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Metallurgical Analysis of the High Flux Isotope Reactor (HFIR) Carrier Lifting Bails

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June 3, 2024
SRNL-STI-2020-00213, Revision 1

srnl.gov

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Printed in the United States of America

Prepared for
U.S. Department of Energy

SRNL-STI-2020-00213
Revision 1

Keywords: *Accelerated Basin De-Inventory, H-Canyon, Spent Fuel, Dissolution, HFIR Carrier*

Retention: *Permanent*

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Savannah River National Laboratory is operated by Battelle Savannah River Alliance for the U.S. Department of Energy under Contract No. 89303321CEM000080.

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EXECUTIVE SUMMARY

The dissolution rates of the aluminum alloys in the High Flux Isotope Reactor (HFIR) element carriers and the Material Test Reactor (MTR) L-bundles in the H-Canyon facility have been identified as the possible cause of extended dissolutions that result in significant time and financial expenditures. A study[1], carried out by Savannah River National Laboratory (SRNL) to determine relationships between the dissolution rates and the metallurgical properties of the aluminum alloy materials of construction of the HFIR carriers and the L-bundles, considered the dissolution rates of aluminum alloy (AA) series 1100, 6061, and 6063. The study determined that the aluminum alloy compositions played a principal role in the dissolution rate of the carrier/bundle components. Higher dissolution rates were correlated with lower concentrations of the minor element additions in the alloys and with specific element concentrations. Aluminum alloys 1100 and 6063 were found to have similar dissolution rates that were approximately two orders of magnitude (100X) greater than those of AA6061. Based on the results of the dissolution behavior study, a Technical Assistance Request (TAR) was first issued to determine if the replacement of AA6061-T6 with AA6063-T6 is feasible for the HFIR carrier lifting bails[2]. A Technical Task Request was then issued to consider AA6063-T5 as well as other alloys to improve possible supply chain issues. The metallurgical properties of the L-bundle (specifically the end caps) were not evaluated in this report because L-Bundle drawings already allow for the use of AA6063-T6 in all structural components[3]

The HFIR carriers are composed of thin-walled components with significant surface areas that allow for relatively quick overall dissolution times. Conversely, the carrier lifting bails and the supporting constituents are composed of solid bars and thick plate regions with relatively small surface areas that experience longer overall dissolution times. While the MTR L-bundle design includes allowances for the materials of construction to be either AA6061-T6 or AA6063-T6, the HFIR carriers are specified to be constructed fully with AA6061-T6 alloy.

This report analyzes the recommendations of the dissolution behavior study[1] to replace the materials of construction of the HFIR carrier lifting bails. The analysis considers the operational requirements of the lifting bail and its supporting structures. To decrease dissolution times, the analysis considers direct replacement of the material as well as reductions in the thicknesses of the components to decrease the mass of the elements. Material reductions are considered on options for using either AA6061 and/or AA6063. The calculations are based on specifications from the American Society of Mechanical Engineer (ASME) and The Aluminum Association, Inc. design codes. The analysis finds that direct replacement of the lifting bail material of construction with AA6063-T6, and AA6063-T5 as well as reductions in the dimensions of the lifting bail components are acceptable. Note that this study considers the structural suitability of the alloys. It does not consider their dissolution rates in the dissolvers.

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LIST OF ABBREVIATIONS

AA	Aluminum Alloy
ADM	Aluminum Design Manual
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
BTH	Below the Hook
FEA	Finite Element Analysis
HFIR	High Flux Isotope Reactor
MTR	Material Test Reactor
SS	Safety Significant
SRNL	Savannah River National Laboratory
TAR	Technical Assistance Request
TTR	Technical Task Request
UNS	Unified Numbering System

1.0 Introduction

The High Flux Isotope Reactor (HFIR) reactor core is composed of an inner and an outer fuel element. After the cores are deemed spent by Oakridge National Laboratory, the elements are separated and transferred to the Savannah River Site's L-Basin. In L-Basin, the elements are placed on carriers under water for storage. Upon request from H-Canyon, the HFIR elements are transported to the H-Canyon facility where they are dissolved. The carriers are currently constructed of aluminum alloy (AA) 6061-T6. For disposition of the spent fuel, the carriers loaded with fuel are charged into the insert wells in the dissolver. During dissolution, the carrier and fuel are expected to fully dissolve during a dissolution process. After completion of the recommended dissolution time, a probe is inserted into the dissolver wells to physically confirm completion of the dissolution. Failure of the probe to reach a specified depth in the well, referred to as a High Probe, indicates that the dissolution process was not completed. If a High Probe occurs, an extended dissolution is performed, and probing is repeated to verify completion of the dissolution. Extended dissolutions and repeated probing should be minimized to prevent significant time and financial expenditure.

The Materials Test Reactor (MTR) fuel carriers, known as L-bundles, use AA6061-T6 and AA6063-T6 as materials of construction for its components. During the dissolution process, the AA6061 components, the end cap which includes the lifting bail, exhibit slower dissolution rates when compared to components fabricated with AA6063, and can result in longer dissolution times than desired and may result in a High Probe. Similarly, the cause of High Probe occurrences for the HFIR carriers has been speculated to result from incomplete dissolution of the carrier lifting bails during the prescribed dissolution time. Although, the fabrication drawing for the MTR L-Bundles allows all components to use AA6063, the L-bundle End Cap lifting bail and top plate are typically constructed using AA6061. The drawings for the HFIR carriers specify AA6061 for all components, including the lifting bails. In addition to the dissolution rate of AA6061 being slower than that of AA6063, the lifting bails possess a low surface area to mass ratio as compared to other carrier components made from the same alloy. The higher surface area to mass ratio of the other carrier components allows for their faster dissolution. Thus, the lifting bails have a higher probability of exhibiting incomplete dissolution during a prescribed dissolution time, resulting in a High Probe, and requiring an extended dissolution period. Replacement of the AA6061 with AA6063 presents a likely mitigation to incomplete dissolutions by taking advantage of the higher dissolution rate for this alloy and should improve the overall dissolution times of the lifting bails.

The analysis in this report follows the recommendations of the "Evaluation of the Dissolution Behavior of L-Bundle End Caps and HFIR Fuel Carriers" study[1], an issued Technical Assistance Request (TAR)[2] and a Technical Taks Request (TTR)[4] to replace the materials of construction of the HFIR carriers. The analysis strictly considers the lifting bail elements of the HFIR inner and outer element carriers and its supporting structures. The evaluation of the dissolution behaviors established that AA1100 (commercially pure aluminum) exhibited the highest dissolution rates of the alloys considered in the study, closely followed by AA6063. Because AA1100 does not possess the mechanical properties necessary to allow for construction of structural components, and AA6063-T6 is not typically available in the desired forms, AA6063-T5 is considered as the replacement alloy. Other alloy options were not considered due to lack of dissolution data for the dissolver and per a request from the customer. The analysis first considers direct replacement of the current AA6061-T6 material based on the current lifting bail designs. Secondly, reductions in the thicknesses of the lifting bails' components are considered to reduce mass. Both, the original AA6061-T6 and AA6063-T6, and AA6063-T5 are evaluated to provide options for reducing the mass of the lifting bail components. This report follows calculations M-CLC-L-00367 Rev.1[5]. The calculations are based on specifications from the American Society of Mechanical Engineers (ASME) construction code and The Aluminum Association, Inc. 2020 Design Manual. The metallurgical properties of the L-bundle (specifically the end caps) were not evaluated in this report because L-Bundle drawings already allows for the use of AA6063-T6 in all structural components[3].

2.0 Approach

This report evaluates the structural integrity of the lifting bails and supporting components for the HFIR inner and outer carrier. The original design calculations for structural integrity of the HFIR carriers have been lost and are not traceable. A re-calculation, C-CLC-L-00134[6], to establish minimum load capacity of the HFIR carrier assembly and to establish minimum design factors for safe rigging was completed in the year 2001 and serves as the current standard.

The evaluation of the lifting bails and supporting components in this report is based on the manufacturing drawings C-CM-L-0016[7] and C-CM-L-0017[8] for the outer and inner carriers, respectively. It was carried out without consulting the current standard calculation to ensure that the new evaluation meets current design standards and specifications. In the drawings, specific components are referred to as "items." Throughout this report, references to "items" followed by a number directly indicate components in the relevant drawing.

For the evaluation, the current design is initially appraised based on specifications from the American Society of Mechanical Engineers (ASME) and The Aluminum Association, Inc. Aluminum Design Manual 2020 (ADM) design and manufacturing codes and recommendations. Because the lifting bails have complex geometries, a finite elements analysis was performed to increase accuracy and validate the ASME and ADM calculations.

Validation of the current design was followed by considerations for the replacement of the AA6061 alloy with AA6063. The AA6063 alloy contains a higher percentage of Al than the AA6061 alloy. Therefore, the rate of dissolution in a nitric acid solution containing Hg should be faster as demonstrated in SRNL-STI-2019-00146[1]. The study indicated that the tempering of aluminum alloys does not have a significant effect on their dissolution rates. The study determined that the AA6063 alloy experiences faster dissolution rates that are approximately two orders of magnitude faster when compared to AA6061.

The same manufacturing drawings specifications and calculations procedure were utilized to determine the suitability of AA6063-T6 and AA6063-T5. Lastly, based on the calculated requirements, modifications to reduce the thickness of the lifting bails and their supporting components are proposed as an optional method to further reduce dissolution times for these components. The suitability for the dissolver environment is not considered.

3.0 Inputs and Assumptions

3.1 Structural Data

Inputs for the structures being evaluated were obtained from drawings C-CM-L-0016 (outer carrier), C-CM-L-0017 (inner Carrier), the previous calculation[6], and drawing revisions [9]. The outer carrier lifting bail is fabricated from 5/8-inch AA6061-T6 solid round bar bent to form the lifting bail. Similarly, the inner carrier lifting bail is fabricated from 3/8-inch AA6061-T6 solid round bar. Dimensions used in the calculations are shown in the figures below.

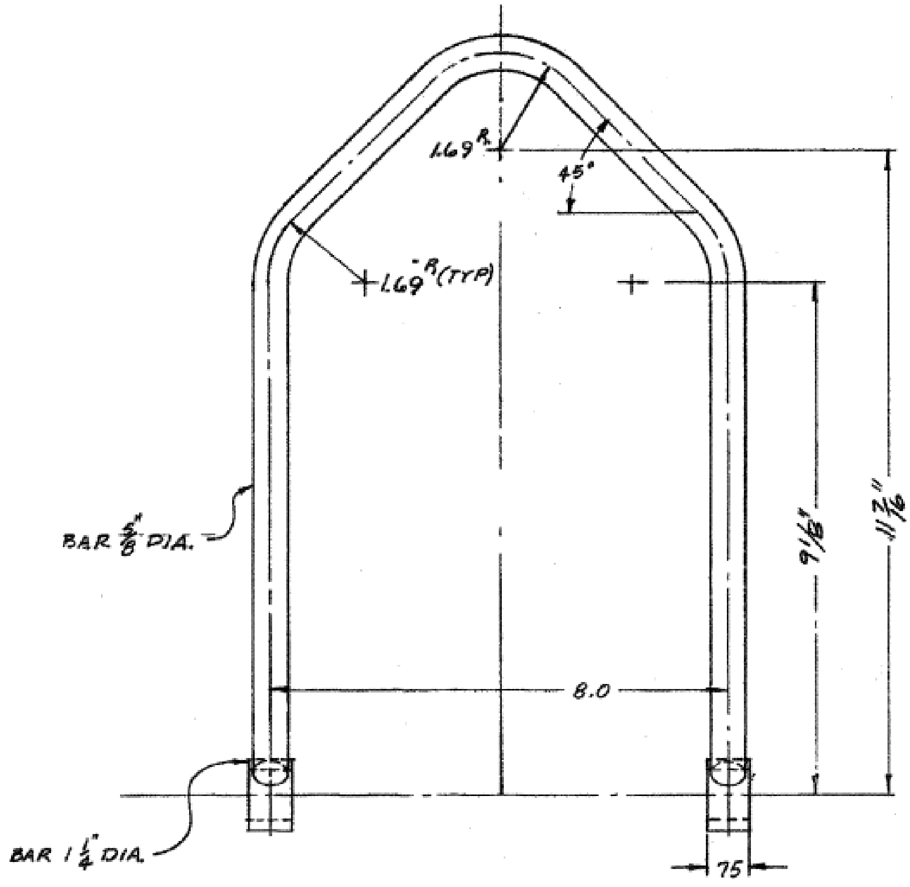


Figure 3-1 HFIR Outer Carrier Lifting Bail (C-CM-L-0016)

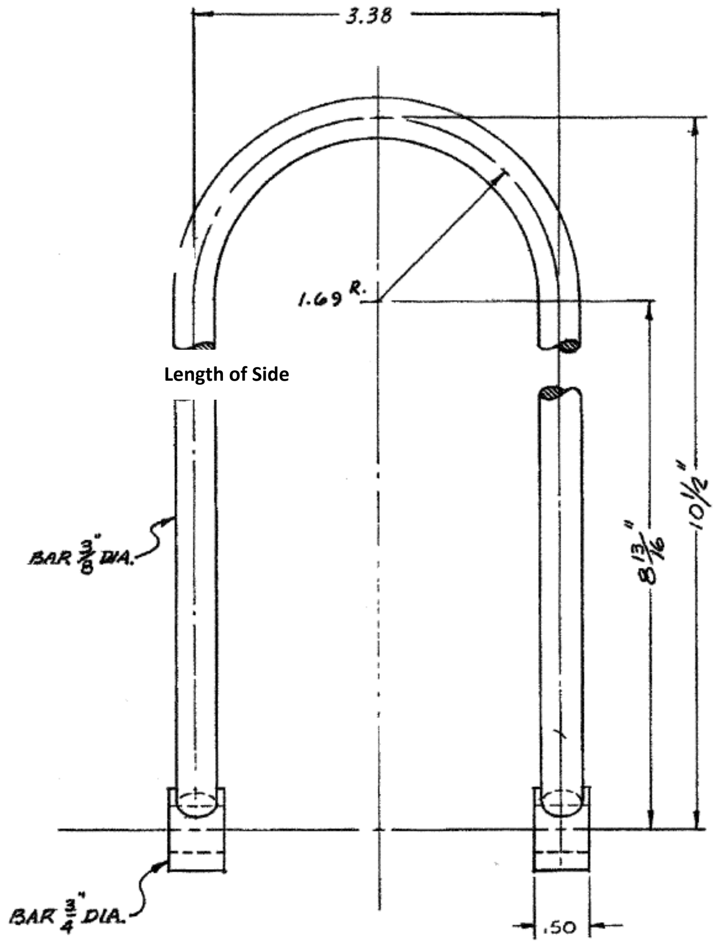


Figure 3-2 HFIR Inner Carrier Lifting Bail (C-CM-L-0017)

