3015133-002, HI-STAR 60 CONCEPTUAL CRADLE WEIGHT

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Document # FS-18-0257
Delivery via email

Russel Walker
Transportation Technology Center, LLC.
55500 D.O.T. Road
Pueblo, CO 81001

October 12, 2018

Subject: **Atlas Railcar CALC-3015133-002, HI-STAR 60 conceptual cradle weight**
Reference: **Contract DE-NE0008390**

Orano Federal Services LLC

10101 David Taylor Drive
Suite 200
Charlotte NC 28262

Tel: 704-805-2990

Dear Mr. Walker;

The weight of the Atlas Railcar HI-STAR 60 conceptual cradle was miscalculated in CALC-3015133-002. The actual weight of the cradle is less than what was calculated and provided to the Transportation Technology Center, LLC (TTCI) in CALC-3015934-001 and CALC-3015276-003. The weight was corrected, resulting in changes to the conceptual cradle weight, center of gravity and mass moment of inertia; however the corrected values remain within the bounding conditions of dynamic modelling inputs evaluated by TTCI.

When the error was identified, a corrective action, CAR 2018-6804, was initiated per the Orano Federal Services corrective action program and the affected calculations were revised. CAR 2018-6804 also includes the action item to notify TTCI and provide the revised documents. It is requested that TTCI consider the changes and advise if there is a possible impact to the completed dynamic modeling results. Please provide a written response by 10/22/2018.

Feel free to contact me with any questions or comments regarding the enclosure. I can be reached at 253-552-1338 or at slade.klein@orano.group.

Best Regards,

KLEIN Slade Digitally signed by KLEIN Slade Date: 2018.10.15 11:04:34 -07'00'

Slade Klein
Engineering Supervisor
Used Fuel and Waste Management

Attachments:
CALC-3015934-002
CALC-3015276-004

Copies (delivery via email):
- Rick Ford, Kasgro Rail
- Mark Denton, Orano
- Todd Heavner, Orano
- Donald Hillstrom, Orano

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1

CALC-3015934-002
Page 1 of 54

FOR INFORMATION
FS-18-0257

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Orano Federal Services

CALCULATION

Document No.:	CALC-3015934	Rev. No.	002	Page 1 of 54	
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 Orano Federal Services (Orano FS) to design the Atlas railcar. This contract includes designing conceptual transport package cradles for 17 spent nuclear fuel transportation casks. Orano FS 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.

FOR INFORMATION

Safety ☐ Non-Safety ☒

Contains Unverified Input / Assumptions: Yes: ☐ No: ☒

Software Utilized: SolidWorks Software Active in FS EASI: Yes: ☒ NA*: ☐ *Not Applicable per Section 5.7 of FS-EN-PRC-002 Error Reports & Associated Corrective Actions Reviewed: Yes: ☒ No: ☐	Version: - 2014 x64 Edition, SP 5.0 -Premium 2016 x64 Edition, SP 5.0	Storage Media: Yes: ☒ No: ☐ Location: COLDStor
Software Utilized: Microsoft Excel Software Active in FS EASI: Yes: ☐ NA*: ☒ *Not Applicable per Section 5.7 of FS-EN-PRC-002 Error Reports & Associated Corrective Actions Reviewed: Yes: ☐ No: ☒	Version: - 2010	Storage Media: Yes: ☒ No: ☐ Location: COLDStor

	Printed Name	Signature	Date
Preparer:	E. Gonsiorowski	[signature]	10/10/18
Checker:	S. Klein	[signature]	10/11/2018
Approver:	D. Hillstrom	[signature]	10/11/18
Other:	N/A		

FS-EN-FRM-002 Rev. 10 (Effective March 1, 2018)
Refer to FS-EN-PRC-002

Orano Federal Services
OCT 15 2018
Records Management

Revision History

Rev.	Changes
000	Initial release
001	Revised project background for editorial changes.
002	Incorporated changes to the HI-STAR 60 Cradle and End Stop

Table of Contents

List of Tables

List of Figures

1.0 PURPOSE

1.1 Project Background

The United States Department of Energy (DOE) is laying the groundwork for implementing an integrated nuclear waste management system. This includes preparing for future large-scale transport of spent nuclear fuel (SNF) and high-level waste (HLW); since transport will be a necessary component of any integrated nuclear waste management system. With this project the DOE will provide for the transportation of SNF and HLW by means of a specific railcar (named by the DOE as the Atlas railcar) to carry SNF and HLW casks.

As part of this project, the DOE has contracted Orano Federal Services (Orano FS) to design the Atlas railcar, including a single set of standardized attachment components (railcar tie-down interface) and transport package conceptual cradle designs for the 17 SNF transportation casks (herein referred to as "packages") listed in Attachment A of the Statement of Work (SOW) [1]. The DOE Atlas railcar (and by extension to subsystems, the package cradles) must be designed and built to satisfy the requirements of Association of American Railroads (AAR) Standard S-2043 [2] and the Orano FS Design Basis Requirements Document (DBRD) [3]. The standardized attachment components are part of the railcar and must also meet the AAR S-2043 requirements.

Orano FS has chosen to divide the 17 packages into 4 families based on the package tie-down methods. The packages contained in each of these four families are listed below:

- Family 1 TN-32B, TN-40, TN-40HT, HI-STAR 60, HI-STAR 100, HI-STAR 100HB (also referred to as HI-STAR HB), HI-STAR 180, HI-STAR 190SL, and HI-STAR 190XL.
- Family 2 MAGNATRAN®, NAC-STC™, NAC-UMS UTC™, and the TN-68.
- Family 3 MP-197, MP-197HB, and the TS125.
- Family 4 MP-187.

As part of the work to be completed to design the Atlas railcar to the AAR S-2043 requirements, dynamic modeling will be performed by Transportation Technology Center, Inc. (TTCI).

1.2 Calculation Purpose

This calculation generates the Atlas Railcar cask and cradle inputs required for the dynamic modeling to be performed by TTCI. Additional dynamic modeling inputs for railcar permanent attachment hardware and railcar ballast are generated in Appendix B.

1.3 Atlas Railcar Cradles

The Atlas Railcar has been designed to transport the 17 packages listed in Section 1.1. Each package is secured to the railcar using a cradle and the standardized attachment components discussed in Section 1.4. An example of a cradle for Family 1 is shown in Figure 1-1.

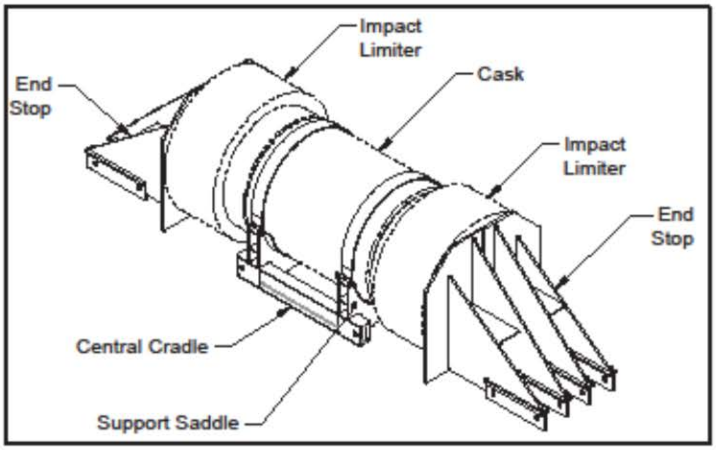

Figure 1-1: Atlas Railcar Family 1 Cradle

1.4 Atlas Railcar Standardized Attachment Components

The Atlas Railcar standardized attachment components are depicted in Drawing DWG-3015278 [4] and are shown in Figure 1-2 below. There are four center pin attachment blocks welded to the railcar that are used for all cradle designs. The cradles are secured laterally and vertically using four attachment pins inserted through the center pin attachment blocks. Longitudinal support for cradle Families 2 through 4 is provided by shear blocks welded to the railcar. Family 1 cradles use end stop assemblies to support the cask longitudinally. The end stop assemblies are attached to the railcar using pins through the eight end stop attachment blocks.

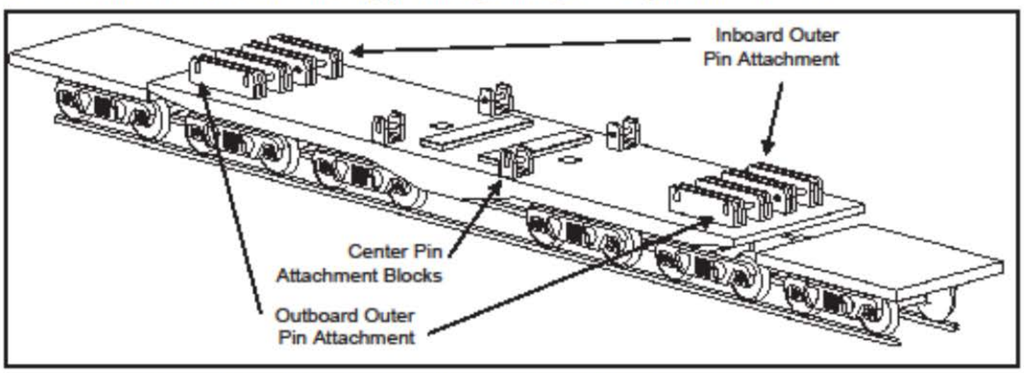

Figure 1-2: Atlas Railcar Standardized Attachment Components

2.0 METHODOLOGY

The inputs required for TTCI dynamic modeling include the cradle, cask, and end stop weights, centers of gravity, and mass moments of inertia. Previously hand-calculated values for cradle and end stop weights and centers of gravity are used with SolidWorks models to determine cradle and end stop mass moments of inertia. Additional hand calculations are performed to integrate cask weights, centers of gravity, and mass moments of inertia with their associated cradles to determine combined system properties for use by TTCI.

2.1 Acceptance Criteria

This calculation is used as an input for further analysis and does not have acceptance criteria.

3.0 ASSUMPTIONS

3.1 Unverified Inputs/Assumptions

None.

3.2 Justified Assumptions

1. Personnel barriers are not included within SolidWorks models since they are less than 2% of the total cask and cradle weight. If a personnel barrier is less than 2% of total cask and cradle weight, it can be considered to have a negligible effect on mass moments of inertia [17].
2. Casks are treated as right cylinders for calculation of mass moments of inertia. The cask center of gravity is not assumed to be at the symmetric center and thus must be accounted for in each calculation. Impact limiter geometry is ignored but impact limiter weight is included in each calculation.

4.0 DESIGN INPUTS

4.1 Transportation Package Design Inputs

Weight and center of gravity (cg) inputs are taken from the following calculations and are listed in the tables below.

1. Atlas Railcar Family 1 Conceptual Cradle Structural Calculation [5]
2. Atlas Railcar Family 2 Conceptual Cradle Structural Calculation [6]
3. Atlas Railcar Family 3 Conceptual Cradle Structural Calculation [7]
4. Atlas Railcar Family 4 Conceptual Cradle Structural Calculation [8]

Table 4-1: Cradle Design Inputs – Families 2-4

Cask	Family	Nominal Cradle Weight (lb)	Cradle Vertical cg from Cradle Bottom (in)[7]	Cradle Longitudinal cg from Center Pin Location (in)	Cradle Lateral cg from Railcar Center (in)[8]
NAC-STC	2	42,000[1]	27[1]	70[1]	0
NAC-UMS UTC	2	42,000[1]	27[1]	70[1]	0
MAGNATRAN	2	42,000[1]	27[1]	70[1]	0
MP187	4	32,500[2]	28.5[2]	125/2 = 62.5[5]	0
MP197	3	26,000[3]	17[3]	125/2 = 62.5[6]	0
MP197HB	3	26,000[3]	17.5[3]	125/2 = 62.5[6]	0
TN-68	2	27,000[4]	26[4]	54[4]	0
TS125	3	30,000[3]	24.5[3]	125/2 = 62.5[6]	0

Notes:

1. Values are taken from Section B-1 of [6].
2. Values are taken from Table 4-1 of [8].
3. Values are taken from Table 5.3-1 of [7]
4. Values are taken from Table B-3 of [6].
5. The MP187 cradle is symmetric and is centered on the attachment pins locations.
6. Per Section 5.2 of [7], the family 3 cradles are symmetrically designed and the longitudinal cradle cg is at the cradle geometric center. The cradle is centered on the attachment pin locations.
7. Cradle bottom is 0.5" above railcar deck due to standardized attachment components shim plate.
8. Determined by inspection.

Casks in family 1 require an axial support (end stops) to support the cask. The total cradle system includes a central cradle and two sets of axial end stops. Weights for the cradles and corresponding end stops are listed separately.

Table 4-2: Cradle Design Inputs – Family 1 Central Cradles

Cask	Nominal Central Cradle Weight (lb)(1)	Central Cradle Vertical cg from Cradle Bottom (in)(1)(3)	Central Cradle Longitudinal cg from Center Pin Location (in)(1)	Central Cradle Lateral cg from Railcar Center (in)(2)
HI-STAR 100	20,545	25.2	66.8	0
HI-STAR 100HB	15,000	27.1	60.2	0
HI-STAR 180	9,182	27.3	62.6	0
HI-STAR 60	16,091	26.6	68.2	0
TN-32B	13,272	35.1	56.9	0
TN-40	12,909	32.0	56.7	0
TN-40HT	12,909	32.0	56.7	0
HI-STAR 190SL	13,364	21.8	62.6	0
HI-STAR 190XL	13,636	21.8	62.6	0

Notes:

1. Values are taken from Tables 5.1 and 6.1 of [5]. Masses are nominalized from reported maximums by dividing by 1.1.
2. Determined by inspection.
3. Cradle bottom is 0.5" above railcar deck due to standardized attachment components shim plate.

Table 4-3: Cradle Design Inputs – Family 1 End Stops

Cask	Nominal End Stop Weight per End (lb)(1)(2)	End Stop Vertical cg from Railcar Deck (in)(1)	End Stop Longitudinal cg from Outboard Outer Pin Location (in)	End Stop Lateral cg from Railcar Center (in)(12)
HI-STAR 100	23,273	52.7	61.2(3)	0
HI-STAR 100HB	29,091	65.5	69.0(4)	0
HI-STAR 180	24,545	60.0	83.1 (5)	0
HI-STAR 60	24,000	47.1	63.2(6)	0
TN-32B	30,364	52.3	90.7(7)	0
TN-40	31,091	50.7	86.9(8)	0
TN-40HT	31,091	50.7	86.9(9)	0
HI-STAR 190SL	21,273	61.9	61.5(10)	0
HI-STAR 190XL	20,000	62.2	57.5(11)	0

Notes:

1. Values are taken from Table 6.1 of [5]. Masses are nominalized from reported maximums by dividing by 1.1.
2. The ends stop weight listed in Table 6.1 of [5] is for one of four end stops, two are used on each end of the railcar. The weight listed here is for one end (2 times the values listed in Table 6.1).
3. Value taken from "CALC 3015133_Hi-Star 100_Railcar Loads.2.17.17.xlsx" [5].
4. Value taken from "CALC 3015133_Hi-Star 100HB_Railcar Loads.2.9.17.xlsx" [5].
5. Value taken from "CALC 3015133_Hi-Star 180_Railcar Loads.2.9.17.xlsx" [5].
6. Value taken from "CALC 3015133_Hi-Star 60_Railcar Loads.08.08.18.xlsx" [5].
7. Value taken from "CALC 3015133_TN-32B_Railcar Loads.2.9.17.xlsx" [5].
8. Value taken from "CALC 3015133_TN-40_Railcar Loads.2.9.17.xlsx" [5].
9. Value taken from "CALC 3015133_TN-40HT_Railcar Loads.2.9.17.xlsx" [5].
10. Value taken from "CALC 3015133_Hi-Star 190SL_Railcar Loads.2.2.17.xlsx" [5].
11. Value taken from "CALC 3015133_Hi-Star 190XL_Railcar Loads.2.1.17.xlsx" [5].
12. Determined by inspection for each set of end stops.

5.0 CALCULATIONS

5.1 TTCI Modeling Inputs

Inputs required for dynamic modeling to be performed by the TTCI are generated in the following sections. Values are taken from other calculations (with references provided in each table) or are calculated as noted.

5.1.1 Transportation Cask TTCI Dynamic Modeling Inputs

The mass moments of inertia for the transportation casks are not listed in the publically available SARs. The mass moments of inertia (MMI) are calculated using equations from [10] for a right circular cylinder using the cask mass, cask length, and cask radius.

$$Rotational\ MMI\ Longitudinal\ Axis = \frac{1}{2}(Cask\ mass)(Cask\ radius)^2$$

$$Rotational\ MMI\ Lateral\ Axis = Rotational\ MMI\ Vertical\ Axis$$
$$= \frac{1}{12}(Cask\ mass)(3(Cask\ radius)^2 + (Cask\ length)^2) + (Cask\ mass)(Longitudinal\ cg)^2$$

The diameter of the cylinder is taken to be the diameter of the cask. All mass moments of inertia are calculated at the cask center of gravity (thus the longitudinal center of gravity must be accounted for since it is different than the symmetric center of gravity). The cask weights and center of gravity locations are shown in Table 5-1. The mass moments of inertia for the casks using the loaded weights are shown in Table 5-2 and the mass moments of inertia using the empty cask weights are in Table 5-3.

Table 5-1: Cask Modeling Inputs – Weight and cg

Cask	Maximum (Loaded) Cask Weight (lb)(1)	Minimum (Empty) Cask Weight (lb)(2)	Cask Vertical cg from railcar deck (in)(3)	Cask Longitudinal cg from railcar center (in)	Cask Lateral cg from railcar center (in)
NAC-STC	254,589	188,767	68.00	2.25(8)	0
NAC-UMS UTC	255,022	178,798	68.00	1.65(8)	0
MAGNATRAN	312,000	208,000	68.00	6.90(8)	0
HI-STAR 100	279,893	179,710	66.50	0.40(9)	0
HI-STAR 100HB	187,200	-(4)	66.50	2.60(9)	0
HI-STAR 180	308,647	-(5)	65.00	18.10(9)	0
HI-STAR 60	164,000	142,530(6)	60.13	11.60(9)	0
HI-STAR 190SL	382,746	282,746	65.00	17.90(9)	0
HI-STAR 190XL	420,769(12)	304,369	65.00	17.70(9)	0
MP187	271,300	190,200	65.00	0(10)	0
MP197	265,100	176,710	62.50	1.15(11)	0
MP197HB	303,600	179,000	64.50	1.63(11)	0
TN-32B	263,000	-(7)	73.00	0.50(9)	0
TN-40	271,500	-(7)	73.00	0(9)	0
TN-40HT	242,343	-(7)	73.00	0(9)	0
TN-68	272,000	-(5)	78.00	6.10(8)	0
TS125	285,000	196,118	73.30	5.00(11)	0

Notes:

1. The loaded cask weight is taken from the DOE SOW Attachment A [1].
2. The empty cask weights are taken from the DOE SOW Attachment A [1] except where noted. Some empty weights are not available.
3. The cask vertical cg is taken from Calculation CALC-315276-004 [9]. Revised values taken from [5] and [8] for families 1 and 4. Values from [5] and [8] are increased 0.5" due to standardized attachment components shim plate.
4. Per the DOE SOW Attachment A [1], the HI-STAR 100HB cask is already loaded and will not be shipped empty.
5. The DOE SOW Attachment A [1] lists an empty weight of less than the loaded weight. An empty weight is provided in the public information; however, this is not a bounding empty condition weight and will not be listed here.
6. The DOE SOW Attachment A [1] lists an empty weight of <164,000 pounds. An empty weight of 142,530 pounds is listed in Section 1.2.1.3 of the HI-STAR 60 SAR, Rev 2 (Docket 71-9336) [16].
7. Per the DOE SOW Attachment A [1], the TN-40 is authorized for a single use shipment and would not be shipped empty. Per [1] this is also assumed to be the case for the TN-32B and TN40HT.

8. Value calculated using values derived from "Minimum/Maximum Combined CG distance from rear cradle pins, X (in)" in Tables B-2 and B-4 of CALC-3015134 [6] and the distance between attachment pins of 125 inches per [4]. Cask cg is the bounding value farthest from railcar center.
9. Value calculated using "Cask CG from pin near cask bottom (P1) (in) (dc_hcg)" from CALC-3015133 Table 5.1 [5] and the distance between attachment pins of 125 inches per [4].
10. The MP187 cask cg is at the center of the attachment points [8].
11. Value calculated using "Cask Length (in)" and Cask Longitudinal CG (in)" from Table 4.1-1 of CALC-3015135 [7]. Where available, bounding values were used. Casks are geometrically centered on their respective cradles.
12. Loaded cask weight adjusted from DOE SOW Attachment A per AFS-RFI-00225-0015-00 [22]

Table 5-2: Cask Modeling Inputs – Loaded Mass Moment of Inertia

Cask	Maximum (Loaded) Cask Weight (lb)	Cask Length (in)[1]	Cask Radius (in)[2]	Rotational Mass Moment of Inertia ($lb*in^2$), Loaded Cask around cg		
				Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
NAC-STC	254,589	193.0	49.50	311903349	947506003	947506003
NAC-UMS UTC	255,022	209.3	46.45	275118052	1069221548	1069221548
MAGNATRAN	312,000	214.0	55.00	471900000	1441500320	1441500320
HI-STAR 100	279,893	203.3	48.00	322436736	1125282050	1125282050
HI-STAR 100HB	187,200	128.0	48.00	215654400	364683072	364683072
HI-STAR 180	308,647	174.4	53.15	435951927	1101392609	1101392609
HI-STAR 60	164,000	158.9	37.88	117661341	425971047	425971047
HI-STAR 190SL	382,746	214.5	53.25	542650102	1861480626	1861480626
HI-STAR-190XL	420,769	237.0	53.25	596558399	2399616416	2399616416
MP187	271,300	201.5	46.25	290163828	1063031116	1063031116
MP197	265,100	208.0	45.75	277435434	1094842179	1094842179
MP197HB	303,600	210.3	48.88	362688818	1301071121	1301071121
TN-32B	263,000	184.0	48.88	314186954	899169893	899169893
TN-40	271,500	183.8	49.76	336124819	932390115	932390115
TN-40HT	242,343	183.8	50.50	309017618	836753630	836753630
TN-68	272,000	197.3	49.00	326536000	1055741027	1055741027
TS125	285,000	210.4	47.10	316123425	1216555513	1216555513

Notes:

1. The cask length is taken as the "Length without Impact Limiters" from the DOE SOW Attachment A [1].
2. The cask radius is taken as half of the "Diameter without Impact Limiters" from the DOE SOW Attachment A [1].

Table 5-3: Cask Modeling Inputs – Empty Mass Moment of Inertia

Cask	Minimum (Empty) Cask Weight (lb)	Cask Length (in)[1]	Cask Radius (in)[2]	Rotational Mass Moment of Inertia ($lb*in^2$), Empty Cask around cg		
				Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
NAC-STC	188,767	193.0	49.50	231263171	702535717	702535717
NAC-UMS UTC	178,798	209.3	46.45	192887506	749639930	749639930
MAGNATRAN	208,000	214.0	55.00	314600000	961000213	961000213
HI-STAR 100	179,710	203.3	48.00	207025920	722506234	722506234
HI-STAR 100HB	-	128.0	48.00	-	-	-
HI-STAR 180	-	174.4	53.15	-	-	-
HI-STAR 60	142,530	158.9	37.88	102257749	370205203	370205203
HI-STAR 190SL	282,746	214.5	53.25	400871977	1375131813	1375131813
HI-STAR 190XL	304,369	237.0	53.25	431528661	1735795291	1735795291
MP187	190,200	201.5	46.25	203424844	745258084	745258084
MP197	176,710	208.0	45.75	184932537	729798421	729798421
MP197HB	179,000	210.3	48.88	213838269	767100562	767100562
TN-32B	-	184.0	48.88	-	-	-
TN-40	-	183.8	49.76	-	-	-
TN-40HT	-	183.8	50.50	-	-	-
TN-68	-	197.3	49.00	-	-	-
TS125	196,118	210.4	47.10	217535066	837152400	837152400

Notes:

1. The cask length is taken as the "Length without Impact Limiters" from the DOE SOW Attachment A [1].
2. The cask radius is taken as half of the "Diameter without Impact Limiters" from the DOE SOW Attachment A [1].

5.1.2 Cradle TTCI Dynamic Modeling Inputs

Weight and cg

The cradle TTCI dynamic modeling inputs are calculated in the following tables. Cradle nominal weights and cg locations are listed in Table 5-4 for Families 2-4. Values for this table are taken from Table 4-1. Cradle and end stop nominal weights and cg locations are listed in Table 5-5 and Table 5-6 for Family 1. Values for these tables are taken from Table 4-2 and Table 4-3.

Mass Moment of Inertia

The mass moments of inertia for the cradles are not currently provided in the cradle structural calculations. The mass moments of inertia for each cradle are calculated using SolidWorks. All mass moments of inertia calculations are done using models built in accordance with drawings [11], [12], [13], [14], and [15]. Hand-calculated cradle masses and center of gravities are used, overriding those calculated by SolidWorks. SolidWorks model materials are defined using densities taken from reference [19]. Each model is composed mostly of carbon steel (0.28 lb/in^3), with some components constructed of stainless steel (0.29 lb/in^3), bronze (0.32 lb/in^3), aluminum (0.10 lb/in^3), and rubber (assumed 0.04 lb/in^3). Although cradle masses are overridden within SolidWorks, materials (specifically, material densities) must be defined to establish relative weight distribution within each model.

Results from Solidworks are listed in Appendix A and shown in Table 5-7 through Table 5-9 below.

Table 5-4: Cradle Modeling Inputs – Weight and cg – Families 2-4

Cask	Nominal Cradle Weight (lb)(1)	Cradle Vertical cg from Railcar Deck (in)(2)	Cradle Longitudinal cg from Railcar Center (in)(3)	Cradle Lateral cg from Railcar Center (in)
NAC-STC	42,000	27.5	7.5	0
NAC-UMS UTC	42,000	27.5	7.5	0
MAGNATRAN	42,000	27.5	7.5	0
MP187	32,500	29.0	0	0
MP197	26,000	17.5	0	0
MP197HB	26,000	18.0	0	0
TN-68	27,000	26.5	8.5	0
TS125	30,000	25.0	0	0

Notes:

1. Nominal weight values rather than maximum or minimum weight values are used in each SolidWorks calculation.
2. The cg is taken from Table 4-1 and increased by 0.5 inches due to the standardized attachment components.
3. The cradle longitudinal cg is adjusted to the center of the railcar by taking the value from Table 4-1 and adjusting using the distance between the pins (125 inches per [4]), x = abs(125/2-d).

Table 5-5: Cradle Modeling Inputs – Weight and cg – Family 1 Central Cradle

Cask	Nominal Central Cradle Weight (lb)(1)	Central Cradle Vertical cg from Railcar Deck (in)(2)	Central Cradle Longitudinal cg from Railcar Center (in)(3)	Central Cradle Lateral cg from Railcar Center (in)
HI-STAR 100	20,545	25.7	4.3	0
HI-STAR 100HB	15,000	27.6	2.3	0
HI-STAR 180	9,182	27.8	0.1	0
HI-STAR 60	16,091	27.1	2.6	0
TN-32B	13,272	35.6	5.6	0
TN-40	12,909	32.5	5.8	0
TN-40HT	12,909	32.5	5.8	0
HI-STAR 190SL	13,364	22.3	0.1	0
HI-STAR 190XL	13,636	22.3	0.1	0

Notes:

1. Nominal weight values rather than maximum or minimum weight values are used in each SolidWorks calculation.
2. The cg is taken from Table 4-2 and increased by 0.5 inches due to the standardized attachment components.
3. The cg is adjusted to the center of the railcar by taking the value from Table 4-2 and adjusting using the distance between the pins (125 inches per [4]), x = abs(125/2-d).

Table 5-6: Cradle Modeling Inputs – Weight and cg – Family 1 End Stops

Cask	Nominal End Stop Weight per End (lb)(1)	End Stop Vertical cg from Railcar Deck (in)	End Stop Longitudinal cg from Railcar Center (in)(2)	End Stop Lateral cg from Railcar Center (in)
HI-STAR 100	23,273	52.7	197.8	0
HI-STAR 100HB	29,091	65.5	190.0	0
HI-STAR 180	24,545	60.0	175.9	0
HI-STAR 60	24,000	47.1	195.8	0
TN-32B	30,364	52.3	168.3	0
TN-40	31,091	50.7	172.1	0
TN40HT	31,091	50.7	172.1	0
HI-STAR 190SL	21,273	61.9	197.5	0
HI-STAR 190XL	20,000	62.2	201.5	0

Notes:

1. Nominal weight values rather than maximum or minimum weight values are used in each SolidWorks calculation.
2. The cg is adjusted to the center of the railcar by taking the value from Table 4-3 and adjusting using the distance between the outer pins (125+148.5+148.5+48+48 inches per [4]), x = abs((125+148.5+148.5+48+48)/2-d).

Table 5-7: Cradle Modeling Results – Families 2-4

Cask	Nominal Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia ($lb*in^2$)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
NAC-STC	42,000	107420031	177507865	245802070
NAC-UMS UTC	42,000	108344606	215505187	283962578
MAGNATRAN	42,000	107996979	214855254	284549589
MP187	32,500	76512209	102544674	129466464
MP197	26,000	53452254	53944950	83293680
MP197HB	26,000	57567432	90162852	119270004
TN-68	27,000	70617158	73796861	112935016
TS125	30,000	63572366	130481182	160163420

Table 5-8: Cradle Modeling Results – Family 1 Central Cradle

Cask	Nominal Central Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, ($lb*in^2$)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 100	20,545	43074602	50542232	67971425
HI-STAR 100HB	15,000	36189820	27793388	44375308
HI-STAR 180	9,182	25366782	28726632	37587666
HI-STAR 60	16,091	36195191	30279548	49192035
TN-32B	13,272	36398191	41030969	53446863
TN-40	12,909	33491643	36922579	48700012
TN-40HT	12,909	33491643	36922579	48700012
HI-STAR 190SL	13,364	31907634	40984186	51573243
HI-STAR 190XL	13,636	32560720	41818848	52626918

Table 5-9: Cradle Modeling Results – Family 1 End Stops

Cask	Nominal End Stop Weight per End(lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 100	23,273	31791742	41822972	40285039
HI-STAR 100HB	29,091	37918666	78764969	78321041
HI-STAR 180	24,545	42279179	51551205	52133252
HI-STAR 60	24,000	27014338	50559633	49547744
TN-32B	30,364	56558696	78818952	69306526
TN-40	31,091	57912871	80706101	70965920
TN-40HT	31,091	57912871	80706101	70965920
HI-STAR 190SL	21,273	38400939	34801023	35530098
HI-STAR 190XL	20,000	36701031	29459126	29937032

5.1.3 Combined Cask and Cradle System TTCI Dynamic Modeling Inputs

The mass moments of inertia dynamic modeling inputs are to be reported to TTCI for each combined cask and cradle system. System mass moments of inertia are found using hand calculation and evaluated around the combined system center of gravity. The combined system center of gravity is a function of the mass and center of gravity of each cask and cradle and is calculated using the follow equations [10]:

$$cg_x = \frac{m_{Cask} * cg_{x,Cask} + m_{Cradle} * cg_{x,Cradle}}{m_{Cask} + m_{Cradle}}$$

$$cg_y = \frac{m_{Cask} * cg_{y,Cask} + m_{Cradle} * cg_{y,Cradle}}{m_{Cask} + m_{Cradle}}$$

$$cg_z = \frac{m_{Cask} * cg_{z,Cask} + m_{Cradle} * cg_{z,Cradle}}{m_{Cask} + m_{Cradle}}$$

Mass moments of inertia for each combined system are calculated using the individual cask and cradle mass moments of inertia and application of the parallel axis theorem. The combined system mass moments of inertia are calculated using the following equations [10]:

Rotational MMI Longitudinal (x) Axis

$$= \left[MMI_{x,Cask} + m_{Cask}\left(\left(cg_{y,System} - cg_{y,Cask}\right)^2 + \left(cg_{z,System} - cg_{z,Cask}\right)^2\right)\right] + \left[MMI_{x,Cradle} + m_{Cradle}\left(\left(cg_{y,System} - cg_{y,Cradle}\right)^2 + \left(cg_{z,System} - cg_{z,Cradle}\right)^2\right)\right]$$

Rotational MMI Lateral (y) Axis

$$= \left[MMI_{y,Cask} + m_{Cask}\left(\left(cg_{x,System} - cg_{x,Cask}\right)^2 + \left(cg_{z,System} - cg_{z,Cask}\right)^2\right)\right] + \left[MMI_{y,Cradle} + m_{Cradle}\left(\left(cg_{x,System} - cg_{x,Cradle}\right)^2 + \left(cg_{z,System} - cg_{z,Cradle}\right)^2\right)\right]$$

Rotational MMI Vertical (z) Axis

$$= \left[MMI_{z,Cask} + m_{Cask}\left(\left(cg_{x,System} - cg_{x,Cask}\right)^2 + \left(cg_{y,System} - cg_{y,Cask}\right)^2\right)\right] + \left[MMI_{z,Cradle} + m_{Cradle}\left(\left(cg_{x,System} - cg_{x,Cradle}\right)^2 + \left(cg_{y,System} - cg_{y,Cradle}\right)^2\right)\right]$$

Combined system mass moments of inertia are calculated for both loaded and empty casks.

Table 5-10: Combined Cask and Cradle Dynamic Modeling Inputs, Loaded Cask

Cask	Mass (lb)	cg relative to Railcar Deck Center (in)			Calculated Rotational Mass Moment of Inertia (lb*in²)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)	Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
NAC-STC	296,589	3.0	0.0	62.3	478458289	1185142470	1194301767
NAC-UMS UTC	297,022	2.5	0.0	62.3	442611789	1345109965	1354418225
MAGNATRAN	354,000	7.0	0.0	63.2	640614030	1717085951	1726063235
HI-STAR 100	300,438	0.7	0.0	63.7	397372649	1207976714	1193544596
HI-STAR 100HB	202,200	2.6	0.0	63.6	272858531	413492021	409059629
HI-STAR 180	317,829	17.6	0.0	63.9	473658043	1145347597	1141869297
HI-STAR 60	180,091	10.8	0.0	57.2	169842899	473423872	476349992
HI-STAR 190SL	396,110	17.3	0.0	63.6	598102106	1930100576	1917145263
HI-STAR-190XL	434,405	17.1	0.0	63.7	653201069	2469608514	2456334633
MP187	303,800	0.0	0.0	61.1	404290112	1203189865	1192497580
MP197	291,100	1.0	0.0	58.5	378835181	1196765935	1178167173
MP197HB	329,600	1.5	0.0	60.8	472040039	1443081392	1420404755
TN-32B	276,272	0.7	0.0	71.2	368257664	958202003	952945378
TN-40	284,409	0.3	0.0	71.2	389829387	989940166	981504675
TN-40HT	255,252	0.3	0.0	71.0	362612405	894191649	885865939
TN-68	299,000	6.3	0.0	73.3	462297386	1194823592	1168817519
TS125	315,000	4.5	0.0	68.7	443017091	1411036566	1377397504

Table 5-11: Combined Cask and Cradle Dynamic Modeling Inputs, Empty Cask

Cask	Mass (lb)	cg relative to Railcar Deck Center (in)			Calculated Rotational Mass Moment of Inertia (lb*in²)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)	Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
NAC-STC	230,767	3.2	0.0	60.6	395035510	937342825	949284722
NAC-UMS UTC	220,798	2.8	0.0	60.3	357018322	1022095262	1034766443
MAGNATRAN	250,000	7.0	0.0	61.2	479913875	1233184943	1245562383
HI-STAR 100	200,255	0.8	0.0	62.3	280791826	804020200	790758089
HI-STAR 100HB	-	-	-	-	-	-	-
HI-STAR 180	-	-	-	-	-	-	-
HI-STAR 60	158,621	10.7	0.0	56.8	154227003	417429962	420568385
HI-STAR 190SL	296,110	17.1	0.0	63.1	456046355	1443425893	1430748206
HI-STAR-190XL	318,005	16.9	0.0	63.2	487885669	1805453195	1792464977
MP187	222,700	0.0	0.0	59.7	315910218	883775924	874724549
MP197	202,710	1.0	0.0	56.7	284281794	829670349	813122076
MP197HB	205,000	1.4	0.0	58.6	320494050	906412081	886430884
TN-32B	-	-	-	-	-	-	-
TN-40	-	-	-	-	-	-	-
TN-40HT	-	-	-	-	-	-	-
TN-68	-	-	-	-	-	-	-
TS125	226,118	4.3	0.0	66.9	341808710	1028985354	997966315

5.2 Cradle to Railcar Clearances

The interface clearances between the cradle and the railcar are shown in Table 5-12 and are calculated below using the following drawing references:

DWG-3015278-002 [4]

DWG-3015137-002 [11]

DWG-3015138-000 [12]

DWG-3015277-000 [13]

DWG-3015139-000 [14]

DWG-3015140-001 [15]

Table 5-12: Maximum Cradle to Railcar Clearances

	Longitudinal	Lateral	Vertical
Maximum Clearance	0.86 inches	0.78 inches	0.432 inches
Minimum Clearance	0.14 inches	0.16 inches	0.128 inches

5.2.1 Longitudinal Clearance

The conceptual cradle designs for Families 2-4 are supported longitudinally by the shear blocks welded to the railcar. The conceptual cradle designs for Family 1 are supported longitudinally by the end stop assemblies which are shimmed to remove any gap. Therefore, there is no clearance in the longitudinal direction for the Family 1 conceptual cradle designs.