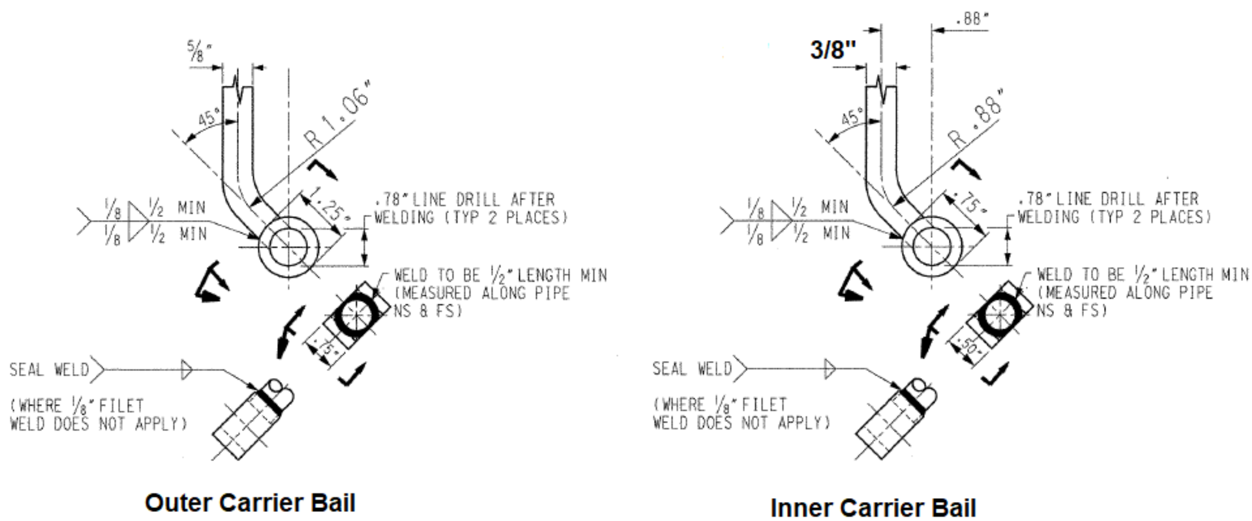


Figure 3-3 Dimensions for Inner Lug for Lifting Bail Attachment Point

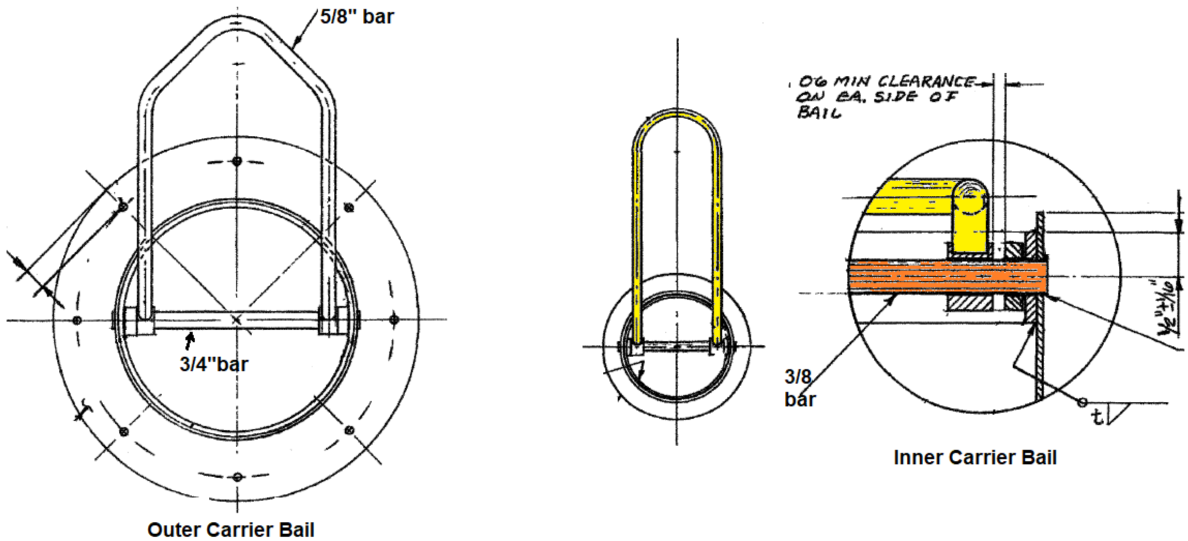


Figure 3-4 Plan view of Bail and Carrier, Showing attachment Joint Details

3.2 Material Specifications

The lift bail is currently fabricated with 6061-T6 aluminum. Properties for 6063-T# aluminum are also shown, to support a future material option. Properties are based on the minimum values listed in the ASME Code, Section II, Part D for ASME SB-209 (plate), SB-211 (bars, rods, wire), and SB-222 for the indicated UNS designation. These properties are at room temperature, and valid if the items are not exposed to temperatures above 300°F for sustained periods (total 1000 hours).

Properties for aluminum 6063-T6 are shown, but this form of aluminum is normally used with extrusions and is not readily available in the product forms needed with the lift bail construction.

For all 60xx aluminum
E_{60xx} = Young's Modulus = 10.0×10^6 psi [Ref.10, Table TM-2]
Density = 0.1 pci [Ref. 10, Table PRD]

6061-T6 Aluminum (UNS A96061)
Yield Stress = Sy = 35,000 psi @ 70°F [Ref. 10 Table 1B]
Tensile Stress = Su = 42,000 psi @ 70°F [Ref. 10Table 1B]
Elongation = 8% [Ref. ASTM B221_21]

6063-T6 Aluminum (UNS A96063)
Specification ASME SB-211 6063-T6
Yield Stress = Sy = 25,000 psi @ 70°F [Ref. 12 Table A.4.3]
Tensile Stress = Su = 30,000 psi @ 70°F [Ref. 12Table A.4.3]
Elongation = 8% [Ref. ASTM B221_21]

6063-T5 Aluminum (UNS A96063)
Specification ASME SB-221 6063-T5
Yield Stress = Sy = 16,000 psi @ 70°F [Ref. 12 Table A.4.3]
Tensile Stress = Su = 22,000 psi @ 70°F [Ref. 12 Table A.4.3]
Elongation = 8% [Ref. ASTM B221_21]

Weld Material and Heat-Affected Zone:
4043 Weld Material, Tensile Su = 24,000 psi [Ref. 12, Table A.4.6]
Shear Su_v = 11,000 psi [Ref. 12, Table A.4.6]
6061-T6 Heat Effected Zone
Yield Strength = 15,000 psi [Ref. 12, Table A.4.3]
Tensile Strength = 24,000 psi [Ref. 12, Table A.4.3 & Ref. 10 Table 1B]
Shear Ultimate = Su_v = 15,000 psi [Ref. 12, Table A.3.5]
6063-T6 Heat Effected Zone
Yield Strength = 8,000 psi [Ref. 12, Table A.4.3]
Tensile Strength = 17,000 psi [Ref. 12, Table A.4.3]
Shear Ultimate = Su_v = 11,000 psi [Ref. 12, Table A.3.5]

Table 3-1 Summary of Material Properties for Bail Construction

Material	**Elastic Modulus** (psi)	**Yield** (psi)	**Ultimate** (psi)	**Shear Ultimate** (psi)	**Elongation** (%)	**Reference**
6061-T6	10.0×10^6 psi	35,000	42,000	NA	8%	[Ref. 10 Table 1B]
6061-T6 HA	10.0×10^6 psi	15,000	24,000	15,000		Ref. 12, Table A.4.3
6063-T6	10.0×10^6 psi	25,000	30,000	NA	8%	Ref. 12, Table A.3.4
6063-T6 HA	10.0×10^6 psi	8,000	17,000	11,000		Ref. 12, Table A.3.4
6063-T5	10.0×10^6 psi	16,000	22,000	NA	8%	Ref. 12, Table A.3.4
6063-T5 HA	10.0×10^6 psi	8,000	17,000	11,000		Ref. 12, Table A.3.4
4043 Weld Material	10.0×10^6 psi	NA	24,000	11,000		Ref. 12, Table A.4.6

1

3.3 Lifting Load Conditions

The carrier assemblies are used to move HFIR elements from a storage rack in L-Basin to the 70-ton cask car and then to an H-area dissolver. Once a HFIR element is placed in a carrier, gravity ensures that it stays in that carrier permanently. Therefore, the total number of lifts of a loaded carrier is less than five, only up to two being without the aid of water buoyancy. Load used for analysis are shown below.

Outer Carrier Lifting Bail
Weight of HFIR Outer Element = 215 lbs
Weight of Outer Carrier = 9 lbs Use 225 lbs Design Load

Inner Carrier Lifting Bail
Weight of HFIR Inner Element = 110 lbs
Weight of Inner Carrier = 3.5 lbs Use 115 lbs Design Load

3.4 Assumptions

All results and conclusions in this analysis are based on there being inconsequential fluid weight added to the HFIR carriers as they are lifted out of water to be charged into the dissolver. This assumption is justified as the system does not have pockets to retain water.

4.0 Analytical Methods and Acceptance Criteria

4.1 Methods

The loads encountered during lifting and the resulting stresses will be evaluated in accordance with Site Standard 1060[11] using the Aluminum Design Manual's Specification for Aluminum Structures (ADM-2020[12]). The American Society of Mechanical Engineers – Below the Hook (ASME BTH-1[13]) methods and acceptance criteria will also be used to compare and supplement the ADM. The actual section forces and moments and stress levels in the bar will be determined by ABAQUS™ FEA software package[14].

4.2 Stress Criteria

Per C-CM-L-0016[7] and C-CM-L-0017[8], the carrier structures are Safety Significant (SS) items[16]. However, the lift condition is not a credited function in the L-Area DSA. The SS functional classification design feature is that the HFIR carriers are designed so that they prevent nesting of the inner and outer HFIR fuel elements. The lifting bail is not specifically associated with this credited function. Therefore, a tiered criterion will be used for analysis:

(1) Using Allowable stresses as if the lifting bail were a SS lifting attachment structure.
(2) Using Allowable stresses consistent with the carrier's low use rate, short load duration, and its credited structural behavior as permitted in ASCE-7 para 2.4.1[17].

4.2.1 *For Safety Credited Equipment Rigging Attachments*

The lifting bail and bail attachment points are integral to the carriers. Site Standard 1060[11] section 5.3.9 states that lift points and structural attachments integral to the item being lifted should be analyzed to the same criteria as the item (e.g., ASCE 7 load combination, and ADM-2020 criteria for aluminum components). To account for dynamic load increase during the lift, a 25% increase in static weight is used [Site Standard 1060[11] section 5.3.9].

In addition to ASCE-7 and ADM-2020, the design rules and criteria of ASME BTH-1 will be used. ASME BTH-1 provides evaluation methods specific to lifting bails, lug plates, pins, and other items associated with lifting and rigging. ASME BTH-1 and ADM-2020 are compared below and shown to provide equivalent criteria.

ASME BTH-1

Design Category = A, per ASME BTH-1, Section 2-2.1 (Loads are well known, environment is controlled)
Service Class = 0, per ASME BTH-1 Section 2-3 and Table 2-3-1 (less than 20,000 load cycles)
Design Factor = Nd = 2.0, per ASME BTH-1, Section 3-1.3.1

Tension Allowable Stresses

Fy/Nd = Fy/2.0 = 50% Yield [Ref. 13 Eq 3-1]
Fu/(1.2 Nd) = Fu/2.4 = 42% Ultimate

Bending Allowable Stresses*

Solid Bar: 1.25*Fy/Nd = 1.25*Fy/2.0 = 63% Yield [Ref. 13 Eq 3-25]
Hollow Tube: 1.1*Fy/Nd = 1.1*Fy/2.0 = 55% Yield [Ref. 13 Eq 3-6]
** see ASME BTH-1 commentary, regarding basis of different allowables for different shapes*

Shear Allowable Stresses
Fy/ (Nd*$\sqrt{3}$)= Fy/ (2.0*1.73) = 29% Yield [Ref. 13 Eq 3-28]

Bearing Allowable Stresses
1.8 Fy / (1.2 Nd) = 75% Yield [Ref. 13 Eq 3-38]

Weld Allowable Stresses
6061-T6: 0.60 * Exx/Nd = 0.60* 24,000psi /2.0 = 0.30 Sut = 7,200 psi [Ref. 13 Eq 3-55]
6063-T5 & T6: 0.60 * Exx/Nd = 0.60* 17,000psi /2.0 = 0.30 Sut = 5,100 psi [Ref. 13 Eq 3-55]
The base material, in the heat affected zone, is subject to the tensile and bending allowable stresses shown above, using the weld affected zone yield and ultimate strengths.

ASME BTH-1 also includes criteria for connections, like pin connected plates. These are presented within the analysis, as needed.

<u>ADM-2020 Criteria</u>
For Allowable Strength Design methods in ADM-2020, the following factors are used
Ω = Safety Factor = 1.65 [Ref. 12 Section D.1, E.1]
Impact "Dynamic" Factor for Lifting Condition = 1.25 [Per Site Std 1060]

Tension Stress Allowable
Yield/1.65 / 1.25 dynamic factor = 48% Yield [Ref. 12 Section D.1, E.1]

Bending Stress Allowable**
Solid Bars: 1.30*Yield/1.65 / 1.25 dynamic factor = 63% Yield [Ref. 12 Section F.7.1]
Tubes: 1.17*Yield/1.65 / 1.25 dynamic factor = 57% Yield [Ref. 12 Section F.6.1]
*** Additional criteria based on fraction ultimate stress are not controlling for the 6061-T6*

Shear Stress Allowable
(Tensile Yield * 0.62)/1.65 / 1.25 dyn factor = 30% Yield [Ref. 12 Section B.5.1]

Weld Stress Allowable
Use the lesser of the welded condition tensile ultimate strengths (base metal or filler), and a 1/1.95 design factor. For the 6061-T6, the 4043 electrode strength is the minimum (11.5 ksi). The shear ultimate for 6063-T5 & T6 is 11 ksi, and a specific allowable is computed.