For the cradles in Families 2-4, the longitudinal interface is shown in Figure 5-1 and evaluated in the table below:

Table 5-13: Cradle to Rail Longitudinal Clearance

DWG-3015278-002 (Cradle Attachment Components)	DWG-3015138-000, DWG-3015139-000, DWG-3015140-001, DWG-3015277-000 (Conceptual Cradle Families 2-4 Drawings)	
Distance between shear blocks = 36.00±.12	Distance between shear blocks =(80.25±.12) – (44.75±.12) = 35.5±.24 =35.5±.12 =35.5±.125 =(80.25±.12) – (44.75±.12) = 35.5±.24	 DWG-3015138-000 DWG-3015139-000 DWG-3015140-001 DWG-3015277-000

The minimum gap is:

$$min\ clearance = (36.00 - .12) - (35.5 + .24) = .14\ inches$$

The maximum gap is

$$max\ clearance = (36.00 + .12) - (35.5 - .24) = .86\ inches$$

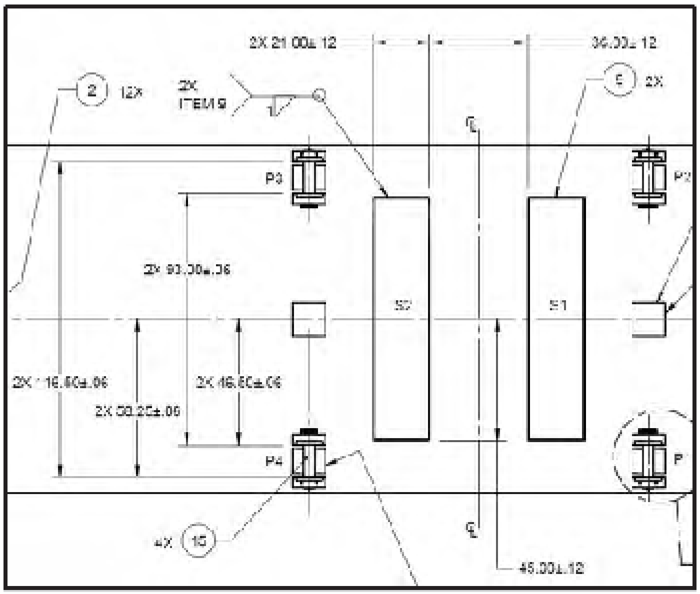

Figure 5-1: Attachment Components Interface

5.2.2 Lateral Clearance

All of the conceptual cradle designs are supported laterally by the center pin attachment blocks. The structural evaluation of the attachment components is performed in CALC-3015276 [9]. From Section 5.2.7 of [9], the conceptual cradle I-beam width is 11.265 inches. The lateral interface is shown in Figure 5-1 and evaluated in the table below:

Table 5-14: Cradle to Railcar Lateral Clearance

DWG-3015278-002 (Cradle Attachment Components)	DWG-3015137-002, DWG-3015138-000, DWG-3015139-000, DWG-3015140-001, DWG-3015277-000 (Conceptual Cradle Drawings)
Edge of inboard center pin attachment blocks dimension =93.00±.06	Inside edged of cradle I-beams =93.50±.25 DWG-3015137-002 =93.50±.25 DWG-3015138-000 =93.50±.12 DWG-3015139-000 =93.50±.25 DWG-3015140-001 =93.50±.25 DWG-3015277-000
Edge of outboard center pin attachment blocks =116.50±.06	Outside of cradle I-beams =93.50±.25+2(11.265) = 116.03±.25

At the inboard center pin attachment to cradle I-beam interface:

The minimum gap is:

$$min\ clearance = (93.50 - .25) - (93.00 + .06) = .19\ inches$$

The maximum gap is

$$max\ clearance = (93.50 + .25) - (93.00 - .06) = .81\ inches$$

At the outboard center pin attachment to cradle I-beam interface:

The minimum gap is:

$$min\ clearance = (116.50 - .06) - (116.03 + .25) = .16\ inches$$

The maximum gap is

$$max\ clearance = (116.50 + .06) - (116.03 - .25) = .78\ inches$$

The cradle will contact the outboard edge of the center pin attachment blocks first. The maximum, worst-case clearance (cradle pushed to one side laterally) is 0.78 inches.

5.2.3 Vertical Clearance

All of the conceptual cradle designs are supported vertically by the center pin attachment blocks. Revised dimensions are per reference [18]. A pinned connection is used with an Ø4.000±.002 pin. The Ø4.13±.06 hole on the cradle is round while the cradle connection is a 4.37+.06/-.00 slotted hole. The maximum clearance can be calculated using the minimum of the slot and hole maximum conditions and the smallest pin diameter. This assumes the hole/slot size is not reduced from misalignment which would reduce the clearance.

The maximum vertical clearance is

$$max\ clearance = (4.37 + .06) - (4.000 - .002) = .432\ inches$$

The minimum vertical clearance can be calculated using the minimum condition hole and slot sizes, with the maximum sized pin, and the maximum misalignment per the hole locations.

The minimum cradle hole size is: 4.13-.06= 4.07

The minimum center pin attachment block slot height is: 4.37-.00 = 4.37

The maximum misalignment comes from the tolerance on the cradle and pin block hole/slot vertical locations.

The center pin attachment block tolerance height from base plate = 9.50± .03

The cradle hole height from base plate (bottom of cradle) = 9.50±.06

The maximum misalignment = .03+.06 = .09

This half difference in slot height – cradle hole = (4.37-4.07)/2 = .15

The minimum through hole due to misalignment = 4.07 – (.09-.15) = 4.130 inches

The maximum pin diameter is 4.002 inches.

$$min\ clearance = 4.130 - 4.002 = .128\ inches$$

6.0 COMPUTER SOFTWARE USAGE

File listings are generated using the "Get-ChildItem" command in PowerShell. File listings include date and time of most recent save, file size in bytes, and file name. Each SolidWorks calculation model consists of a large number of part models as well as associated assembly models and drawings. The results of each SolidWorks mass moments of inertia calculation are saved both as a .pdf text output as well as a .jpeg screen capture. The screen captures are included in Appendix A.

COMPUTER RUN RECORD	
Run description	See input/output file names and the discussions in the body of the calculation
Software used	SolidWorks 2014 x64 Edition (Rev. 0) SolidWorks Premium 2016 x64 Edition (Rev. 2)
Computer name	EGONSIOROWSKI1
Hardware (processor name)	Intel® Xeon® CPU E5-1650 v2 @ 3.50 GHz
Operating system	64-bit Windows 7 Enterprise, Service Pack 1
Unique run identifier	See input/output file names and associated date/time stamps
List of input/output files	See input/output file names

Due to the large size of the SolidWorks model file listing (~800 lines), the file listing is contained in "SolidWorks Model Listing.txt" ("TN-40 Skid Assembly_Rev2.txt" and "Hi-Star 60 End Stop_Rev2.txt" for revision 2 models). The mass moments of inertia calculation output files are listed below.