6061-T6 & 4043 Weld Metal Shear = Su_v / 1.95 / 1.25 = 0.41Su_v = 11,500 psi * 0.41 = 4700 psi
6063-T5 & -T6 Weld Shear Stress = Su/1.95 / 1.25 = 0.41Su_v =11,000 psi* 0.41 = 4500 psi
Bearing Stress Allowable
1.33 Ultimate /1.95 / 1.25 dynamic factor = 55% Ultimate [Ref. 12 Section J7]

Table 4-1 Basic Stress Allowables for 6061-T6 (See Table 4-4 for 1.33X @ Level B)

Stress Type	ASME BTH-1	ADM	Use	Property	6061-T6
Tension	Min(0.5 Sy, 0.42Su)	0.48 Sy	0.5Sy	Sy=32,000 psi	16,000 psi
Bending, Bar	Min(0.63 Sy, 0.69Su)	0.63 Sy	0.63Sy	Sy=32,000 psi	20,200 psi
Bending, Tube	Min(0.55 Sy, 0.60Su)	0.57 Sy	0.55Sy	Sy=32,000 psi	17,600 psi
Shear	0.29 Sy	0.30 Sy	0.29Sy	Sy=32,000 psi	9,300 psi
Bearing	0.75 Sy	0.55 Su	0.55Su	Su=38,000 psi	20,900 psi
Weld Effected Zone	Same as above, but using weld zone material properties		0.63Sy	Sy_0 =11,000 psi	6,900 psi
Weld	0.30 Su_t	0.41Su_v	0.41Su_v[1]	Su_v=11,500 psi	4,700 psi

[1] This is the more conservative, since shear ultimate is ~ 60% of the tensile ultimate

Table 4-2 Basic Stress Allowables for 6063-T6 (See Table 4-4 for 1.33X @ Level B)

Stress Type	ASME BTH-1	ADM	Use	Property	6063-T6
Tension	Min(0.5 Sy, 0.42Su)	0.48 Sy	0.5 Sy	Sy=25,000 psi	12,500 psi
Bending, Bar	Min(0.63 Sy, 0.69Su)	0.63 Sy	0.63 Sy	Sy=25,000 psi	15,800 psi
Bending, Tube	Min(0.55 Sy, 0.60Su)	0.57 Sy	0.55 Sy	Sy=25,000 psi	13,800 psi
Shear	0.29 Sy	0.30 Sy	0.29 Sy	Sy=25,000 psi	7,300 psi
Bearing	0.75 Sy	0.55 Su	0.55 Su	Su=30,000 psi	16,500 psi
Weld Effected Zone	Same as above, but using weld zone material properties		0.63 Sy	Sy_0=8,000 psi	5,000 psi
Weld	0.30 Su_t	0.41Su_v	0.41Su_v	Su_v=11,000 psi	4,500 psi

Table 4-3 Basic Stress Allowables for 6063-T5 (See Table 4-4 for 1.33X @ Level B)

Stress Type	ASME BTH-1	ADM	Use	Property	6063-T6
Tension	Min(0.5 Sy, 0.42Su)	0.48 Sy	0.5 Sy	Sy=16,000 psi	8,000 psi
Bending, Bar	Min(0.63 Sy, 0.69Su)	0.63 Sy	0.63 Sy	Sy=16,000 psi	10,100 psi
Bending, Tube	Min(0.55 Sy, 0.60Su)	0.57 Sy	0.55 Sy	Sy=16,000 psi	8,800 psi
Shear	0.29 Sy	0.30 Sy	0.29 Sy	Sy=16,000 psi	4,600 psi
Bearing	0.75 Sy	0.55 Su	0.55 Su	Su=22,000 psi	12,100 psi
Weld Effected Zone	Same as above, but using weld zone material properties		0.63 Sy	Sy_0=8,000 psi	5,000 psi
Weld	0.30 Su_t	0.41Su_v	0.41Su_v	Su_v=11,000 psi	4,500 psi

4.2.2 *Allowable Stresses for Low Usage, Non-Critical Conditions*

The code safety factors and load factors are developed to address sustained cyclic use of equipment, uncertainty in load environment, and dynamic impacts. The allowable stresses shown in Table 4-1, through Table 4-3 are consistent with ASME BPVC Section III Service level A, which allows repeated load cycles. For a limited use load condition, with maximum loads very well defined, stress allowables consistent with ASME B&PVC Service Level B are justified. Per ASME III NCA, paragraph 2142.2, Level B criteria ensures the component can withstand the design loads without damage requiring repair. As additional safety, none of the stresses will be allowed to exceed 90% of yield. This 1.33 stress, while not referenced in ASME BTH-1, can be used because the carrier bail is “equipment” and not a below-the-hook lifting device that is used day-in and day-out.

Allowable Increase for Level B = 1.33

Table 4-4 Stress Allowables for Low Usage, Non Critical Load Condition

Stress Type	Service Level A Limit	Increase for Low Use Lift	6061-T6	6063-T6	6063-T5
Tension	0.5Sy	1.33	21,300 psi	16,600 psi	10,600 psi
Bending, Bar	0.63Sy	1.33	26,800 psi	20,900 psi	13,400 psi
Bending, Tube	0.55Sy	1.33	23,400 psi	18,300 psi	11,700 psi
Shear	0.29Sy	1.33	12,300 psi	9,600 psi	6,200 psi
Bearing	0.55Su	1.33, but < 0.9Fy	27,800 psi	21,900 psi	14,400 psi
Weld Effected Zone	0.63Sy	1.33	9,200 psi	7,200 psi	6,700 psi
Weld	0.41Su_v	1.33	6,300 psi	6,000 psi	6,000 psi

1

4.2.3 *Additional Criteria*

Effects of Bar Curvature

The bails are curved beams subjected to bending in the plane of the curve. This curvature creates an increase in stress at the inside edge of the curve and a decrease on the outside, as compared stresses computed using straight beam equations. Per ASME BTH-1, this effect should be accounted for in fatigue calculations (if high cycles), but not for static strength load capacity if the flexural member can develop a full plastic moment (ASME BTH-1, Section 3-1.5). The stress increases shown below from curvature, per Table 9.1, case 6 of Roark [15] as suggested by ASME BTH-1, Para C-1.5, are not significant for the low cycle use of these bails, thus no fatigue calculation is performed.

Table 4-5 Correction factor for straight beam equations

Location	**Bend Radius, R**	**Bar Radius, C**	**R/C**	**Stress Correction K**
Inner Bail, Top	1.69 inch	=0.375 inch /2	9.01	1.09
Inner Bail, Bottom	0.88 inch	=0.375 inch /2	4.69	1.19
Outer Bail, Top	1.69 inch	=0.625 inch /2	5.41	1.15
Outer Bail, Bottom	1.06 inch	=0.625 inch /2	3.39	1.25

Full Plastic Section

A solid bar is considered a class 1 cross-section, in that it can form a plastic hinge without a reduction in resistance. (Research Report VTT-R-02326-16[18])

5.0 Analysis

5.1 Finite Element Models

Because of the bent shape of the lifting bails, the bails are evaluated using an ABAQUS finite element model. This allows an accurate calculation of the forces, moments and stress distribution in the lifting bail and bail attachment. The FEA model, shown in Figure 5-2 for the Inner Carrier and Figure 5-3 for the Outer Carrier, is comprised of ABAQUS B31 beam elements. The beam elements are given a circular cross section of 3/8-inch diameter for inner carrier and 5/8-inch diameter for outer carrier. Aluminum material properties are specified. Mesh refinement of the model is such that there are approximately 100 total beam elements, resulting in element lengths less than half the beam cross-section dimension on average. This is more than enough to capture local behavior and capture stresses around the bar bends. The input listing is included as attachment A.

5.1.1 *FEA Model Loads*

Model Loads: Inner Carrier Lifting Bail → a 115 lbs concentrated load is applied to the bail top.
Outer Carrier Lifting Bail → a 225 lbs concentrated load is applied to the bail top.

The above loads are applied at two locations, based on the ¾-inch width of the Keepered hook[19] and its 3/16” relief radius (see Figure 5-1).

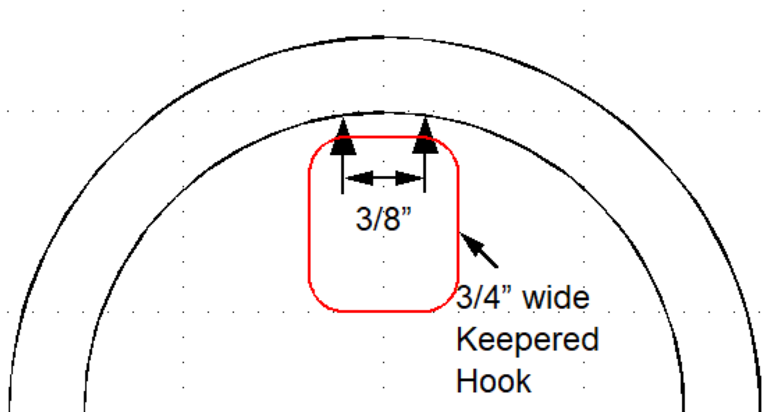


Figure 5-1 Hook to Bail Contact Points

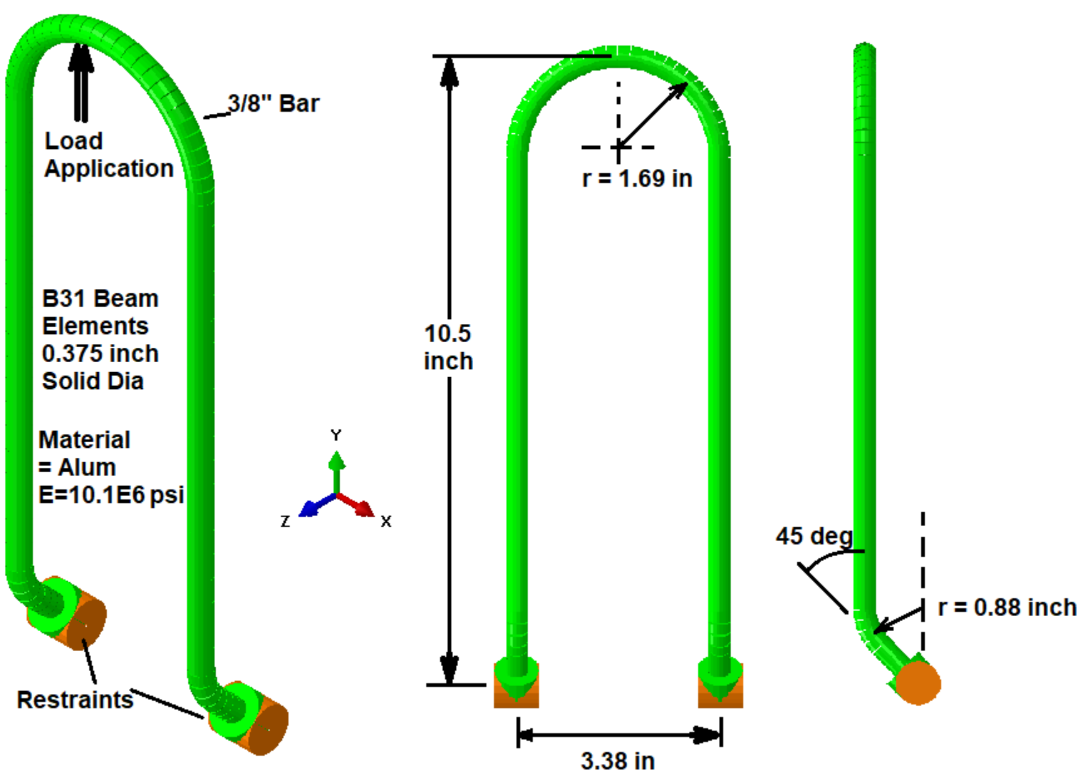


Figure 5-2 Inner Carrier Lift Bar FEA Model

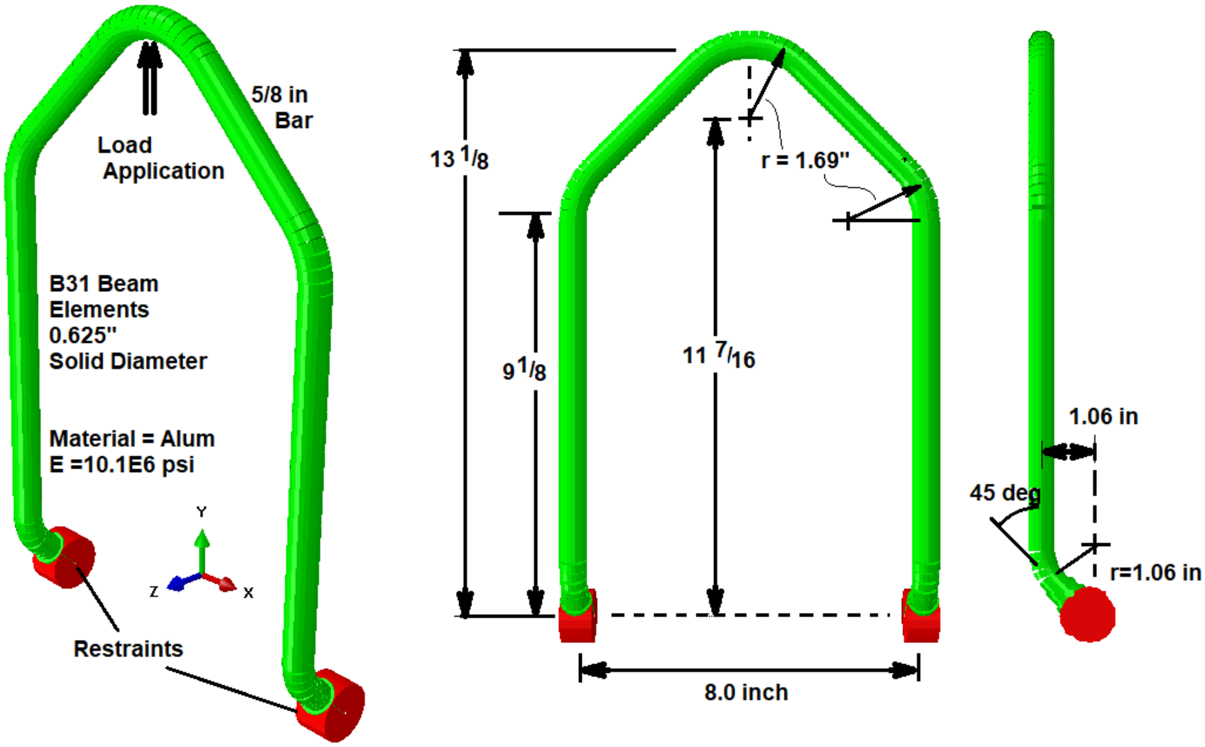


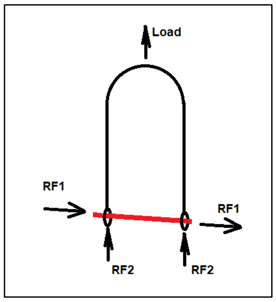
Figure 5-3 Outer Carrier Lift Bar FEA Model

5.1.2 *Bail End Link Boundary Conditions*

The lifting bail ends terminate into eyelets that slide on solid bar shafts. This allows the bail to rotate on the shaft. Stops are placed on the shaft to prevent the bail assembly from sliding off the shaft. During a lift, the bail ends will tend to move inward (toward each other) and the shaft/eyelet doesn't prevent this. This movement, even if slight, affects the stress response. The FEA model simulate two conditions as follows:

(1) The eyelets are free to slide
(2) The eyelets are not free to slide.

For each, the reactions loads are obtained, and the ability of friction to constrain sliding is assessed. The output is shown below:



No Friction Case

THE FOLLOWING TABLE IS PRINTED FOR NODES BELONGING TO NODE SET NHOLD

NODE	RF1(x)	RF2(y)	RF3(z)	RM1(x)	RM2(y)	RM3(z)
1	0.000000E+00	-5.730000E+01	-4.8059992E+00	0.00000E+00	0.00000E+00	0.00000E+00
77	0.000000E+00	-5.730000E+01	-4.8059992E+00	0.00000E+00	0.00000E+00	0.00000E+00

Friction Case

```
   THE FOLLOWING TABLE IS PRINTED FOR NODES BELONGING TO NODE SET NHOLD

    NODE     RF1(x)         RF2(y)         RF3(z)         RM1(x)         RM2(y)         RM3(z)
  1     -1.92414E+00 -5.730000E+01 -4.8059992E+00  0.00000E+00  0.00000E+00  0.00000E+00
 77      1.92414E+00 -5.730000E+01 -4.8059992E+00  0.00000E+00  0.00000E+00  0.00000E+00
```

Therefore, a coefficient of friction of 1.92 lbs/57.3 lbs = 3.4% is all that is required to achieve the case 2 condition. Typical friction coefficients for aluminum are far greater than 10% [Ref. 20 Table. 6-25].