Revision 0

```
       Directory: \Results
Mode                LastWriteTime     Length Name
d----         3/20/2017   1:28 PM            Family 1
d----         3/20/2017   1:28 PM            Family 2
d----         3/20/2017   1:28 PM            Family 3
d----         3/20/2017   1:28 PM            Family 4
-a---         3/14/2017  10:58 AM     144765 Ballast Load.JPG
-a---         3/14/2017  10:57 AM      10997 Ballast Load.pdf
-a---         3/15/2017  11:36 AM     137925 Railcar Hardware.JPG
-a---         3/15/2017  11:35 AM      10825 Railcar Hardware.pdf
    Directory: \Results\Family 1
-a---          3/8/2017  12:48 PM     139240 Hi-Star 100 Cradle.JPG
-a---          3/8/2017  12:48 PM      10984 Hi-Star 100 Cradle.pdf
-a---          3/8/2017   1:08 PM     120662 Hi-Star 100 End Stop.JPG
-a---          3/8/2017   1:07 PM      11094 Hi-Star 100 End Stop.pdf
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-a---          3/8/2017  12:49 PM      11120 Hi-Star 100HB Cradle.pdf
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-a---          3/8/2017   1:12 PM      11092 Hi-Star 180 End Stop.pdf
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-a---          3/9/2017   2:08 PM      10958 Hi-Star 190XL Cradle.pdf
-a---          3/9/2017   2:02 PM     129767 Hi-Star 190XL End Stop.JPG
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-a---         2/14/2017   1:44 PM      10870 TN-68.pdf
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-a---         2/14/2017   2:43 PM       10812 MP197HB.pdf
-a---         2/14/2017   3:01 PM      160391 TS125.JPG
-a---         2/14/2017   2:57 PM       10819 TS125.pdf
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-a---          3/3/2017   8:25 AM      152752 MP187.JPG
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Revision 2

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-a---         10/4/2018   2:33 PM      143666 Hi-Star 60 End Stop Rev2.JPG
-a---         10/4/2018   2:34 PM       11076 Hi-Star 60 End Stop Rev2.pdf
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COMPUTER RUN RECORD	
Software used	Excel 2010

Revision 0

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Revision 2

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Mode                 LastWriteTime     Length Name
-a---         10/8/2018   8:15 AM       34041 Hand Calculation_Rev2.xlsx
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6.1 In-Use Testing of SolidWorks

In-use testing of SolidWorks 2014 x64 Edition and SolidWorks Premium 2016 x64 Edition on computer EGONSIOROWSKI1 are covered in the associated software dedication reports, [23] and [24] respectively.

7.0 RESULTS/CONCLUSIONS

Results of this calculation are shown in Section 5.

7.1 Literature Search and other Background Data

A formal literature search was not applicable to this scope of work. All required background information is given under Section 1.1, *Project Background*.

8.0 REFERENCES

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2. Association of American Railroads, *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*, 2008
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6. AREVA Federal Services Calculation, CALC-3015134, *Atlas Railcar Family 2 Conceptual Cradle Structural Calculation*, Rev. 0
7. AREVA Federal Services Calculation, CALC-3015135, *Atlas Railcar Family 3 Conceptual Cradle Structural Calculation*, Rev. 0
8. AREVA Federal Services Calculation, CALC-3015136, *Atlas Railcar Family 4 Conceptual Cradle Structural Calculation*, Rev. 1
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13. AREVA Federal Services Drawing, DWG-3015277, *Atlas Railcar, Cradle Family 2 (TN-68), Conceptual Drawing*, Rev. 0.
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19. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section II, Part D, "Properties (Customary), Table PRD", 2015

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21. AREVA Federal Services Drawing, DWG-3018955, *Atlas Railcar Ballast Load Conceptual Drawing*, Rev. 0

22. AREVA Federal Services Request For Information, AFS-RFI-00225-0015-00, November 2016

23. AREVA Federal Services Calculation, CALC-3018479, *Software Dedication Report for SolidWorks 2014 x64 Edition*, Rev. 0

24. AREVA Federal Services Calculation, CALC-3019535, *Software Dedication Report for SolidWorks Premium 2016 x64 Edition*, Rev. 0

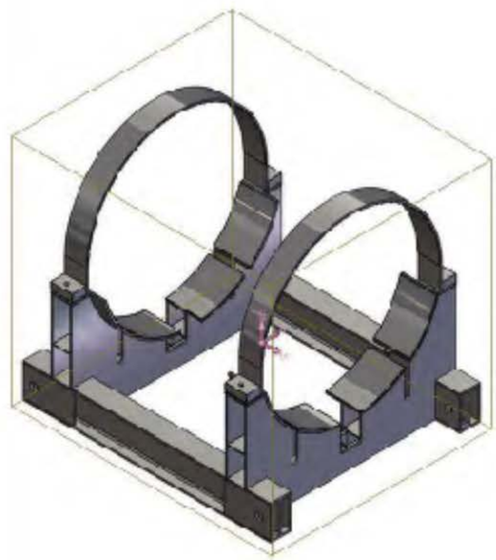
FOR INFORMATION
FS-18-0257

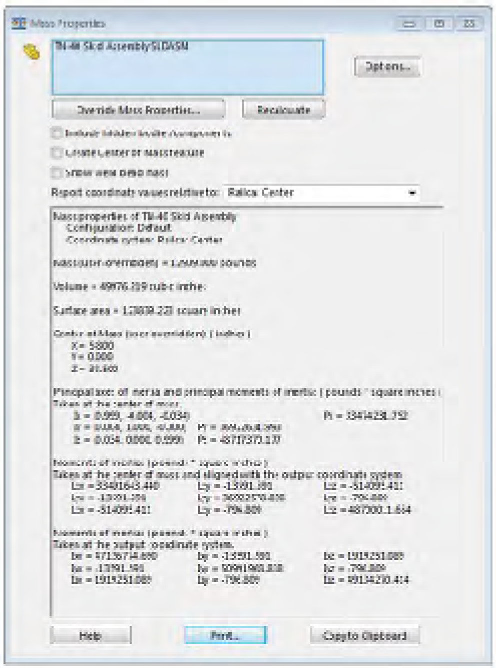
APPENDIX A: SOLIDWORKS CALCULATION OUTPUTS

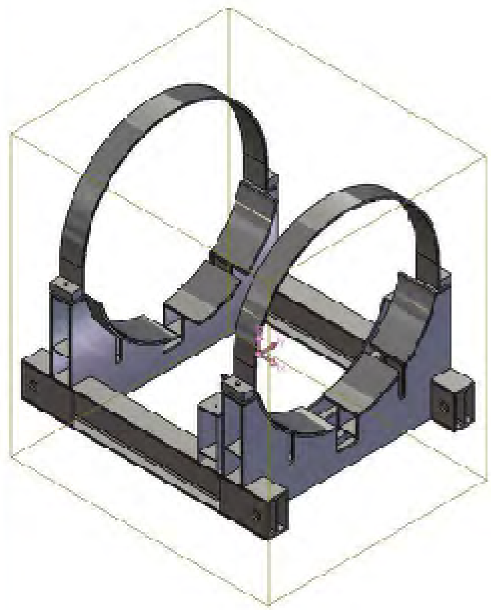
The mass moment of inertia for each cradle design is calculated within SolidWorks. The personnel barrier geometries are not included in each model but are included in the assembly masses. The mass moments of inertia are taken at the center of gravity of each model and aligned with the output coordinate system. The cradle masses and center of gravities are overridden within SolidWorks using hand-calculated values (overriding the center of gravity does not change the output of interest).

A.1 Family 1 Conceptual Cradles

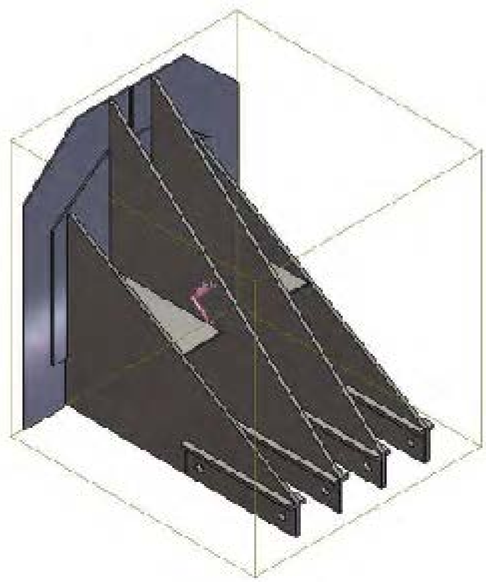
A.1.1 TN-40, TN-40HT and TN-32B

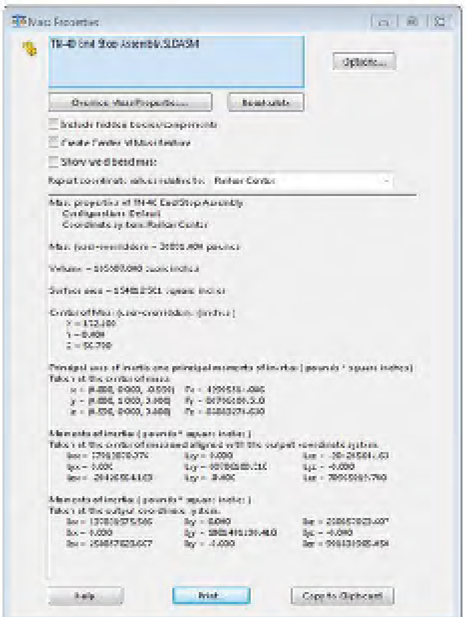


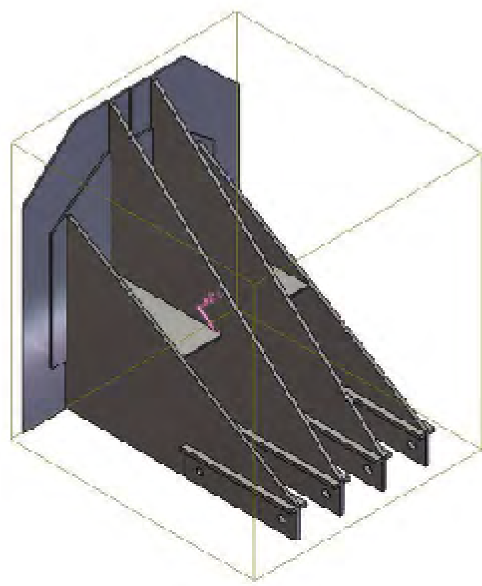




Cask	Nominal Central Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
TN-32B	13,272	36398191.476	41030969.263	53446863.383
TN-40	12,909	33491643.440	36922578.828	48700011.654
TN-40HT	12,909	33491643.440	36922578.828	48700011.654

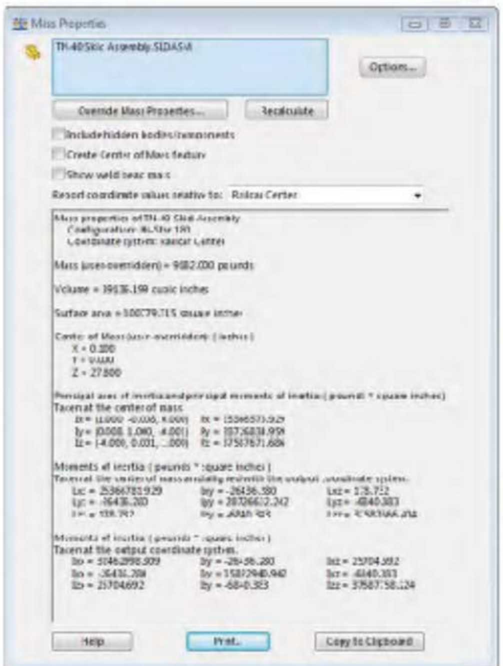


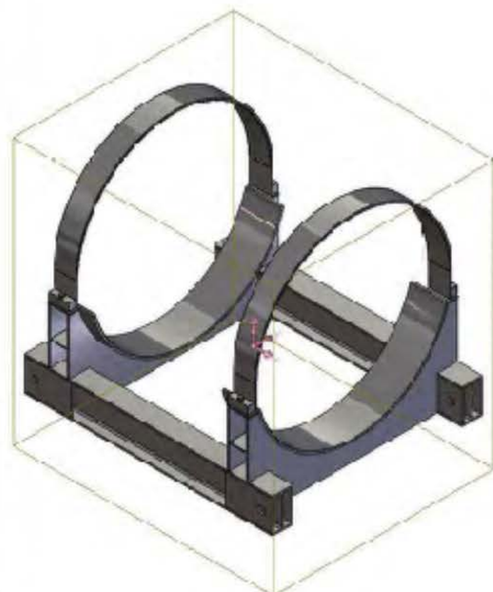




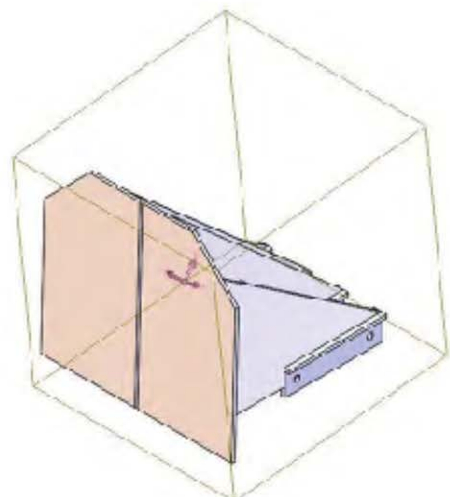
Cask	Nominal End Stop Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in²)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
TN-32B	30,364	56558695.903	78818951.984	69306525.585
TN-40	31,091	57912870.976	80706100.518	70965919.740
TN-40HT	31,091	57912870.976	80706100.518	70965919.740

A.1.2 HI-STAR 180



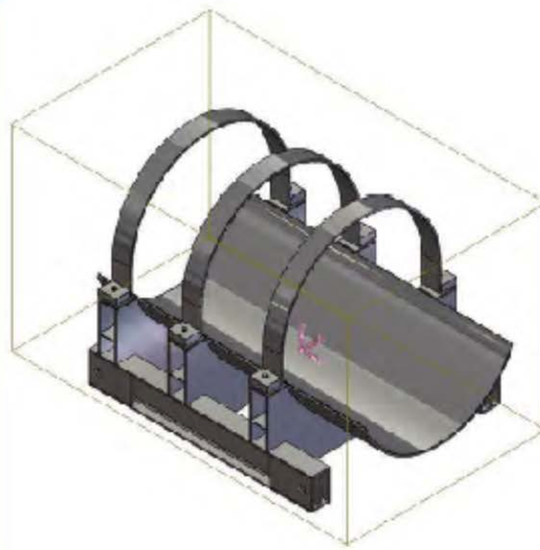


Cask	Nominal Central Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 180	9,182	25366781.929	28726632.242	37587666.404

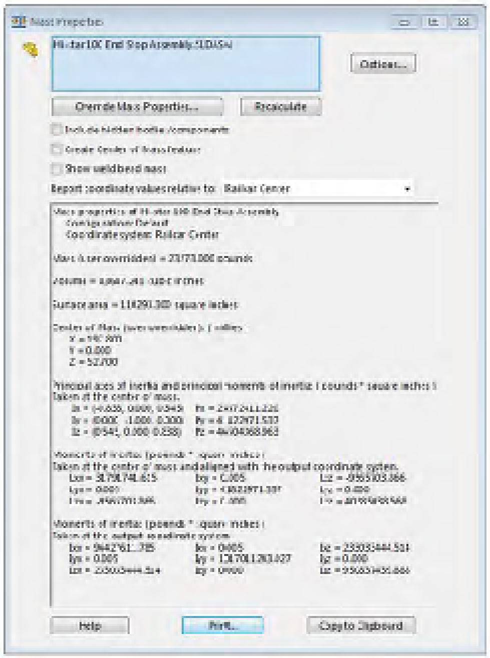


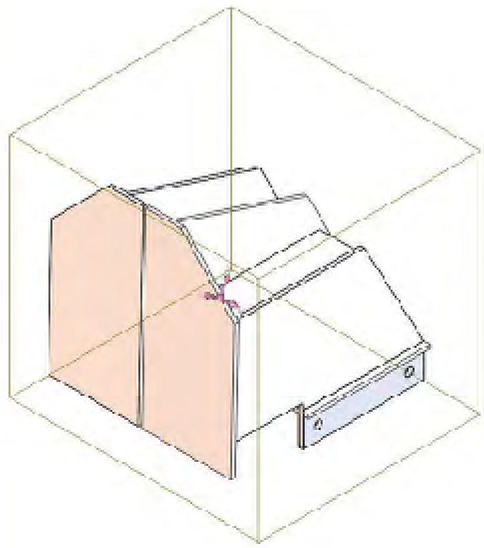
Cask	Nominal End Stop Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in²)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 180	24,545	42279179.300	51551204.651	52133252.111

A.1.3 HI-STAR 100



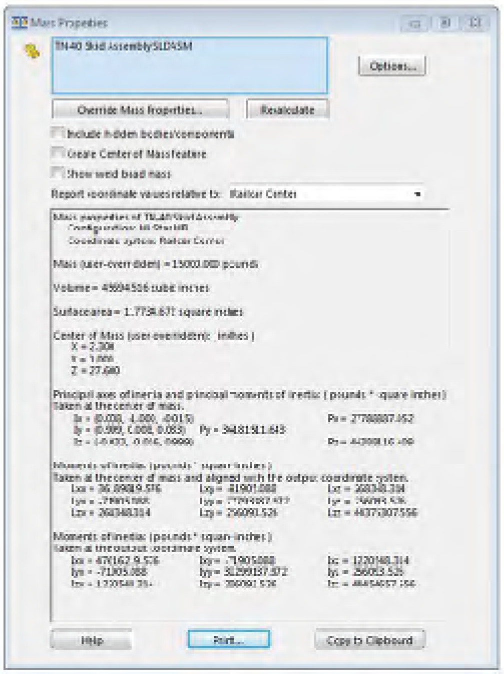
Cask	Nominal Central Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in²)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 100	20,545	43074601.740	50542231.734	67971424.922

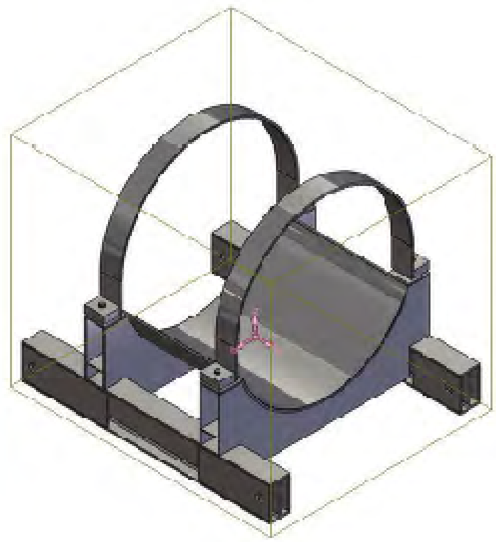




Cask	Nominal End Stop Weight (lb)	Calculated Rotational Mass Moment of Inertia, ($lb*in^2$)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 100	23,273	31791741.615	41822971.537	40285038.568

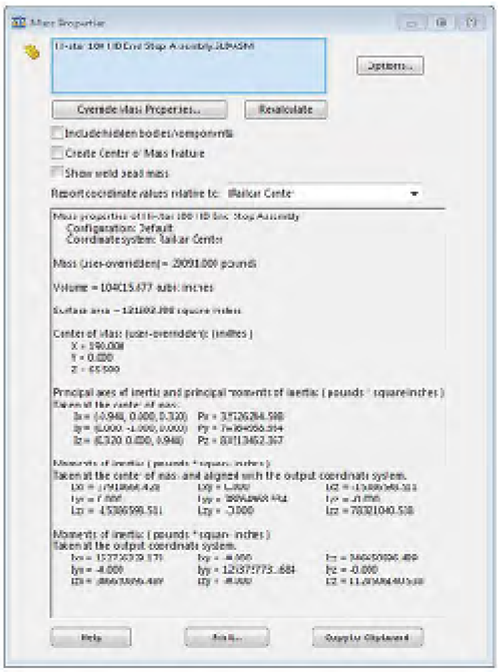
A.1.4 HI-STAR 100HB

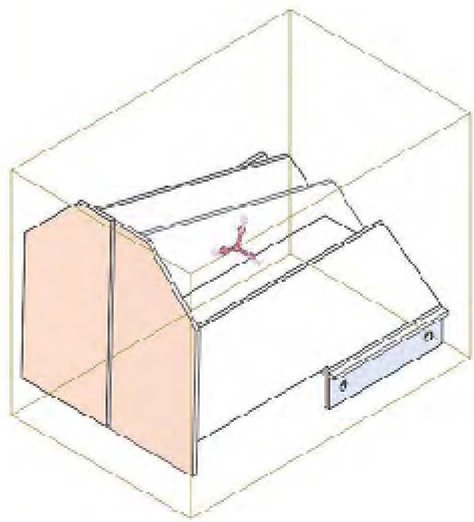




Cask	Nominal Central Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in²)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 100HB	15,000	36189819.576	27793387.972	44375307.556

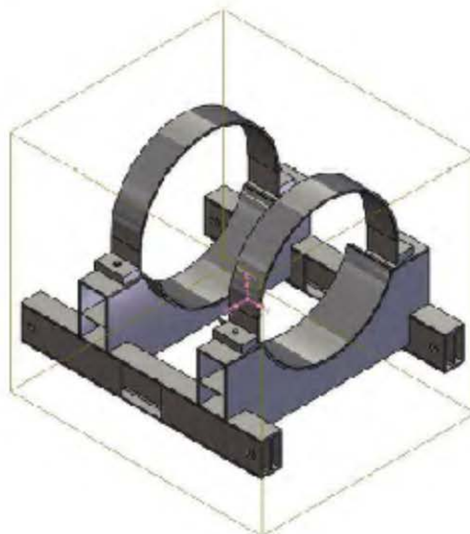
FOR INFORMATION
FS-18-0257





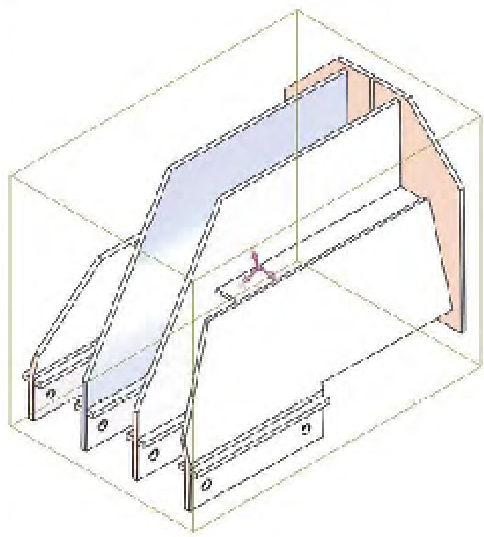
Cask	Nominal End Stop Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 100HB	29,091	37918666.428	78764968.934	78321040.538

A.1.5 HI-STAR 60



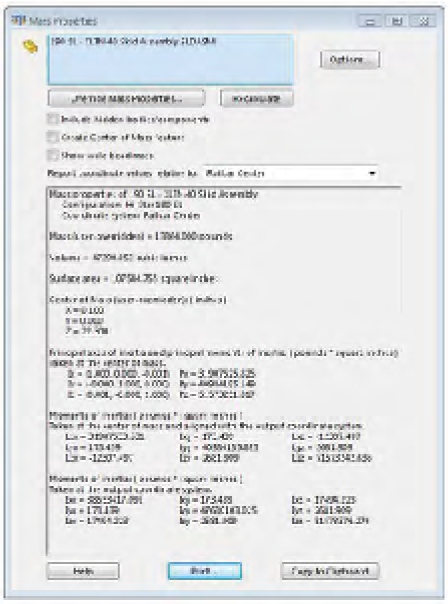
Cask	Nominal Central Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in²)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 60	16,091	36195190.708	30279548.253	49192034.902

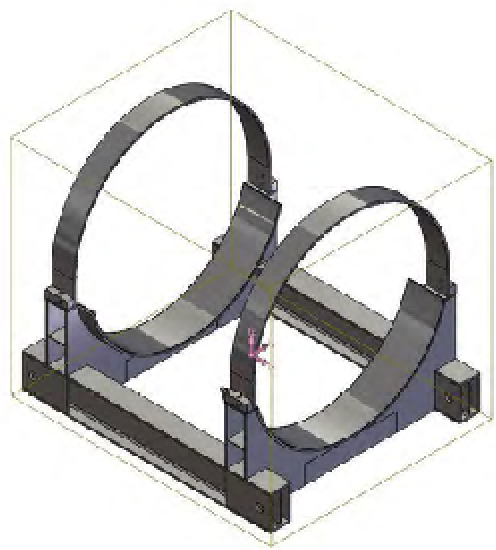
FOR INFORMATION
FS-18-0257



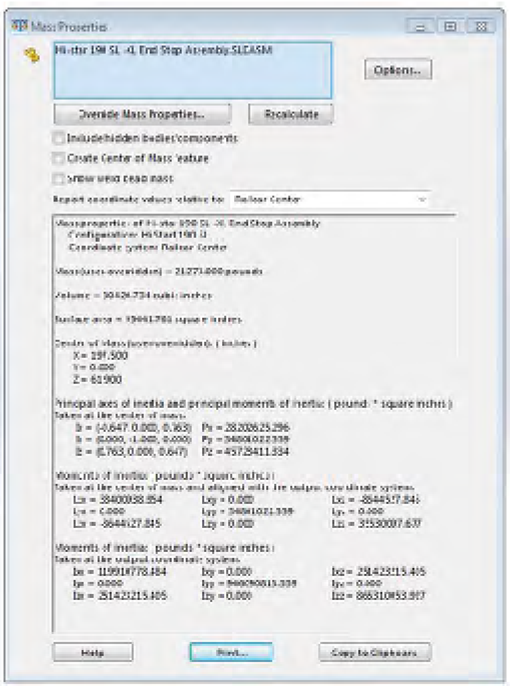
Cask	Nominal End Stop Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 60	24,000	27014338.421	50559632.859	49547743.907

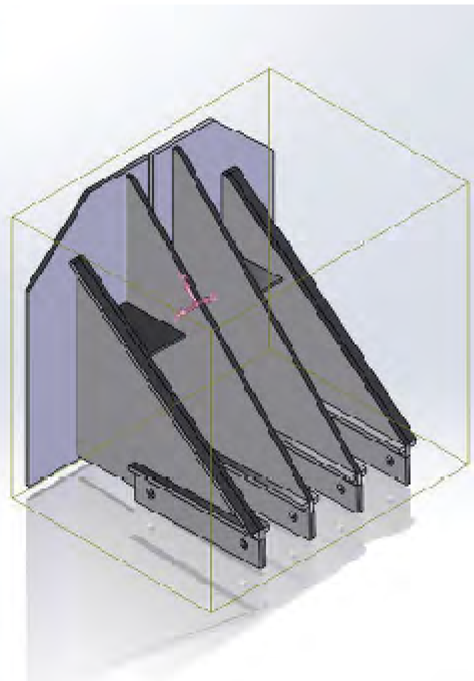
A.1.6 HI-STAR 190SL





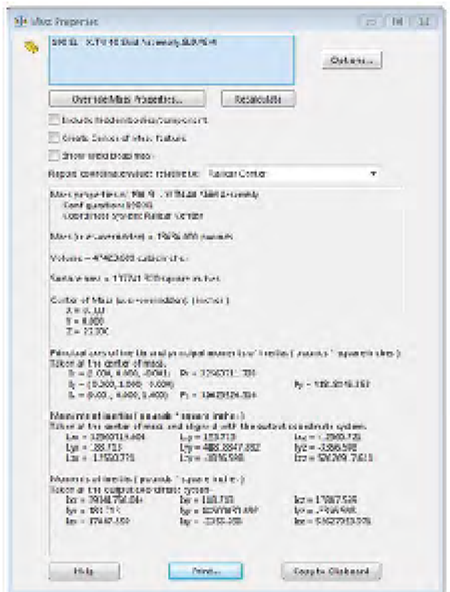
Cask	Nominal Central Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 190SL	13,364	31907633.531	40984185.825	51573242.636

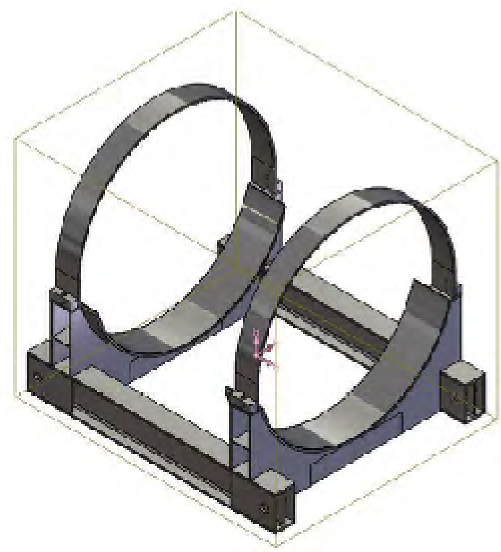




Cask	Nominal End Stop Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in²)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 190SL	21,273	38400938.954	34801022.559	35530097.677

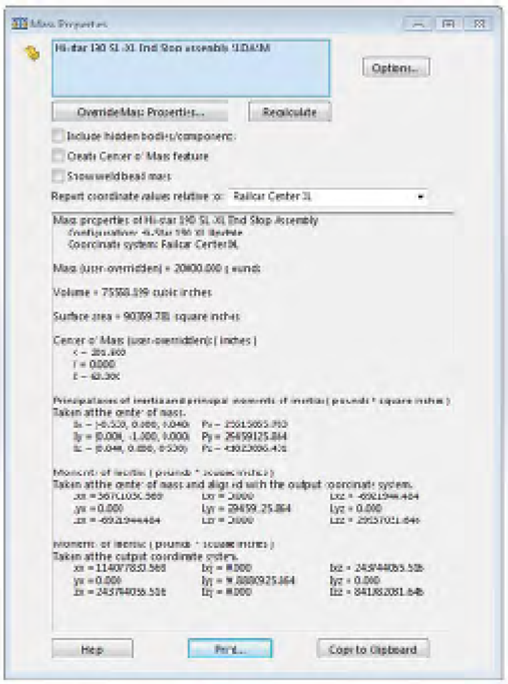
A.1.7 HI-STAR 190XL

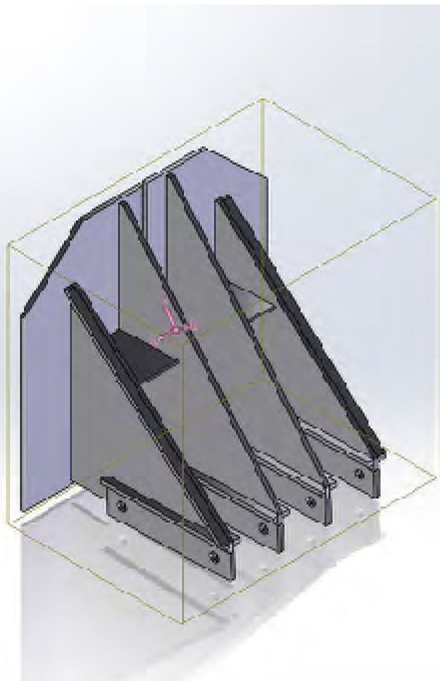




Cask	Nominal Central Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 190XL	13,636	32560719.604	41818847.892	52626917.611

FOR INFORMATION
FS-18-0257

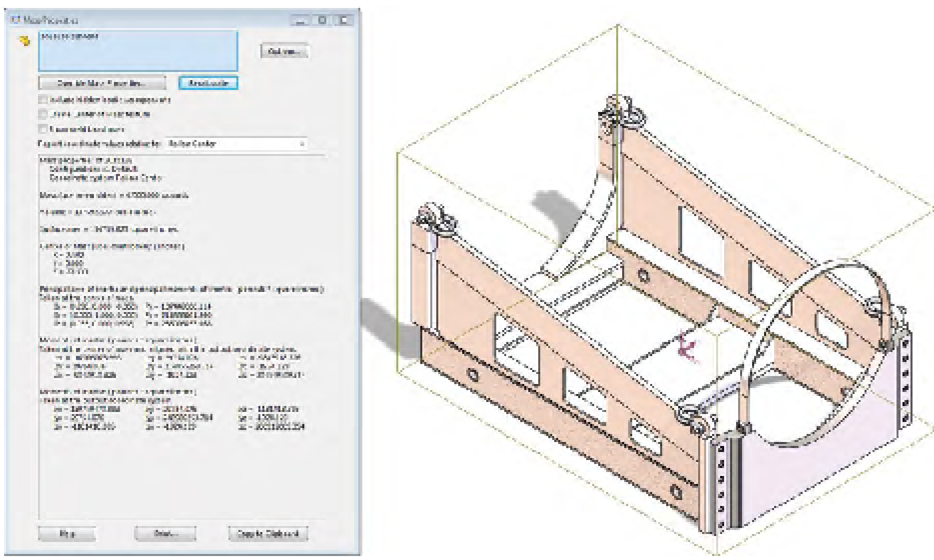




Cask	Nominal End Stop Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
HI-STAR 190XL	20,000	36701030.569	29459125.864	29937031.646

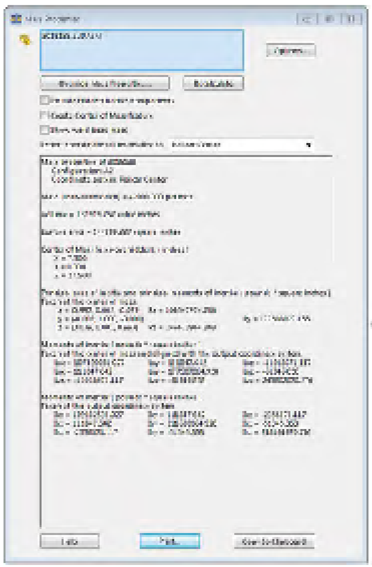
A.2 Family 2 Conceptual Cradles

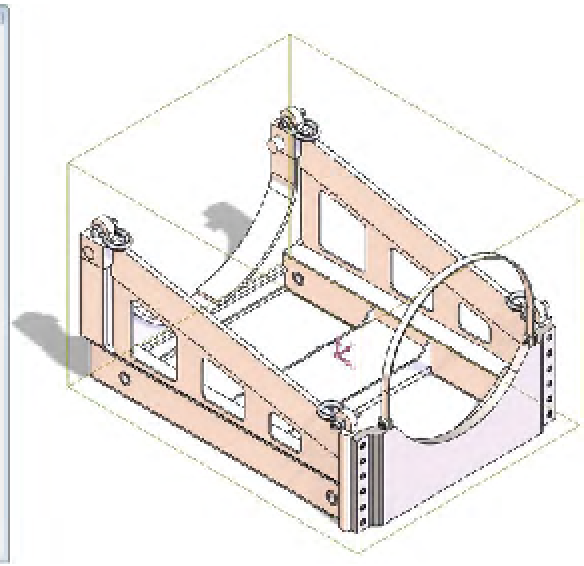
A.2.1 NAC MAGNATRAN



Cask	Nominal Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
MAGNATRAN	42,000	107996978.993	214855253.714	284549589.354

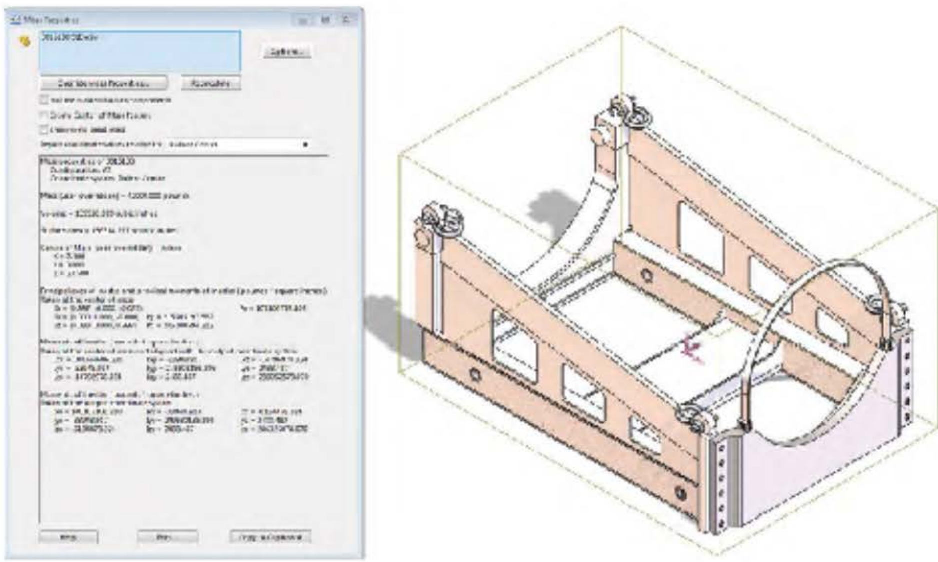
A.2.2 NAC STC





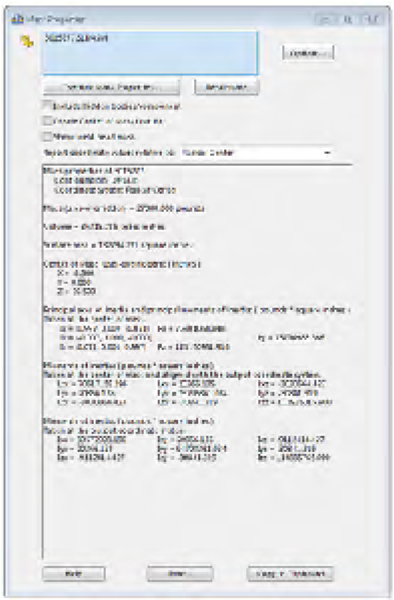
Cask	Nominal Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, ($lb*in^2$)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
NAC-STC	42,000	107420031.027	177507864.928	245802070.276

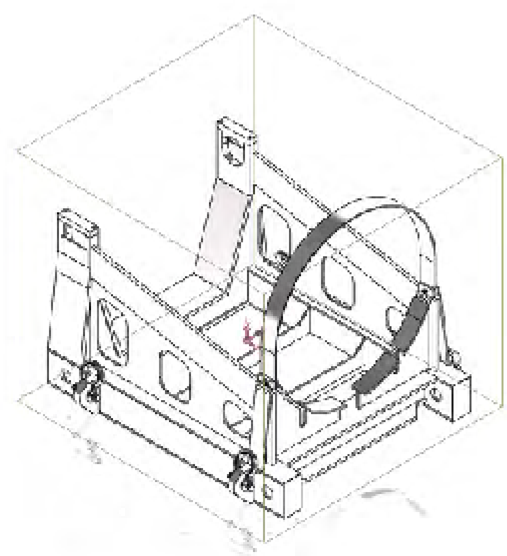
A.2.3 NAC-UMS UTC



Cask	Nominal Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
NAC-UMS UTC	42,000	108344606.230	215505186.896	283962578.070

A.2.4 TN-68

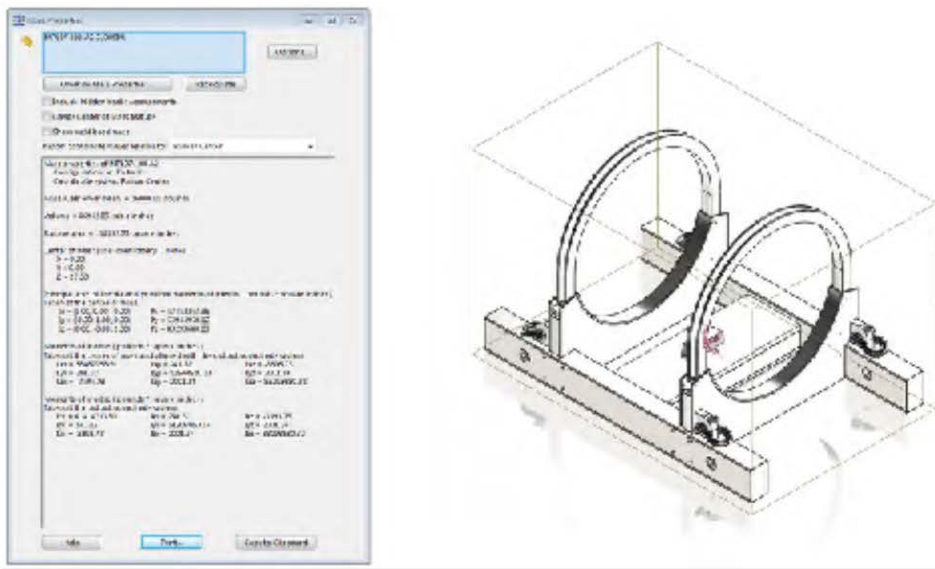




Cask	Nominal Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, ($lb*in^2$)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
TN-68	27,000	70617158.196	73796861.034	112935015.900

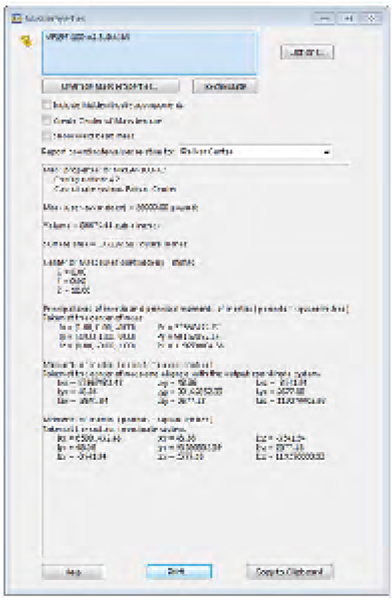
A.3 Family 3 Conceptual Cradles

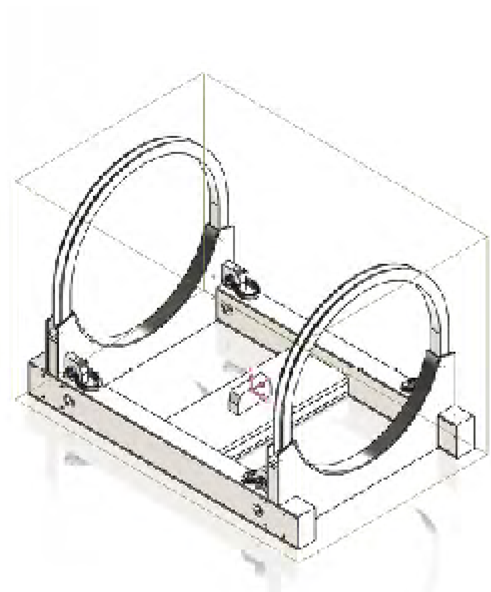
A.3.1 MP197



Cask	Nominal Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
MP197	26,000	53452253.91	53944950.14	83293680.32

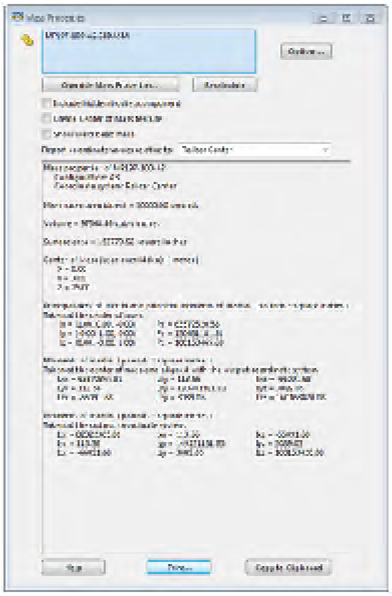
A.3.2 MP197HB

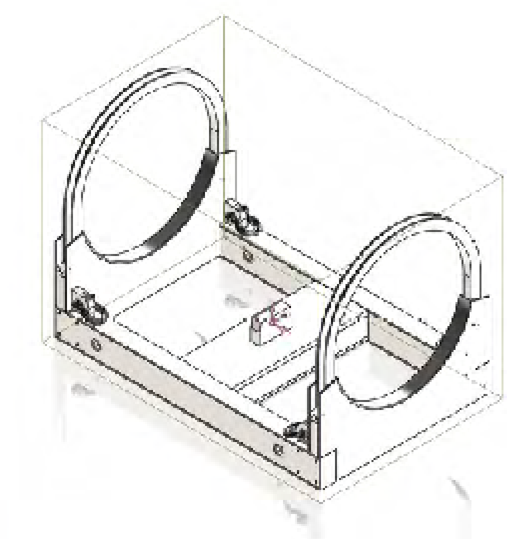




Cask	Nominal Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
MP197HB	26,000	57567432.48	90162852.39	119270003.93

A.3.3 TS125

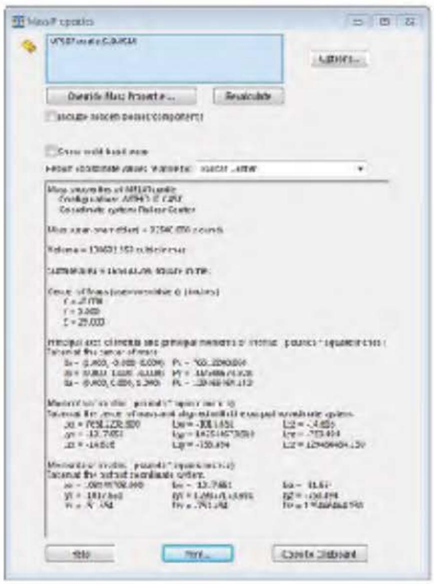


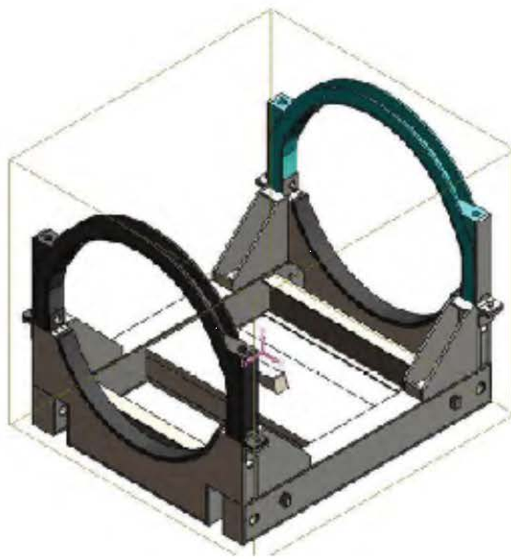


Cask	Nominal Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
TS125	30,000	63572365.81	130481181.83	160163420.08

A.4 Family 4 Conceptual Cradle

A.4.1 MP187



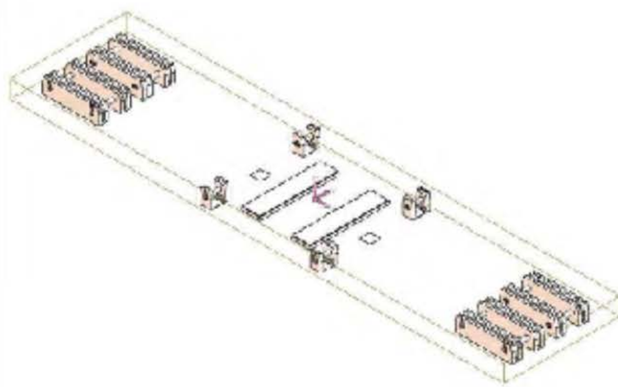


Cask	Nominal Cradle Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in²)		
		Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
MP187	32,500	76512208.900	102544673.910	129466464.130

APPENDIX B: ADDITIONAL DYNAMIC MODELING INPUTS

B.1 Attachment Hardware Permanently Attached to the Railcar Deck

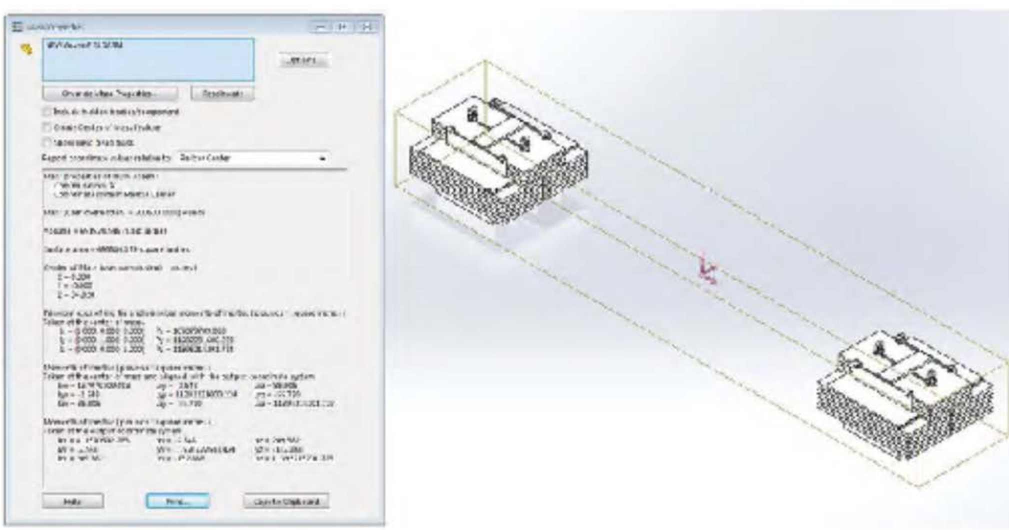
Permanently attached railcar hardware must be accounted for in TTCI's cask and cradle dynamic models. The mass moments of inertia for the permanently attached railcar hardware are calculated in SolidWorks. The hardware models are built in accordance with drawing [4]. Hand-calculated hardware mass and center of gravity from Table 9-1 in [9] are used, overriding values calculated by SolidWorks. The hardware mass is 28,331.6 pounds with a vertical center of gravity of 7.99 inches from the railcar deck (hardware is symmetrical along longitudinal and lateral axes). The model is composed of carbon steel (0.28 lb/in^3) and stainless steel (0.29 lb/in^3) to establish the model weight distribution. Mass moments of inertia are evaluated around the railcar deck center and are shown below.



Nominal Hardware Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
	Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
28331.6	26899955.590	1233094554.924	1258392165.941

B.2 Ballast Load

The Atlas railcar will require additional mass, a ballast load, to be able to be transported without a cask and cradle loading. The mass moments of inertia for the ballast load are calculated in SolidWorks. The hardware is built in accordance with drawing [21]. Hand-calculated load mass and center of gravity from Table 4-2 in [20] are used, overriding values calculated by SolidWorks. The load mass is 200,500 pounds for a ballast load pair (one assembly at each end of the railcar). The vertical center of gravity is 32.42 inches from the bottom of the ballast assembly (each ballast load is symmetrical along the longitudinal axis; a pair is symmetrical along the lateral axis). The ballast load pin hole center is 7.5 inches from the bottom of the ballast assembly [21], while the attachment hardware pin hole center is 10 inches from the railcar deck [4]. Thus, the vertical center of gravity of the ballast assembly is (32.42-7.5+10) = 34.92 inches from the railcar deck. The model is composed of carbon steel (0.28 lb/in^3) and stainless steel (0.29 lb/in^3) to establish the model weight distribution. Mass moments of inertia are evaluated around the railcar deck center and are shown below.



Nominal Ballast Weight (lb)	Calculated Rotational Mass Moment of Inertia, (lb*in^2)		
	Longitudinal Axis (x)	Lateral Axis (y)	Vertical Axis (z)
200,500	167079709.083	11282231600.224	11395215201.723

CALC-3015276-004
Page 1 of 42

FOR INFORMATION
FS-18-0257

Orano Federal Services				
CALCULATION				
Document No.:	CALC-3015276	Rev. No.	004	Page 1 of 42
Project No.:	00225.03.0050	Project Name:	DOE Atlas Railcar	
Title:	Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation			

Summary:

This calculation contains the structural evaluation of the Atlas Railcar standardized attachment components. This calculation also calculates the combined center of gravity (cg) and weight for the railcar, cradles and packages.

This document is not safety related.

FOR INFORMATION

Safety ☐ Non-Safety ☒

Contains Unverified Input / Assumptions: Yes: ☐ No: ☒

Software Utilized: None Software Active in FS EASI: Yes: ☐ NA*: ☒ *Not Applicable per Section 5.7 of FS-EN-PRC-002 Error Notices & Associated Corrective Actions Reviewed: Yes: ☐ No: ☒	Version: N/A	Storage Media: Yes: ☐ No: ☒ Location: N/A

	Printed Name	Signature	Date
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Other:	N/A		

FS-EN-FRM-002 Rev. 10 (Effective March 1, 2018)
Refer to FS-EN-PRC-002

Orano Federal Service
OCT 15 2018
Records Management

Revision History

Rev.	Changes
000	Initial issue
001	Revised to update railcar to 12 axle design.
002	Revised to update for HI-STAR 190 casks/cradles and to add attachment components weight calculation. Revised for updated Atlas railcar deck heights and Family 1 and 4 cradle changes. Removed weld evaluation. Also, revised attachment component hole/slot size and added ballast load. Other editorial changes.
003	Revised project background for editorial changes. Revision bars left from revision 2 for clarity.
004	Revised to update for changes to HI-STAR 60 conceptual cradle design. Also revised Section 5.2.7 to neglect cladding from attachment pin bending calculation. Updated for company name change.

Table of Contents

List of Tables

List of Figures

1.0 PURPOSE

1.1 Project Background

The United States Department of Energy (DOE) is laying the groundwork for implementing an integrated nuclear waste management system. This includes preparing for future large-scale transport of spent nuclear fuel (SNF) and high-level waste (HLW); since transport will be a necessary component of any integrated nuclear waste management system. With this project the DOE will provide for the transportation of SNF and HLW by means of a specific railcar (named by the DOE as the Atlas railcar) to carry SNF and HLW casks.

As part of this project, DOE has contracted with Orano Federal Services (FS), formerly AREVA Federal Services LLC (AFS), to design the Atlas railcar including standardized attachment components (railcar tie-down interface), and transport package conceptual cradle designs for the 17 SNF transportation casks (herein referred to as "packages") listed in Attachment A of the Statement of Work (SOW) [1].

The DOE Atlas railcar (and by extension to subsystems, the package cradles) must be designed and built to satisfy the requirements of Association of American Railroads (AAR) Standard S-2043 [2] and the FS Design Basis Requirements Document (DBRD) [3]. Application of this standard to the conceptual design analyses is described in Section 2.0. The standardized attachment components are part of the railcar and must also meet the AAR S-2043 requirements.

FS has chosen to divide the 17 packages into 4 families based on the package tie-down methods. The packages contained in each of these four families are listed below:

Family 1 TN-32B, TN-40, TN-40HT, HI-STAR 60, HI-STAR 100, HI-STAR 100HB (also referred to as HI-STAR HB), HI-STAR 180, HI-STAR 190 SL and the HI-STAR 190 XL.

Family 2 MAGNATRAN®, NAC-STC™, NAC-UMS UTC™, and the TN-68.

Family 3 MP-197, MP-197HB, and the TS125.

Family 4 MP-187.

The empty Atlas railcar will require a ballast load to meet the requirements of AAR Standard S-2043. The ballast load conceptual design is a separate payload from the cask/cradles and must be considered in the attachment design.

1.2 Calculation Purpose

This calculation contains the structural evaluation of the Atlas Railcar standardized attachment components. This calculation also calculates the combined center of gravity (cg) and weight for the railcar, cradles and packages.

1.3 Atlas Railcar Standardized Attachment Components

The Atlas Railcar Standardized Attachment Components are depicted in FS Drawing DWG-3015278 [4] and are shown in Figure 1-1 below. There are four center pin attachment blocks welded to the railcar that are used for cradle designs in families 1 through 4. The cradles are secured laterally and vertically using four attachment pins inserted through the center pin attachment blocks. Longitudinal restraint for cradle families 2 through 4 is provided by shear blocks welded to the railcar. Family 1 cradles are restrained longitudinally by end stop assemblies attached to the railcar using the outer eight attachment blocks, each of which has two pin locations. The end stop assemblies are pinned in place.

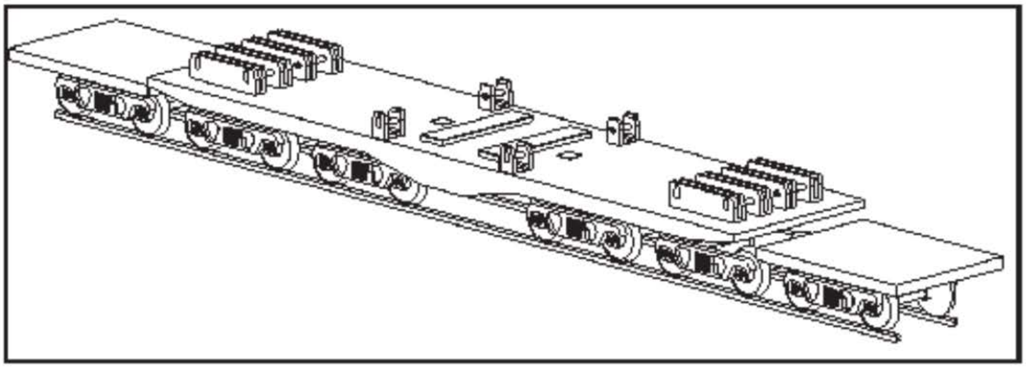


Figure 1-1: Atlas Railcar Standardized Attachment Components

2.0 METHODOLOGY

The conceptual design of each cradle and ballast load was evaluated to determine the tie-down loads applied to the railcar via the standardized attachment components. Each cradle or ballast load is required to support the 7.5g/2g/2g tie-down loads taken individually per Section 2.2.2.13 of the DBRD [3]. The bounding loads from the 17 package designs and associated conceptual cradle designs and the ballast load conceptual design are applied to the standardized attachment components and the bounding loads are shown in Section 4.0.

This calculation uses manual calculations to evaluate the standardized attachment components including the pin attachment blocks, the shear blocks and the attachment pins shown in FS drawing DWG-3015278 [4]. Material properties are taken at 100 °F per the DBRD [3].

The combined cg and weight of the railcar and load is determined using the package weights and vertical cg locations, calculated weights and vertical cg locations of the conceptual cradle designs, calculated weight and vertical cg location of the conceptual ballast design and the railcar deck height and railcar vertical cg location provided by KASGRO [27].

The fatigue capability of the design will be explored to provide reasonable assurance that the attachment components will support the fatigue loads of Chapter 7 of M-1001 [28] for the design life of the railcar. The fatigue analysis of the railcar should cover the weld details between the attachment components and the railcar.

2.1 Acceptance Criteria

Stresses for the attachment components shall be compared to the allowable stresses. The allowable stress for the standardized attachment components is yield strength for tensile and compressive stresses per Section 2.2.2.13 of [3], and 0.6 of yield stress for shear stresses. Where necessary, stresses will be combined to determine the von Mises stress per equation 6-18 of [7] shown below and compared to the allowable tensile stress.

$$\sigma_v = \sqrt{\sigma_x^2 + 3\tau_{xy}^2}$$

Per Section 2.2.1.1 of [3], the cask car and buffer car must comply with the AAR's Manual of Standards and Recommended Practices which includes M-1001 [28]. Per Section 2.1.3 of M-1001, the combined cg of a fully loaded car must be less than 98 inches. The combined weight of the railcar, cradle and loaded cask or railcar and ballast load must be less than 65,750 pounds per axle (789,000 pound loaded car limit) per AFS-IN-16-0039 [6].

The attachment components must allow for impact limiter removal for all 17 of the packages listed in Attachment A of the SOW [1].

2.2 Margin of Safety

A margin of safety is used to indicate the degree of confidence in the allowable loads and stresses. For acceptance the margin of safety must be greater or equal to zero. The margin of safety (MS) of component stresses is calculated as:

$$MS = \frac{\text{Allowable Stress}}{\text{Actual Stress}} - 1 \geq 0$$

Additional design confidence and increased conservatism is provided from 10% increase in load discussed in Section 4.1. All calculated margins of safety greater than or equal to zero include this additional factor.

3.0 ASSUMPTIONS

3.1 Unverified Inputs/Assumptions

None.

3.2 Justified Assumptions

None.

4.0 DESIGN INPUTS

4.1 Transportation Package Design Inputs

Design inputs for the tie-down loading are taken from the following calculations:

1. Atlas Railcar Family 1 Conceptual Cradle Structural Calculation [10]
2. Atlas Railcar Family 2 Conceptual Cradle Structural Calculation [11]
3. Atlas Railcar Family 3 Conceptual Cradle Structural Calculation [12]
4. Atlas Railcar Family 4 Conceptual Cradle Structural Calculation [13]
5. Atlas Railcar Conceptual Ballast Load Structural Calculation [17]

The tie-down loadings for each cask family were taken from the above calculations and compiled to list the maximum loading value at each attachment point as shown in Table 4-1. Pin locations are shown in Figure 4-1.

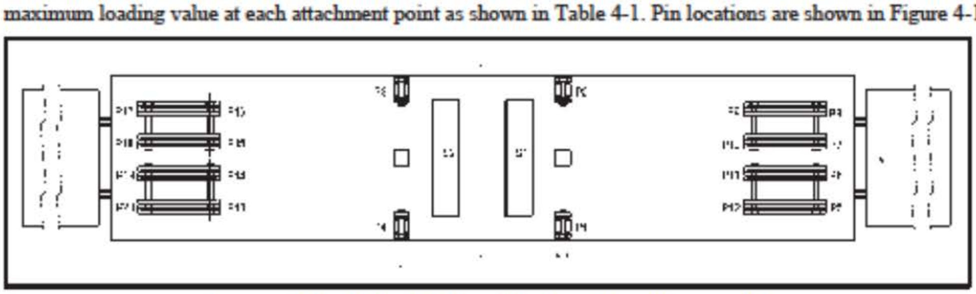


Figure 4-1: Atlas Railcar Pin Location Nomenclature

Table 4-1: Initial Tie-Down Loading Inputs (kips)

	Pin Location 1(1)	Pin Location 2(1)	Pin Location 3(1)	Pin Location 4(1)
vertical (+z)	664	664	664	664
vertical (-z)	664	664	664	664
lateral (y)(3)	555	555	555	555
	Shear Block(1)			
axial (x)	2,655			
	Pin Location 5-8(2)	Pin Location 9-12(2)	Pin Location 13-16(2)	Pin Location 17-20(2)
Axial (+x)	0	858	207	0
Axial (-x)	0	207	858	0
vertical (+z)	107	979	979	107
vertical (-z)	979	107	107	979
lateral (y)	132	132	132	132

Notes:

1. The bounding vertical and axial (longitudinal) loads are from the MAGNATRAN package per Table 6-1 of [11]. The bounding lateral load is from Table 2.2 of HI-STAR 190 XL [10].

   The bounding vertical load is calculated based on the following assumptions: 1) the Family 1 casks are assumed to be restrained without motion by the end stop assemblies and impact limiter and shims (if required) are assumed to be rigid under the securement tie-down loads (7.5 g). 2) if crush of the impact limiter could occur under load, the cask vendor will need to add a shear key and address other features of the cradle that may be affected by the new load path. The vendor will also need to ensure that all SAR requirements are met. 3) shims (if required) are assumed to be rigid and captured.

2. The bounding loads for Pin locations 5-20 are taken from Table 2.2 of [10] or Table 6-1 of [17].

3. The maximum lateral load is from the HI-STAR 190 XL package per [10]. Conservatively, the lateral loading is assumed to result in a combined loading at one pin location. The maximum vertical load from any lateral load case is 283.6 kips from Table 2.2 of [10].

The standardized attachment components will be fabricated and attached to the Atlas railcar. These attachment points must accommodate both the conceptual and the final cradle designs for all 17 packages listed in the SOW. The conceptual cradle designs are not final and some small changes are anticipated in the final cradle design (to be performed at a later date). Therefore, an additional factor of 1.1 was added to the loadings to provide increased conservatism in the attachment component design. Final tie-down loading inputs are shown in Table 4-2.

Table 4-2: Final Tie-Down Loading Inputs (kips)

	Pin Location 1	Pin Location 2	Pin Location 3	Pin Location 4
vertical (+z)	730	730	730	730
vertical (-z)	730	730	730	730
lateral (y)[1]	611	611	611	611
	Shear Block			
axial (x)	2,921			
	Pin Location 5-8	**Pin Location 9-12**	**Pin Location 13-16**	**Pin Location 17-20**
Axial (+x)	0	944	228	0
Axial (-x)	0	228	944	0
vertical (+z)	118	1,077	1,077	118
vertical (-z)	1,077	118	118	1,077
lateral (y)	145	145	145	145

Notes: 1. The adjusted maximum vertical load to be combined with the lateral load in the lateral load case is 283.6(1.1) = 312 kips

To calculate the combined weight and center of gravity location, the maximum (loaded) cask weight, cask vertical cg location, minimum cradle weight, cradle vertical cg location as well as the railcar weight, deck height (when loaded) and railcar vertical cg location are required. The cask weights and cg locations are shown in Table 4-3. Cradle design inputs are shown in Table 4-4.

Table 4-3: Cask Design Inputs

Cask	Family	Maximum (Loaded) Cask Weight, lb	Minimum (Empty) Cask Weight, lb[1]	Cask Vertical cg from railcar deck, in[2]	Reference
NAC-STC	2	254,589	188,767	67.50+0.5 = 68.00	Table B-2 of [11]
NAC-UMS UTC	2	255,022	178,798	67.50+0.5 = 68.00	Table B-2 of [11]
MAGNATRAN	2	312,000	208,000	67.50+0.5 = 68.00	Table B-2 of [11]
HI-STAR 100	1	279,893	179,710	66.00+0.5 = 66.50	Table 4.1 of [10]
HI-STAR 100HB	1	187,200	-	66.00+.05 = 66.50	Table 4.1 of [10]
HI-STAR 180	1	308,647	<308,647	64.50+0.5 = 65.00	Table 4.1 of [10]
HI-STAR 60	1	164,000	<164,000	59.63+0.5 = 60.13	Table 4.1 of [10]
HI-STAR 190 SL	1	382,746	282,746	64.50+0.5 = 65.00	Table 4.1 of [10]
HI-STAR 190 XL	1	420,769[3]	304,369	64.50+0.5 = 65.00	Table 4.1 of [10]
MP187	4	271,300	190,200	64.5+0.5 = 65.00	Table 4.1 of [13]
MP197	3	265,100	176,710	62.00+0.5 = 62.50	Table 5.3-1 of [12]
MP197HB	3	303,600	179,000	64.00+0.5 = 64.50	Table 5.3-1 of [12]
TN-32B	1	263,000	-	72.5+0.5 = 73.00	Table 4.1 of [10]
TN-40	1	271,500	-	72.5+0.5 = 73.00	Table 4.1 of [10]
TN40HT	1	242,343	-	72.5+0.5 = 73.00	Table 4.1 of [10]
TN-68	2	272,000	<272,000	77.50+0.5 = 78.00	Table B-4 of [11]
TS125	3	285,000	196,118	72.80+0.5 = 73.30	Table 5.3-1 of [12]

Notes:

1. The empty cask weights are taken from the DOE SOW Attachment A [1].
2. The cg is increased by 0.5 inches due to the standardized attachment components shim plate.
3. The maximum weight for the HI-STAR 190 XL cask is from AFS-RFI-0015 [5].

Table 4-4: Cradle Design Inputs

Cask	Family	Nominal Cradle Weight, lb	Cradle Vertical cg from railcar deck, in[(1)]	Reference
NAC-STC	2	42,000	27+0.5 = 27.5	Table B-1 of [11]
NAC-UMS UTC	2	42,000	27+0.5 = 27.5	Table B-1 of [11]
MAGNATRAN	2	42,000	27+0.5 = 27.5	Table B-1 of [11]
HI-STAR 100	1	67,091[(2)]	44.5+0.5 = 45.0	Table 6.1 of [10]
HI-STAR 100HB	1	73,182[(2)]	57.2+0.5 = 57.7	Table 6.1 of [10]
HI-STAR 180	1	58,273[(2)]	54.4+0.5 = 54.9	Table 6.1 of [10]
HI-STAR 60	1	64,091[(2)]	41.6+0.5 = 42.1	Table 6.1 of [10]
HI-STAR 190 SL	1	55,909[(2)]	52.0+0.5 = 52.5	Table 6.1 of [10]
HI-STAR 190 XL	1	53,636[(2)]	51.6+0.5 = 52.1	Table 6.1 of [10]
MP187	4	32,500	28.5+0.5 = 29.0	Table 4-1 of [13]
MP197	3	26,000	17 +0.5 = 17.5	Table 5.3-1 of [12]
MP197HB	3	26,000	17.5+0.5 = 18.0	Table 5.3-1 of [12]
TN-32B	1	74,000[(2)]	48.8+0.5 = 49.3	Table 6.1 of [10]
TN-40	1	75,091[(2)]	47.0+0.5 = 47.5	Table 6.1 of [10]
TN40HT	1	75,091[(2)]	47.0+0.5 = 47.5	Table 6.1 of [10]
TN-68	2	27,000	26 +0.5 = 26.5	Table B-3 of [11]
TS125	3	30,000	24.5 +0.5 = 25.0	Table 5.3-1 of [12]

Notes: 1. The cg is increased by 0.5 inches due to the standardized attachment components shim plate.

2. The central cradle weight is added to the end stop weight to calculate to total nominal cradle weight. Values are scaled from maximum.

4.2 Material Properties

The material properties listed in Table 4-5 are used in the design. The yield and ultimate strengths are the minimum values found in the ASTM standards [14] and [15]. Material density is from ASME B&PV Code Section II, Part D Table PRD [16]. The structure is primarily ASTM A572, Grade 50, high-strength low-alloy columbium-vanadium structural steel. Material properties at 100 °F are used. The attachment pins are constructed from ASTM A564, Type 630, Condition H1025, hot-rolled and cold-finished age-hardening stainless steel.

Table 4-5: Material Properties

Material	Yield Stress (ksi)	Ultimate Stress (ksi)
ASTM A572, Grade 50	50	65
ASTM A564, Type 630, Condition H1025	145	155

5.0 CALCULATIONS

5.1 Allowable Stresses

The allowable minimum yield strength and ultimate strength of ASTM A572, Grade 50 is 50 ksi and 65 ksi respectively [14]. The minimum yield and ultimate stress for ASTM A564, Type 630, Condition H1025 is 145 ksi and 155 ksi respectively [15].

The tie-down loading stresses for the 7.5/2/2g load cases are compared directly against yield strength. The pin attachment blocks and shear blocks are ASTM A572, Grade 50. The attachment pins are ASTM A564, Type 630, Condition H1025. The allowable stresses are:

Attachment Block/Shear Block allowable stress: $S_{AT} = S_y = 50$ ksi

Attachment Block/Shear Block allowable shear stress: $S_{AS} = 0.6S_y = 30$ ksi

Attachment Pin allowable stress: $S_{A564} = S_y = 145$ ksi

5.2 Standardized Attachment Components

The following components are evaluated to determine the adequacy of the attachment component design:

- Center Pin Attachment Blocks
- Shear Blocks
- Outer Pin Attachment Blocks
- Attachment Pins

5.2.1 Center Pin Attachment Blocks

The center pin attachment blocks (Item 7 and 8 of [4]) are shown in Figure 5-1 and are used to secure the cradles to the railcar. The pin blocks are subjected to lateral and vertical tie-down loads. Using the bounding loads from Table 4-2 the tie-down loading is:

Center pin block (CPB) lateral tie-down load, $F_{CPB\_lat} = 611$ kip and the vertical load from lateral tie-down load, $F_{CPB\_vlat} = 312$ kip (load is shared by two blocks, Item 7 and 8 of [4]) is taken from Section 4.1 (Note 1 following Table 4-2).

Center pin block vertical tie-down load, $F_{CPB\_v} = 730$ kips (load is shared by two blocks, Item 7 and 8 of [4]).

As shown in Section 5.2.7, the load on the attachment pin which is applied to the center pin attachment blocks is not shared equally. The load can be offset in either direction. The maximum load distribution is 379.5/730 = .52.

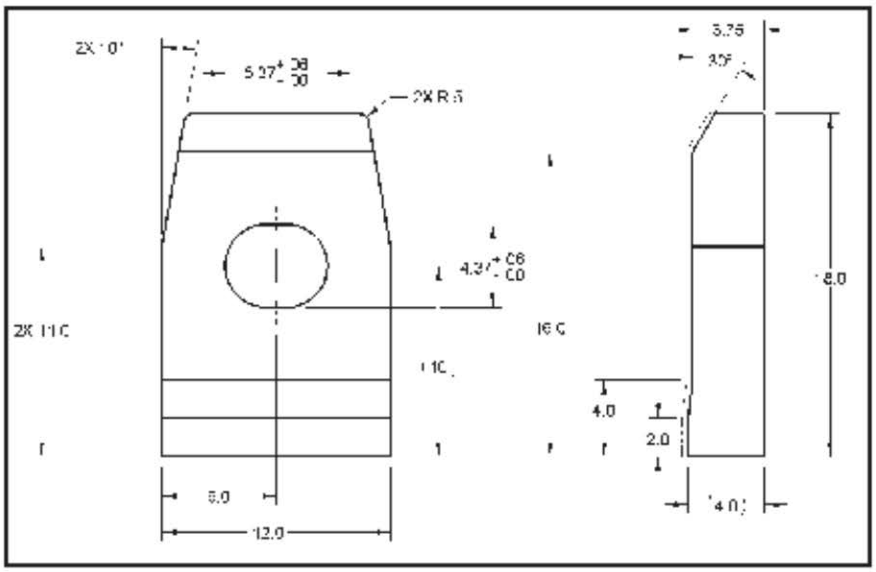


Figure 5-1: Center Pin Attachment Block

Center Pin Attachment Blocks - Vertical Load

The center pin attachment blocks are subjected to tension loading, shear tear-out, and bearing from the vertical tie-down load.

Tensile loading

The minimum tensile area is located at the hole center and is:

$$A = (12.00 - 5.37)(3.62) = 24.0\ in^2$$

where the block length is 12.00 inches, the slotted hole length is 5.37 inches and the block thickness is 3.75-0.13 = 3.62 inches (maximum stainless steel facing of 0.13 inches allowed per flag note 8 of [4] is conservatively neglected) at the hole per the drawing dimensions [4]. The tensile stress is:

$$\sigma = \frac{F_{CPB\_v}}{A} = \frac{730(.52)}{24.0} = 15.8\ ksi$$

From Section 5.1, the allowable tensile stress, S_{AT} = 50 ksi. The margin of safety is:

$$MS = \frac{50}{15.8} - 1 = +2.16$$

Shear tear-out

The pin block is subjected to shear-tear out from vertical loading. The shear tear-out area is conservatively calculated using twice the straight line distance:

$$A = (2)\left(16.0 - 10.0 - \frac{4.37}{2}\right)(3.62) = 27.6\ in^2$$

where the height of the pin block chamfer is 16.0 inches, the height of the slotted hole is 10.0 inches, the slot diameter is 4.37 inches and the thickness of the block is 3.62 inches (see discussion above) per the drawing dimensions [4]. Conservatively, this neglects the material at less than the full 3.75 inch thickness. The shear tear-out stress is:

$$\tau = \frac{F_{CPB\_v}}{A} = \frac{730(.52)}{27.6} = 13.8\ ksi$$

From Section 5.1, the allowable shear stress, S_{AS} = 30 ksi. The margin of safety is:

$$MS = \frac{30}{13.8} - 1 = +1.17$$

<u>Bearing stress</u>

The pin attachment block features a slotted hole that interfaces with the round attachment pin. However, there is no normal loading condition that will exceed the weight of the cask and cradle to load the pin and attachment block. Therefore, bearing is not a concern for normal loading. The tie-down loading will load the pin; however bearing is not considered a failure and will not be evaluated here.

Center Pin Attachment Blocks - Lateral Load

The center pin attachment blocks are subjected to shear and bending from the lateral load. There is also combined stress from the vertical load created from the lateral load moment. The pin attachment blocks support the lateral load at their base. The blocks have a 4.00 inch thick boss that extends 2 inches up the 18 inch high block. This boss face with the opposite pin block boss face create the 11.75 inch opening for cradle I-beam insertion. The lateral load results in a shear stress at the base of the block as well as a bending stress from the 2 inch high contact region. The moment is applied at the center of the contact or 1.25 inches (2.0 contact region and 0.5 inch high pad on railcar deck (2-0.5)/2+0.5 = 1.25 inches) from the railcar deck. Due to the moment and resisting load created by the lateral load being applied at the package cg, there is also a vertical load on the pin block. The tensile load is added to the bending stress and then combined with the shear stress to determine the combined stress. The combined tension and shear is also checked at the hole location.

The center pin block (CPB) lateral load, F_{CPB_lat} = 611 kip

The CPB vertical load from lateral tie-down load, F_{CPB_vlat} = 312 kip (load is shared by two blocks) is taken from Section 4.1.

<u>At Block base</u>

The pin block is subjected to shear, bending, and tension at the base. The base cross-section area is:

$$A = (12.00)(3.87) = 46.4\ in^2$$

where the width of the attachment block is 12.00 inches, and the thickness of the block at the base is 4.00-0.13 = 3.87 inches (maximum stainless streel facing of 0.13 inches allowed per flag note 8 of [4] is conservatively neglected) per [4]. The moment of inertia at the base is:

$$I = \frac{1}{12}(12.00)(3.87)^3 = 58.0\ in^3$$

The tensile stress is:

$$\sigma = \frac{F_{CPB_{vlat}}(.52)}{A} = \frac{312(.52)}{46.4} = 3.50\ ksi$$

The shear stress is:

$$\tau = \frac{F_{CPB\_lat}}{A} = \frac{611}{46.4} = 13.2\ ksi$$

The bending moment is:

$$M = (F_{CPB_{lat}})(1.25) = (611)(1.25) = 764\ in-kip$$

The bending stress is:

$$\sigma_b = \frac{My}{I} = \frac{764(\frac{4.00}{2})}{58.0} = 26.3\ ksi$$

where the overall thickness is conservatively used. The combined stress is:

$$\sigma_v = \sqrt{(\sigma + \sigma_b)^2 + 3\tau^2} = \sqrt{(3.50 + 26.3)^2 + 3(13.2)^2} = 37.6\ ksi$$

From Section 5.1, the allowable tensile stress, S_{AT} = 50 ksi. The margin of safety is:

$$MS = \frac{50}{37.6} - 1 = +0.33$$

5.2.2 Center Pin Attachment Block Welds

The weld connection to the railcar deck will be specified by KASGRO Rail. The transportation loads applied to the center pin attachment blocks are listed below. The weld is loaded separately from the vertical and lateral tie-down loading with the lateral loading producing a combined load.

The vertical load shown below is applied separately at the pin hole:

Pin hole, center pin block (CPB) vertical load, F_{CPB_v} = 730 kips (load is shared by two blocks)

The vertical and lateral loads shown below are applied simultaneously at the pin hole:

Pin hole, center pin block lateral load, F_{CPB_lat} = 611 kip

Pin hole, vertical load from lateral tie-down load, F_{CPB_vlat} = 312 kip (load is shared by two blocks)

5.2.3 Shear Blocks

The shear blocks (Item 9 of [4]) are shown in Figure 5-2 and are used to react the axial tie-down loads from the cradles. The shear blocks are subjected to the longitudinal load only. Using the bounding loads from Table 4-2, the loading is:

Shear block (SB) longitudinal load, F_{SB_long} = 2,921 kip

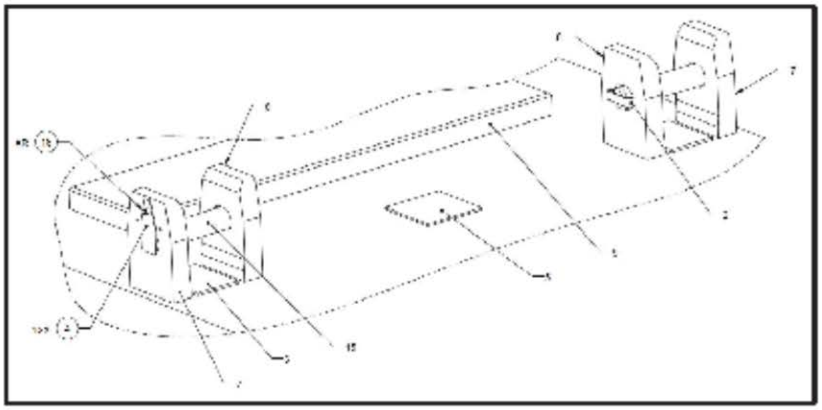


Figure 5-2: Shear Blocks

The shear blocks are subjected to shear from the longitudinal load. The shear area is:

$$A = (90.00)(21.00) = 1{,}890\ in^2$$

where the shear block width is 90.00 inches and the shear block length is 21.00 inches per the drawing dimensions [4]. The shear stress is:

$$\tau = \frac{F_{SB\_long}}{A} = \frac{2{,}921}{1{,}890} = 1.55\ ksi$$

From Section 5.1, the allowable shear stress, S_{AS} = 30 ksi. The margin of safety is:

$$MS = \frac{30}{1.55} - 1 = +18.4$$

5.2.4 Shear Blocks Weld

The weld connection to the railcar deck will be specified by KASGRO Rail. The transportation loads applied to the shear block are listed below.

The weld is loaded from the longitudinal tie-down loading

Shear block longitudinal load, F_{SB_long} = 2,921 kips

5.2.5 Outer Pin Attachment Blocks

The outer pin attachment blocks are used to secure the end stops to the railcar. The longitudinal tie-down load applies a combined longitudinal and vertical load (at P9-P12 and P13-P16) and a vertical load (at P5-P8 and P17-P20) to the outer pin blocks. See Figure 4-1 for pin locations and Figure 5-4 and Figure 5-5 for loading. The outer pin blocks are also loaded separately by the lateral and vertical tie-down loads. These loads are very small as the outer attachment blocks only restrain the end stop structure weight or ballast weight in these directions. The lateral and vertical tie-down loads are bounded by the loads applied at the center pin attachment blocks. The center pin attachment blocks are subjected to much higher loads and have a much shorter length.

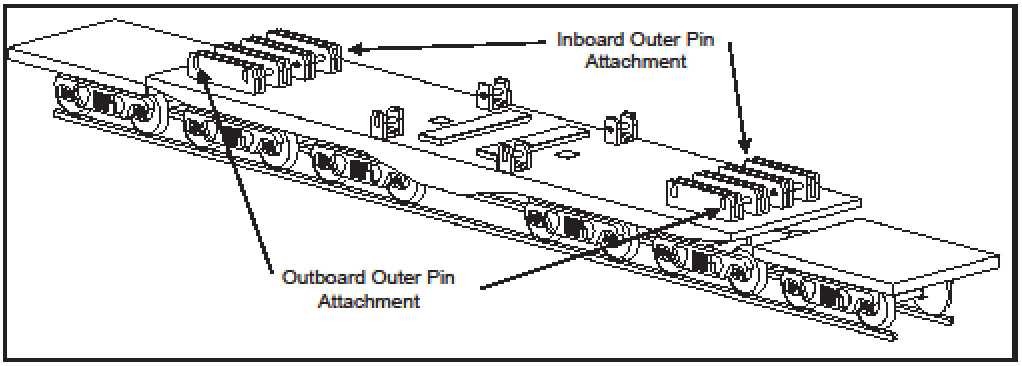


Figure 5-3: Outer Pin Attachment Block Nomenclature

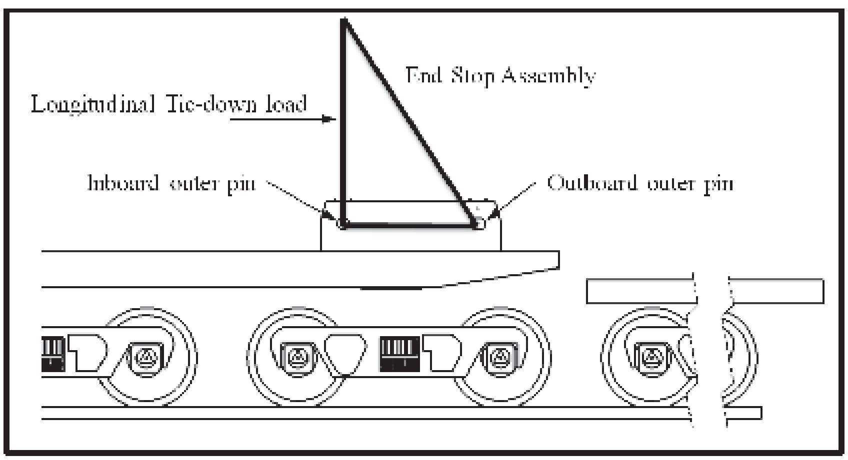


Figure 5-4: Outer Pin Attachment Block Tie-down Loading

Outer Pin Attachment Blocks –Loading

These loads are applied simultaneously. Using the bounding loads from Table 4-2, the loading is:

Inboard outer pin (IOPB) longitudinal load, F_{IOPB_long} = 944 kip

Inboard outer pin (IOPB) vertical (+) load, F_{IOPB_v} = 1,077 kip

Outboard outer pin (OOPB) vertical (-) load, F_{OOPB_v} = 1,077 kip

The combined load at the inboard pin location is:

$$F_{IOPB\_c} = \sqrt{944^2 + 1{,}077} = 1{,}432\ kip$$

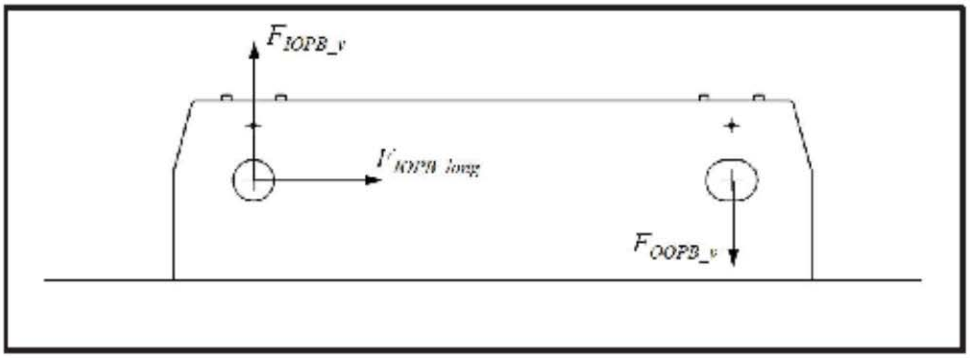


Figure 5-5: Outer Pin Attachment Block Loading

The outer pin attachment blocks (See Figure 5-9) are subjected to tension loading, shear tear-out, and bending from the combined longitudinal and vertical loads.

Tension Loading

The minimum tensile area is perpendicular to the line of action of the force as shown in Figure 5-6 below.

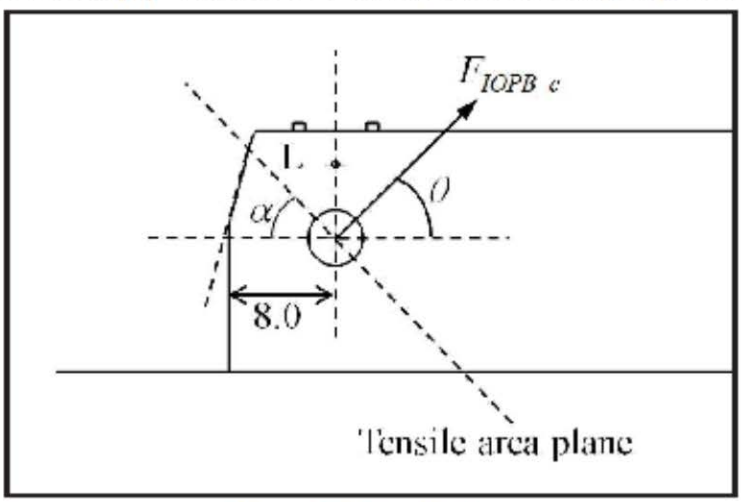


Figure 5-6: Tensile Area

Conservatively twice the distance from the pin hole to the chamfer edge will be used. The angles formed by the combined force are

$$\theta = \arctan\left(\frac{1{,}077}{944}\right) = 48.8°$$

$$\alpha = 90 - \theta = 41.2°$$

To calculate the edge distance, L, the chamfer line is extended down to the height of the pin hole to form the triangle shown in Figure 5-7 below.

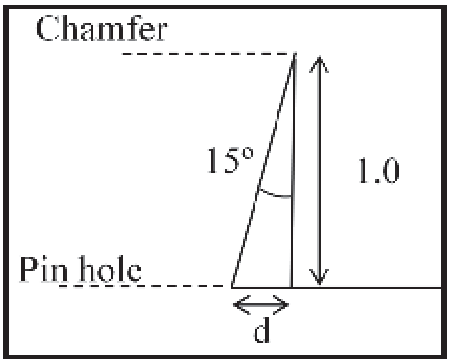


Figure 5-7: Chamfer Distance

The distance d is calculated as:

$$d = 1.0\tan(15) = .268\ in$$

The triangle formed by the intersection of the pin hole, extended chamfer line and distance L is shown in Figure 5-8 below.

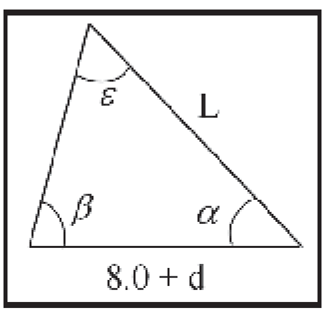


Figure 5-8: Tensile Area Geometry

The angles β and ε can be calculated as:

$$\beta = 90 - 15 = 75°$$

$$\varepsilon = 180 - 75 - 41.2 = 63.8°$$

The distance L can then be calculated using the law of sines

$$L = \frac{\sin(\beta)(8.0 + d)}{\sin(\epsilon)} = \frac{\sin(75)(8.0 + .268)}{\sin(63.8)} = 8.90\ in$$

The tensile area is

$$A = 2(2)\left(8.90 - \frac{4.37}{2}\right)(3.87) = 103.9\ in^2$$

where the block leg thickness is 4.0-.13 = 3.87 inches (maximum stainless steel facing of 0.13 inches allowed per flag note 8 of [4] is conservatively neglected), and there are two block legs per the drawing dimensions [4]. The tensile stress is:

$$\sigma = \frac{F_{IOPB\_C}}{A} = \frac{1{,}432}{103.9} = 13.8\ ksi$$

From Section 5.1, the allowable tensile stress, S_{AT} = 50 ksi. The margin of safety is:

$$MS = \frac{50}{13.8} - 1 = +2.62$$

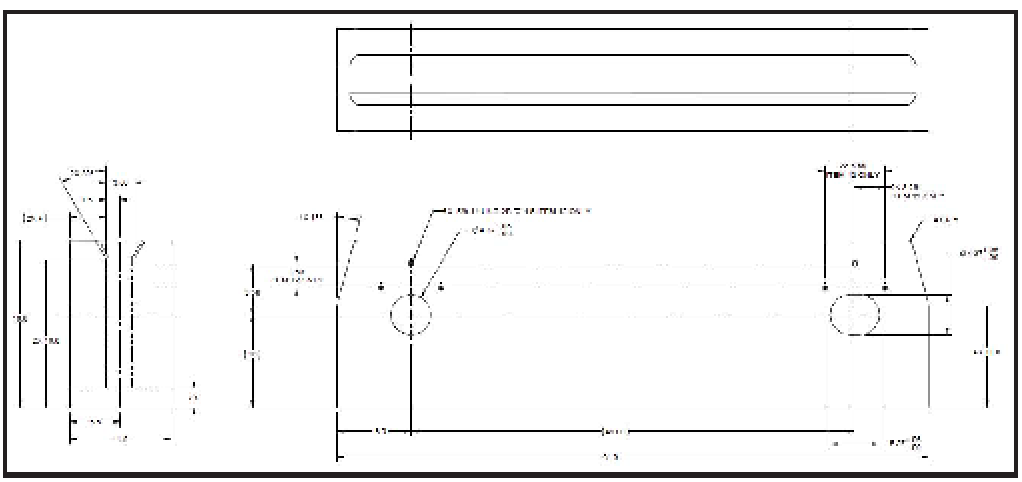


Figure 5-9: Outer Pin Attachment Block

Shear tear-out

The pin block is subjected to shear-tear out from combined loading at the inboard hole location. The shear tear-out area is conservatively calculated using twice the straight line vertical distance:

$$A = 2(2)\left(16.0 - 10.0 - \frac{4.37}{2}\right)(3.87) = 59.1\ in^2$$

where the height of the pin block chamfer is 16.0 inches, the center of the hole is 10.0 inches, the hole diameter is 4.37 inches and the thickness of the block leg is 3.87 inches (as discussed above), and there are two legs per [4]. Conservatively, this neglects the material at less than the full 4.0 inch thickness. Conservatively applying the combined load to the vertical tear-out area, the shear tear-out stress is:

$$\tau = \frac{F_{IOPB\_C}}{A} = \frac{1{,}432}{59.1} = 24.2\ ksi$$

From Section 5.1, the allowable tensile stress, S_{AS} = 30 ksi. The margin of safety is:

$$MS = \frac{30}{24.2} - 1 = +0.24$$

<u>Bending</u>

The outer pin blocks are not subjected to bending from bounding longitudinal tie-down load. The tensile and shear tear-out evaluations performed above are bounding.

5.2.6 Outer Pin Attachment Block Welds

The weld connection to the railcar deck will be specified by KASGRO Rail. The transportation loads applied to the outer pin attachment blocks are listed below.

The longitudinal and vertical loads shown below are applied simultaneously.

Applied at the pin hole, inboard outer pin block (IOPB) longitudinal load, F_{IOPB_long} = 944 kip

Applied at the pin hole, inboard outer pin block (IOPB) vertical (+) load, F_{IOPB_v+} = 1,077 kip

Applied at the pin hole, outboard outer pin block (OOPB) vertical (-) load, F_{OOPB_v-} = 1,077 kip

5.2.7 Attachment Pin

The attachment pins used by the center pin attachment blocks (Item 15 of [4]) are used to secure the cradles to the railcar. They are inserted through the center pin attachment blocks and the holes in the cradle main beams. The attachment pins used by the outer pin attachment blocks (Item 16 of [4]) to secure the end stop assemblies are double length and are used to secure both legs of the end stop. However the loading condition on each pin is similar for each location (double or single).

<u>Pin at Center Pin Attachment Block</u>

The maximum load on the attachment pin at the center pin attachment blocks is from the vertical tie-down load taken from Section 5.2.1:

$$F_{pin} = F_{CPB\_v} = 730\ kip$$

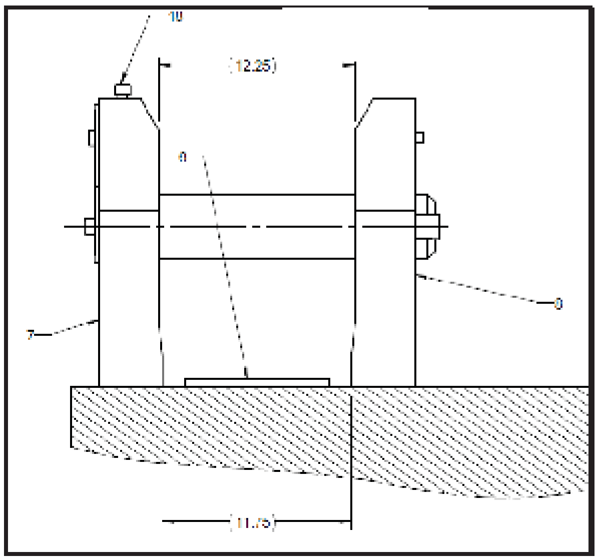


Figure 5-10: Attachment Pin Connection (Item 15)

The pin is subjected to shear and bending from the gap between the center pin attachment blocks and the cradle beams. The pin cross sectional area is:

$$A = \frac{\pi}{4}(4.00)^2 = 12.6\ in^2$$

where the pin diameter is 4.00 inches from [4]. The pin section modulus is:

$$S = \frac{\pi}{32}(4.00)^3 = 6.28\ in^3$$

Using Table 42, Case 5 of [19] and conservatively assuming the gap is maximized toward one end leaving only a 0.25 inch gap due to the boss at the block bottom, the load P is:

$$P = (F_{pin})/2 = 730/2 = 365\ kip$$

As shown on Figure 5-11, the reactions R1 and R2 are:

$$R_1 = \frac{P(L-a+c)}{L} = \frac{365(12.25-0.735+0.25)}{12.25} = 350.5\ kip$$

$$R_2 = \frac{P(L-c+a)}{L} = \frac{365(12.25-0.25+0.735)}{12.25} = 379.5\ kip$$

where the opening between the center pin attachment blocks is, L = (11.75+0.25+0.25) = 12.25 inches per [4], the connecting cradle I-beam is W18x119 per [20], [21], [22], [23] and [24], per [25], the width b = 11.265, the length a = 12.25-11.265-0.25 = 0.735 inches and the length c = 0.25 inches. The bending moments are:

$$M_1 = R_1 a = 350.5(0.735) = 257.6\ in-kip$$

$$M_2 = R_2 c = 379.5(0.25) = 94.9\ in-kip$$

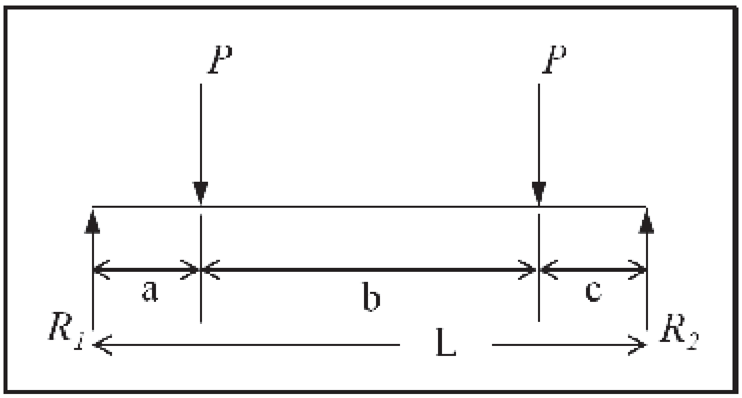


Figure 5-11: Attachment Pin Bending

The shear stress is:

$$\tau = \frac{MAX(R_1, R_2)}{A} = \frac{379.5}{12.6} = 30.1\ ksi$$

The bending stress is:

$$\sigma_b = \frac{MAX(M_1, M_2)}{S} = \frac{257.6}{6.28} = 41.0\ ksi$$

The von Mises stress is:

$$\sigma_v = \sqrt{\sigma_b{}^2 + 3(\tau^2)} = \sqrt{(41.0)^2 + 3(30.1)^2} = 66.3\ ksi$$

From Section 5.1, the allowable tensile stress, S_{A564} = 145 ksi. The margin of safety is:

$$MS = \frac{145}{66.3} - 1 = +1.19$$

<u>Pin at Outer Pin Attachment Block</u>

The maximum load on the attachment pin used at the outer pin attachment block is taken from Section 5.2.5 as:

$$F_{pin} = F_{IOPB\_c} = 1{,}432\ kip$$

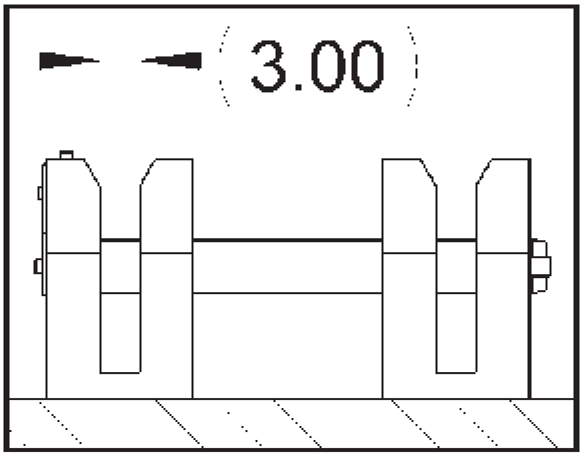


Figure 5-12: Attachment Pin Connection (Item 16)

The pin is subjected to shear and bending from the gap between the outer pin attachment blocks and the end stop plates. The pin cross sectional area is:

$$A = \frac{\pi}{4}(4.00)^2 = 12.6\ in^2$$

where the pin diameter is 4.00 inches from [4]. The pin section modulus is:

$$S = \frac{\pi}{32}(4.00)^3 = 6.28\ in^3$$

Again using Table 42, Case 5 of [19] the load P is:

$$P = (F_{pin})/2 = 1{,}432/2 = 716\ kip$$

As shown on Figure 5-11, the reactions R1 and R2 are:

$$R_1 = \frac{P(L-a+c)}{L} = \frac{716(3.26-0+0.76)}{3.26} = 881.2\ kip$$

$$R_2 = \frac{P(L-c+a)}{L} = \frac{716(3.26-0.76+0)}{3.26} = 550.8\ kip$$

where the opening between the outer pin attachment blocks is, L = 3.26 inches per [4] (conservatively neglecting the maximum allowed cladding of .13 inches on each side per flag note 8 of [4]), the connecting end stop plates are 2.00 +.25 +.25 inches (Items 4(2x) and 5 of [20]) wide, b = 2.50 inches, the length a = 3.26-2.50-0.76 = 0 inches and the length c = 0.76 inches. The bending moments are:

$$M_1 = R_1 a = 882.9(0) = 0\ in-kip$$

$$M_2 = R_2 c = 549.1(0.76) = 417.3\ in-kip$$

The shear stress is:

$$\tau = \frac{MAX(R_1, R_2)}{A} = \frac{882.9}{12.6} = 70.1\ ksi$$

The bending stress is:

$$\sigma_b = \frac{MAX(M_1, M_2)}{S} = \frac{417.3}{6.28} = 66.4\ ksi$$

The von Mises stress is:

$$\sigma_v = \sqrt{\sigma_b{}^2 + 3(\tau^2)} = \sqrt{(66.4)^2 + 3(70.1)^2} = 138.4\ ksi$$

From Section 5.1, the allowable tensile stress, S_{A564} = 145 ksi. The margin of safety is:

$$MS = \frac{145}{138.4} - 1 = +0.05$$

5.3 Cradle Weight

Weights for the conceptual cradle designs are listed in Table 4-4. To bound the dynamic response of the railcar and any changes in the future final cradle designs, a range of ±10% is added to the cradle weight. The nominal, maximum, and minimum cradle weights are shown in Table 5-1 below:

Table 5-1: Adjusted Cradle Weights

Cask	Family	Nominal Cradle Weight, lb	Maximum Cradle Weight, lb	Minimum Cradle Weight, lb
NAC-STC	2	42,000	46,200	37,800
NAC-UMS UTC	2	42,000	46,200	37,800
MAGNATRAN	2	42,000	46,200	37,800
HI-STAR 100	1	67,091	73,800	60,382
HI-STAR 100HB	1	73,182	80,500	65,864
HI-STAR 180	1	58,273	64,100	52,446
HI-STAR 60	1	64,091	70,500	57,682
HI-STAR 190 SL	1	55,909	61,500	50,318
HI-STAR 190 XL	1	53,636	59,000	48,272
MP187	4	32,500	35,750	29,250
MP197	3	26,000	28,600	23,400
MP197HB	3	26,000	28,600	23,400
TN-32B	1	74,000	81,400	66,600
TN-40	1	75,091	82,600	67,582
TN40HT	1	75,091	82,600	67,582
TN-68	2	27,000	29,700	24,300
TS125	3	30,000	33,000	27,000

5.4 Combined cg and Railcar Weight

In order to meet the combined cg requirement of 98 inches, as required by Rule 89 of the AAR Field Manual of the AAR Interchange Rules [8], the railcar weight must be considered. The required railcar weight is determined using the package weights and vertical cg locations, the conceptual cradle designs calculated weights and vertical cg locations, the attachment components (AC) calculated weights and vertical cg locations (Appendix A), the ballast load weight and vertical cg location and the railcar deck height and railcar vertical cg location provided by KASGRO [27].

The total cg of the cask, cradle and railcar is shown in the following table. The unloaded railcar deck height was provided by KASGRO to be 59.25 inches [27]. This value is lower when under load. Per KASGRO, the loaded deck height from the rails is 55.375 inches [27]. Conservatively, the unloaded deck height of 59.25 inches will be used. This value was used to adjust the cask and cradle cg's provided in Table 4-3 and Table 4-4. The railcar cg (unloaded condition) is 35.3 inches from the rails [27]. To calculate the worst case cg for each cask and cradle combination, the maximum cask weight is used from Table 4-3 and the minimum cradle weight is used from Table 5-1. The minimum attachment components weight is used from Appendix A. The total cg is calculated as follows:

$$total\ cg = \frac{Railcar\ W \times Railcar\ cg + AC\ W\ \times AC\ cg + Cradle\ W \times Cradle\ cg + Cask\ W \times Cask\ cg}{Total\ Weight}$$

The combined total cg's are calculated and shown in Table 5-2, Table 5-3 and Table 5-4 below. Three railcar weights are considered, 195,000 lb., 200,000 lb. and 205,000 lb.. These weights were selected based on the range provided by KASGRO. The minimum railcar weight of 195,000 lb. was selected to provide the minimum required railcar weight needed to meet the cg limit with an acceptable margin. The allowable cg is 98 inches per Section 2.1. The cg margins for each of the casks are calculated in Table 5-5. The bounding cask is the HI-STAR 190 XL which has a margin of 98-96.08 = 1.92 inches for a 195,000 lb. railcar.

The maximum railcar weight of 205,000 lb. was selected to meet the maximum allowed combined weight. The maximum combined weight of the railcar, cradle and loaded cask must be less than 65,750 pounds per axle (789,000 pound loaded car limit) per AFS-IN-16-0039 [6]. The maximum combined weight is calculated using the maximum cask weight from Table 4-3, the maximum cradle weight from Table 5-1, the maximum attachment components weight calculated in Appendix A, and the railcar weight. Maximum weights are shown in Table 5-6 below. The minimum margin is 73,066 pounds for the HI-STAR 190 XL loaded on a 205,000 pound railcar.

The maximum ballast load weight and cg are taken from Table 4.2 of [17] as 220,600 lb. and 32.42 inches (from the bottom of the ballast load assembly). The ballast cg from the rails can be calculated as 32.42 -7.5 + 10 +59.25 = 94.17 inches [4][18]. The maximum combined ballast and railcar cg is:

$$total\ cg = \frac{Railcar\ W \times Railcar\ cg + AC\ W\ \times AC\ cg + Ballast\ W \times Ballast\ cg}{Total\ Weight}$$

$$total\ cg = \frac{195{,}000 \times 35.3 + 31{,}165\ \times 67.24 + 220{,}600 \times 94.17}{195{,}000 + 31{,}165 + 220{,}600}$$

$$total\ cg = 66.60\ inches$$

where the maximum attachments components weight (31,165 lb.) and cg height (67.24 inches) is used from Appendix A. The ballast load cg is very low compared to the conceptual cradle and cask payload and will not be bounding for the maximum cg case.

Table 5-2: Combined CG Height, 195,000 lb. Railcar

Cask	Family	Cask cg(1), in	Max Cask Weight, lb	Cradle cg(1), in	Min Cradle Weight, lb	Total Weight(2), lb	Total cg(1), in
NAC-STC	2	127.25	254,589	86.75	37,800	512,887	86.32
NAC-UMS UTC	2	127.25	255,022	86.75	37,800	513,320	86.36
MAGNATRAN	2	127.25	312,000	86.75	37,800	570,298	90.44
HI-STAR 100	1	125.75	279,893	104.25	60,382	560,773	89.32
HI-STAR 100HB	1	125.75	187,200	116.95	65,864	473,562	84.13
HI-STAR 180	1	124.25	308,647	114.15	52,446	581,590	91.02
HI-STAR 60	1	119.38	164,000	101.35	57,682	442,180	76.94
HI-STAR 190 SL	1	124.25	382,746	111.75	50,318	653,562	94.52
HI-STAR 190 XL	1	124.25	420,769	111.35	48,272	689,540	96.08
MP187	4	124.25	271,300	88.25	29,250	521,048	86.15
MP197	3	121.75	265,100	76.75	23,400	508,998	83.83
MP197HB	3	123.75	303,600	77.25	23,400	547,498	87.63
TN-32B	1	132.25	263,000	108.55	66,600	550,098	92.00
TN-40	1	132.25	271,500	106.75	67,582	559,580	92.42
TN40HT	1	132.25	242,343	106.75	67,582	530,423	90.23
TN-68	2	137.25	272,000	85.75	24,300	516,798	92.91
TS125	3	132.55	285,000	84.25	27,000	532,498	91.36

Notes:

1. A value of 59.25 inches is added for the deck height of the railcar. The cg is measured from the rails.
2. Includes railcar weight and the minimum attachment components weight (25,498 lb.) and cg 7.99+ 59.25 = 67.24 inches from the rail.

Table 5-3: Combined CG Height, 200,000 lb. Railcar

Cask	Family	Cask cg(1), in	Max Cask Weight, lb	Cradle cg(1), in	Min Cradle Weight, lb	Total Weight(2), lb	Total cg(1), in
NAC-STC	2	127.25	254,589	86.75	37,800	517,887	85.83
NAC-UMS UTC	2	127.25	255,022	86.75	37,800	518,320	85.86
MAGNATRAN	2	127.25	312,000	86.75	37,800	575,298	89.96
HI-STAR 100	1	125.75	279,893	104.25	60,382	565,773	88.84
HI-STAR 100HB	1	125.75	187,200	116.95	65,864	478,562	83.62
HI-STAR 180	1	124.25	308,647	114.15	52,445	586,590	90.54
HI-STAR 60	1	119.38	164,000	101.35	57,682	447,180	76.48
HI-STAR 190 SL	1	124.25	382,746	111.75	50,318	658,562	94.07
HI-STAR 190 XL	1	124.25	420,769	111.35	48,273	694,540	95.65
MP187	4	124.25	271,300	88.25	29,250	526,048	85.67
MP197	3	121.75	265,100	76.75	23,400	513,998	83.36
MP197HB	3	123.75	303,600	77.25	23,400	552,498	87.15
TN-32B	1	132.25	263,000	108.55	66,600	555,098	91.49
TN-40	1	132.25	271,500	106.75	67,582	564,580	91.92
TN40HT	1	132.25	242,343	106.75	67,582	535,423	89.72
TN-68	2	137.25	272,000	85.75	24,300	521,798	92.35
TS125	3	132.55	285,000	84.25	27,000	537,498	90.84

Notes:

1. A value of 59.25 inches is added for the deck height of the railcar. The cg is measured from the rails.
2. Includes railcar weight and the minimum attachment components weight (25,498 lb.) and cg 7.99+ 59.25 = 67.24 inches from the rail.

Table 5-4: Combined CG Height, 205,000 lb. Railcar

Cask	Family	Cask cg(1), in	Max Cask Weight, lb	Cradle cg(1), in	Min Cradle Weight, lb	Total Weight(2), lb	Total cg(1), in
NAC-STC	2	127.25	254,589	86.75	37,800	522,887	85.35
NAC-UMS UTC	2	127.25	255,022	86.75	37,800	523,320	85.38
MAGNATRAN	2	127.25	312,000	86.75	37,800	580,298	89.49
HI-STAR 100	1	125.75	279,893	104.25	60,382	570,773	88.38
HI-STAR 100HB	1	125.75	187,200	116.95	65,864	483,562	83.12
HI-STAR 180	1	124.25	308,647	114.15	52,445	591,590	90.07
HI-STAR 60	1	119.38	164,000	101.35	57,682	452,180	76.02
HI-STAR 190 SL	1	124.25	382,746	111.75	50,318	663,562	93.63
HI-STAR 190 XL	1	124.25	420,769	111.35	48,273	699,540	95.22
MP187	4	124.25	271,300	88.25	29,250	531,048	85.19
MP197	3	121.75	265,100	76.75	23,400	518,998	82.90
MP197HB	3	123.75	303,600	77.25	23,400	557,498	86.69
TN-32B	1	132.25	263,000	108.55	66,600	560,098	90.99
TN-40	1	132.25	271,500	106.75	67,582	569,580	91.42
TN40HT	1	132.25	242,343	106.75	67,582	540,423	89.22
TN-68	2	137.25	272,000	85.75	24,300	526,798	91.81
TS125	3	132.55	285,000	84.25	27,000	542,498	90.33

Notes:

1. A value of 59.25 inches is added for the deck height of the railcar. The cg is measured from the rails.
2. Includes railcar weight and the minimum attachment components weight (25,498 lb.) and cg 7.99+ 59.25 = 67.24 inches from the rail.

Table 5-5: Total cg's and Margin to 98 inches

Cask	Family	195,000 lb. railcar		200,000 lb. railcar		205,000 lb. railcar	
		total cg, in	margin, in	total cg, in	margin, in	total cg, in	margin, in
NAC-STC	2	86.32	11.68	85.83	12.17	85.35	12.65
NAC-UMS UTC	2	86.36	11.64	85.86	12.14	85.38	12.62
MAGNATRAN	2	90.44	7.56	89.96	8.04	89.49	8.51
HI-STAR 100	1	89.32	8.68	88.84	9.16	88.38	9.62
HI-STAR 100HB	1	84.13	13.87	83.62	14.38	83.12	14.88
HI-STAR 180	1	91.02	6.98	90.54	7.46	90.07	7.93
HI-STAR 60	1	76.94	21.06	76.48	21.52	76.02	21.98
HI-STAR 190 SL	1	94.52	3.48	94.07	3.93	93.63	4.37
HI-STAR 190 XL	1	96.08	1.92	95.65	2.35	95.22	2.78
MP187	4	86.15	11.85	85.67	12.33	85.19	12.81
MP197	3	83.83	14.17	83.36	14.64	82.90	15.10
MP197HB	3	87.63	10.37	87.15	10.85	86.69	11.31
TN-32B	1	92.00	6.00	91.49	6.51	90.99	7.01
TN-40	1	92.42	5.58	91.92	6.08	91.42	6.58
TN40HT	1	90.23	7.77	89.72	8.28	89.22	8.78
TN-68	2	92.91	5.09	92.35	5.65	91.81	6.19
TS125	3	91.36	6.64	90.84	7.16	90.33	7.67

Table 5-6: Total Weight and Margin to 789,000 pounds

Cask	Family	195,000 lb. railcar		200,000 lb. railcar		205,000 lb. railcar	
		Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.
NAC-STC	2	526,954	262,046	531,954	257,046	536,954	252,046
NAC-UMS UTC	2	527,387	261,613	532,387	256,613	537,387	251,613
MAGNATRAN	2	584,365	204,635	589,365	199,635	594,365	194,635
HI-STAR 100	1	579,858	209,142	584,858	204,142	589,858	199,142
HI-STAR 100HB	1	493,865	295,135	498,865	290,135	503,865	285,135
HI-STAR 180	1	598,912	190,088	603,912	185,088	608,912	180,088
HI-STAR 60	1	460,665	328,335	465,665	323,335	470,665	318,335
HI-STAR 190 SL	1	670,411	118,589	675,411	113,589	680,411	108,589
HI-STAR 190 XL	1	705,934	83,066	710,934	78,066	715,934	73,066
MP187	4	533,215	255,785	538,215	250,785	543,215	245,785
MP197	3	519,865	269,135	524,865	264,135	529,865	259,135
MP197HB	3	558,365	230,635	563,365	225,635	568,365	220,635
TN-32B	1	570,565	218,435	575,565	213,435	580,565	208,435
TN-40	1	580,265	208,735	585,265	203,735	590,265	198,735
TN40HT	1	551,108	237,892	556,108	232,892	561,108	227,892
TN-68	2	527,865	261,135	532,865	256,135	537,865	251,135
TS125	3	544,165	244,835	549,165	239,835	554,165	234,835

Notes:

1. The weight limit of 789,000 pounds is based on a selected limit of 65,750 lb/axle for a 12 axle railcar.
2. The maximum combined weight is the summation of the maximum cradle weight from Table 5-1, the maximum cask weight from Table 4-3, the maximum attachment components weight from Appendix A, and the provided railcar weight.

5.5 Attachment Components Cask Interface

Some of the packages must have their impact limiters installed on the railcar deck. Table 5-7 shows the distance required for impact limiter removal/insertion for the two packages (MP187, HI-STAR 190 XL) that are bounding. It can be seen from [4] that the distance between the attachment components is:

$$125 + 2(148.50) - 2(8) = 406 \text{ } inches$$

The minimum required clearance for impact limiter removal of the MP187 is 372 inches from [26]. In this case there is 34 additional inches of clearance. However, the clearance was calculated assuming the impact limiter has a flat bottom end. In reality all of the cask impact limiters have some taper which provides additional clearance.

The minimum required clearance for impact limiter removal of the HI-STAR 190 XL is 406 inches. The package is 362 inches long and 18 inches is required on each end for impact limiter removal. The package vendor requested that an additional 4 inches of clearance be added to each side for a total of 406 inches [9]. In this case the design meets the requirement.

Table 5-7: Bounding Required Impact Limiter Clearance

Family	Cask	Total length (to facilitate removal of impact limiters)
4	MP187	Package Length: 308 inches (see SOW Appendix A [1]) Impact Limiter Overlap: 32 inches (SAR DWG NUH-05-4000NP R9 & DWG NUH-05-4001NP R13 [26]) =308+ 2(32) = **372 inches**
1	HI-STAR 190 XL	Package Length: 362 inches (see SOW Appendix A [1]) Impact Limiter Overlap: 18 inches (Information from vendor [9]) Additional Clearance: 4 inches (Requested by vendor) = 362 + 2(18) + 2(4) = 406 inches.

5.6 Fatigue

The railcar is expected to perform service for up to 50 years and are not expected to travel more than the maximum value of 3,000,000 miles per Section 7.1.2.1 of M-1001 [28]. While this period of performance is not expected to be maintenance free, it is reasonable to assume that the structure would perform its support function without major component failure. To this end, this analysis presents a cursory examination of the fatigue loading over this lifespan. The detailed fatigue analysis will be included with the evaluation of the railcar.

An example of the accepted method for calculating fatigue life is shown in Chapter 7 of the M-1001. From the example case Figure 7-3, it can be seen that 97 percent of the vertical fatigue loading is due to stress ranges under 0.3g. As this is from an example, case it is assumed to be normal in comparison to other railcar response curves. Since a majority of the fatigue loading is within this range, the fatigue life of the cradle is assumed to be defined by these loads.

The attachment component structural analysis demonstrates that a bounding acceleration load of 2g in the vertical direction can be supported when compared against yield strength. This is equivalent to using an allowable stress of ½ yield stress under normal gravity loading. All of the attachment component analyses demonstrate that this yield criterion is met.

If we assume that the stress variation due to cyclic loading is no more than +/- 0.2g (or a range of 0.4g), and that the allowable stress is just met at one gravity, the minimum and maximum stress that will be found in any component with a yield stress of 50 ksi due to cyclic loading will be due to the variable stress. This stress is:

Mean Stress:	$S = \frac{1}{2}\ 50\ \text{ksi} = 25\ \text{ksi}$
Variable Stress:	$S_v = 0.2S = 5\ \text{ksi}$
Maximum Stress:	$S_{mx} = 30\ \text{ksi}$
Minimum Stress:	$S_{mn} = 20\ \text{ksi}$

Stress Ratio: $R = \frac{S_{mn}}{S_{mx}} = \frac{2}{3}$

The stress that produces failure in steel at 2,000,000 cycles can be computed from cases in Table 7.55 of Chapter 7 of M-1001. This table presents values for determining the fatigue properties of the Modified Goodman Diagram (MGD) for a particular member. As an example, the allowable stress is 50 ksi for an A992 beam. From Table 7.55, Flg. No. 7.4.1.8 the following information is available:

Y intercept of MGD:	$b = 26$ ksi
MGD Slope:	$m = 0.9$
S-N Curve Slope:	$k = 0.16$
Cycles at Fatigue Stress S_e:	$N_e = 2 \times 10^6$cycles

The stress at which the beam is expected to fail at two million cycles is:

Fatigue Stress (at Ne): $S_e = \frac{b}{1-mR} = 65$ ksi

Since the Fatigue Limit is greater than the maximum load, the S-N curve slope is half the value above.

Cycles to failure: $N = \frac{N_e}{\left(\frac{S_{mx}}{S_e}\right)^{\frac{2}{k}}} = 31.5 \times 10^9$cycles

For a 50 year life, the railcar is expected to cover 3,000,000 miles. Assuming a cyclic rate of β= 300 cycles per mile (based on the example of Section 7.2.4.1.1.2 of M-1001), the expected life will be:

$$\text{Life} = \frac{N}{\beta} = (31.5 \times 10^9 \text{ cycles})/(300 \text{ cycles/mile}) = 105 \times 10^6 \text{ miles}$$

The life prediction for this component is much larger than the required lifespan for the component; therefore, it is reasonable to say that it will support fatigue loading without any modification. Similar analysis performed on an axially loaded flat plate for material with a 50 ksi yield stress limit demonstrates improved fatigue life in comparison to the beam section.

6.0 COMPUTER SOFTWARE USAGE (IF SOFTWARE IS USED)

No computer software is used in this calculation.

7.0 RESULTS/CONCLUSIONS

7.1 Standardized Attachment Components

The results of the analyses in this calculation demonstrated that the standardized attachment components are adequate to perform required function. The margins of safety for the evaluated components are shown in Table 7-1.

Table 7-1: Margins of Safety

Component	Loading	Margin of Safety
Center Pin Attachment Blocks (Section 5.2.1)	Tensile stress from vertical load	+2.16
	Shear tear-out from vertical load	+1.17
	Combined stress from lateral load at base	+0.33
Shear Blocks (Section 5.2.3)	Combined stress from longitudinal load	+18.4
Outer Pin Attachment Blocks (Section 5.2.5)	Tension Stress from combined load	+2.62
	Shear tear-out from combined load	+0.24
Attachment Pin (Section 5.2.7)	Combined stress (minimum)	+0.05

All margins of safety are positive and the components are adequate to support the applied loading.

7.2 Standardized Attachment Components Welds

The forces applied to the welds between the attachment components and the railcar deck are taken from Section 5.2.2, Section 5.2.4, and Section 5.2.6 and are shown in Table 7-2.

Table 7-2: Required Weld Strength

Weld	Forces Applied to Weld
Center Pin Attachment Block Weld (Section 5.2.2), (Item 7-8 of [4])	730 kip (vertical) at pin slot
	611 kip (lateral) at bracket and 312 kip (vertical) at pin slot
Shear Blocks Weld (Section 5.2.4), (Item 9 of [4])	2,921 kips (longitudinal)
Outer Pin Attachment Block Welds (Section 5.2.6) (Item 12-14 of [4])	944 kip (longitudinal) and 1,077 kip (vertical +) at inboard pin hole and 1,077 (vertical -) at outboard pin slot

7.3 Combined cg and Railcar Weight

The bounding combined cg and maximum weight are taken from Table 5-5 and Table 5-6 are shown in Table 7-3.

Table 7-3: Total cg's and Weight

Bounding Combined cg and Minimum Margin to 98 Inches							
		195,000 lb. railcar		200,000 lb. railcar		205,000 lb. railcar	
Cask	Family	total cg, in	margin, in	total cg, in	margin, in	total cg, in	margin, in
Maximum Margin = HI-STAR 60	1	76.94	21.06	76.48	21.52	76.02	21.98
Minimum Margin = HI-STAR 190 XL	1	**96.08**	**1.92**	95.65	2.35	95.22	2.78
Bounding Total Weight and Minimum Margin to 789,000 pounds							
Cask	Family	Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.
Maximum Margin = HI-STAR 60	1	460,665	328,335	465,665	323,335	470,665	318,335
Minimum Margin = HI-STAR 190 XL	1	705,934	83,066	710,934	78,066	715,934	**73,066**

7.4 Literature Search and other Background Data

A formal literature search was not applicable to this scope of work. All required background information is given under Section 1.1, *Project Background*.

8.0 REFERENCES

The following references were used in this analysis:

1. Department of Energy Contract DE-NE0008390, Part 1, Section C, *Statement of Work*.
2. Association of American Railroads, *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*, 2009
3. Orano Federal Services Engineering Information Record, EIR-3014611, *Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar*, Rev. 9.
4. Orano Federal Services Drawing, DWG-3015278, *Atlas Railcar Cradle Attachment Conceptual Drawing*, Rev. 2.
5. Orano Federal Services LLC, Request for Information, AFS-RFI-0015-00, November 2016.
6. Orano Federal Services, LLC Incoming Document AFS-IN-16-0039, Submitted and Requested Information to AFS for Cask Car, August 9, 2016.
7. Joseph Shigley, Charles Mischke, Mechanical Engineering Design, 5th Edition, McGraw-Hill, 2002.
8. Association of American Railroads, *Field Manual of the AAR Interchange Rules*.
9. Phone communication with Steve Agace, Holtec International (October 27, 2016).

10. Orano Federal Services Calculation, CALC-3015133, *Atlas Railcar Family 1 Conceptual Cradle Structural Calculation*, Rev. 4
11. Orano Federal Services Calculation, CALC-3015134, *Atlas Railcar Family 2 Conceptual Cradle Structural Calculation*, Rev. 0
12. Orano Federal Services Calculation, CALC-3015135, *Atlas Railcar Family 3 Conceptual Cradle Structural Calculation*, Rev. 0
13. Orano Federal Services Calculation, CALC-3015136, *Atlas Railcar Family 4 Conceptual Cradle Structural Calculation*, Rev. 1
14. American Society for Testing and Materials, ASTM A572/A572M, *Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel*, 2007.
15. American Society for Testing and Materials, ASTM A564/A564M, *Standard Specification for Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes*, 2010.
16. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section II, Part D, "Properties (Customary)," 2015.
17. Orano Federal Services Calculation, CALC-3018954, *Atlas Railcar Conceptual Ballast Load Structural Calculation*, Rev 1.
18. Orano Federal Services Drawing, DWG-3018955, *Atlas Railcar Ballast Load Assembly Conceptual Drawing*, Rev. 0.
19. The Aluminum Association, Aluminum Construction Manual, Section 3, Engineering Data for Aluminum Structures, Fifth Edition, December 1986.
20. Orano Federal Services Drawing, DWG-3015137, *Atlas Railcar, Cradle Family 1, Conceptual Drawing*, Rev. 2
21. Orano Federal Services Drawing, DWG-3015138, *Atlas Railcar, Cradle Family 2 (NAC), Conceptual Drawing*, Rev. 1
22. Orano Federal Services Drawing, DWG-3015277, *Atlas Railcar, Cradle Family 2 (TN-68), Conceptual Drawing*, Rev. 0.
23. Orano Federal Services Drawing, DWG-3015139, *Atlas Railcar, Cradle Family 3, Conceptual Drawing*, Rev. 0
24. Orano Federal Services Drawing, DWG-3015140, *Atlas Railcar, Cradle Family 4, Conceptual Drawing*, Rev. 1
25. AISC MO16, Manual of Steel Construction, Allowable Stress Design, 9th Edition
26. Docket 71-9255, *Safety Analysis Report for the NUHOMS®-MP187 Multi-Purpose Cask*, Non-Proprietary Version, Rev 17, July 2003
27. Orano Federal Services, LLC Incoming Document AFS-IN-17-0008, Needed Center of Gravity and Deck Height Data for Atlas Project, March 15, 2017.
28. Association of American Railroads, *Manual of Standards and Recommended Practices*, Section C, Part II *Design, Fabrication, and Construction of Freight Cars*, M-1001, 2011

9.0 APPENDIX A – ATTACHMENT COMPONENTS WEIGHT CALCULATION

The weight and center of gravity of the attachment components from the railcar deck is calculated below. The Attachment component geometry is taken from DWG-3015278 [4]. The weight of each component is calculated using hand calculations. The density of stainless steel is taken as 0.290 lb/in^3 and the density of carbon steel is taken as .280 lb/in^3 [16]. For the ease of some calculations, geometry is simplified, resulting in a small conservative increase in weight. Only the weight of the items present for transport is calculated.

Pin Stop Bar (Item 2)

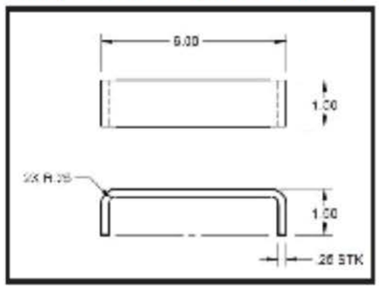
Length: 6.00 + 1.5 + 1.5 = 9 in.

Width: 1.5 in.

Thickness: .25 in.

Weight: .290(9)(1.5)(.25) = .98 lb.

cg from railcar deck: 10 in.



Pin Tray Keeper (Item 3)

The pin tray keeper is part of the pin loading weldment assembly, which is not attached during transport.

Pin Keeper Plate (Item 4)

Width: 4.0 in.

Height: 10.0 in

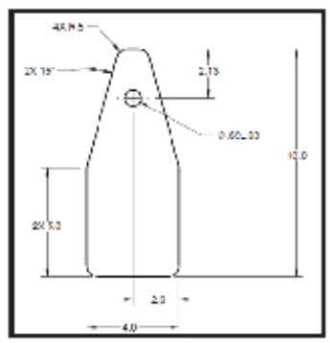
Thickness: .25 in.

Weight: .290(4.0)(10.0)(.25) = 2.90 lb.

(Assuming the shape to be a rectangle and neglecting the hole)

cg from railcar deck: 18 in.

(conservatively assumed to be top of pin attachment block)



Deck Spacer Plate (Item 5)

Length: 12.0 in.

Width: 12.0 in.

Thickness: .38 in

Weight: .290(12.0)(12.0)(.38) = 15.9 lb.

cg from deck: .38/2 = .19 in.

FOR INFORMATION
FS-18-0257

Deck Spacer Plate (Item 6)

Length: 12.0 in.

Width: 9.0 in.

Thickness: .50 in

Weight: .290(12.0)(9.0)(.50) = 15.7 lb.

cg from deck: .50/2 = .25 in.

Center Pin Attachment Block (Item 7- 8)

Height: 18.0 in.

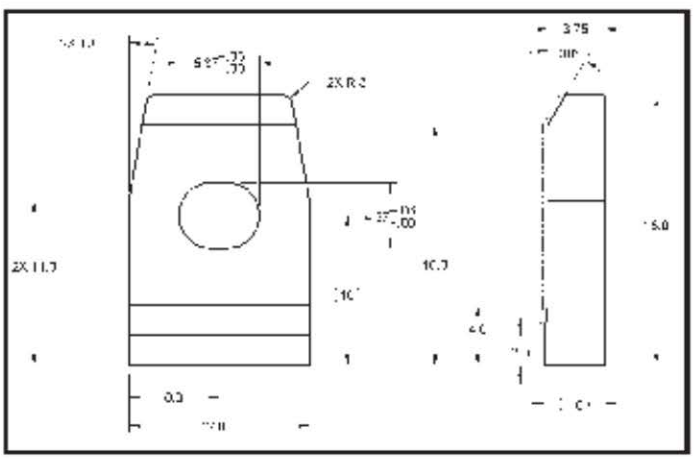
Width: 12.0 in.

Thickness (bottom): 4.0 in

Thickness (top): 3.75

Weight: $.280((12.0)(4.0)(4.0) + (3.75)[12(18.0 - 4.0) - \pi/4(4.37)^2 - 4.37(1)]) = 209.8$ lb.

cg from deck: 18/2 = 9 in.



Shear Block (Item 9)

Height: 4.0 in.

Width: 90.0 in.

Length: 21.0 in.

Weight: .280(4.0)(90.0)(21.0) = 2116.8 lb.

cg from deck: 4.0/2 = 2 in.

Outer Pin Attachment Block (Item 12-14)

Height: 18.0 in.

Width: 11.0 in.

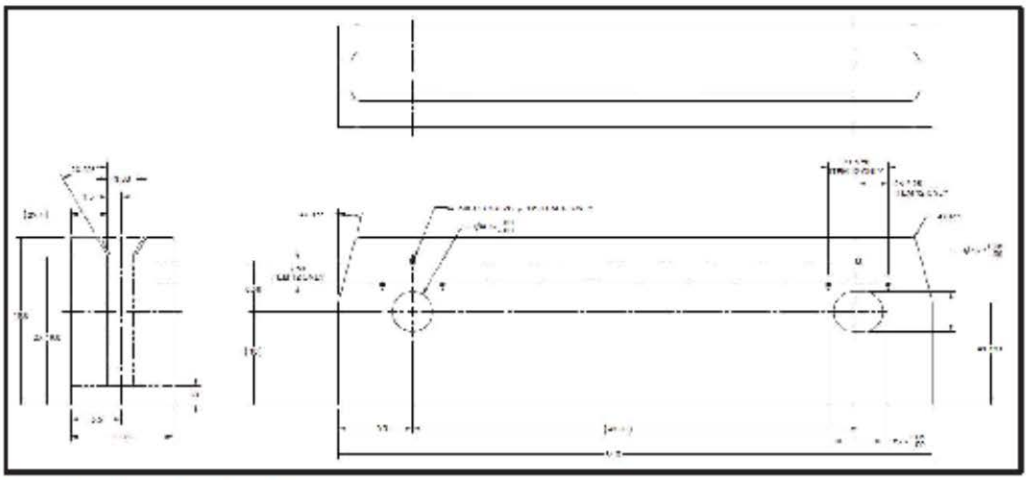
Length: 64.0 in.

Thickness (base): 2.0 in

Thickness (legs): 4 in.

Weight: $.280[(2.0)(11.0)(64.0) + 2(4)\{(64.0)(18.0\text{-}2.0) – \pi/4(4.37)^2 – \pi/4(4.37)^2 \text{ -}1(4.37)\}] = 2611.0$ lb.

cg from deck: 18/2 = 9 in.



Center Attachment Pin (Item 15)

Diameter: 4.000 in.

Length: 20.70 in.

Weight: $.290(\pi/4(4.000)^2(20.70)) = 75.4$ lb.

cg from deck: 10 in.

Outer Attachment Pin (Item 16)

Diameter: 4.000 in.

Length: 37.20 in.

Weight: $.290(\pi/4(4.000)^2(37.20)) = 135.6$ lb.

cg from deck: 10 in.

Pin Attachment Tray (Item 17)

The pin attachment tray is part of the pin loading weldment assembly, which is not attached during transport.

Fasteners (Item 18)

Diameter: 5/8 (0.625) in.

Length: 1.25 in.

Weight: $.289(\pi/4(.625)^2(1.25)) = .11$ lb.

cg from deck: 18 in.

(conservatively assumed to be top of the pin attachment block)

Table 9-1: Attachment Components Weight Summary

Component	Item	Qty.	Weight each (lb.)	cg each (in)	Total Weight (lb.)	W x (cg)
Pin Stop Bar	2	12	0.98	10	11.8	118
Pin Tray Keeper						
Pin keeper Plate	4	12	2.9	18	34.8	626.4
Deck Spacer Plate	5	2	15.9	0.19	31.8	6
Deck Spacer Plate	6	4	15.7	0.25	62.8	15.7
Center Pin Attach Block (outer)	7	4	209.8	9	839.2	7552.8
Center Pin Attach Block (inner)	8	4	209.8	9	839.2	7552.8
Shear Block	9	2	2116.8	2	4233.6	8467.2
DELETED	10					
DELETED	11					
Outer Pin Attachment Block (left)	12	2	2611	9	5222	46998
Outer Pin Attachment Block (right)	13	2	2611	9	5222	46998
Outer Pin Attachment Block (center)	14	4	2611	9	10444	93996
Center Attachment Pin	15	4	75.4	10	301.6	3016
Outer Attachment Pin	16	8	135.6	10	1084.8	10848
Pin Attachment Tray	17					
Fasteners	18	36	0.11	18	4	72
				Total:	28,331.6	226,266.9

The Attachment Components weigh 28,331.6 pounds and have a vertical cg, measured from the railcar deck, of 226,266.9/28,331.6 = 7.99 inches. The vertical cg measured from the rails, is 7.99 + 59.25 = 67.24 inches.

To bound the dynamic response of the railcar and any changes in the future final attachment component design, a range of ±10% is added to the weight. The nominal, maximum, and minimum attachment components weights are: 28,331.6 lb. (nominal), 31,165 lb. (maximum), 25,498 lb. (minimum)

APPENDIX J.3: FS-IN-18-0057, TITLED "RESPONSE ATLAS RAILCAR HI-STAR 60 CONCEPTUAL CRADLE WEIGHT"

Transportation Technology Center, Inc.

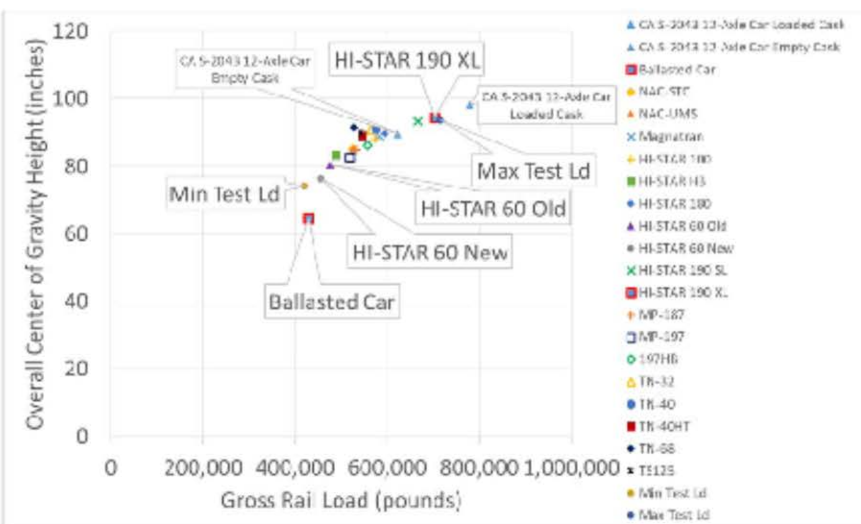
55500 DOT Road
P.O. Box 11130
Pueblo, Colorado 81001-0130

Russell Walker
(719) 584-0505
e-mail: russ_walker@aar.com

Document Number CR-18-006
Date: October 17, 2018
Slade Klein, Engineering Supervisor

Dear Mr. Klein,

I reviewed the changes to the weight of the Atlas Railcar HI-STAR 60 conceptual cradle that you described in letter FS-18-0257. The change did not cause the HI-STAR 60 to fall outside the range of weight and CG simulated with the other cask types as shown in the figure below.



The revised mass properties were used to repeat simulations of the Dynamic Curve regime. The vehicle dynamics predictions with the revised HI-STAR 60 properties changed very little from the predictions using the properties provided in 2017. The results for the 2017 and revised HI-STAR 60 mass properties are shown in the table below. Results for the Ballasted Car and the HI-STAR 190XL are shown as well to demonstrate the range of results.

Criterion	Limiting Value	Ballasted Car	Holtec Intl.		
			HI-STAR 60-2017	HI-STAR 60-Rev.	HI-STAR 190 XL
Gross Rail Load (pound)		429,000	476,000	456,000	703,000
Combined CG height (inch)		65	81	76	94
CGx Carbody and Load from C/L (inch)		0.0	5.4	5.7	12.7
CGy Carbody and Load from C/L (inch)		0.0	0.0	0.0	0.0
CGz Carbody and Load from TOR (inch)		79.4	98.5	93.9	108
Mass Carbody and Load (pound-s^2/inch)		809.2	931.3	880.5	1518.4
Ixx Carbody and Load (pound-s^2-inch)		1,099,705	1,830,703	1,632,427	3,310,523
Iyy Carbody and Load (pound-s^2-inch)		38,414,690	18,468,965	15,585,481	20,271,816
Izz Carbody and Load (pound-s^2-inch)		38,220,731	17,415,528	14,685,925	18,962,033
Maximum carbody roll angle (degree)	4.0	0.9	1.0	1.0	1.2
Maximum wheel L/V	0.80	0.71	0.72	0.72	0.88[a]
Maximum truck side L/V	0.50	0.36	0.37	0.37	0.37
Minimum vertical wheel load (%)	25	54	56	56	49
Peak-to-peak carbody lateral acceleration (g)	1.30	0.19	0.18	0.19	0.16
Maximum carbody lateral acceleration (g)	0.75	0.16	0.15	0.18	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	0.07	0.06
Maximum vertical suspension deflection (%)	95	43	49	47	78

The results using revised mass property inputs for the HI-STAR 60 cask and cradle combination met S-2043 requirements for Dynamic Curving and were close to the previous HI-STAR 60 predictions

Sincerely,

Russell Walker
Principal Investigator

Cc(via e-mail):
Richard Joy, TTCI
Rick Ford, Kasgro Rail
Mark Denton, Orano
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APPENDIX J.4: CALC-3015133, REV 005, ATLAS RAILCAR FAMILY 1 CONCEPTUAL CRADLE STRUCTURAL CALCULATION

CALC-3015133-005
Page 1 of 31

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CALCULATION

Document No.: CALC-3015133	**Rev. No.** 005	**Page 1 of 31 (31 Total Pages)**	
Project No.: 00225.03.0050	**Project Name:** DOE Atlas Railcar		
Title: Atlas Railcar Family 1 Conceptual Cradle Structural Calculation			

Summary:

This calculation documents the suitability of the conceptual design of the Family 1 Atlas Railcar cradles. Family 1 includes: AREVA-TN: TN40, TN40HT, TN328 and Holtec: Hi-Star 100, Hi-Star 100HB, Hi-Star 180, Hi-Star 190SL, and Hi-Star 190XL casks.

Contains Unverified Input / Assumptions: Yes: ☐ No: ☒

Software Utilized (Name and Revision):	**Location of Computer Files:**
Microsoft Excel 2010 Version 14.0.7232.5000 (32 bit)	COLDStor

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FS-EN-FRM-002 Rev. 11 (Effective January 7, 2019)
Refer to FS-EN-PRC-002

Revision History

Rev.	Changes
0	Initial Issue
1	Revised calculation to add Holtec Hi-Star 190SL and Hi-Star 190XL casks. Update Table 2.2 to reduce conservatisms. Added the personnel barrier to the weight and CG of the Hi-Star 100 Cask. Revised the end stops for all remaining casks to accommodate rail car attachment changes. Revised the cradles for the Hi-Star 100 and Hi-Star 100HB to lower the casks to meet the AAR Plate E height requirements. Revised Table 5.1 to report cradle weight with 10% increase. Added Tables 5.3, Summary of Cradle Stresses and 5.4 Summary of Cradle Attachment Weld Stresses.
2	Revised to correct TOC and list of tables page numbers, and errors in Table 5.1 references on pages 25 and 27.
3	The weight of the end stop assembly for the HI-STAR 60 conceptual cradle design was previously calculated using simplifications which resulted in unrealistic weight and CG values. Revised Hi-Star 60 End Stop Weight and CG Calculation and updated Table 2.2, Table 5.5, and Table 6.1 and updated reference files.
4	The HI-STAR 60 conceptual central cradle was revised to increase weight. Updated Table 2.2, Table 4.1, Table 5.1, Table 5.2, Table 5.5 and Table 6.1
5	Table 5.3 was updated to correct the saddle section modulus for the HI-STAR 190XL and HI-STAR 190SL cradles.

Table of Contents

Page

List of Tables

Page

List of Figures

Page

1.0 PURPOSE

This calculation evaluates and documents the structural capabilities of the Atlas Railcar Cradle design concepts for the Family 1 casks. Family 1 includes the following casks: AREVA TN:

TN-40, TN-40HT and TN-32B, Holtec International: Hi-Star 60, Hi-Star 100, Hi-Star 100HB (also referred to as the Hi-Star HB), Hi-Star 180, Hi-Star 190SL and, Hi-Star 190XL. This cask family (Family 1) is defined by the restraints defined/assumed for the cask. These casks all include end stops to restrain axial cask movement on the railcar during transport as shown in Figure 1.

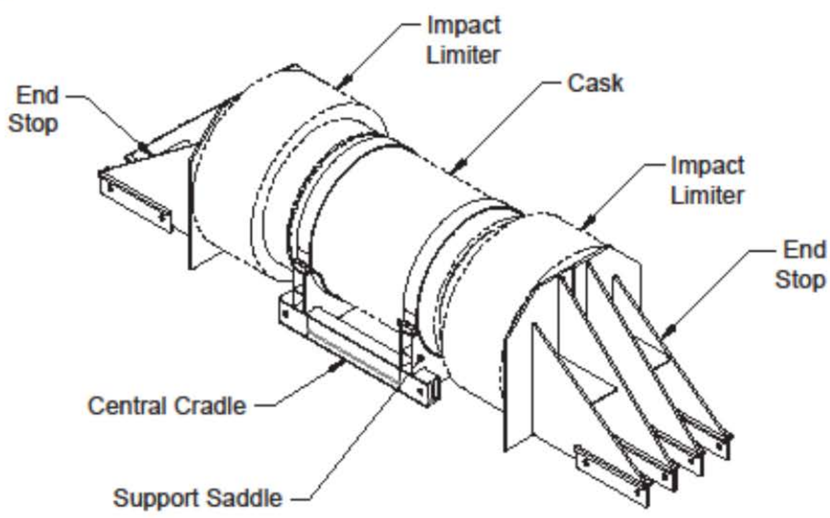


Figure 1: Typical Family 1 Cask and Cradle

The various designs, within Family 1, share the end stop requirement, however due to variations in the cask's geometries and licensing requirements, there are variations in the details.

The purpose of this design effort is the design of a railcar. In support of this, conceptual cradle designs are generated to define the height of each cask center-of-gravity above the bottom of the cradle and the weight on each rail car axle along with other information required to perform the analysis and provide simulated cask weights and supporting information needed for testing of the railcar.

This calculation also documents the loads to the railcar attachments due to the defined tie-down loads of ± 7.5 g Axial (Longitudinal), ± 2g Vertical and ± 2g Lateral applied independently per § 2.2.2.13 of [7.4].

As such, the cradle and end stop designs are only concepts and the design of the cradle and end stops will not be completed (these cask supports will be designed by each cask vendor). This evaluation serves only to validate this design concept.

The casks included here are grouped by the means of support for the transport cask on the rail car. All of the above casks are supported by a central support frame (used to react the vertical and lateral loads) and end stops (used to react the axial loads). All of the casks, with the exception of the Hi-Star 60 and Hi-Star 180 are rotated to the horizontal orientation for rail transport prior to placement on the rail car. The Hi-Star 60 and Hi-Star 180 are expected to have the option of this rotation on the rail car. In the case this is required (the facility has rail access to the cask loading location), a removable rotation fixture, such as is currently used by Holtec International is expected to be used. The loads on the rail car will be bounded by the loads from the heavier Magnatran cask (312 kip), a Family 2 cask vs. the Hi-Star 60 (164 kip) or Hi-Star 180 (309 kip) per Attachment A of [7.1].

The Family 1 support saddles are of similar design and the central cradle varies largely based on the cask length and height above the deck of the rail car. All of the Family 1 designs are shown in drawing Atlas Railcar Cradle Family 1 Conceptual Drawing [7.2]. The cradles for the AREVA-TN casks include slots in the cradle support to provide clearance for the tie-rods used to support impact limiter attachment.

Similarly, the end stops are all similar. For both the end stops and the central cradle, the attachment points to the rail car are the same.

Using these similarities, only the bounding loads for each component evaluated will be included and will thus bound all designs for Family 1.

Evaluation of the proposed attachment points and associated pins are included in the Attachment calculation [7.3].

The attachment lugs are located on the rail car deck [7.5]. The central cradle and end stops are pinned to the attachment lugs using 4 inch diameter pins. The holes in the four lugs used to attach the central cradle are slotted such that the lugs react only vertical and lateral loads. The holes in the lugs used to attach the end stops have round holes in the eight pair (four pair at each end) of lugs located nearer the center of the railcar and slotted holes for the remaining eight pair of attachment lugs, thus only the pin locations nearest the cask react the cask axial loads.

2.0 METHODOLOGY

2.1 Geometry

The Family 1 casks vary in outside diameter (at the cask support locations) from approximately 75-3/4 inches for the Hi-Star 60 cask to approximately 106-1/2 inches for the Hi-Star 190 casks. The largest diameter impact limiters are used on the TN-40 cask (144 inches) and the smallest are on the Hi-Star 60 (approximately 114-3/4 inches). The impact limiter diameter, with a 1 inch clearance, is the closest any cask may be located to the rail car deck. Some casks, due to their geometry, are located higher above the rail car deck, but in any case, the height above the deck is minimized in order to reduce the loads to the rail car as well as minimize the height of the Center-of-Gravity (C.G.) for the system (cask, cask supports and rail car).

The component weights and C.G.'s for both the casks and cradle/end stop designs are documented in ten (10) spreadsheets [7.10 through 7.19]. The spreadsheets are also used to determine the loads on the rail car attachment points.

Materials of Fabrication:

The main support beams for the central cradle are W18 X 119 per ASTM A992. The remaining components (plate) are fabricated from ASTM A572, Grade 42(for portions of the Hi-Star 190 SL & XL cradles), Grade 50, Grade 65 (for portions of the Hi-Star 190XL End stops). Material properties are shown in Table 2.3.

The loads specified in § 2.2 are design loads and use the material yield strength for the allowable stress per § 2.2.2.13 of the DBRD [7.4]. The acceptability of each component evaluated to the loads of § 2.2 will be determined by comparison with the yield strength and a Margin-of-Safety calculated as follows:

$$MS = \frac{\text{Allowable Load}}{\text{Applied Load}} - 1 \text{ or } \frac{\text{Allowable Stress}}{\text{Applied Stress}} - 1 \geq 0$$

2.2 Loads

Loads result from the accelerations specified in § 2.2.2.13 of [7.4]. The specified accelerations, listed in Table 2.1, are applied to each component/assembly. Each acceleration is applied separately. The resultant loads on the attachment points are developed in [7.10] through [7.19] and are summarized in Table 2.2. The component weights for the central cradle and end stops are increased by 10% in the determination of resultant loads per § 2.2.2.3(a) of [7.4].

Table 2.1 – Applied Accelerations

(Tie Downs)

Direction	Acceleration (g)
Longitudinal (Axial)	7.5
Vertical	2
Lateral	2

Notes:
1. Above values from § 2.2.2.13 of [7.4]. The values shown are the net accelerations.

Table 2.2 – Summary of Loads

	HI-STAR 100 (kip)	HI-STAR 100HB (kip)	HI-STAR 180 (kip)	HI-STAR 190XL (kip)	HI-STAR 190SL (kip)	HI-STAR 60 (kip)	TN-32B (kip)	TN-40 (kip)	TN-40HT (kip)
Pin Block 1 / Pin Block 4									
vertical (+z)	155.5	108.1	209.9	283.6	258.8	105.3	161.6	167.1	149.5
vertical (-z)	-155.5	-108.1	-209.9	-283.6	-258.8	-105.3	-161.6	-167.1	-149.5
lateral (y)	303.3	212.2	408.5	555.0	507.5	211.1	277.4	287.1	256.4
Pin Block 5									
Axial (+x)	–	–	–	–	–	–	–	–	–
Axial (-x)	–	–	–	–	–	–	–	–	–
vertical (+z)	42.5	69.1	52.8	44.9	47.3	38.3	55.3	54.2	54.2
vertical (-z)	-703.1	-520.8	-739.6	-979.2	-901.0	-395.8	-739.6	-755.2	-687.5
lateral (y)	12.8	16.0	12.3	11.0	11.7	13.2	16.7	17.1	17.1
Pin Block 9									
Axial (+x)	611.1	441.8	648.4	858.3	788.9	390.2	584.5	599.6	544.9
Axial (-x)	-48.0	-60.0	-50.6	-41.3	-43.9	-49.5	-62.6	-64.1	-64.1
vertical (+z)	703.1	520.8	739.6	979.2	901.0	395.8	739.6	755.2	687.5
vertical (-z)	-42.5	-69.1	-52.8	-44.9	-47.3	-38.3	-55.3	-54.2	-54.2
lateral (y)	12.8	16.0	13.5	11.0	11.7	13.2	16.7	17.1	17.1
Pin Block 13									
Axial (+x)	47.9	59.8	50.7	41.3	43.7	49.5	62.7	63.9	63.9
Axial (-x)	-611.1	-441.8	-648.4	-858.3	-788.9	-390.2	-584.5	-599.6	-544.9
vertical (+z)	703.1	520.8	739.6	979.2	901.0	395.8	739.6	755.2	687.5
vertical (-z)	-21.6	-35.1	-26.8	-44.9	-47.3	-19.4	-55.3	-54.2	-54.2
lateral (y)	12.8	16.0	12.3	11.0	11.7	13.2	16.7	17.1	17.1
Pin Block 17									
Axial (+x)	–	–	–	–	–	–	–	–	–
Axial (-x)	–	–	–	–	–	–	–	–	–
vertical (+z)	21.6	35.1	52.8	44.9	47.3	19.4	55.3	54.2	54.2
vertical (-z)	-703.1	-520.8	-739.6	-979.2	-901.0	-395.8	-739.6	-755.2	-687.5
lateral (y)	12.8	16.0	13.5	11.0	11.7	13.2	16.7	17.1	17.1

Notes:

1. The loads are from [7.10] through [7.19]. Due to symmetry, the load magnitudes for pin locations 5 - 8, 9 - 12, 13 - 16 and 17 - 20, the loads are the same, therefore, Table 2.2 lists the loads at the first pin location in each group for each cask. Locations are defined in the attachment drawing [7.5].
2. An example calculation for P1 - P4 is shown in § 5.5 and for the axial loading for P5 - P20 in § 5.3

2.3 Allowable Stress

The acceptance criteria for the loads resulting from the accelerations shown in Table 2.1 is the material yield strength per § 2.2.2.13 of the DBRD [7.4]. The acceptance criteria for fillet welds and partial penetration groove welds is 0.6 times the yield strength. Conservatively, the base material yield strength will be used.

2.4 Material Properties

Material Properties are shown in Table 2.3 below.

Table 2.3 – Material Properties for ASTM A992 and A572

ASTM Material	Yield Strength (ksi)	Ultimate Strength (ksi)
A992	50	65
A572, Grade 65	65	80
A572, Grade 50	50	65
A572, Grade 42	42	60

Notes:
1. Properties from American Society for Testing and Materials [7.6] and [7.7].
2. ASTM A572, Grade 42 is for materials greater than 4 inches in thickness.

2.5 Beam Properties