5.2 HFIR Inner Carrier Stress Analysis[8]

The finite element analysis provides stress results for the lifting bar, and forces and moments at the reaction points. These values are used to compare allowable stresses and to perform additional calculations for stress in the bail attachment structure. The following results are for a 115 lbs load.

5.2.1 *Item 1 - Carrier Bail Stress*

Bar stresses are shown in Figure 5-4, showing a maximum stress of 12,726 psi occurring at the top center region of the lifting bail. At the lower bend, the stress is 9,013 psi and bounded by the 12,726 psi stress at the top. The stress in the weld affected zone is checked in section 5.2.2.

Table 5-1 Demand percentage on the allowable stress for the inner carrier lifting bail

	Level A Limits (6061-T6)		**Level B Limits (6061-T6)**	
Maximum Stress	Stress Limit	Demand/Allowable	Stress Limit	Demand/Allowable
12,726 psi	20,200 psi	63 %	26,800 psi	47 %

In addition to the direct stress output, stresses can be computed from the section forces and moments. These values are shown in Figure 5-5 and Figure 5-6. At the top center, the sections forces and moments are listed below, respectively:

SF1 = 0.0 lbs
SM1 = 66 in-lb

$$Bar\ Cross - Sectional\ Area\ =\ A_{bar}\ =\ \frac{\pi d^2}{4} = \frac{\pi 0.375^2}{4}\ =\ 0.11\ in^2$$

$$Bar\ Section\ Modulus\ =\ S_{bar}\ =\ \frac{\pi \cdot d^3}{32}\ =\ 0.0052\ in^3$$

$$\sigma = K\left(\frac{SF1}{A} + \frac{SM1}{S}\right) = K\left(\frac{0}{A} + \frac{66\ in - lb}{0.0052 in^3}\right)\ =\ K \cdot 12{,}700 psi$$

The 12,700 psi computed value matches the Figure 5-4 output value of 12,726 psi. The K factor pertains to the stress increase/decrease that occurs due to bar curvature. The Code allowable used for the static strength does not employ this factor. This factor is applicable to fatigue evaluation. Since this lifting bail does not see high frequency use, fatigue evaluation is not required. The FEA output of stress also does not incorporate the stress enhancement and it can be directly compared to the Code stress allowable.

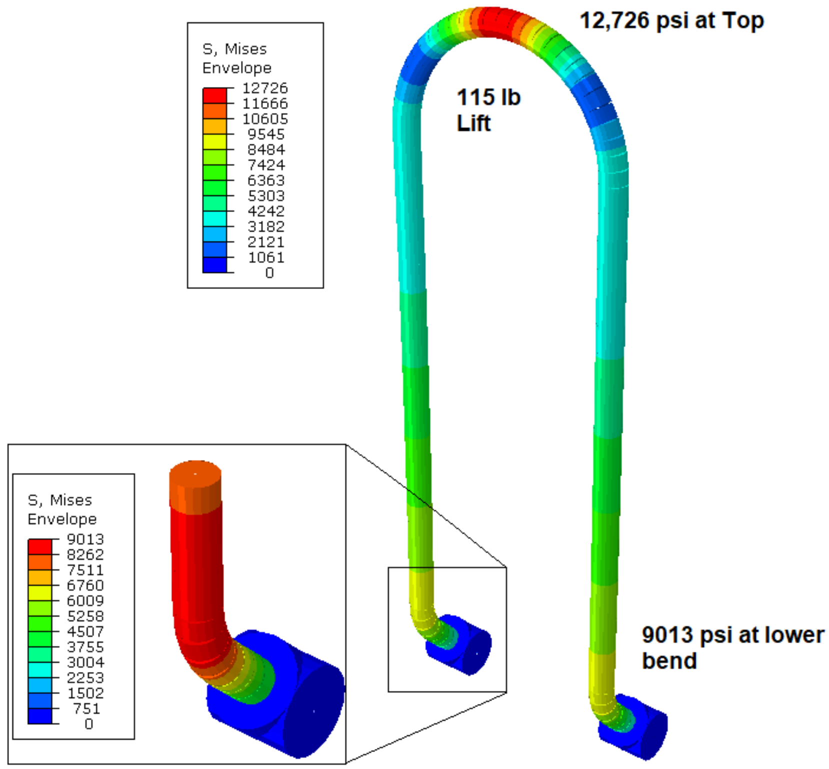


Figure 5-4 FEA Stress Output in 3/8- inch Lift Bar, 115 lbs Load.

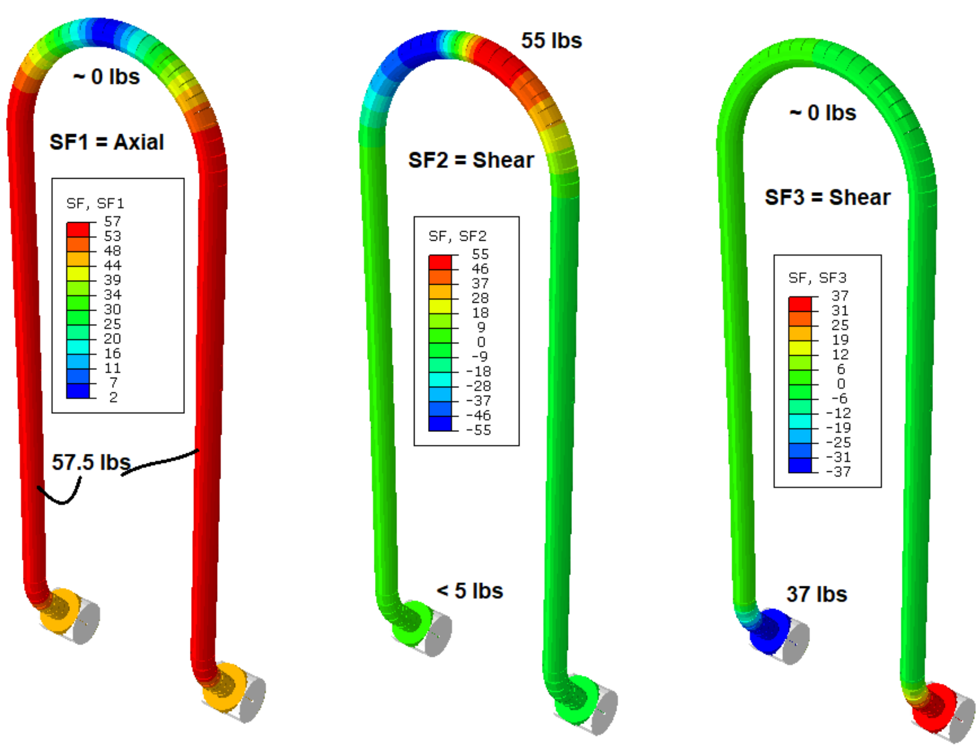


Figure 5-5 FEA Section Force Output in 3/8-inch Lift Bar, 115 lbs Load.

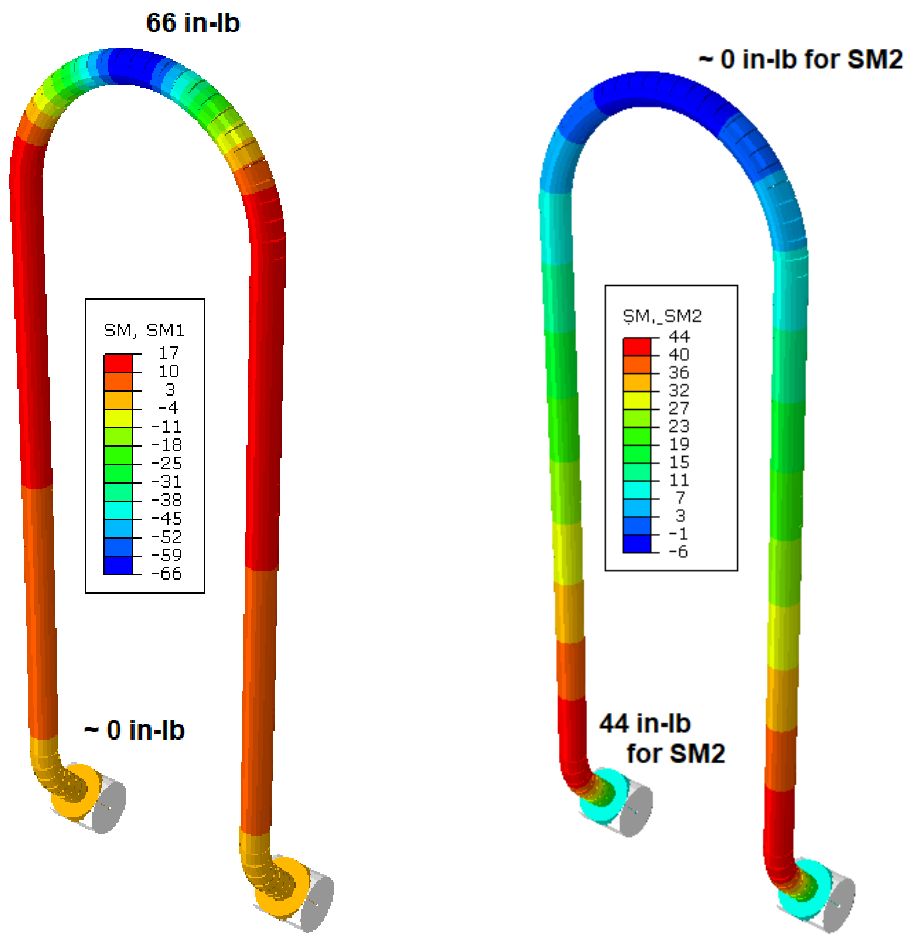


Figure 5-6 FEA Moment Output in 3/8-inch Lift Bar, 115 lbs Load.

5.2.2 *Bail Welds*

<u>Weld Description</u>

For the inner carrier, the 3/8-inch diameter solid rod used for the lifting bail is welded to a ¾-inch diameter by ½-inch long pivot lug. The weld is a ⅛-inch fillet all-around, except that on the sides, the ½-inch length of the ¾-inch bar prevents the full weld. Therefore, the drawing specifies the fillet weld to be at least ½-inch length on each side of the ⅜-inch bar (see Figure 5-6).

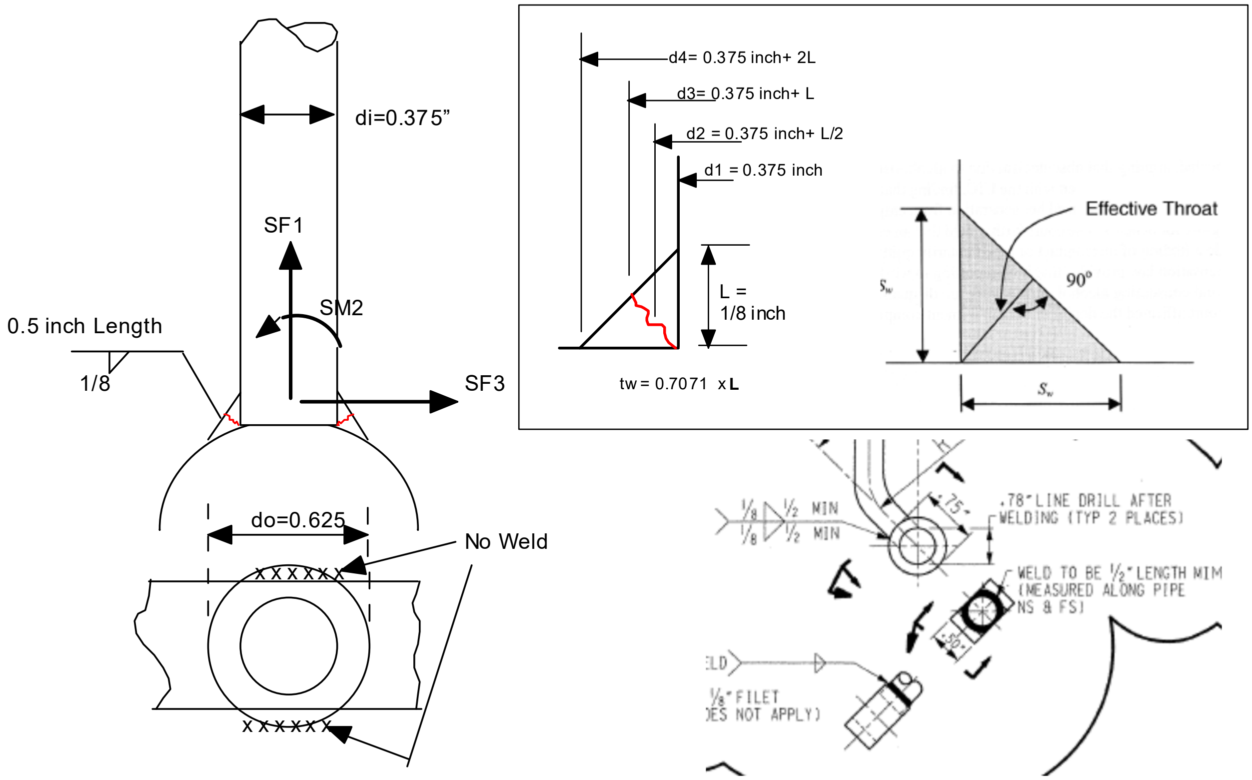


Figure 5-7 Weld Detail for Lift Bar, Inner Carrier

Loads on Weld

The loads at the bail to lug are obtained from the section forces and moments from the FEA model. Because of the angle at the lifting bail end, the weld load from the lift condition is a combination of bar tension, bar shear, and bar bending. These loads are shown below. Output is per the inch, lbs system, and SF# denotes section force, and SM# denotes section moment, as illustrated in Figure 5-7.