The longitudinal beam is a W18 x 119 with the following section properties (from AISC [7.8]):

$A_b := 35.1\ in^2 \quad d := 19\ in \quad b_f := 11.3\ in \quad t_f := 1.06\ in \quad I_x := 2190\ in^4$ and $I_y := 253\ in^4$

The beam is boxed at the ends (from the end of the beam to the first saddle) with 1 inch thick A572 plate. The composite beam has the following section properties:

$$S_{maj} = \left[2190\ in^4 + 2\frac{1\ in\ (19\ in - 2 \times 1.06\ in)^3}{12}\right]\frac{2}{19\ in} = 315\ in^3$$

$$S_{min} = \left[253\ in^4 + 2\frac{((1\ in)^3 (19\ in - 2 \times 1.06\ in))}{12} + (1\ in)(19\ in - 2 \times 1.06\ in)\left[\frac{11.3\ in - 1\ in}{2}\right]^2\right]\frac{2}{11.3\ in}$$

$$= 204\ in^3$$

3.0 ASSUMPTIONS

3.1 Justified Assumptions

3.1.1 Nominal dimensions are used throughout this calculation. This is standard practice.

3.1.2 The TN-40HT cask is not yet licensed for transportation. This cask is a version of the TN-40 used for high burnup fuel. The same impact limiter geometry and attachment method used on the licensed TN-40 cask is assumed. This is reasonable due to the relationship between the TN-40 and TN-40HT casks.

3.1.3 The TN-32B cask is not yet licensed for transportation. The same impact limiter geometry and attachment method used for the TN-40 cask is assumed. This assumption is reasonable due to the likeness of the TN-32 cask to both the licensed TN-40 and TN-68 casks. Both casks have similar impact limiters and impact limiter attachments. Additionally, this same assumption (as to the similarity of impact limiter geometry and impact limiter attachment) has been made on the TN-32B High Burnup (TN-32B HBU) demonstration cask project.

3.2 Unverified Inputs/Assumptions

None

4.0 DESIGN INPUTS

Table 4.1 – Design Inputs

Cask	Cask Weight[1] Maximum (lb) (Wc)	Cask Vert CG[2] from bottom of cradle (in) (d_{c_vcg})	Cradle Vert CG[3] from bottom of Cradle (in) (d_{cr_vcg})
HI-STAR 100 ($_{hs100}$)	279,893	66.0	25.2
HI-STAR 100HB ($_{hshb}$)	187,200	66.0	27.1
HI-STAR 180 ($_{hs180}$)	308,647	64.5	27.3
HI-STAR 190XL($_{hs190XL}$)	420,769	64.5	21.8
HI-STAR 190SL($_{hs190SL}$)	382,746	64.5	21.8
HI-STAR 60 ($_{hs60}$)	164,000	59.63	26.6
TN-32B ($_{TN32}$)	263,000	72.5	35.1
TN-40 ($_{TN40}$)	271,500	72.5	32.0
TN40HT ($_{TN40HT}$)	242,343	72.5	32.0

Notes:
1. Values from Attachment A of the Statement of Work [7.1] except values for the HI-Star 190 casks are from RFI AFS-RFI-0015 [7.21].
2. Values from Cradle Family 1 Conceptual Drawing.
3. Values from [7.11] – [7.19].

5.0 CALCULATIONS

5.1 Check Bending of Longitudinal Beams

The longitudinal beams are attached to the railcar at the attachment lug locations (P1 - P4 on the attachment drawing [7.5]). The vertical loads are reacted by either the 1/2 inch thick shim plates (Item 6 on [7.5]) (downward) or the 4 inch diameter pins (upward). The loads on the beam are from the lateral and vertical accelerations only, the cask axial loads are reacted by the end stops. The centers of the attachment lugs (and pins) are located 125 inches apart (see Figure 2).

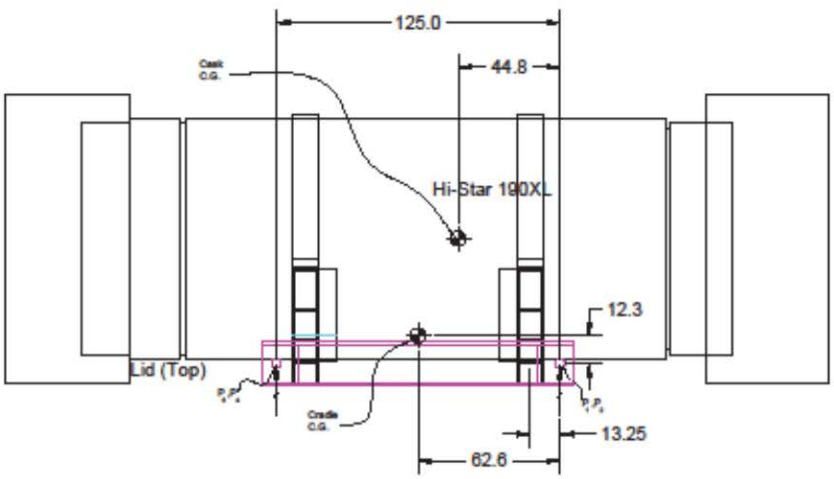


Figure 2: Hi-Star 190XL Free Body Diagram (FBD), Vertical

The vertical load is shared equally between the two beams and the lateral load is conservatively assumed to be reacted by only a single beam. The lateral load also causes a vertical load on the beam opposite the beam reacting the horizontal load. An example calculation of the moments is shown immediately below. The moments are calculated, using the same method as shown below for the remaining cradles and reported in Table 5.1.

The moment on the beam is simply the load at the attachment location (conservatively assume the center of the pin in lieu of the edge of the lug or shim plate) multiplied by the distance from the pin to the edge of the saddle. Conservatively, the dimension to the center of the saddle is used.

The force at the attachment is calculated by summing moments at pin location P1 as follows (the example is for the maximum moment case, the Hi-Star 190XL at the end near pin P3, see Figure 2 for FBD):

$$\text{Load}_{P3} = a_d \frac{W_{C\_190XL} \times d_{c\_hcg\_190XL} + W_{cr\_190XL} \times d_{cr\_hcg\_190XL}}{2 \times 125\ \text{in}}$$

$$= -2 \times \frac{420.769\text{kip} \times 44.8\text{inch} + 15\text{kip} \times 62.6\text{inch}}{2 \times 125\text{inch}} = -158.3\text{kip}$$

The load at P1 is:

$$Load_{P1}=\frac{a_d(W_{C\_190XL}+W_{cr\_190XL})\text{-}2\times Load_{P3}}{2}$$

$$=\frac{-2\times(420.769kip+15kip)\text{-}2\times(\text{-}158.3kip)}{2}=-277.5kip$$

The moment from the vertical load on the beam is: M = $Load_{P1}$ ×13.25 inch = 3,667 in·kip where 13.25 inch is the distance from the pin location to the center of the saddle. The horizontal load for the lateral load is double the vertical load (the load is reacted by a single beam). Additionally, the opposite beam reacts a vertical load for the righting moment from the lateral load. The vertical reactions at each end are proportional to the distance from the C.G. to the attachments.

Determine the vertical reactions resulting from the lateral acceleration by summing moments, counter clockwise positive. The restoring moment from the cask weight is conservatively neglected.

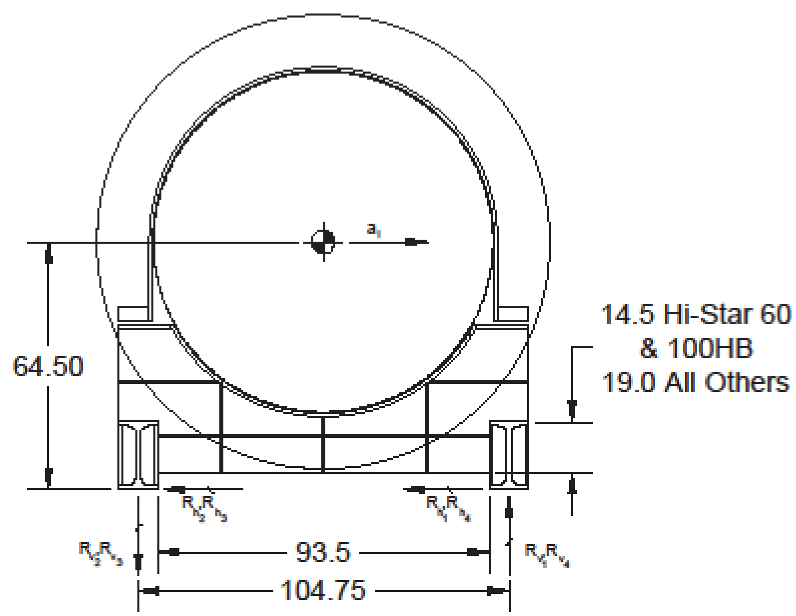


Figure 3 - Hi-Star 190XL Free Body Diagram (FBD), Lateral

$$+\circlearrowleft \quad \sum M_{P1} = 0 = -a_l\left(W_{c\_190XL}\, d_{c\_vgc\_190XL} + W_{cr\_190XL}\, d_{cr\_vcg\_190XL}\right) - 104.75\,\text{in}\,(R_{v2} + R_{v3})$$

where $a_l = 2\,g$ (Table 2.1), $d_{c\_vcg\_190XL}$= 64.5 inches (Table 4.1), $d_{cr\_vcg\_190XL}$= 21.8 inches (Table 6.1)

Sum forces in the vertical direction:

$$+\uparrow \quad \sum F_y = 0 = R_{v1} + R_{v4} - R_{v2} - R_{v3}, \text{ therefore } R_{v1} + R_{v4} = R_{v2} + R_{v3}$$

As noted above, the reactions on each beam are inversely proportional to the distance from the centroid. The combined longitudinal centroid for the Hi-Star 190XL cask and cradle is:

$$d_{hcg} = \frac{W_{c\_190XL} \times d_{c\_hcg\_190XL} + W_{cr\_190XL} \times d_{cr\_hcg\_190XL}}{W_{c\_190XL} + W_{cr\_190XL}}$$

$$= \frac{420.769\,\text{kip} \times 44.8\,\text{inch} + 13.6\,\text{kip} \times 62.6\,\text{inch}}{420.769\,\text{kip} + 13.6\,\text{kip}} = 45.4\,\text{inch}$$

Using the CG and the distance between the pins of 125 inches, the following relationship is found for vertical reactions: R_{v1} x 45.4 inch = R_{v4} (125 inch-45.4 inch) and the same relationship holds for R_{v2} and for R_{v3} respectively.

Substituting and solving for R_2:

$$R_{v2} = \frac{a_l[W_{c\_190XL} \times (d_{c\_vcg\_190XL} - 9.5\text{ in}) + W_{cr\_190XL} \times (d_{cr\_vcg\_190XL} - 9.5\text{ in})]}{104.75\text{in}\left(1 + \frac{45.4}{125 - 45.4}\right)}$$

$$= \frac{2 \times [420.769\text{kip} \times (64.5\text{inch} - 9.5\text{inch}) + 15.0\text{kip} \times (21.8\text{inch} - 9.5\text{inch})]}{104.75\text{in}\left(1 + \frac{45.4}{125 - 45.4}\right)} = 283.6\text{kip}$$

, $R_{v3} = \frac{45.4}{125 - 45.4} R_{v2} = 161.8\,\text{kip}$. The corresponding moments are

$M_{v2} = R_{v2}\,12.75$ inch = 3,616 in kip and $M_{v3} = R_{v3}\,13.25$in = 2143 in ·kip These moments resulting from the lateral acceleration are greater than the moments resulting from the vertical acceleration. However, these moments act on the strong axis of the longitudinal beams. The horizontal component of the lateral acceleration is also reacted by the single beam. Referring to Figure 2 and summing the forces in the horizontal direction (positive right),

$\rightarrow+ \quad \sum F_h = a_l = (W_{c\_190XL} + W_{cr\_190XL}) - R_{h1} - R_{h4}, R_{h1}\, 45.4\,in = R_{h4}\,(125\,in - 45.4\,in).$

Solving for R_{h1}: $R_{h1} := a_l \dfrac{(W_{c\_190XL} + W_{cr\_190XL})}{1 + \dfrac{45.4}{125 - 45.4}} = 555$ kip and the resulting moment is :

$M_{h1} = R_{h1}\, 13.25\ in = 7354 in{\cdot}kip$ and the moment on the opposite end of the beam is:

$M_{h4} = R_{h1} \frac{45.4}{125-45.4} 12.75\ in = 4036\ in \cdot kip$ The moments resulting from the horizontal components are higher and the section modulus of the beam resisting this moment is lower, therefore, evaluation of the horizontal component is bounding for the beam.

The resulting stress for the composite W18X119 beam is: $\sigma_{minor} = \frac{M_{h1}}{S_{min}} = 36.0$ ksi where $S_{min} = 204\,in^3$ is from § 2.5.

The resulting Margin of Safety is: $MS = \frac{F_{y992}}{\sigma_{minor}} = 0.39$ → Okay

The loads and moments on the central cradles are summarized in Tables 5.1 and 5.2, and demonstrate that the moment on the Hi-Star 190XL bounds the remaining cradles. Note that the values shown in the tables are for the vertical acceleration and are for comparison only (used to demonstrate the bounding cradle).

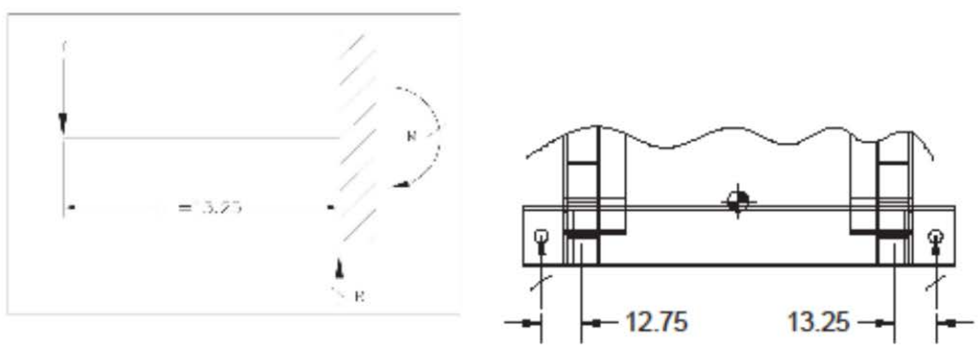


Figure 4 - Beam & Moment Diagram

Table 5.1 – Summary of Loads on Central Cradle

Cask	Cask Weight Maximum (lb) (W_c)	Cask CG from pin (P1) (in) (d_{c_hcg})	Central Cradle weight (kip) (W_{cr})	Central Cradle CG from P1 (in) (d_{cr_hcg})	Load at P3 (kip) ($Load_{P3}$)	Load at P1 (kip) ($Load_{P1}$)
HI-STAR 100($\_{hs100}$)	279,893	62.9	22.6	66.8	151.7	149.6
HI-STAR 100HB($\_{hshb}$)	187,200	59.9	16.5	60.2	97.7	106.0
HI-STAR 180($\_{hs180}$)	308,647	44.4	10.1	62.6	114.2	204.1
HI-STAR 190XL($\_{190XL}$)	420,769	44.8	15.0	62.6	158.3	277.5
HI-STAR 190SL($\_{190SL}$)	382,746	44.6	14.7	62.6	143.3	253.5
HI-STAR 60($\_{hs60}$)	164,000	50.9	17.7	68.2	76.4	105.3
TN-32B($\_{TN32}$)	263,000	63.0	14.6	56.9	139.6	138.3
TN-40($\_{TN40}$)	271,500	62.5	14.2	56.7	142.2	143.5
TN40HT($\_{TN40HT}$)	242,343	62.5	14.2	56.7	127.6	128.9

Notes:

1. The loads in Table 5.1 and the moments in Table 5.2 result from the vertical acceleration on the cask/cradle. As such, the reactions are opposite the applied acceleration in all cases and since the applied accelerations are bi-lateral (±7.5 g axial, ±2 g vertical and lateral) only the magnitude is of importance.
2. In the table above, the column defines the main variable (such as W_c for cask weight) and the row defines the specific (such as _hs100). The variable name is, for this example, W_{c_hs100} and is the weight of the Hi-Star 100 cask.
3. The cradle weights shown in the above table include an additional 10% factor.

Table 5.2 – Summary of Moments on Central Cradle Beam

Cask	Distance from P1 to center of saddle (in) (d_{P1s})	Distance from P3 to center of saddle (in) (d_{P3s})	Moment	
			P3 End (in-kip) (M_{P3})	P1 End (in-kip) (M_{P1})
HI-STAR 100	13.375	12.625	1,916	2,001
HI-STAR 100HB	27.06	34.26	3,347	2,870
HI-STAR 180	13.25	12.75	1,456	2,704
HI-STAR 190XL	13.25	12.75	2,019	3,676
HI-STAR 190SL	13.25	12.75	1,827	3,359
HI-STAR 60	16.25	35.27	2,696	1,711
TN-32B	13.25	15.15	2,115	1,833
TN-40	13.25	15.15	2,154	1,901
TN40HT	13.25	15.15	1,933	1,708

5.2 Evaluate the Saddles for the Design Loads

The saddles support the vertical and lateral loads from the casks (the axial loads are reacted by the end stops).

The analysis below assumes a distributed load increasing toward the center of the cradle plates on the saddles. The saddles for the TN-40/TN-40HT and the TN-32 include cutouts for the tie-rods connecting the impact limiters. These cutouts reduce the depth of the saddles on these two cradles.

The weight of the TN-40 cask exceeds that of the TN-32 cask and the central cross-section of the TN-32 is less than that of the TN-40 [TN-40HT] cradle, therefore, the cross section of the TN-32 cradle will be used with the loads of the TN-40 cask, thus bounding both cradles.

The remaining cradles include reinforcement in the center. The reinforcement is comprised of two 3-1/4 inch thick doubler plates attached to each one inch thick vertical cradle support plate, except for the Hi-Star 190SL and Hi-Star 190XL cask cradles where a longer (50.7 inch long, ASTM A572, Grade 42) bar replaces the two one inch thick vertical cradle plates. The thickness of the bar is greater than 4 inches necessitating the use of grade 42 material.

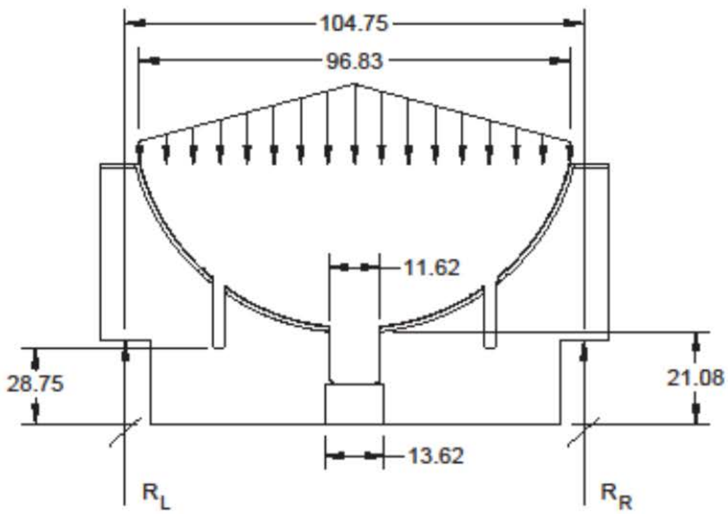


Figure 5 - TN-40 cradle Saddle with Major Points Identified - Vertical Loading

The saddle is modeled as a simply supported beam with a distributed load increasing toward the center. The moment is the highest at the center of the beam. The moment will be calculated using superposition, combining the moment calculated using case 8 (page VI-85) from Aluminum Design Manual [7.9] with the moment from the support offset to the edge of the cradle plate.

The moment at the center is:

$$M_{v\_saddle} = a_d \frac{(W_{c\_TN40})96.83\,in}{2 \times 6} + a_d \frac{104.75\,in - 96.83\,in}{2} \frac{W_{c\_TN40}}{2}$$

$$M_{v\_saddle} = 5457\,in \cdot kip$$

Where: $W_{c\_TN40} = 271.5\,kip$ is from Table 5.1, 96.83 inches is the horizontal distance of the saddle plate (2(48.875+.25+1)cos(15°) = 96.83in), 48.875 is the radius of the TN-32 Cask, .25 and 1 are the thickness of the rubber and the cradle plate and a_d=2g is the vertical acceleration.

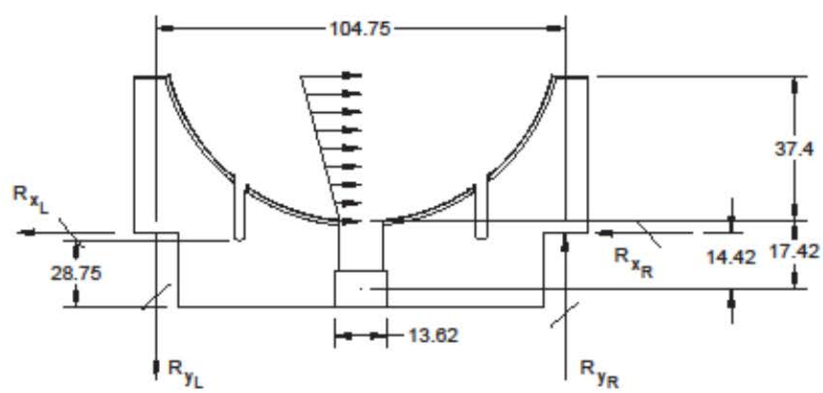


Figure 6 - TN-40 cradle Saddle with Major Points Identified - Lateral Loading

In addition to the vertical loading, the lateral acceleration would also cause a moment on the central area of the saddle. Figure 6 above shows the loading where a triangular load distribution is assumed. In the lateral load case shown above, the load from cask weight is modeled as a triangle with the area equal to the weight of the cask. Each saddle supports one half of the cask weight and the saddles are supported by the W18 X 119 longitudinal beams. The first step is to determine the loads.

The triangular distribution is equivalent to the entire weight of the cask applied at the centroid of the area or 1/3 of the length from the top of the saddle.

Summing the moments (positive clockwise):

$$\circlearrowright + \qquad \sum M_R = 0 = \left(17.42 + \frac{2 \times 37.4}{3}\right)\frac{W_{c\_TN40}}{2} - 104.75\,R_{yL} - 14.42\,R_{xL} - 14.42\,R_{xR}$$

$R_{yL} = 2\,\frac{17.42 + \frac{2\times 37.4}{3}}{104.75}\,\frac{W_{c\_TN40}}{2} = 110$ kip where the moment resulting from the horizontal reactions is conservatively neglected, the multiplier of 2 accounts for the applied lateral acceleration and the divisor of 2 accounts for the load sharing between the two saddles.

The resulting moment is simply the force multiplied by the distance:

$$M_{L\_saddle} = R_{yL}\,\frac{104.75\,\text{in}}{2} = 5761\,\text{in}\cdot\text{kip}$$

The TN-40 saddle, at the center section, is 9.15 inches tall (see Drawing 3015137, Sheet 1, Zone A7 [7.2]) and in addition to the 1 inch thick saddle plate, includes two 3-1/4 inch thick doublers.

The corresponding section modulus of the plates at the center is:

$S_{saddle} = 2\left[\frac{1\,\text{in}(9.15\,\text{in})^2}{6} + \frac{3.25\,\text{in}\,(9.15\,\text{in})^2}{6}\right] = 118.6\,\text{in}^3$. The moment due to the lateral load is bounding and the resulting stress is: $\sigma_{b\_TN40} = \frac{M_{L\_saddle}}{S_{saddle}} = 48.6\,\text{ksi}$

The Corresponding Margin of Safety is: $MS = \frac{F_{y572\_50}}{\sigma_{b\_TN40}} - 1 = 0.03$ where $F_{y572\_50} = 50$ ksi is the material of the cradle and doubler plate.

The Hi-Star 190SL and 190XL have a two piece doubler plate (each 5 inches thick) forming the center section of the cradle. This section is 11-1/2 inches wide, 50.7 inches long and 10 inches thick. The thickness limit of ASTM A572 for Grade 50 material requires this bar to be fabricated from multiple pieces, two ASTM A572, Grade 42 plates with a yield strength of 42 ksi were chosen to achieve the total 10 inch thickness.

The TN40 doubler plate is only 2 inches longer than the 11.62 inch wide cutout. Assuming the same moment is present at the point where the doubler plate ends, the stress is:

$\sigma_{b2\_TN40} = \frac{M_{L\_saddle}}{S_{2\_saddle}} = 38.9\,\text{ksi}$ where

$S_{2\_saddle} = 2\frac{1\,\text{in}\,(21.08\,\text{in})^2}{6} = 148.1\,\text{in}^3$. This is the shortest unreinforced section of the saddle plates and because the maximum moment was used, bounds all other sections.

The resulting margin of safety is: $MS = \frac{F_{y572\_50}}{\sigma_{b2\_TN40}} - 1 = 0.285$ where $F_{y572\_50} = 50\,\text{ksi}$ is from Table 2.3.

Table 5.3 – Summary of Saddle Stress

Cask	R_{cask} (in)	Saddle Angle (deg)	Width (in)	Moment (in-kip)		Distance (in)		S_{cradle} (in^3)	Stress (ksi)	
				Vert	Hor	To cask Bottom	To Saddle Top		Vert	Hor
HI-STAR 100	48	20	92.56	4,016	2,839	9.625	31.2	93.5	30.4	43.0
HI-STAR 100HB	48	20	92.56	4,029	2,637	7.375	31.2	87.5	30.1	46.0
HI-STAR 180	53.15	14.72	105.23	5,339	4,919	5.675	39.3	111	44.3	48.1
HI-STAR 190XL	53.15	14.72	105.23	7,279	6,827	6.25	39.3	191.7	35.6	38.0
HI-STAR 190SL	53.15	14.72	105.23	6,621	6,210	6.25	39.3	191.7	32.4	34.5
HI-STAR 60	37.875	20	73.53	4,570	2,098	9.25	24.5	106.7	19.7	42.8
TN-32B	48.875	15	96.83	5,286	5,662	19.125	35.9	118.6	47.7	44.6
TN-40	50.5	14.67	100.13	5,158	5,749	17.42	37.4	118.6	48.5	43.5
TN40HT	50.5	14.67	100.13	4,604	5,132	17.42	37.4	118.6	43.3	38.8

Note: The allowable stress for all cradle components except the Hi-Star 190SL & 190XL is 50 ksi. The allowable stress for the Hi-Star 190SL & 190XL is 42 ksi.

Sample Calculation - Weld attaching the Saddle to the Longitudinal Beams

The attachment weld is a 3/4 inch fillet weld on each outer side of the saddle plates (See Drawing 3015137, Sheet 2, Zone B3, Section B-B [7.2]). The two legs are horizontal across the beam flange and vertical along the 1 inch thick beam closure plate. Referring to Figure 3 and summing the moment about the weld on the right hand (R_{v1}, R_{v4}) beam.

+↺

$$\sum M_{Rv1} = 0 = -a_l W_{c\_hshb}\left[d_{c\_vcg\_hshb} - 19in + (14.5in - 10.43in)\right] + 2F_{Rv23}(93.5in + 2 \times 2.5in)$$

Solving for F_{Rv23} (the load reacted by the weld):

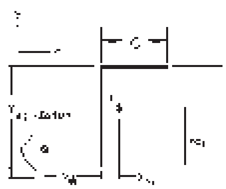
$$R_{v23} = \frac{a_l W_{c\_hshb}\left[d_{c\_vcg\_hshb} - 19in + (14.5in - 10.43in)\right]}{2(93.5in + 2 \times 2.5in)} = 97\ kip$$

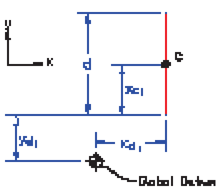
where a_l=2 is for the 2g lateral load, the 2 in the denominator is for the number of saddles sharing the load, $d_{c\_vcg\_hshb}$ = 66.0 inches is the height of the Hi-Star 100HB cask above the bottom of the cradle from Table 4.1, 93.5 inches is the distance between the Item 1 beams and 19 inches is the height of the Item 1 beams from Figure 3 and 2.5 inches (rounded from 2.47 inches) and 10.43 inches is the location of the weld centroid (calculated below). The calculated values for all of the casks are shown in Table 5.4 following this sample calculation.

Calculate fillet weld properties

Each of the two welds are comprised of two legs, the vertical and the horizontal. The horizontal leg is the width of the W18 X 119 flange. On all cradles except the Hi-Star 60 and the Hi-Star 100HB, the vertical leg of the weld is the height of the W18 X 119 beam (19 inches). On the two exceptions, the saddle plates are shorter to provide clearance to the shear key on the Railcar. These two welds have a vertical leg 14.5 inches long as shown in Figure 3. The distance between the welds is the same for all cradles. The Hi-Star 100HB cask is heavier than the Hi-Star 60

The complete weld is shown below:





Weld Geometry

Weld Throat: $h = \frac{.75\,in}{\sqrt{2}} = 0.53\,in$

Dimensions: d = 14.5 in where d is the length of the vertical leg of the weld as shown in Figure 3.

Weld Properties (Weld Number i:= i + 1, i = 1)

Weld Area: $A_i = d \cdot h = 7.7\,in^2$

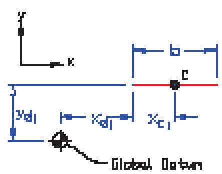
Weld Centroid: $x_{d_i} = 0\,in$

$y_{c_i} = \frac{d}{2} = 7.25\,in$

Weld Offset

$X_{d_i} = 0\,in$

$Y_{d_i} = 0\,in$



Weld Geometry

Weld Throat: $h = 0.53\,in$

Dimensions: $b = b_f = 11.3\,in$ where b_f is the flange width of the W18 X 119 beam

Weld Properties (Weld Number $i := i + 1$, $i = 2$)

Weld Area: $A_i = b \cdot h = 6\,in^2$

Weld Centroid: $x_{d_i} = \frac{b}{2} = 5.65\,in$

$y_{c_i} = 0\,in$

Weld Offset

$X_{d_i} = 0\,in$

$Y_{d_i} = d$

Composite Section Properties: (Welds $j := 1 \ldots i$, $i = 2$)

Area: $A_c = \sum_j A_j = 13.7\,in^2$

Centroid:

$$x_c = \frac{\sum_j \left(x_{d_j} + X_{d_j}\right) A_j}{A_c} = 2.47\,in \qquad y_c = \frac{\sum_j \left(y_{c_j} + Y_{d_j}\right) A_j}{A_c} = 10.43\,in$$

The weld shear stress is: $\tau_{weld} = \frac{R_{v23}}{A_c} = 7.1\,ksi$ and the Resulting Margin of Safety

Is: $MS = \frac{0.6 \times F_{y572\_50}}{\tau_{weld}} - 1 = 3.23$ → Okay

Table 5.4 – Cradle Attachment Weld Stresses

Cask	Cask Weight Maximum (W_c) (lb)	Vertical Weld Leg Length (in)	Weld Centroid		Vertical Load (R_{v23}) (kip)	Weld Area (in^2)	Weld Stress (ksi)	Margin of Safety
			Hor (x) (in)	Ver (y) (in)				
HI-STAR 100 ($_{hs100}$)	279,893	19.0	2.11	13.04	152	16.1	9.4	2.19
HI-STAR 100HB ($_{hshb}$)	187,200	14.5	2.47	10.43	97	13.7	7.1	3.23
HI-STAR 180 ($_{hs180}$)	308,647				163	16.1	10.1	1.97
HI-STAR 190XL($_{190XL}$)	420,769	19.0	2.11	13.04	222	16.1	13.8	1.17
HI-STAR 190SL($_{190SL}$)	382,746				202	16.1	12.5	1.40
HI-STAR 60 ($_{hs60}$)	164,000	14.5	2.47	10.43	74	13.7	5.4	4.56
TN-32B ($_{TN32}$)	263,000				160	16.1	9.9	2.03
TN-40 ($_{TN40}$)	271,500	19.0	2.11	13.04	165	16.1	10.2	1.91
TN40HT ($_{TN40HT}$)	242,343				147	16.1	9.1	2.26

5.3 Evaluate the End Stops

The end stops are constructed of largely the same materials and the construction is similar. The end stops are constructed largely from ASTM A572, Grade 50 plate, 2 inches thick except at the attachment locations where a 1/4 inch thick doubler is attached on each side of the 2 inch plate and the stiffener plates are 1 inch thick. The pin attachment plates at the base of the Hi-Star 190XL are constructed from (2) 1-1/4 inch thick ASTM A572, Grade 65 plates in lieu of the 2 inch thick plate with (2) 1/4 inch thick doubler plate as is typical of the remaining end stops.

The plates are pinned to the rail car attachment lugs using Ø 4 inch pins in Ø 4.13 inch holes or slots (the slots are in the attachment lugs at the pin locations closest to the end of the rail car and allow axial motion while the round holes serve to react the axial load from the cask).