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ELEMENT	PT	SF1	SF2	SF3	SM1	SM2	SM3
83	1	**43.92**	-1.924	*37.12*	0.8836	**17.04**	0.0

Weld Section Properties

Weld Size = 1/8-inch fillet (L=1/8-inch) x ½-inch length on opposite sides of bar

tw = Weld throat = 0.7071 x 0.125 = 0.0884 in

d1 = 0.375 inch

d2 = d1 + L/2 = 0.4375 inch

d3 = d1 + L = 0.500 inch

d4 = d1 + 2L = 0.625 inch

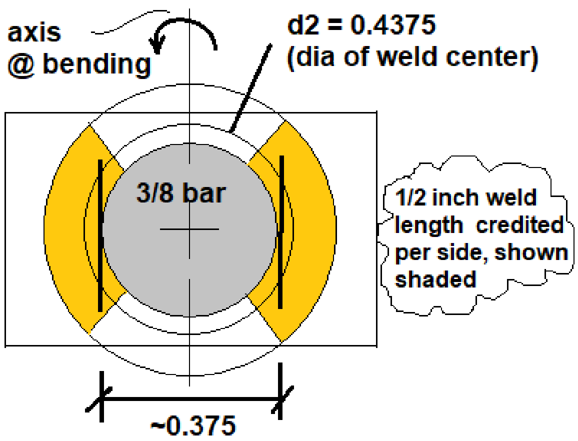


Figure 5-8 Weld length detail

Weld Length = L = 0.5 inch per side (see schematic)
Weld throat = tw = 0.0884 inch
Centerline diameter of weld = d2 = 0.4375 inch
Centroid spacing, due to curvature = d= 0.375 inch

$$Weld\ Area\ =\ Aw\ =\ 2\cdot L\cdot tw\ =\ 2\cdot 0.5\cdot 0.0884$$
$$=0.0884\ in^2, use\ 0.088\ in^2$$

$$Moment\ of\ Inertia\ =\ Iw\ =\ 2\cdot\left(\frac{Aw}{2}\right)\cdot\left(\frac{d}{2}\right)^2$$
$$=\ 2\cdot 0.0442 in^2\cdot(0.1875 in)^2$$
$$=0.0031\ in^4$$

$$Section\ Modulus\ =\ Sw\ =\ \frac{Iw}{(d4/2)}=\frac{0.0031\ in^4}{(0.625/2)}$$
$$Sw\ =\ 0.0099 in^3$$

Weld Stress
Conservatively adding the tensile and shear terms using direct addition, and weld stress is computed as:

$$\sigma=\left(\frac{SF1}{Aw}+\frac{SF3}{Aw}+\frac{SM2}{Sw}\right)\ =\ \left(\frac{44lb}{0.088in^2}+\frac{37lb}{0.088in^2}+\frac{17\ in-lb}{0.0099in^3}\right)\ =\ 2{,}640\ psi$$

Bar Stress – Weld Heat Affected Zone (HAZ)
For the bar cross-section tension plus bending stress, only the tensile (SF1) and bending terms are used:

$$\sigma=\left(\frac{SF1}{Abar}+\frac{SM2}{Sbar}\right)\ =\ \left(\frac{44lb}{0.11in^2}+\frac{17\ in-lb}{0.0052in^3}\right)\ =\ 3{,}700\ psi$$

Table 5-2 Demand percentage on the allowable stress for the inner carrier welds

Location	Stress Demand	Level A Limits (6061-T6)		Level B Limits (6061-T6)	
		Limit	Demand/Allowable	Limit	Demand/Allowable
Weld	2,640 psi	4,700 psi	56 %	6,300 psi	42 %
Bar - HAZ	3,700 psi	6,900 psi	54%	9,200 psi	40 %

5.2.3 *Pivot Bar Stress (Item 4)*

The reaction and counter reaction between the lifting bail and the carrier body creates bending and shear on the Pivot Bar.

Bar Size = 3/8-inch diameter
P = 115 lb/2 = 57.5 lbs (or from FEA output = sqrt($43.92^2 + 37.12^2$) = 57.5 lbs
a = bending distance = 0.81 inch (see schematic, next page)
Moment = $P\cdot a$ = 57.5 lb * 0.81 inch = 47 in-lb

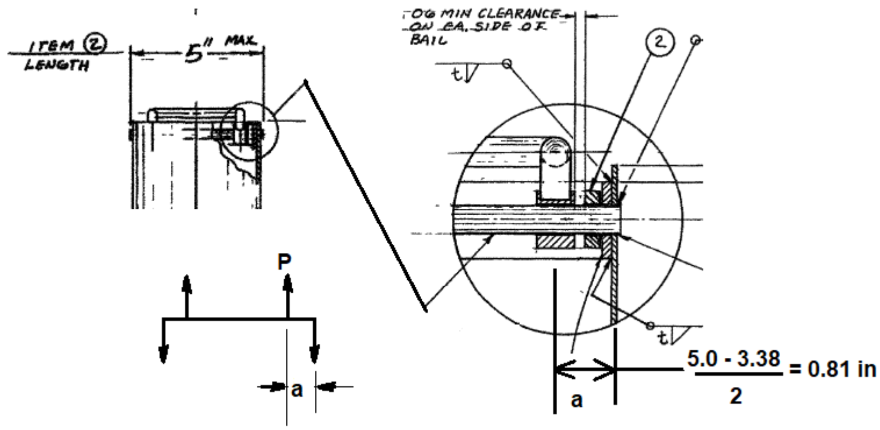


Figure 5-9 Pivot bar detail

$$Bar\ Cross - Section\ Area\ =\ Abar\ = \frac{\pi d^2}{4} = \frac{\pi 0.375^2}{4}\ =\ 0.11\ in^2$$

$$Bar\ Section\ Modulus\ =\ Sbar\ = \frac{\pi \cdot\ d^3}{32}\ =\ 0.0052\ in^3$$

Bar Bending

$$\sigma = \frac{M}{Sbar} = \frac{47\ in - lb}{0.0052 in^3}\ =\ 9{,}040\ psi$$

Bar Shear

$$\tau = \frac{P}{A} = \frac{57.5 lb}{0.11 in^2}\ =\ 523\ psi$$

Bearing Stress

Bearing Stress Area = 0.125 x 0.375 inch = 0.0469 in^2

$$\sigma = \frac{P}{A} = \frac{57.5 lb}{0.0469 in^2}\ =\ 1{,}226\ psi$$

Table 5-3 Demand percentage on the allowable stress for the pivot bar

Type	Stress Demand	Level A Limits (6061-T6)		Level B Limits (6061-T6)	
		Limit	Demand/Allowable	Limit	Demand/Allowable
Bar Bending	9,040 psi	20,200 psi	45 %	26,800 psi	34 %
Bar Shear	523 psi	9,300 psi	6%	12,300 psi	4%
Bar Bearing	1,226 psi	20,900 psi	6%	27,800 psi	4%

5.2.4 *Retaining Ring (Item 3)*

The 6061-T6 aluminum reinforcing ring (item 3) is evaluated per ASME BTH-1 as this Code provides specific and applicable equations for the stresses around the pin holes in the ring. Because the calculation from equation 3-45 (ASME BTH-1 3-3.3.1, tensile rupture) results in a much greater capacity than the applied load (1,021 lbs. >> 57.5 lbs.), the equation 3-49 (fracture) and 3-50 (shear) are unnecessary since they result in similar capacity as EQ 3-45.

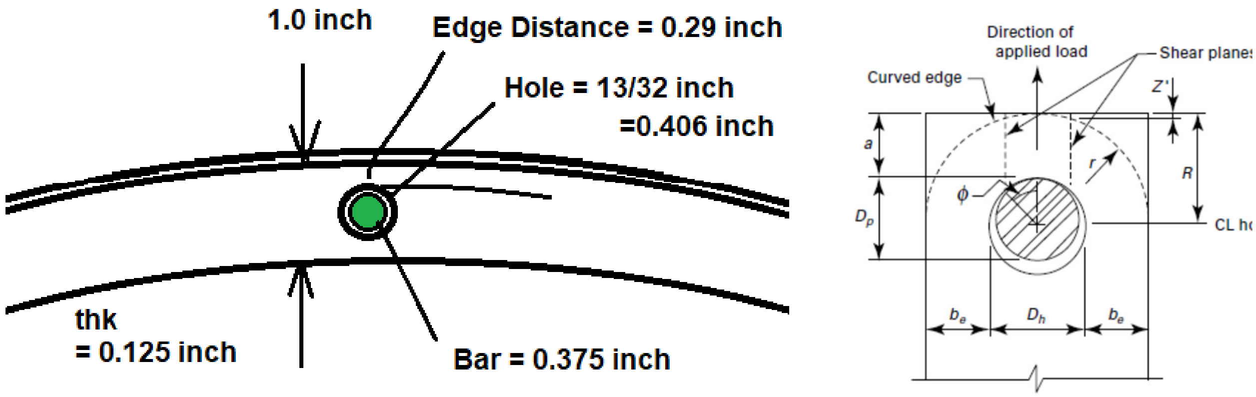


Figure 5-10 Schematic of Bar and Pin Hole Connection

Pin Diameter = D_P = 0.375 inch
Hole Diameter = D_h = 13/32 = 0.406 inch
b_{eff} = (1.0 inch – 13/32)/2 = 0.29 inch
t = 0.125 inch

$C_r = 1 - 0.275\sqrt{1 - \frac{D_p^2}{D_h^2}} = 0.89$

Allowable tensile strength through pinhole = $P_t = C_r \frac{F_u}{1.20\,N_d} 2tb_{eff}$

$$= 0.89 \frac{38{,}000\,psi}{1.20 * 2.0} 2 \cdot 0.125" \cdot 0.29" \;=\; 1{,}021\ lbs\ \ vs\ (58\ lbs\ demand)$$

5.2.5 *Item 6 – Carrier Body and Weld Attachments*

The carrier body is a 5-inch diameter tube by 0.063-inch wall. The load on this tube is the 110 lbs HFIR-inner weight, carried as an axial stress on the tube, and shear stress on the welds (ring to tube, tube to lower plate). The welds are fillet welds of 0.063-inch thickness.

$$Body\ Cross\ Section\ Area \;=\; Atube \;=\; \pi dt = \pi \cdot 5.0\ inch \cdot 0.125\ inch \;=\; 1.96\ in^2$$
$$Weld\ Shear\ \ Area \;=\; 0.7071\ \cdot Atube \;=\; 1.38\ in^2$$

The 110 lbs. load results in less than 100 psi axial stress in the tube wall and less than 100 psi weld shear stress. The lower plate is not subject to the bending stress as computed in C-CLC-L-00134, since the HFIR payload is stiffer than the lower plate (item 5), and the payload weight will shift toward the innermost portion of the lower support plate. This minimizes bending, and results in the weld shear being the stress of concern.

5.3 HFIR Outer Carrier Stress Analysis

The finite element analysis provides stress results for the lifting bar, and forces and moments at the reaction points. These values are used to compare to allowable stresses, and to perform additional calculations for stress in the bail attachment structure. The following results are for a 225 lbs load.

5.3.1 *Item 1 - Carrier Bail Stress*

Bar stresses are shown in Figure 5-11, showing a maximum stress of 10,628 psi occurring at the top center region of the lifting bail. At the lower bend, the stress is 4,740 psi and bounded by the 10,628 psi stress at the top. The stress in the weld effected zone is checked in section 5.2.2.

Table 5-4 Demand percentage on the allowable stress for the outer carrier lifting bail

	Level A Limits (6061-T6)		Level B Limits (6061-T6)	
Maximum Stress	Stress Limit	Demand/Allowable	Stress Limit	Demand/Allowable
10,628 psi	20,200 psi	53 %	26,800 psi	40 %

In addition to the direct stress output, stresses can be computed from the section forces and moments. These values are shown in Figure 5-12 and Figure 5-13. At the top center, the sections forces and moments are:

SF1 = 0.0 lbs
SM1 = 254 in-lb

$$Bar\ Cross - Sectional\ Area\ = A_{bar}\ = \frac{\pi d^2}{4} = \frac{\pi 0.625^2}{4}\ =\ 0.307\ in^2$$

$$Bar\ Section\ Modulus\ = S_{bar}\ = \frac{\pi \cdot d^3}{32}\ =\ 0.024\ in^3$$

$$\sigma = K\left(\frac{SF1}{A_{bar}} + \frac{SM1}{S_{bar}}\right) = K\left(\frac{0}{0.307\ in^2} + \frac{254\ in - lb}{0.024 in^3}\right)\ =\ K \cdot 10{,}583\ psi$$

The 10,583 psi computed value matches the Figure 5-11 output value of 10,628 psi (small difference is in how FEA extrapolates discrete integration point output to intermediate locations along the bar). The K factor pertains to the stress increase/decrease that occurs due to bar curvature. The Code allowable used for the static strength does not employ this factor. This factor is applicable to fatigue. Since this lifting bail does not see high frequency use, fatigue is not applicable. The FEA output of stress also does not incorporate the stress enhancement.

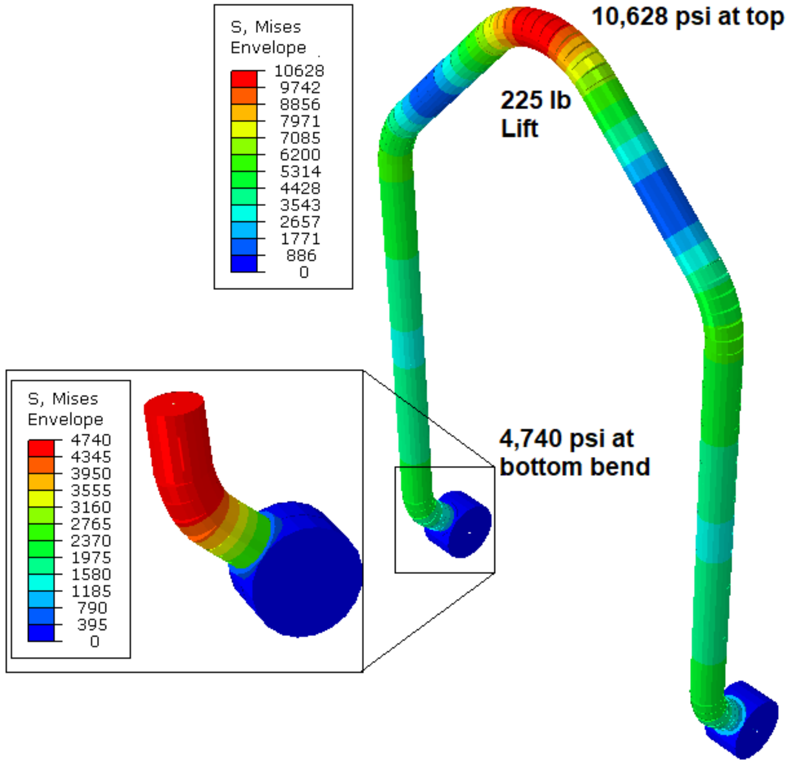


Figure 5-11 FEA Stress Output in 5/8-inch Lift Bar, 225 lbs Load.

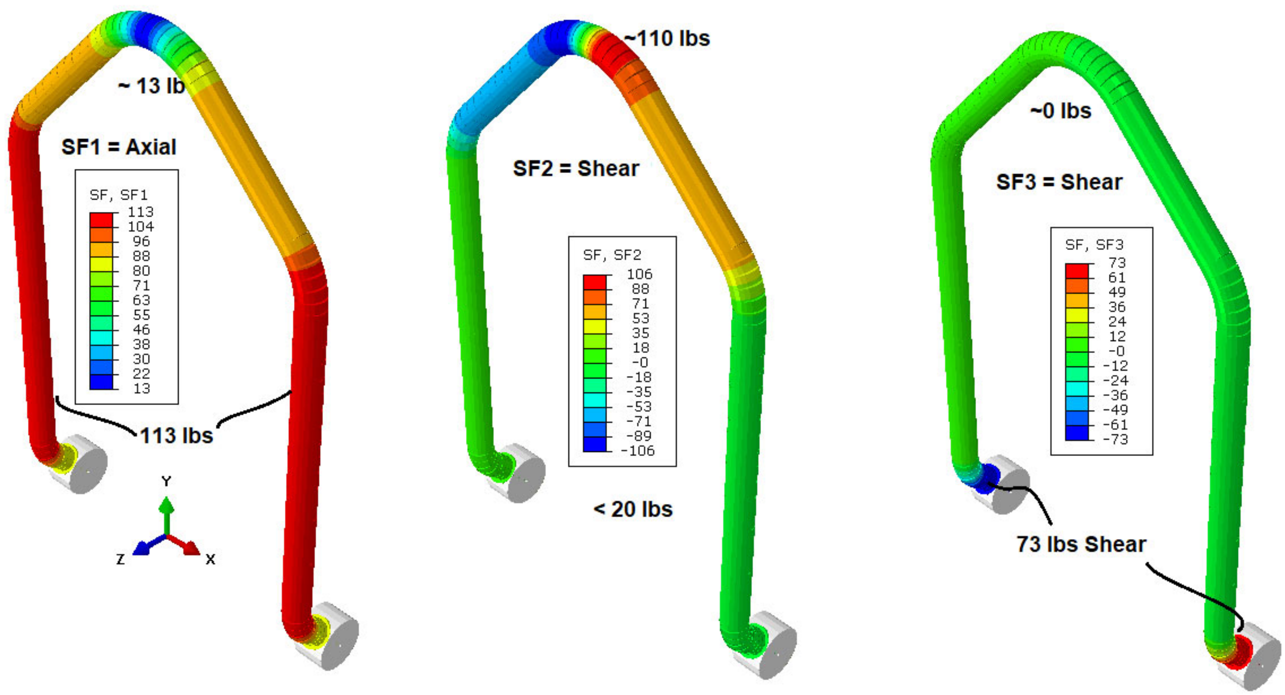


Figure 5-12 FEA Section Force Output in 5/8-inch Lift Bar, 225 lbs Load.

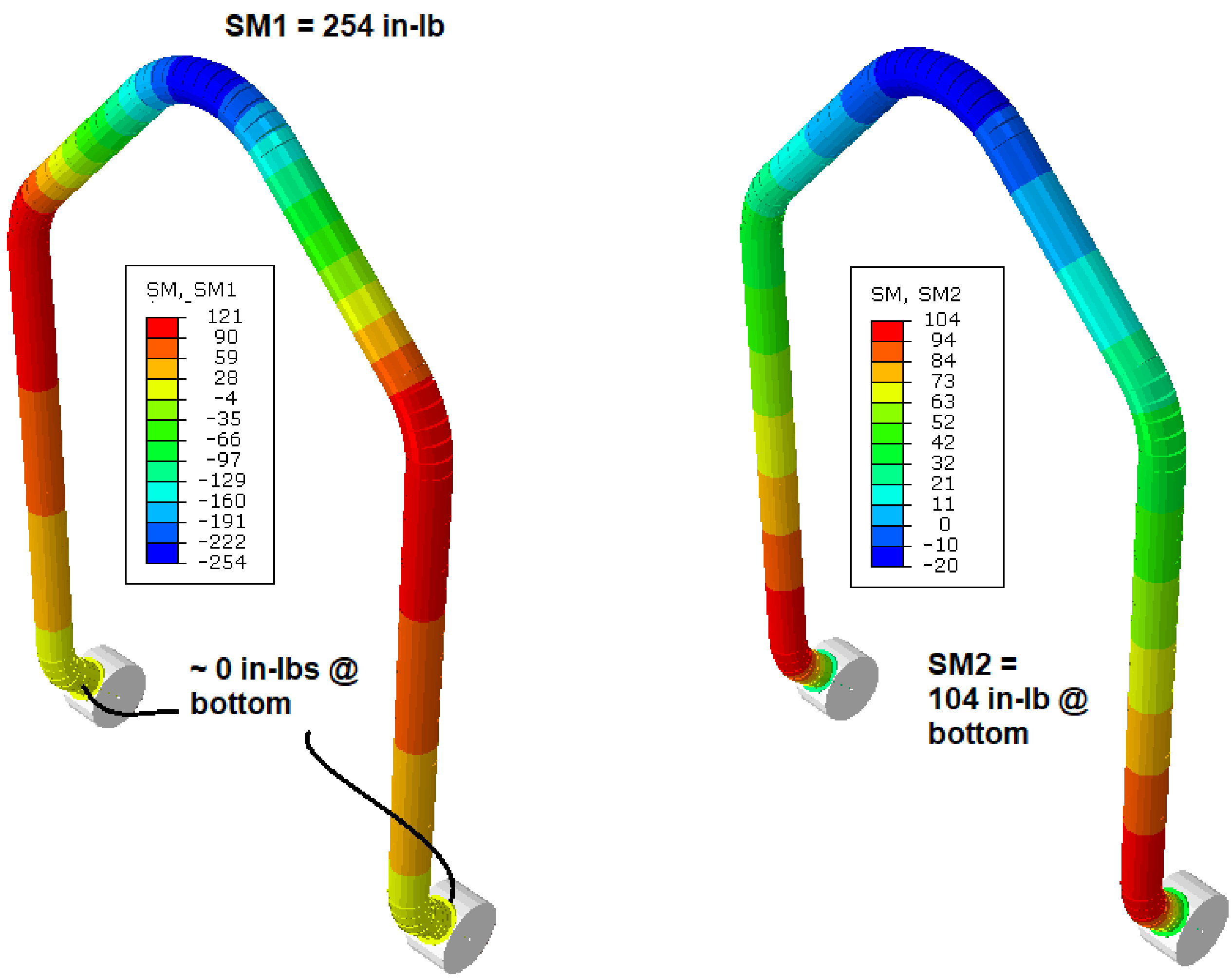


Figure 5-13 FEA Moment Output in 5/8-inch Lift Bar, 225 lbs Load.

5.3.2 *Bail Welds*

Weld Description

For the outer carrier, the 5/8-inch diameter solid rod used for the lifting bail is welded to a 1¼-inch diameter by ¾-inch long pivot lug. The weld is a ⅛-inch fillet, except that on the sides, the ¾-inch length of the pivot bar does not provide enough length for the ⅝-inch bar to get a ⅛ fillet weld on the sides. Therefore, the drawing specifies the fillet weld to be at least ½-inch length on each side.

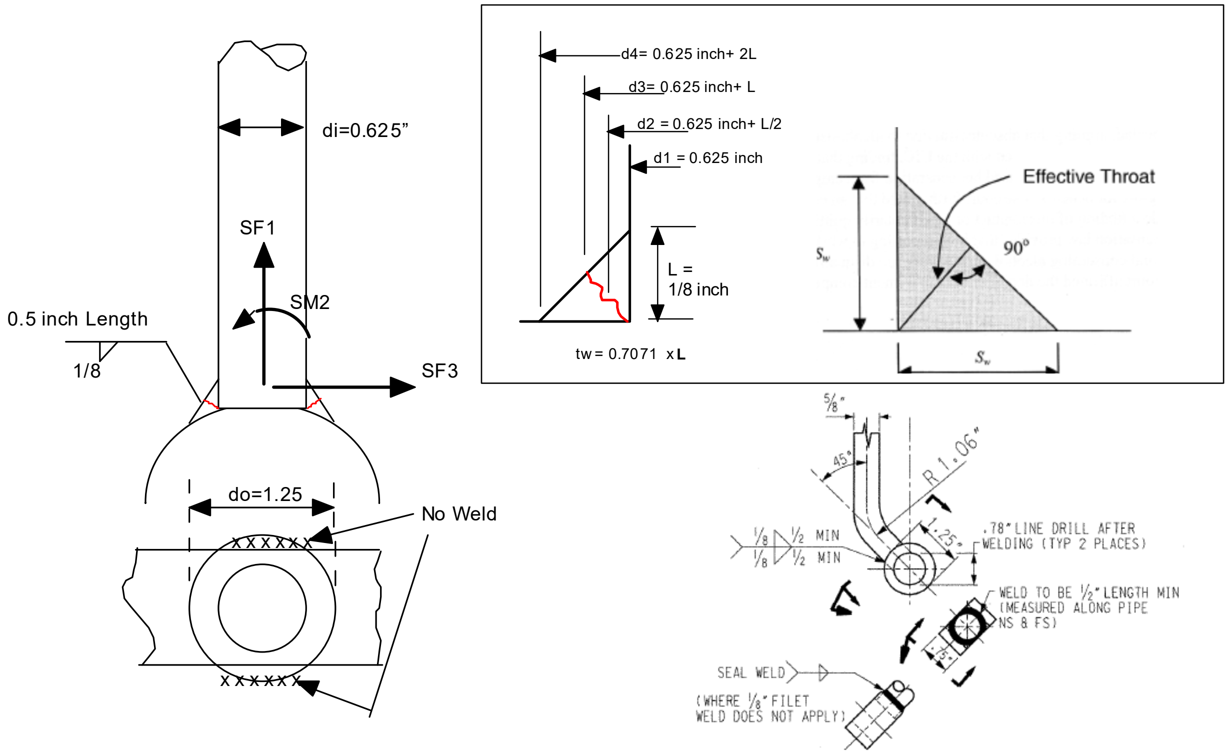


Figure 5-14 Weld Detail for Lift Bar, Outer Carrier

Loads on Weld

The loads at the bail to lug are obtained from the section forces and moments from the FEA model. Because of the angle at the lifting bail end, the weld load from the lift condition is a combination of bar tension, bar shear, and bar bending. These loads are shown below. Output is per inch, lbs system, and SF# denotes section force, and SM# denotes section moment, as illustrated in Figure 5-14.

ELEMENT	PT	SF1	SF2	SF3	SM1	SM2	SM3
102	1	**85.69**	-13.23	72.87	4.134	**22.77**	0.0

Weld Section Properties

Weld Size = ⅛-inch fillet (L = ⅛-inch) x ½-inch length on opposite sides of bar

tw = Weld throat = 0.7071 x 0.125 = 0.0884 in

d1 = 0.625 inch

d2 = d1 + L/2 = 0.6875 inch

d3 = d1 + L = 0.750 inch

d4 = d1 + 2L = 0.875 inch

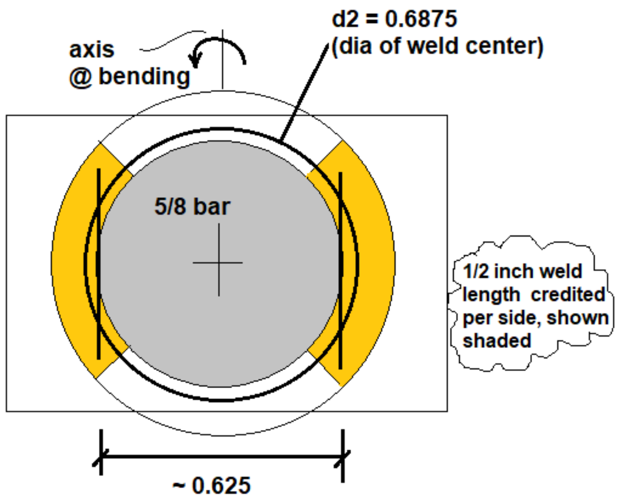


Figure 5-15 Weld length detail

Weld Length = L = 0.5 inch per side (see schematic)
Weld throat = tw = 0.0884 inch
Centerline diameter of weld = d2 = 0.6875 inch
Centroid spacing, due to curvature = d= 0.625 inch

$$Weld\ Area\ =\ Aw\ =\ 2 \cdot L \cdot tw\ =\ 2 \cdot 0.5 \cdot 0.0884$$
$$=0.0884\ in^2, use\ 0.088\ in^2$$

$$Moment\ of\ Inertia\ =\ Iw\ =\ 2 \cdot \left(\frac{Aw}{2}\right) \cdot \left(\frac{d}{2}\right)^2$$
$$=\ 2 \cdot 0.0442 in^2 \cdot (0.3125 in)^2$$
$$=0.0086\ in^4$$

$$Section\ Modulus\ =\ Sw\ =\ \frac{Iw}{(d4/2)}\ =\frac{0.0086\ in^4}{(0.875/2)}$$

$$Sw\ =\ 0.0197 in^3$$

<u>Weld Stress</u>

Conservatively adding the tensile and shear terms using direct addition, and weld stress is computed as:

$$\sigma = \left(\frac{SF1}{Aw}+\frac{SF3}{Aw}+\frac{SM2}{Sw}\right) = \left(\frac{86lb}{0.088in^2}+\frac{73lb}{0.088in^2}+\frac{22.7\ in-lb}{0.0197in^3}\right)\ =\ 3{,}000\ psi$$

<u>Bar Stress– Weld Heat Affected Zone (HAZ)</u>

For the bar cross-section tension plus bending stress, only the tensile (SF1) and bending terms are used:

$$\sigma = \left(\frac{SF1}{Abar}+\frac{SM2}{Sbar}\right) = \left(\frac{86lb}{0.307in^2}+\frac{22.7\ in-lb}{0.024in^3}\right)\ =\ 1{,}225\ psi$$

Table 5-5 Demand percentage on the allowable stress for the outer carrier welds

Location	Stress Demand	Level A Limits (6061-T6)		Level B Limits (6061-T6)	
		Limit	Demand/Allowable	Limit	Demand/Allowable
Weld	3,000 psi	4,700 psi	64 %	6,300 psi	48 %
Bar - HAZ	1,225 psi	6,900 psi	18 %	9,200 psi	13 %

5.3.3 *Pivot Bar Stress (C-CM-L-0016 Item 5[7])*

The reaction and counter reaction between the bail and the carrier body creates bending and shear on the Pivot Bar.

Bar Size = ¾-inch

P = 225 lb/2 = 112.5 lbs (or from FEA output = sqrt($85.69^2 + 72.87^2$) = 112.5 lbs

Bending Distance = a = 1.24 inch (see next page)

$$Moment\ = P\ \cdot a\ \ =\ 112.5\ lb \cdot 1.24\ inch\ =\ \ 140\ in-lb$$

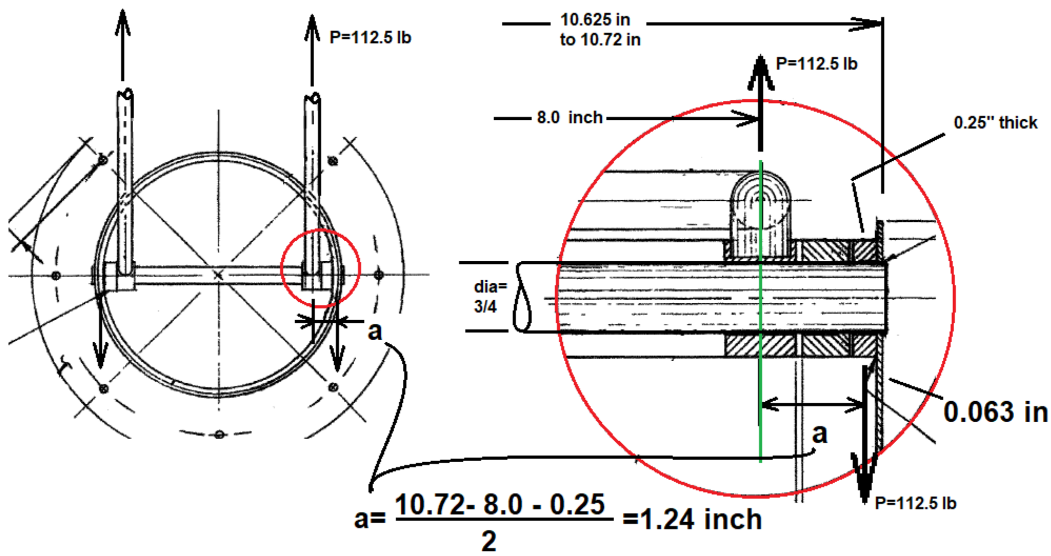


Figure 5-16 Pivot bar detail

$$Bar\ Cross - Section\ Area\ =\ Abar\ = \frac{\pi d^2}{4} = \frac{\pi 0.75^2}{4}\ =\ 0.44\ in^2$$

$$Bar\ Section\ Modulus\ =\ Sbar\ = \frac{\pi \cdot d^3}{32}\ =\ 0.041\ in^3$$

Bar Bending

$$\sigma = \frac{Moment}{Sbar} = \frac{140\ in - lb}{0.041 in^3}\ =\ 3{,}415\ psi$$

Bar Shear

$$\tau = \frac{P}{A} = \frac{112.5 lb}{0.44 in^2}\ =\ 256\ psi$$

Bearing Stress

Bearing Stress Area = 0.25 x 0.75 inch = 0.18 in^2

$$\sigma = \frac{P}{A} = \frac{112.5 lb}{0.18 in^2}\ =\ 625\ psi$$

Table 5-6 Demand percentage on the allowable stress for the outer carrier pivot bar

Type	Stress Demand	Level A Limits (6061-T6)		Level B Limits (6061-T6)	
		Limit	Demand/Allowable	Limit	Demand/Allowable
Bar Bending	3,415 psi	20,200 psi	17 %	26,800 psi	13 %
Bar Shear	256 psi	9,300 psi	3%	12,300 psi	2%
Bar Bearing	625 psi	20,900 psi	3%	27,800 psi	2%

5.3.4 *Reinforcing Ring (C-CM-L-0016 Item 2)*

The 6061-T6 aluminum reinforcing ring (item 2) is evaluated per ASME BTH-1 as this Code provides specific and applicable equations for the stresses around the pin holes in the ring. Because the calculation from equation 3-45 (ASME BTH-1 3-3.3.1, tensile rupture) results in a much greater capacity than the applied load (1,675 lbs >> 113 lbs), the equation 3-49 (fracture) and 3-50 (shear) are unnecessary since they result in similar capacity as EQ 3-45.