A pair of end stops is located at each end of the rail car. Each end stop is comprised of 2, 2 inch thick vertical plates and a face plate (adjacent to the cask's impact limiters) of 2 inch thick plate or 2, 1 inch thick plates (total thickness 2 inches). There are additional 1 inch thick plates placed between the vertical plates to act as stiffeners (as shown in Figure 7).

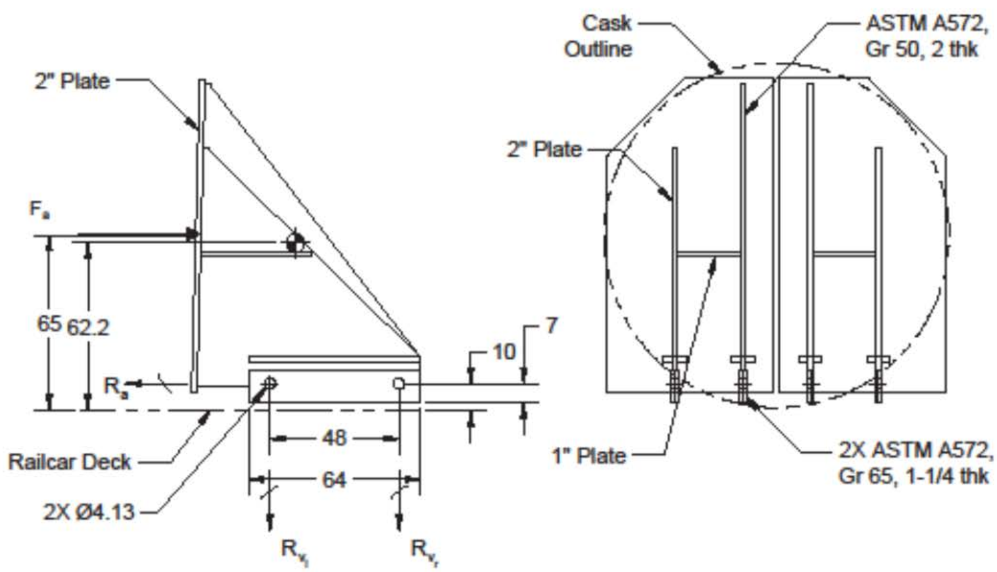


Figure 7- End Stop - Hi-Star 190XL

Evaluate Bending on the Vertical Plates

The maximum moment on any plate is at the pin attachment locations and all end stops are configured identically in this area, therefore, the cask/end stop with the largest applied moment bounds all others.

The combination of cask height, weight and central cradle weight for the Hi-Star 190XL produces the highest moment load (see Table 5.5 below). The combined moment is:

$$M_{ES} = a_{ax}\left[\left(W_{C\_190XL} + W_{cr\_190XL}\right)\left(d_{c\_vcg\_190XL} - 9.5\text{in}\right) + 2 \times W_{ES\_190XL} \times \left(d_{ES\_190XL} - 10\text{in}\right)\right]$$

$$= 7.5 \times [(420.769\text{kip} + 15.0\text{kip})(64.5\text{inch} - 9.5\text{inch}) + 2 \times 11\text{kip} \times (62.2\text{inch} - 10\text{inch})]$$

$$= 188 \times 10^3 \text{in} \cdot \text{kip}$$

Where a_{ax}=7.5 g is the axial acceleration, W_{c_190XL} = 420.769 kip is the cask weight, W_{cr_190XL} = 15.0 kip is 110% of the central cradle weight both from Table 5.1, $d_{c\_vcg\_190XL}$ = 64.5 + .5 = 65 inches, W_{ES_190XL} = 11 kip from Table 6.1, d_{ES_190XL} = 62.2 inches is the end stop vertical centroid location and 10 inches are from Figure 7 and 0.5 inches is the offset from the rail car deck provided by the shim plate located between the lugs.

The vertical reaction at the pin location is found by dividing the moment above by the distance between the holes. $R_{vL} = M_{ES}\frac{1}{4 \times 48in} = 979.2\text{ kip}$ where the 4 accounts for the number of lugs sharing the load and 48 inches is the distance between the holes from Figure 7.

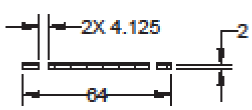
The axial load on the end stop pins (R_a) is simply the axial load equally distributed over the number of pins sharing the load. As discussed in § 1.0, only the 4 end stop pin locations nearest the cask react the axial load (the holes in the lugs furthest away from the pins are slotted and only react vertical loading).

$$R_a = a_{ax}[W_{c\_190XL} + W_{cr\_190XL} + 2 \times W_{ES\_190XL}]/4$$

$= 7.5 \times [420.769\text{kip} + 15.0\text{kip} + 2 \times 11\text{kip}]/4 = 858.3\text{kip}$ where W_{ES_190XL}=11 kip is from Table 6.1.

The moment is reacted by four vertical end stop plates, conservatively neglecting the doublers. The length of the plates through the pins is 64 inches and the corresponding section modulus, through the holes, (for one plate) is:

$$S_{ES} = \frac{2\text{ in}(64\text{ in})^3}{12} - 2\left[\frac{2\text{ in}(4.125\text{ in})^3}{12} + 2\text{ in}(4.125\text{ in})\left(\frac{64\text{ in}}{2} - 8\text{ in}\right)^2\right] = 1068\text{ in}^3$$



The end stops are divided into two halves on each end and are symmetric. There are two vertical plates on each end stop half (refer to Figure 7). The moment reacted by each plate is therefore, one quarter the total calculated above and the maximum bending stress is:

$\sigma_{b\_ES} = \frac{M_{ES}}{4\ S_{ES}} = 43.8\text{ ksi}$ and the corresponding margin of safety is:

$$MS = \frac{F_{y572\_50}}{\sigma_{b\_ES}} - 1 = 0.142 \quad \rightarrow \quad \text{Okay}$$

The end stops for all designs with the exception of the Hi-Star 190SL and 190XL are comprised of a 2 inch thick plate with 1/4 inch thick doublers on each side. The material is ASTM A572, Grade 50. The Hi-Star 190XL end stop is constructed using 2, 1-1/4 inch thick ASTM A572, Grade 65 plates (for the same overall 2-1/2 inch thickness). Conservatively, a thickness of 2 inches and ASTM A572, Grade 50 was used in the calculations to qualify all end stops.

Stiffeners were added between the vertical plates on this design concept. If buckling or crippling is identified as a concern in the detailed design, additional stiffeners may be added.

Table 5.5 – Moments on End Stops

Cask	Cask Weight Maximum (W_c) (lb)	Cask Vert cg from bottom of cradle (d_{c_vcg}) (in)	Central Cradle weight (W_{cr}) (kip)	Moment at Base of End Stop (M_{ES}) (10^3 in-kip)
HI-STAR 100 ($_{hs100}$)	279,893	66.0	22.6	136
HI-STAR 100HB ($_{hshb}$)	187,200	66.0	16.5	100
HI-STAR 180 ($_{hs180}$)	308,647	64.5	10.1	142
HI-STAR 190XL($_{190XL}$)	420,769	64.5	15.0	188
HI-STAR 190SL($_{190SL}$)	382,746	64.5	14.7	173
HI-STAR 60 ($_{hs60}$)	164,000	59.63	17.7	76
TN-32B ($_{TN32}$)	263,000	72.5	14.6	142
TN-40 ($_{TN40}$)	271,500	72.5	14.2	145
TN40HT ($_{TN40HT}$)	242,343	72.5	14.2	132

Note: The cradle weights shown the above table include an additional 10% factor.

Evaluate Shear Tear-out

The same moment is reacted by the plate in shear at the attachment pin locations, however, the attachment loads for the attachment locations closest to the cask include both the vertical and axial loads acting at a single pin location. The highest combined load occurs for the Hi-Star 190XL cask. Evaluation of this load bounds all other designs. The loads conservatively include the self weight of the end stops. The shear force, at one of the pin locations is:

$f_s = \sqrt{R_a{}^2 + R_{v1}{}^2} = \sqrt{(858.3\,\text{kip})^2 + (979.2\,\text{kip})^2} = 1302\,\text{kip}$ where 858.3 kip and 979.2 kip are the maximum attachment lug loads from Table 2.2 for Pin Block 9 on the Hi-Star 190XL cask. Note: The lug located further from the cask (e.g. P8) has a slotted hole and reacts only a vertical load. The distance to the edge of a plate, parallel to the applied load, is:

$d_{min} = \dfrac{7\,\text{in}}{\cos\left(a\tan\left(\dfrac{858.3}{979.2}\right)\right)} - \dfrac{4.125\,\text{in}}{2} = 7.2\,\text{in}$ where 7 inches is the distance from the center of the hole to the bottom edge of the plate. The shear area is:

$A_{s\_ES} = 2 \times 2.5\,\text{in} \times d_{min} = 36.0\,\text{in}^2$ where 2.5 inches is the thickness of the plates at the lower end stop attachment and the resulting shear stress is: $\tau_{ES} = \dfrac{f_s}{A_{s\_ES}} = 36.2\text{ksi}$

and the Resulting Margin of Safety is: $MS = \frac{0.6 \times F_{y572\_65}}{\tau_{ES}} - 1 = 0.08$ → Okay

where F_{y572_65} = 65 ksi is from Table 2.3 and the 0.6 multiplier is defined in § 2.3. Using the same method, the shear stress for the Hi-Star 190SL end stop is 33.1 ksi and for the Hi-Star 180 (the next highest end stop pin load) is 27.8 ksi. The Hi-Star 180 meets the allowable shear stress of 30 ksi for ASTM A572, Grade 50.

5.4 Evaluate Strap Attachment Fasteners

The straps are attached using 2, 1 1/2-6 UNC ASTM A490 bolts threaded into nuts welded to the underside of the saddle plate for all cradles except the Hi-Star 190 cradles which use (2) 1 3/4-5 ASTM A574 Hex Head Cap Screws and compatible nuts.

Determine the required strength for the attachment bolts

The bolts react the load from the vertical load case or 2 g up. All cradle designs include 2 or more saddles and straps, therefore, sharing the load between two tie down straps bounds all load cases.

The maximum cask weight, from Table 5.1 W_{c_190XL} = 420.769 kip. The load on a single bolt is: $f_{bolt} = 2\frac{W_{c\_190XL}}{2 \times 2} = 210$ kip where the multiplier of 2 is for the 2g up load case and the two's in the denominator are for the number of saddle straps and number of bolts on each strap. The bolts have a tensile area of: $A_{bolt} = 1.9$ in^2 from ASTM A574 [7.22]. The stress on each bolt is: $\sigma_{bolt} = \frac{f_{bolt}}{A_{bolt}} = 111$ ksi. The yield strength of the bolt will be used as the allowable strength. The margin of safety is: $MS = \frac{F_{ybolt}}{\sigma_{bolt}} - 1 = 0.216$ → Okay

where F_{y_bolt} = 135 ksi is from ASTM A574 for a 1 3/4-5 UNC bolt. The cradles for other than the Hi-Star 190 casks use 1-1/2-6 UNC ASTM A490 bolts [7.20] with a yield strength of 130 ksi and a maximum bolt stress of 110 ksi for the Hi-Star 180 cask.

5.5 Example Calculation of Attachment Lug Loads – Central Cradle

The Railcar attachment lug loads are shown in Table 2.2. An example calculation for the lug loads is shown below. The examples are for the Hi-Star 100 Cask and do not necessarily constitute the bounding lug load.

The lug loads result from the applied tiedown accelerations shown in Table 2.1. Lugs P1 - P4 are used to attach the central cradle. These lugs are slotted and will not react the axial loads resulting from the ± 7.5 g axial acceleration. These lugs react only the vertical and lateral loads.

The load on lug P1 due to the vertical acceleration is determined by summing moments about the P3-P4 end of the central cradle:

$$+\circlearrowleft \quad \sum M_{P34} = 0 = a_u \begin{bmatrix} -W_{c\_hs100}\left(125\,in - d_{c\_hcg\_hs100}\right) \\ -W_{cr\_hs100}\left(125\,in - d_{cr\_hcg\_hs100}\right) \end{bmatrix} + \left(F_{P1v} + F_{P2v}\right) 125\,in$$

The reactions at P1 and P2 are the same (the cradle is laterally symmetric). Rearranging and solving for F_{P1v}:

$$+\uparrow \quad F_{P1v} = a_u \frac{W_{c\_hs100}\left(125\,in - d_{c\_hcg\_hs100}\right) + W_{cr\_hs100}\left(125\,in - d_{cr\_hcg\_hs100}\right)}{2 \times 125\,in}$$

$$F_{P1v} = 149.6\,kip$$

where: a_u = 2 g is the upward vertical acceleration (Table 2.1), W_{c_hs100} = 279893 lbf is the weight of the Cask (Table 4.1), W_{cr_hs100} = 20.5 kip is the weight of the central cradle (Table 5.1), $d_{c\_hcg\_hs100}$ = 62.9 inch and $d_{cr\_hcg\_hs100}$ = 66.8 inch are the distances of the centroids from lug P1 for the cask and central cradle respectively (Table 5.1) and 125 inches is the longitudinal distance between the pins of the central cradle (Figure 2).

The vertical reactions at lugs P1/P2 and P3/P4 are inversely proportional to the distance from the combined centroid of the cask and central cradle. The combined centroid is:

$$d_{hcg\_hs100} = \frac{W_{c\_hs100} d_{c\_hcg\_hs100} + W_{cr\_hs100} d_{cr\_hcg\_hs100}}{W_{c\_hs100} + W_{cr\_hs100}} = 63.1 in.$$

The load on the lugs at the opposite end of the central cradle are found by summing moments about the combined centroid: $\sum M_{comb} = 0 = 2\,F_{P1v}\,d_{c\_hcg\_hs100} - 2\,F_{P3v}\left(125\,in - d_{c\_hcg\_hs100}\right)$ where FP3v = FP4v due to lateral symmetry. Solving for FP3v,

$$F_{P3v} = F_{P1v} \frac{d_{c\_hcg\_hs100}}{125in - d_{c\_hcg\_hs100}} = 151.7\,kip$$

There is a vertical load on lugs P1 - P4 in reaction to the lateral acceleration. The vertical load on lug P1 is found by summing moments about the line formed by lugs P2-P3:

$$\sum M_{P23} = 0 = -a_l \begin{bmatrix} -W_{c\_hs100}\left(d_{c\_vcg\_hs100} - 10\,in\right) \\ -W_{cr\_hs100}\left(d_{cr\_vcg\_hs100} - 10\,in\right) \end{bmatrix} + \left(F_{P1vl} + F_{P4vl}\right) 104.75\,in$$

The vertical loads on the ends are again inversely proportional to the distance from the combined centroid. Substituting and solving for FP1vl finds:

$$F_{P1vl} = -a_l \frac{W_{c\_hs100}\left(d_{c\_vcg\_hs100} - 10\,in\right) + W_{cr\_hs100}\left(d_{cr\_vcg\_hs100} - 10\,in\right)}{104.75\,in\left(1 + \dfrac{d_{hcg\_hs100}}{125\,in - d_{hcg\_hs100}}\right)}$$

where: a_l = 2 g, W_{c_hs100} = 279.893 kip, W_{cr_hs100} = 22.6 kip, $d_{c\_vcg\_hs100}$ = 66.5 inch and $d_{cr\_vcg\_hs100}$ = 25.7 inch are the vertical centroid heights above the deck for the cask and cradle respectively from Table 4.1 including the 0.5 inch offset from the deck to the bottom of the cradle, d_{hcg_hs100} = 63.1 inch is the combined cradle / cask CG calculated above and 10 inches is the offset from the railcar deck to the hole in the lug as shown in Figure 2 and .5 inches is the offset from the deck to the bottom of the cradle.

$F_{P1vl} = -152.6$ kip, $F_{P4vl} = F_{P1vl} \frac{d_{hcg\_hs100}}{125\ in - d_{hcg\_hs100}} = -154.9$ kip F_{P4vl} has the greater magnitude and is reported in Table 2.2.

The lateral load on the central cradle attachment lugs is simply a sum of the forces calculation with the proportional load sharing as above. As discussed in § 5.1, the only one of the central cradle beams reacts the lateral load.

$$\sum F_{lat} = 0 = -a_l(W_{c\_hs100} + W_{cr\_hs100}) - F_{P1l} - F_{P4l} \text{ and } F_{P4l} = F_{P1l} \frac{d_{hcg\_hs100}}{125in - d_{hcg\_hs100}}$$

Solving for F_{P1l} yields: $F_{P1l} = a_l \frac{W_{c\_hs100} + W_{cr\_hs100}}{1 + \frac{d_{hcg\_hs100}}{125\ in - d_{hcg\_hs100}}} = 297.5$ kip and

$$F_{P4l} = F_{P1l} \frac{d_{hcg\_hs100}}{125\ in - d_{hcg\_hs100}} = 303.3 \text{ kip}$$

6.0 RESULTS AND CONCLUSIONS

Table 6.1 – Summary of Cradle and End Stop Weights and C.G.'s

Cask	Central Cradle weight (kip)	Central Cradle cg from Bottom of Cradle (in)	End Stop weight (Each) (kip)	End Stop CG from Deck (in)	Total Cradle CG from Bottom of Cradle (in)
HI-STAR 100	22.6	25.2	12.8	52.7	44.5
HI-STAR 100HB	16.5	27.1	16.0	65.5	57.2
HI-STAR 180	10.1	27.3	13.5	60.0	54.4
HI-STAR 190XL	15.0	21.8	11.0	62.2	51.6
HI-STAR 190SL	14.7	21.8	11.7	61.9	52.0
HI-STAR 60	17.7	26.6	13.2	47.1	41.6
TN-32B	14.6	35.1	16.7	52.3	48.8
TN-40	14.2	32.0	17.1	50.7	47.0
TN40HT	14.2	32.0	17.1	50.7	47.0

Notes: 1. There are four (4) end stops for each configuration, two (2) on each end. As discussed in § 5.3, two (2) end stops are located at each end. Total end stop weight is four (4) times the value shown in Table 6.1.
2. The values shown for the weights of the central cradle and end stops include an additional 10% factor.

All stresses are below the maximum allowable stress as shown above. The cradles are acceptable for their intended use.

6.1 Results of applicable literature searches

A literature search was not required for this calculation.

7.0 REFERENCES

7.1 Department of Energy Contract DE-NE0008390, Part 1, Section C, Statement of Work.

7.2 AREVA Federal Services Drawing, DWG-3015137, Atlas Railcar Cradle Family 1 Conceptual Drawing, Rev. 2.

7.3 AREVA Federal Services Calculation, CALC-3015276, Atlas Railcar Cradle Attachment Calculation, Rev. 2.

7.4 AREVA Federal Services Engineering Information Record, EIR-3014611, Design Basis Requirements Document (DBRD) for the Atlas Railcar, Rev. 6.

7.5 AREVA Federal Services Drawing, DWG-3015278, Atlas Railcar Attachment, Rev. 2.

7.6 American Society for Testing and Materials, ASTM A992/A992M, Standard Specification for Structural Steel Shapes, 2011.

7.7 American Society for Testing and Materials, ASTM A572/A572M, Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel, 2007.

7.8 Steel Construction Manual, American Institute of Steel Construction, 13th Edition, Second Printing, July 2006.

7.9 Aluminum Design Manual, The Aluminum Association, 2010.

7.10 CALC 3015133_Atlas - Loads Fam 1_8.08.18.xlsx

7.11 CALC 3015133_Hi-Star 60_Railcar Loads .8.08.18.xlsx

7.12 CALC 3015133_Hi-Star 100_Railcar Loads.2.17.17.xlsx

7.13 CALC 3015133_Hi-Star 100HB_Railcar Loads.2.9.17.xlsx

7.14 CALC 3015133_Hi-Star 190XL_Railcar Loads.2.1.17.xlsx

7.15 CALC 3015133_Hi-Star 190SL_Railcar Loads.2.2.17.xlsx

7.16 CALC 3015133_Hi-Star 180_Railcar Loads.2.9.17.xlsx

7.17 CALC 3015133_AREVA TN TN-32B_Railcar Loads.2.9.17.xlsx

7.18 CALC 3015133_AREVA TN TN-40_Railcar Loads.2.9.17.xlsx

7.19 CALC 3015133_AREVA TN TN-40HT_Railcar Loads.2.9.17.xlsx

7.20 American Society for Testing and Materials, ASTM A490, Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength, 2010.

7.21 AREVA Federal Services Request for Information, AFS-RFI-0015-00, 11/3/16.

7.22 American Society for Testing and Materials, ASTM A574, Standard Specification for Alloy Steel Socket-Head Cap Screws, 2010.

APPENDIX J.5: DWG-3015137-002, ATLAS RAILCAR CRADLE FAMILY 1 CONCEPTUAL DRAWING

DWG-3015137-002
Page 1 of 8

DWG NO 3015137 REV 2 SH 1

NOTES, UNLESS OTHERWISE SPECIFIED:

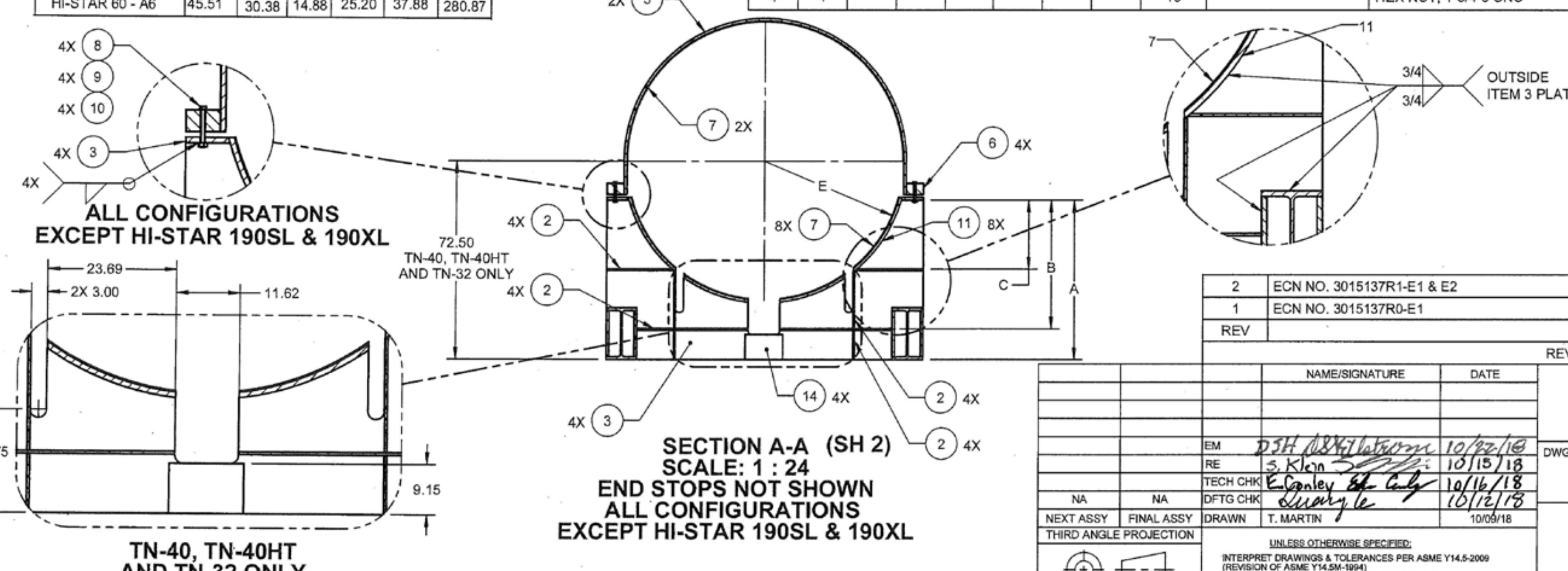
1. CONCEPTUAL DESIGN ASSUMES ALL WELDS ARE FULL PENETRATION UNLESS OTHERWISE NOTED. ALL WELDS WILL BE FURTHER SPECIFIED IN A FINAL DESIGN.
2. FABRICATION SHALL BE PERFORMED IN ACCORDANCE WITH AWS D1.1.
3. DIMENSIONS WITH TOLERANCES SPECIFIED ARE RAILCAR INTERFACE DIMENSIONS AND SHOULD BE CONSIDERED DURING FINAL CRADLE DESIGN.
4. ALL SURFACES OF THE CRADLE WELDMENT, EXCEPT FOR THREADED HOLES AND THE 4.13 DIAMETER HOLES, SHALL BE BLAST CLEANED PER SSP-SP-10 AND COATED WITH SELF-PRIMING ENAMEL, 2 COATS. THE NON-PAINTED CRADLE WELDMENT SURFACES SHALL BE LIGHTLY COATED WITH NUCLEAR GRADE "NEVER-SEEZ" GREASE.
5. ATTACHMENTS FOR PERSONNEL BARRIER TO THE CRADLE ARE TO BE DEFINED DURING THE FINAL DESIGN.
6. THE ADDITION OF ALIGNMENT MARKS BETWEEN THE CRADLE AND RAILCAR INTERFACE SHOULD BE CONSIDERED IN THE DETAILED DESIGN TO SUPPORT LOADING OPERATIONS.
7. CASK AND ATTACHED CRADLE ARE LIFTED USING A LIFTING STRAP LOCATED BENEATH THE PROTRUDING CRADLE PLATES (ITEM 11) LOCATED INTERIOR TO THE END SADDLES AND COMBINED WITH A LIFTING BEAM.
8. FOLLOWING INSTALLATION OF CENTRAL CRADLE, CASK WITH IMPACT LIMITERS AND END STOPS ON RAILCAR, INSTALL SHIMS BETWEEN END STOPS AND IMPACT LIMITERS TO CLOSE GAP.
9. END STOPS FOR ASSEMBLIES A1 AND A2 EXCEED AAR PLATE E DIMENSIONS WHEN INSTALLED IN TRANSPORTATION CONFIGURATION.
10. LOCATE 2 SHACKLES OR HOIST RINGS FOR LIFTING END STOPS ABOVE CENTER OF GRAVITY LOCATIONS IDENTIFIED IN TABLE 1 MINIMUM WORKING LOAD TO BE AS SHOWN IN TABLE 1. ALTERNATIVELY, USE SLOTTED HOLES AT OR ABOVE THE LOCATIONS SHOWN AND INSTALL ENDLESS STRAPS FOR LIFTING.

LIST OF MATERIALS

QTY A8	QTY A7	QTY A6	QTY A5	QTY A4	QTY A3	QTY A2	QTY A1	ITEM NO	PART NO	DESCRIPTION	SPECIFICATION
							X	A1		TN-40 AND TN-40HT CRADLE ASSEMBLY	
						X		A2		TN-32 CRADLE ASSEMBLY	
					X			A3		HI-STAR 180 CRADLE ASSEMBLY	
				X				A4		HI-STAR 100 CRADLE ASSEMBLY	
			X					A5		HI-STAR 100HB CRADLE ASSEMBLY	
		X						A6		HI-STAR 60 CRADLE ASSEMBLY	
	X							A7		HI-STAR 190SL CRADLE ASSEMBLY	
X								A8		HI-STAR 190XL CRADLE ASSEMBLY	
2	2	2	2	2	2	2	2	1		W18X119	ASTM A992
12	12	16	16	24	14	16	16	2		PLATE, 1/2 THK	ASTM A572, GR 50
18	18	18	18	23	14	26	26	3		PLATE, 1 THK	ASTM A572, GR 50
		16	16	16	16	16	16	4		PLATE, 1/4 THK	ASTM A572, GR 50
28	28	24	24	24	24	24	24	5		PLATE, 2 THK	ASTM A572, GR 50
4	4	4	4	6	4	4	4	6		PLATE, 4 THK	ASTM A572, GR 50
4	4	4	3	4	4	10	10	7		RUBBER, 1/4 THK	80 DURO
		4	4	6	4	4	4	8		HEX BOLT, 1 1/2-6 UNC X 7 LG	ASTM A490, TYPE 1
		4	4	6	4	4	4	9		WASHER, Ø1 1/2 NOM	ASTM F436
		4	4	6	4	4	4	10		HEX NUT, 1 1/2-6 UNC	ASTM A563, GR DH PLAIN
2	2	2	1	1	2	8	8	11		CRADLE PLATE, 1 THK	ASTM A572, GR 50
10	10	10	10	10	10	10	10	12		ANGLE, 3 X 3 X 1/4	ASTM A36
4	4	4	4	4	4	4	4	13		EXPANDED METAL	RYTEX 1-1/2 NO. 6 OR EQUIV
		4	4	6	4	4	4	14		BAR, 3.25 X 9.15 X 13.63	ASTM A572, GR 50
4	4							15		PLATE OR BAR, 5 X 11 1/2 X 50.7	ASTM A572, GR 42
16	16							16		PLATE, 1 1/4 THK	ASTM A572. GR 65
4	4							17		SHCS, 1-3/4-5 UNC X 7.25 LG	ASTM A574
4	4							18		WASHER, Ø1 3/4 NOM	ASTM F436
4	4							19		HEX NUT, 1-3/4-5 UNC	ASTM A563, GR DH PLAIN

CRADLE DIMENSIONS TABLE:

CONFIGURATIONS	DIMENSIONS					
	A	B	C	D	E	F
TN-40 - TN-40HT - A1	58.36	47.11	25.28	32.51	50.50	262.75
TN-32B - A2	58.79	47.54	23.52	32.51	48.88	259.75
HI-STAR 180 - A3	49.68	39.58	16.48	23.13	53.15	294.50
HI-STAR 100 - A4	48.00	32.87	17.38	28.75	48.00	315.71
HI-STAR 100HB - A5	48.00	32.87	17.38	28.75	48.00	239.40
HI-STAR 60 - A6	45.51	30.38	14.88	25.20	37.88	280.87



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OCT 23 2018
Records Management

REV	DESCRIPTION
2	ECN NO. 3015137R1-E1 & E2
1	ECN NO. 3015137R0-E1

REVISION HISTORY

	NAME/SIGNATURE	DATE
EM	DSH D.S. Hilstrom	10/22/18
RE	S. Klein	10/15/18
TECH CHK	E. Conley	10/16/18
DFTG CHK		10/12/18
DRAWN	T. MARTIN	10/09/18

NEXT ASSY: NA
FINAL ASSY: NA
THIRD ANGLE PROJECTION

UNLESS OTHERWISE SPECIFIED:
INTERPRET DRAWINGS & TOLERANCES PER ASME Y14.5-2009 (REVISION OF ASME Y14.5M-1994)
INTERPRET WELD CALLOUTS PER ANSI/AWS A2.4
DIMENSIONS ARE IN INCHES

Orano Federal Services LLC
Packaging Projects
Federal Way, WA 98003

DWG TITLE: ATLAS RAILCAR CRADLE FAMILY 1 CONCEPTUAL DRAWING

SCALE: SHOWN | WT. ~ LBS
REV: 2 | SHEET 1 OF 8
DWG SIZE: D | DWG NO. 3015137
CADFILE: 3015137-2.SLDDRW
DWG-3015137-002

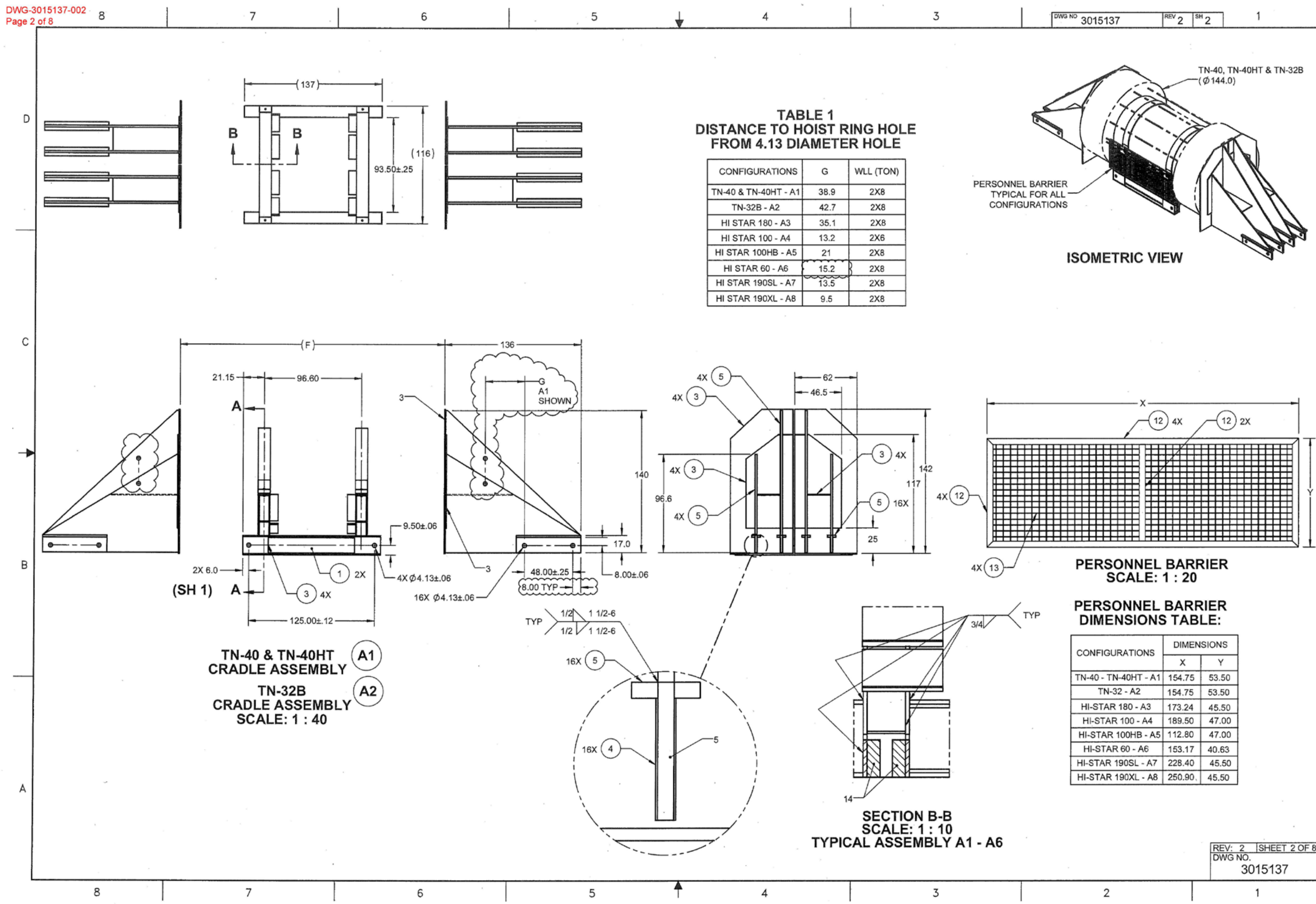


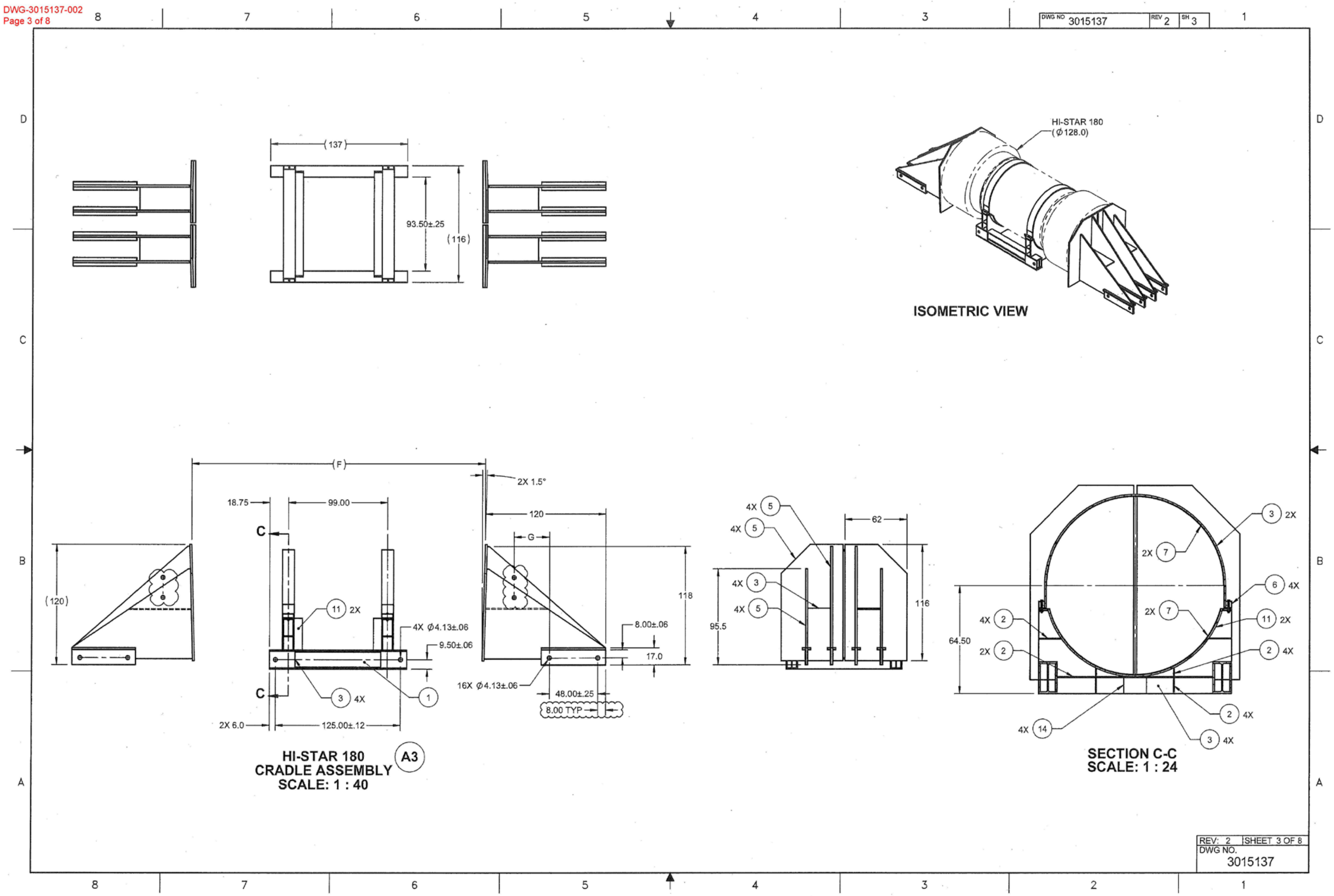
TABLE 1
DISTANCE TO HOIST RING HOLE FROM 4.13 DIAMETER HOLE

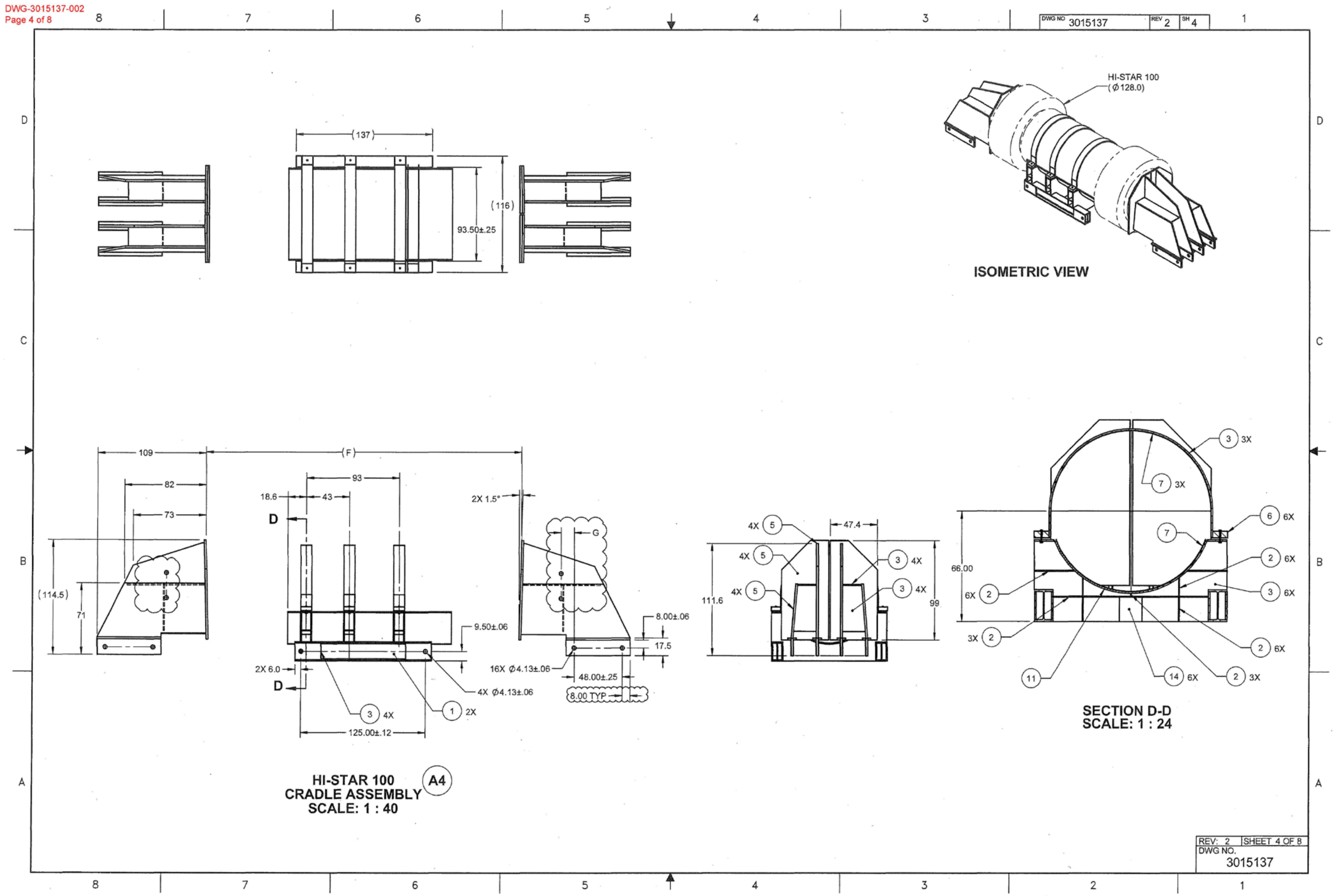
CONFIGURATIONS	G	WLL (TON)
TN-40 & TN-40HT - A1	38.9	2X8
TN-32B - A2	42.7	2X8
HI STAR 180 - A3	35.1	2X8
HI STAR 100 - A4	13.2	2X6
HI STAR 100HB - A5	21	2X8
HI STAR 60 - A6	15.2	2X8
HI STAR 190SL - A7	13.5	2X8
HI STAR 190XL - A8	9.5	2X8

PERSONNEL BARRIER DIMENSIONS TABLE:

CONFIGURATIONS	DIMENSIONS	
	X	Y
TN-40 - TN-40HT - A1	154.75	53.50
TN-32 - A2	154.75	53.50
HI-STAR 180 - A3	173.24	45.50
HI-STAR 100 - A4	189.50	47.00
HI-STAR 100HB - A5	112.80	47.00
HI-STAR 60 - A6	153.17	40.63
HI-STAR 190SL - A7	228.40	45.50
HI-STAR 190XL - A8	250.90	45.50

DWG-3015137-002
Page 3 of 8

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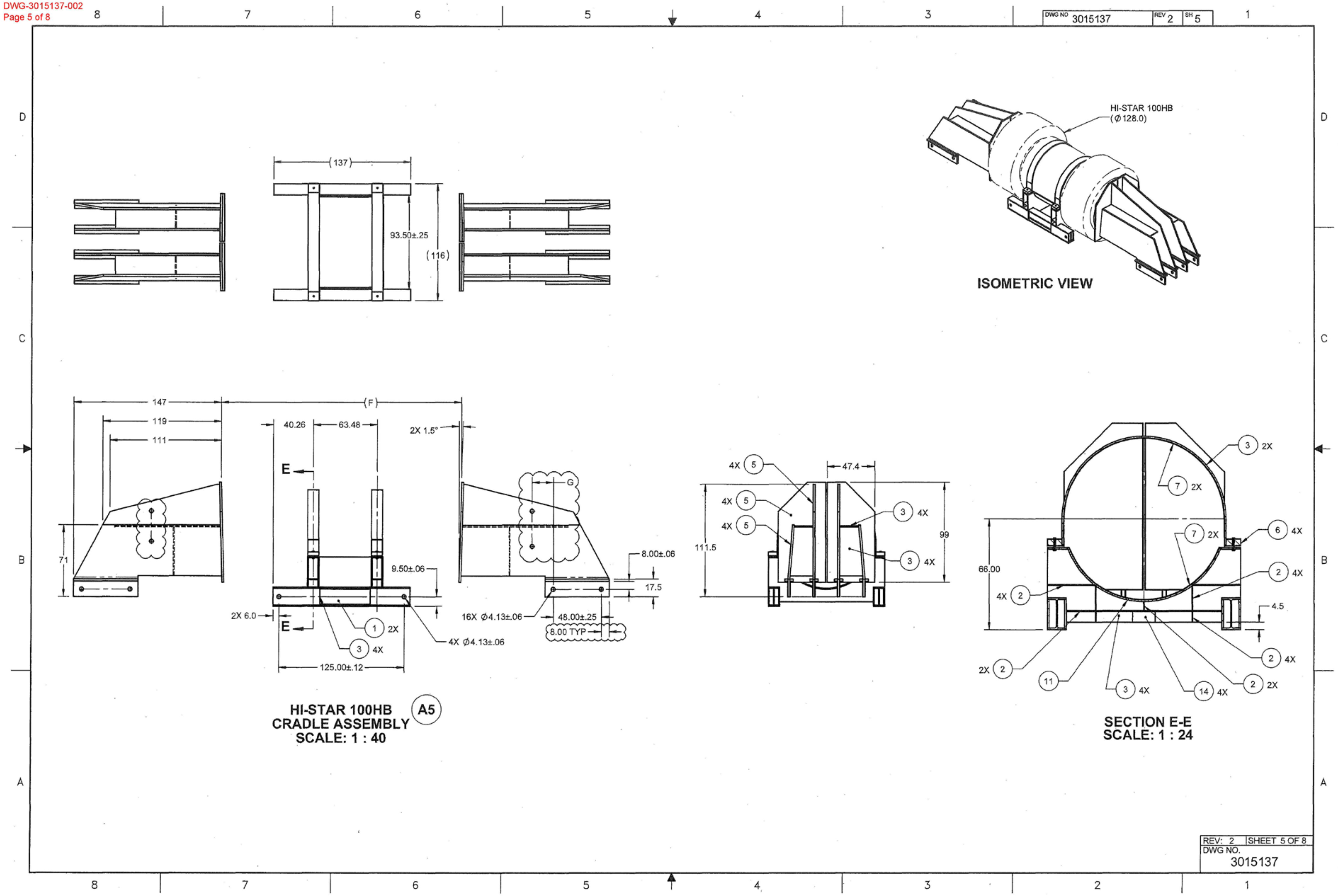
Page 4 of 8
DWG NO 3015137 REV 2 SH 4
HI-STAR 100
(Ø 128.0)
ISOMETRIC VIEW
(137)
(116)
93.50±.25
109
(F)
82
73
93
18.6
43
2X 1.5°
G
(114.5)
71
9.50±.06
8.00±.06
17.5
2X 6.0
16X Ø4.13±.06
48.00±.25
4X Ø4.13±.06
8.00 TYP
125.00±.12
47.4
111.6
99
66.00
HI-STAR 100
CRADLE ASSEMBLY
SCALE: 1 : 40
A4
SECTION D-D
SCALE: 1 : 24
REV: 2 SHEET 4 OF 8
DWG NO.
3015137

DWG-3015137-002
Page 5 of 8



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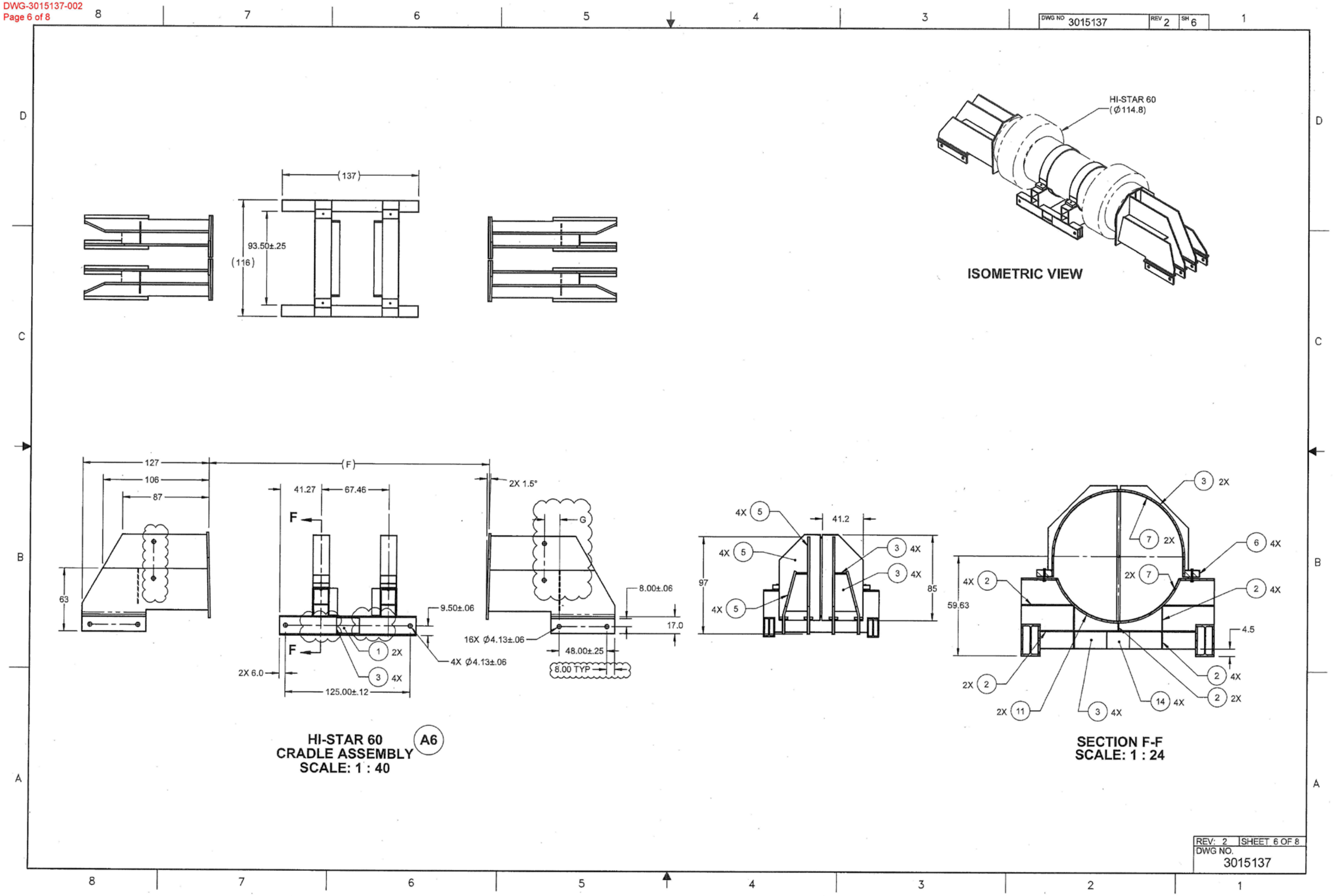
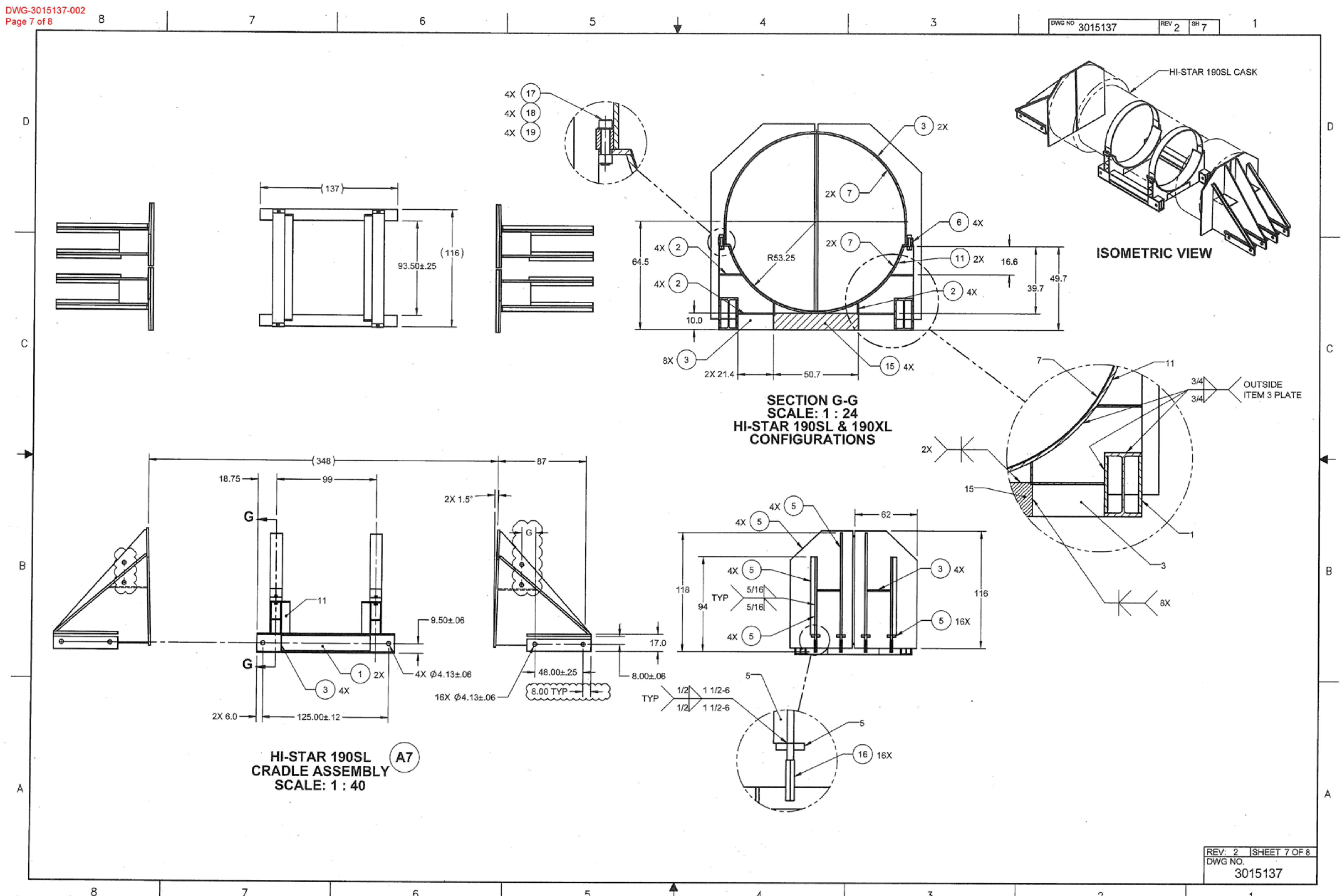
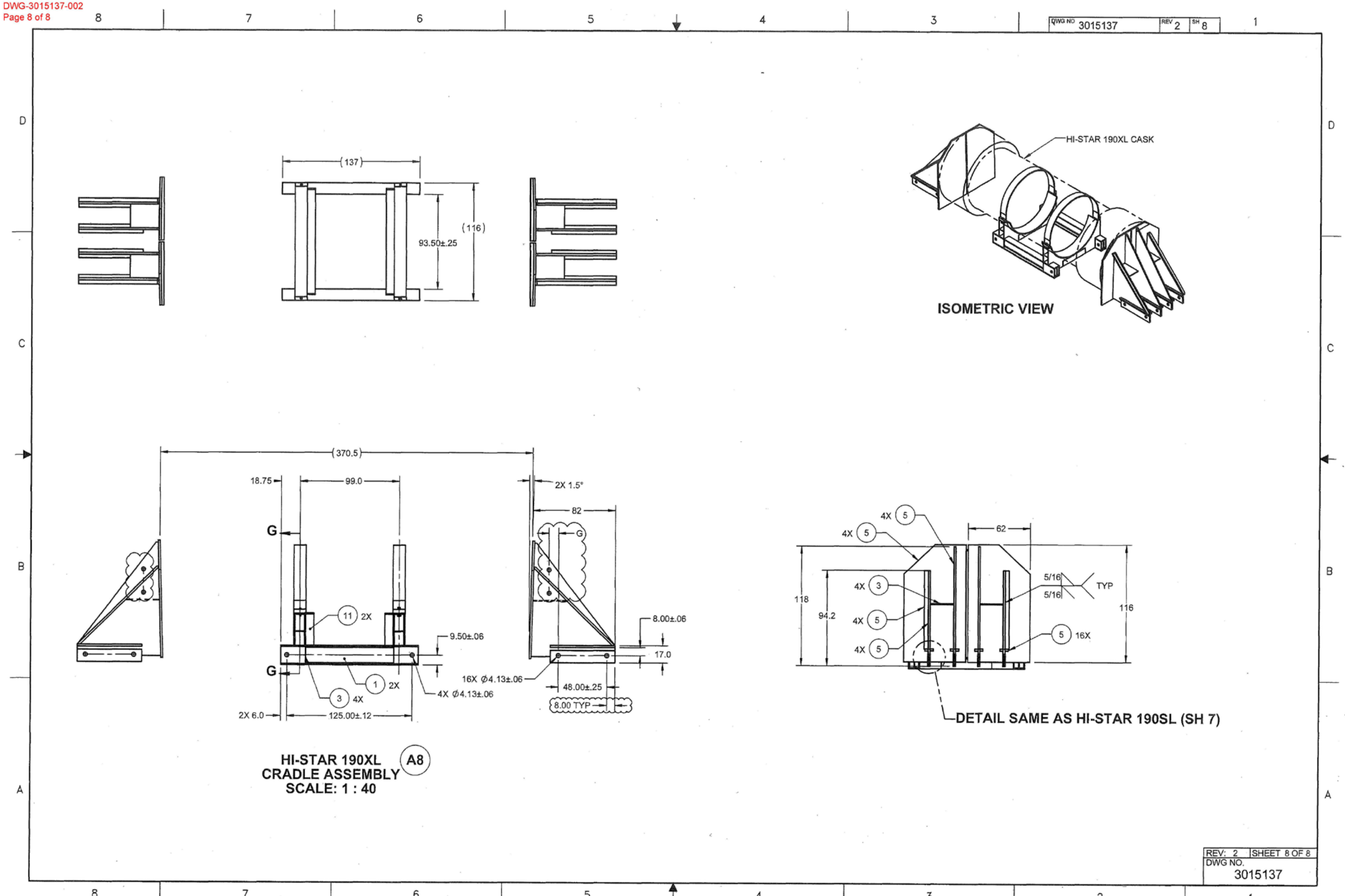
Page 6 of 8




DWG-3015137-002
Page 7 of 8
3015137
2
7
HI-STAR 190SL CASK
ISOMETRIC VIEW
SECTION G-G
SCALE: 1 : 24
HI-STAR 190SL & 190XL
CONFIGURATIONS
OUTSIDE
ITEM 3 PLATE
HI-STAR 190SL
CRADLE ASSEMBLY
SCALE: 1 : 40
A7
REV: 2 SHEET 7 OF 8
DWG NO.
3015137

DWG-3015137-002
Page 8 of 8



HI-STAR 190XL CRADLE ASSEMBLY (A8)
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