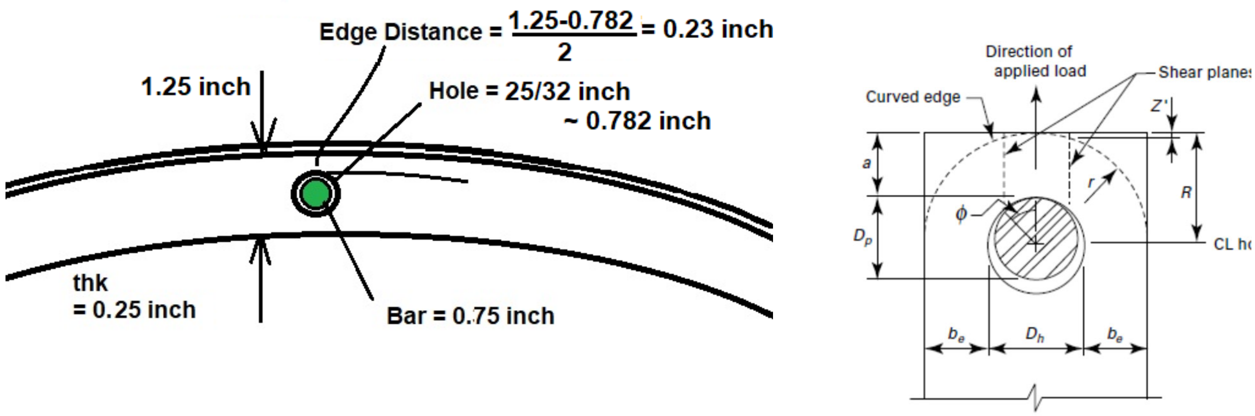


Figure 5-17 Schematic of Bar and Pin Hole Connection

Pin Diameter = D_P = 0.75 inch
Hole Diameter = D_h = 25/32 = 0.782 inch
b_{eff} = (1.25 inch – 25/32)/2 = 0.23 inch
t = 0.25 inch

$C_r = 1 - 0.275\sqrt{1 - \frac{D_p^2}{D_h^2}} = 0.92$

Allowable tensile strength through pinhole = $P_t = C_r \frac{F_u}{1.20\, N_d} 2tb_{eff}$

$$= 0.92 \frac{38{,}000\ psi}{1.20*2.0} 2 \cdot 0.25" \cdot 0.23" \ = \ 1{,}675\ lbs\ \ vs\ (113\ lbs\ demand)$$

5.3.5 *Item 4 – Carrier Body and Weld Attachments*

The carrier body is a 10.625-inch diameter tube by 0.063-inch wall. The load on this tube is the 215 lbs HFIR-outer weight, carried as an axial stress on the tube, and shear stress on the welds (ring to tube, tube to lower plate). The welds are fillet welds of 0.063-inch thickness.

$$Body\ Cross\ Section\ Area\ =\ Atube\ =\ \pi dt = \pi \cdot 10.6\ inch \cdot 0.25\ inch\ =\ 8.32\ in^2$$
$$Weld\ Shear\ \ Area\ =\ 0.7071\ Atube\ =\ 5.88\ in^2$$

The 215 lbs load results in less than 100 psi axial stress in the tube wall, and less than 100 psi weld shear stress. The lower plate is not subject to the bending stress as computed in C-CLC-L-00134, since the HFIR payload is stiffer than the lower plate (item 7), and the payload weight will shift toward the innermost portion of the lower support plate. This minimizes bending, and results in the weld shear being the stress of concern.

6.0 Summary of Results – Existing Design

For both the inner carrier assembly and the outer carrier assembly, the controlling stress item is the lifting bail (item 1 per both C-CM-L-0016 and C-CM-L-0017). The 3/8-inch diameter bar on the inner carrier is stressed to 44% of the allowable stress targeted for limited, controlled usage with 115 lbs load. The 5/8-inch diameter bar on the outer carrier is stressed to 37% of the allowable stress targeted for limited, controlled usage with 225 lbs. load.

The lifting bail to pivot bar weld also showed similar demand/allowable ratios. For the inner carrier, the weld stress interaction was slightly less than the stress interaction for the 3/8-inch bar itself. For the outer carrier, the calculated stress of 3,000 psi did result in a stress interaction exceeding that of the 5/8-inch bar. The drawing indicates a 1/8-inch fillet weld all around the bar, where possible. Referring to Figure 5-14, the side regions prevent the full fillet, and the weld is specified as a seal weld. A minimum 0.5-inch length of 1/8-inch fillet weld on each side is called for. Based on the 5/8-inch diameter, the actual weld length will be longer, such that the weld strength is higher than credited.

The results for each carrier are summarized in the tables below.

Table 6-1 Results Summary for Inner Carrier Lifting Condition

Location	Stress Demand	Level A Limits (6061-T6)		Level B Limits (6061-T6)	
		Limit	D/C*	Limit	D/C
Bail Bar @ Top	12,726 psi	20,200 psi	63%	26,800 psi	47 %
Bar Weld	2,726 psi	4,700 psi	58 %	6,300 psi	42 %
Bar @ bottom - HAZ	3,700 psi	6,900 psi	54 %	9,200 psi	40 %
Pivot Bar Bending	9,040 psi	20,200 psi	45 %	26,800 psi	34 %
Pivot Bar Shear	523 psi	9,300 psi	6 %	12,300 psi	4 %
Pivot Bar Bearing	1,226 psi	20,900 psi	6 %	27,800 psi	4 %
Retaining Ring Hole	57.5 lbs	1,021 lbs	6 %	1,021 lbs	6 %
Carrier Tube & Welds	< 100 psi	4,700 psi	2 %	6,300 psi	1 %

* D/C = Demand/Allowable

Table 6-2 Results Summary for Outer Carrier Lifting Condition

Location	Stress Demand	Level A Limits (6061-T6)		Level B Limits (6061-T6)	
		Limit	D/C	Limit	D/C
Bail Bar @ Top	10,628 psi	20,200 psi	53 %	26,800 psi	40 %
Bar Weld	3,000 psi	4,700 psi	64 %	6,300 psi	48 %
Bar @ bottom - HAZ	1,225 psi	6,900 psi	18 %	9,200 psi	13 %
Pivot Bar Bending	3,415 psi	20,200 psi	17 %	26,800 psi	13 %
Pivot Bar Shear	256 psi	9,300 psi	3 %	13,900 psi	2 %
Pivot Bar Bearing	625 psi	20,900 psi	3 %	27,800 psi	2 %
Retaining Ring Hole	112.5 lbs	1,675 lbs	7 %	1,675 lbs	7 %
Carrier Tube & Welds	< 100 psi	4,700 psi	2 %	6,300 psi	1 %

6.1 Lifting Bail Redesign – Material and Diameter Changes

6.1.1 *Minimum Required Solid Bar for Lifting Bail*

The stress analysis results of the existing lift bails can be used to back-calculate reduced bar sizes or to justify material changes. The scaling can be done because the section forces and moments in the bail are essentially statically determinant, given the basic bail geometry (e.g, very low dependence on the bail bar diameter).

For both the inner carrier bail and the outer carrier bail, the controlling stress was in the bar at the top of the bail. The demand/allowable ratio was 47% for the inner carrier bail and 40% for the outer carrier bail. The minimum required bar size that still meets Code allowbles is computed below. The results are shown in Table 6-3.

Inner Carrier Bail (Existing is 3/8 inch bar)
Demand @ 115 lbs lift: Bending = SM1 = 66 in-lbs (results in 12,726 psi stress, vs 26,800 psi allowable)

Solve for minimum required **Solid** Bail Bar Diameter:

$$6061-T6, \quad Allowable = 26{,}800\,psi = \frac{SM1}{S} = \frac{66\,in-lb}{S} \Rightarrow S_{req} = 0.0025\,in^3$$

$$Sbar = \frac{\pi \cdot d^3}{32} = 0.0025\,in^3 \Rightarrow d = 0.293\,in, \quad Use\,0.30\,inch$$

$$6063-T6, \quad Allowable = 20{,}900\,psi = \frac{SM1}{S} = \frac{66\,in-lb}{S} \Rightarrow S_{req} = 0.0032\,in^3$$

$$Sbar = \frac{\pi \cdot d^3}{32} = 0.0032\,in^3 \Rightarrow d = 0.318\,in, Use\,0.32\,inch$$

$$6063-T5, \quad Allowable = 13{,}400\,psi = \frac{SM1}{S} = \frac{66\,in-lb}{S} \Rightarrow S_{req} = 0.0049\,in^3$$

$$Sbar = \frac{\pi \cdot d^3}{32} = 0.0049\,in^3 \Rightarrow d = 0.369\,in \;\; Use\,\frac{3}{8}\,inch$$

Outer Carrier Bail (Existing is 5/8-inch diameter)
Demand @ 225 lbs load: Bending = SM1 = 254 in-lbs (results in 10,600 psi vs 26,800 psi allowable)

Solve for minimum required **Solid** Bail Bar Diameter

$$6061-T6, \quad Allowable = 26{,}800\,psi = \frac{SM1}{S} = \frac{254\,in-lb}{S} \Rightarrow S_{req} = 0.0095\,in^3$$

$$Sbar = \frac{\pi \cdot d^3}{32} = 0.0095\,in^3 \Rightarrow d = 0.46\,in$$

$$6063-T6, \quad Allowable = 20{,}900\,psi = \frac{SM1}{S} = \frac{254\,in-lb}{S} \Rightarrow S_{req} = 0.0122\,in^3$$

$$Sbar = \frac{\pi \cdot d^3}{32} = 0.0122\,in^3 \Rightarrow d = 0.498\,in, Use\,0.50\,inch$$

$$6063-T5, \quad Allowable = 13{,}400\,psi = \frac{SM1}{S} = \frac{254\,in-lb}{S} \Rightarrow S_{req} = 0.0190\,in^3$$

$$Sbar = \frac{\pi \cdot d^3}{32} = 0.0190\,in^3 \Rightarrow d = 0.578\,in \;\; Use\,0.58\,inch$$

Table 6-3 Minimum Required Lifting Bail Bar Sizes (For Solid Bar)

	6061-T6	**6063-T6**	**6063-T5**
Inner Carrier Bail	0.30 inch	0.32 inch	0.375 inch
Outer Carrier Bail	0.46 inch	0.50 inch	0.58 inch

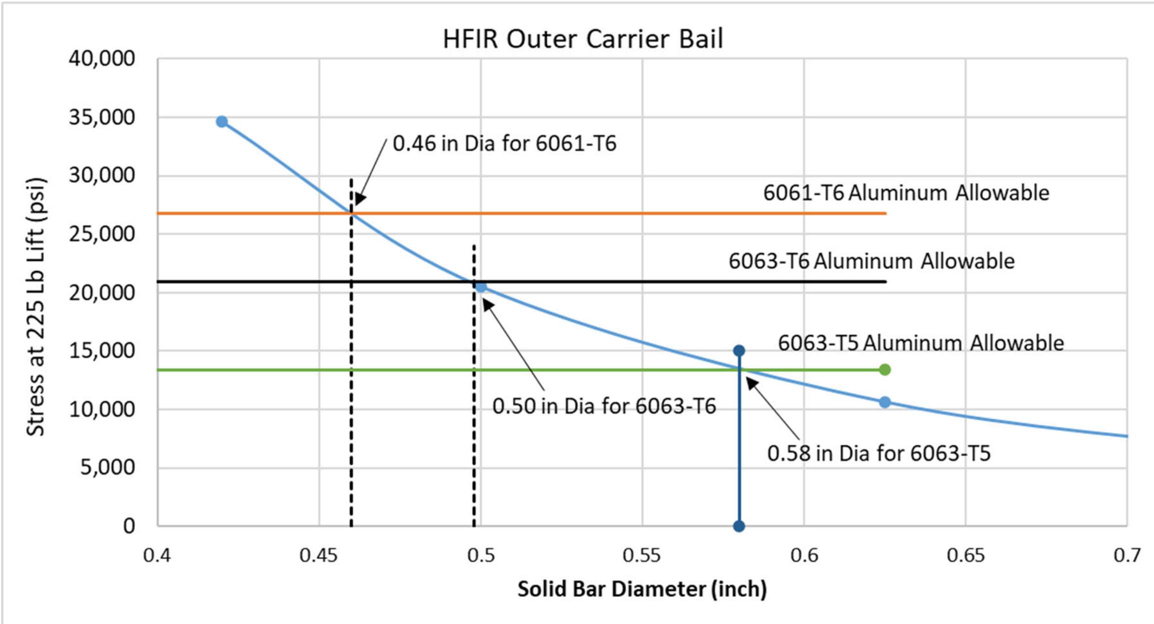


Figure 6-1 Stress vs Bar Size for Outer Carrier at 225 lbs Lift

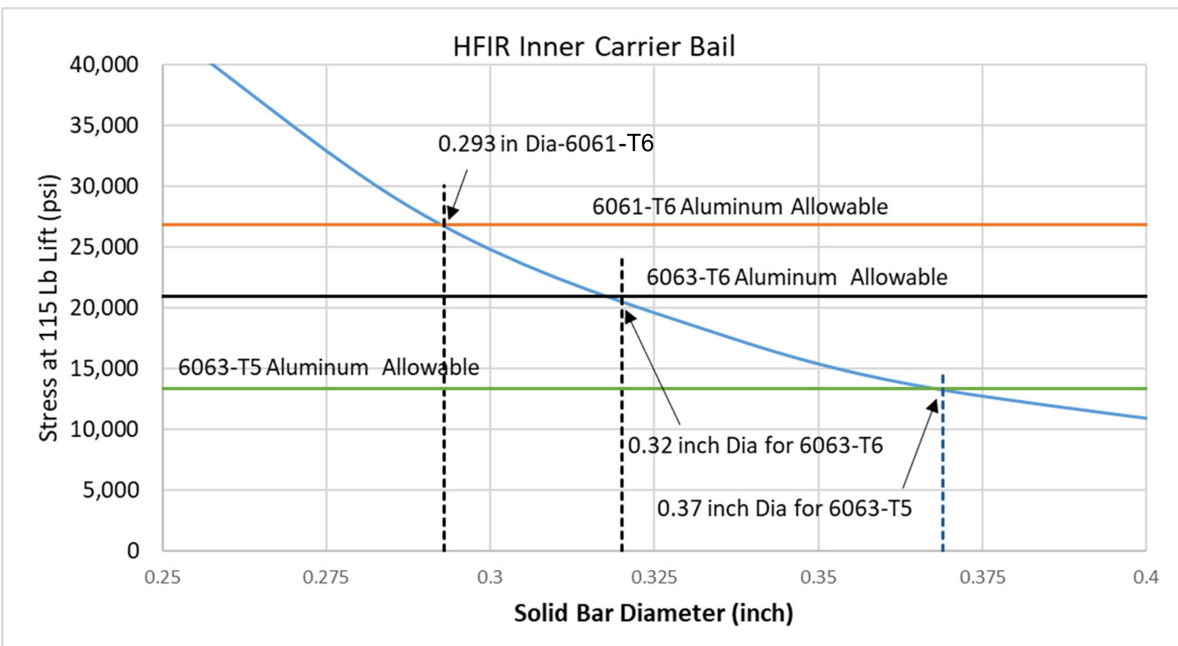


Figure 6-2 Stress vs Bar Size for Inner Carrier at 115 lbs Lift

6.1.2 *Pivot Bar Modifications*

<u>Outer Carrier Pivot</u>

The ¾ inch bar maximum D/C was 12%, from the 140 in-lb bending moment (Section 6.3.3).

Solve for minimum required Diameter over different materials

$$6061-T6, \quad Allowable = 26{,}800\,psi = \frac{SM1}{S} = \frac{140\ in-lb}{S} \Rightarrow S_{req} = 0.0052\ in^3$$

$$Sbar = \frac{\pi \cdot d^3}{32} = 0.0052\ in^3 \Rightarrow d = 0.376\ in$$

$$6063-T6, \quad Allowable = 20{,}900\,psi = \frac{SM1}{S} = \frac{140\ in-lb}{S} \Rightarrow S_{req} = 0.0067\ in^3$$

$$Sbar = \frac{\pi \cdot d^3}{32} = 0.0067\ in^3 \Rightarrow d = 0.41\ in$$

$$6063-T5, \quad Allowable = 13{,}400\,psi = \frac{SM1}{S} = \frac{140\ in-lb}{S} \Rightarrow S_{req} = 0.0104\ in^3$$

$$Sbar = \frac{\pi \cdot d^3}{32} = 0.0104\ in^3 \Rightarrow d = 0.474\ in\ (use\ 0.48)$$

1

Inner Carrier Pivot
The 3/8 inch bar maximum D/C was 31%, from the 47 in-lb bending moment (Section 6.2.3).

Solve for minimum required Diameter. Both 6061-T6 and 6063-T6 will be lumped together using 6063-T6 properties.

$$6063-T6, \quad Allowable = 20{,}900\,psi = \frac{SM1}{S} = \frac{47\ in-lb}{S} \Rightarrow S_{req} = 0.0022\ in^3$$

$$Sbar = \frac{\pi \cdot d^3}{32} = 0.0022\ in^3 \Rightarrow d = 0.284\ in$$

$$6063-T5, \quad Allowable = 13{,}400\,psi = \frac{SM1}{S} = \frac{47\ in-lb}{S} \Rightarrow S_{req} = 0.0035\ in^3$$

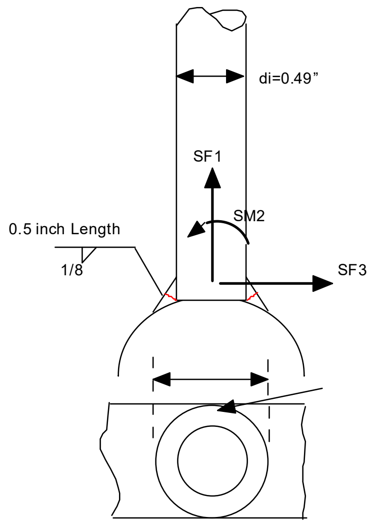
$$Sbar = \frac{\pi \cdot d^3}{32} = 0.0035\ in^3 \Rightarrow d = 0.329\ in$$

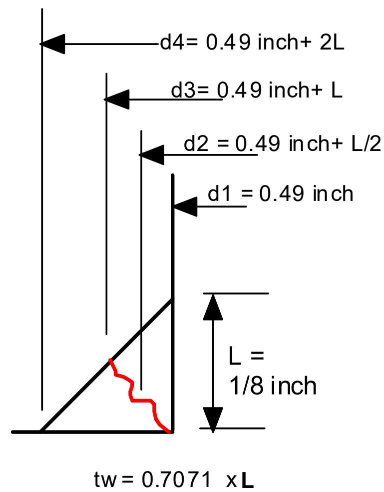
Table 6-4 Minimum Required Pivot Bar Sizes

	6061-T6	**6063-T6**	**6063-T5**
Inner Carrier Bail Pivot	0.28 inch	0.28 inch	0.33 inch
Outer Carrier Bail Pivot	0.38 inch	0.41 inch	0.48 inch

6.1.3 *Bar to Pivot Connection Options*

Using Current Details with Reduced Bar Size Weld Stress
For the outer carrier and a reduced bar size to 0.50 inch (using 6061-T6), the 1/8 inch fillet weld would be possible all around. The weld analysis is re-performed below for the outer carrier. Weld properties are computed using a circular line weld (per Blodgett), conservatively based on 0.49 inch bar, versus 0.50 inch bar (for tolerance).





Weld size = L = 1/8 inch fillet
Weld throat = tw = 0.0884 inch

d1 = 0.49 inch
d2 = 0.49+1/16 = 0.5525 inch
d3 = 0.49+1/8 = 0.615 inch
d4 = 0.49+1/4 = 0.74 inch

Centerline diameter of weld = d2 = 0.5525 inch

$$Weld\ Area\ =\ Aw\ =\ \pi \cdot d2 \cdot tw\ =\ 3.14 \cdot 0.5525 \cdot 0.0884 = 0.15\ in^2$$

$$Moment\ of\ Inertia\ =\ Iw\ =\ \pi \cdot \left(\frac{d2}{2}\right)^3 \cdot tw\ =\ \pi \cdot (0.276)^3 \cdot 0.0884in = 0.0058\ in^4$$

$$Section\ Modulus\ =\ Sw\ =\ \frac{Iw}{(d4/2)} = \frac{0.0058\ in^4}{(0.74/2)} = Sw\ =\ 0.0157in^3$$

$$\sigma = \left(\frac{SF1}{Aw} + \frac{SF3}{Aw} + \frac{SM2}{Sw}\right)\ =\ \left(\frac{86lb}{0.15in^2} + \frac{73lb}{0.15in^2} + \frac{22.7\ in - lb}{0.0157in^3}\right)\ =\ 2{,}510\ psi$$

This stress is within the allowable. The stress is also less than computed for the existing weld detail. Therefore, the same weld detail is deemed acceptable for the inner carrier with reduced bar size.

The following shows that even with a reduced bail bar diameter, the pivot bushing length should remain at ¾ inch length.

Outer Carrier (for bar size = 0.49 inch)
current bushing length = ¾ inch)
New permitted Bushing Length = 0.49 inch + 1/8 inch x 2 = 0.74 inch (keep at 0.75 inch)

Inner Carrier (for bar size = 0.31 inch)
current bushing length = ½ inch)
New permitted Bushing Length = 0.31 inch + 1/8 inch x 2 = 0.56 inch (keeping at 0.5 inch is still acceptable, with the weld reduced on side, as in current design)

6.1.4 *Use of Tubular vs. Solid Bar*

A method to maintain strength, while reducing metal volume is to use tubular cross section. The strength for both the lifting bail and pivot bar were controlled by bending stress. For tube sections, both ADM and ASME BTH-1 invoke reduced stress allowables for tubular products (55% Yield, vs. 63% Yield, per section 4.2.1), Therefore the reduced allowable will be incorporated and will yield diminishing returns for tube sections. 1

$$Moment\ of\ Inertia\ =\ I_{tube}\ =\ \frac{\pi(Do^4 - Di^4)}{64}$$

$$Section\ Modulus\ =\ S_{tube}\ =\ \frac{I_{tube}}{(Do/2)}$$

Tube Section for Lifting Bail

Options for replacing the lift bail with tube sections are shown in the table below. Only tube sizes with OD not exceeding the existing solid bar are considered, since larger diameter tubes results in too thin of a wall to reach the goal of reduced cross-sectional area. Calculations are shown for 6063-T5 material for the outer carrier bail (Existing is 5/8 inch Do, solid):

Lifting Condition Demand on Outer Bail = 254 in-lb, Allowable = 11,700 psi for 6063-T5
Try Do = 5/8 inch, Di = 3/8 inch

1

$$S_{tube}\ =\ \frac{\pi(Do^4 - Di^4)}{32 \cdot Do} =\ 0.0209\ in^3$$

$$Stress = \sigma = \frac{254\ in - lb}{S_{tube}} =\ 12{,}153\ psi\ (76\%\ of\ yield)$$

Per Table 4-4, the allowable bending is 73% of yield. The above condition is judged acceptable based on the localized region for which the 254 in-lb moment is applicable (Figure 5-13). Other tube options are summarized below:

For the inner bail, the controlling demand is the 66 in-lb bending. The bending stress for the 6063-T5 solid bar option was already approaching the stress limit, such that no practically sized tube option is viable for the 6063 aluminum, either T6 or T5.

Outer Carrier Bail	• For 6061-T6, 5/8" OD tube x 1/16" wall reduces volume of metal by 64% vs existing design, and 44% versus a 1/2-inch solid bar • For 6063-T6 and 6063-T5, 5/8" OD tube x 1/18" wall reduces volume of metal by 36% vs existing design (6061 or 6063)
Inner Carrier Bail	• For 6061-T6, 3/8" OD tube x 1/16" wall reduces volume of metal by 44% vs existing design, and 14% versus a 0.30-inch solid bar • For 6063-T6 or -T5, a 3/8" OD solid bar is the minimum option. No practical Tube option is viable

Tube Section for Pivot Bar

The pivot bar (longitudinal bar that the bail pivots on) is low stress thus replacement with a tube section is viable. The outer carrier pivot bar is ¾ inch solid, and its demand/allowable ratio is only 13% (6061-T6), driven by bending stress. The required 6061-T6 section modulus is 0.0052 in^3 for solid bar and 15% higher for a tube section (0.0060 in^3) because of the lower allowable stress for tube sections The inner Pivot Bar (3/8 inch, solid) is also low stress, at 34% of allowable.

Tube options for 6061-T6 and 6063-T5 are shown below. Calculations are shown for 6063-T5 material for the outer carrier pivot bar (Existing is 3/4 inch Do, solid):

Required Section Modulus for 6063-T5 Solid Bar = 0.0104 in^3 (Section 6.1.2)
Required Section Modulus for 6063-T5 Tubular = (115% of) Sreq @ 0.0104 in^3 = 0.0120 in^3
Try Do = 3/4 inch, Di = 0.625 inch

$$S_{tube}\ =\ \frac{\pi(Do^4 - Di^4)}{32 \cdot Do} =\ 0.0214\ in^3$$

$$Stress = \sigma = \frac{140\ in - lb}{S_{tube}} = \ 6{,}540\ psi\ (41\%\ of\ yield)$$

Per Table 4-4, the allowable bending is 73% of yield, so the above option is still well below the stress limit. Other tube options are summarized below:

Outer Carrier	• For 6061-T6, 3/4" OD tube x 1/16" wall reduces volume of metal by 69% vs existing ¾" Solid bar. Recall that using 3/8" solid bar design reduces area by 75% • For 6063-T6, 3/4" OD tube x 1/16" wall reduces volume of metal by 69% vs existing design of ¾" Solid bar
Inner Carrier	• For 6061-T6, 3/8" OD tube x 1/16" wall reduces volume of metal by 44% vs existing design, and 14% versus a 0.30-inch solid bar • For 6063-T6 or 6063-T5, A 3/8" OD Tube x 1/16" wall reduces metal volume by 44% vs. existing solid bar design.

6.1.5 *Retaining Ring*

The inner carrier retaining ring is 1/8 inch thick. With 6061-T6 material, the allowable load is more than 1000 lbs per end, versus a demand of 58 lbs. With 6063-T5 material, the allowable load would be (scaling by ratio of ultimate strength)

Capacity 1,000 lbs * 22,000 psi/42,000 psi = 520 lbs (vs 58 lb demand)
Therefore, 6063-T5 is a suitable material option.

6.1.6 *Carrier Body and Welds*

The inner carrier body is 5 inch diameter x 0.063 inch wall. The outer carrier is a 10.625 inch diameter x 0.063 inch wall. Both have 0.063 inch fillet welds to the ¼ inch thick lower plate. Per section 6.2.5 and 6.3.5, the stress levels are less than 100 psi. Therefore, 6063-T5 is a suitable material option.

<u>Using Perforations in Carrier Body</u>

Outer Carrier = 10 $^{9}/_{16}$" OD, 31 inch Height

- Use 1" holes on 1 $^{7}/_{16}$" inch spacing circumferentially and vertically
- Stagger adjacent rows (hole centers of even # rows are centered between holes of odd # rows).
- 18 rows of holes around the perimeter, 23 holes per row.
- Exclude uppermost and lowermost 2.78 inch (start first row at 3.28" distance to hole centerline)
  - (31 inch – (18 rows -1) spaces at 1.4375 – 1 inch diameter) / 2 ends = 2.78 inch

The area reduction due to these holes is: 1

Unreduced area = 31 inch * 10.5625"*π = 31" x 33.18" = 1029 in^2
Single Hole Area (d=1 inch) = π * d^2/4 = π * 1^2/4 = 0.785 in^2
Total Hole Area = 18 rows x 23 holes/row * 0.785 in^2 = 325 in^2
Weight Reduction = 325/1029 = 32%

Inner Carrier = 4 ¾" OD, 30.5 inch Height

- Use 1" holes on 1 $^{7}/_{16}$" inch spacing circumferentially and vertically
- Stagger adjacent rows (hole centers of even # rows are centered between holes of odd # rows).
- 18 rows of holes around the perimeter, 10 holes per row.
- Exclude uppermost and lowermost 2.53 inch (start first row at 3.03" distance to hole centerline)
  - (30.5 inch – (18 rows -1) spaces at 1.4375 – 1 inch diameter) / 2 ends = 2.53 inch

The area reduction due to these holes is:

Unreduced area = 30.5 inch * 4.75”*π = 30.5” x 14.92” = 455 in^2
Single Hole Area (d=1 inch) = $\pi * d^2/4 = \pi * 1^2/4 = 0.785$ in^2
Total Hole Area = 18 rows x 10 holes/row * 0.785 in^2 = 141 in^2
Weight Reduction = 141/455 = 31%

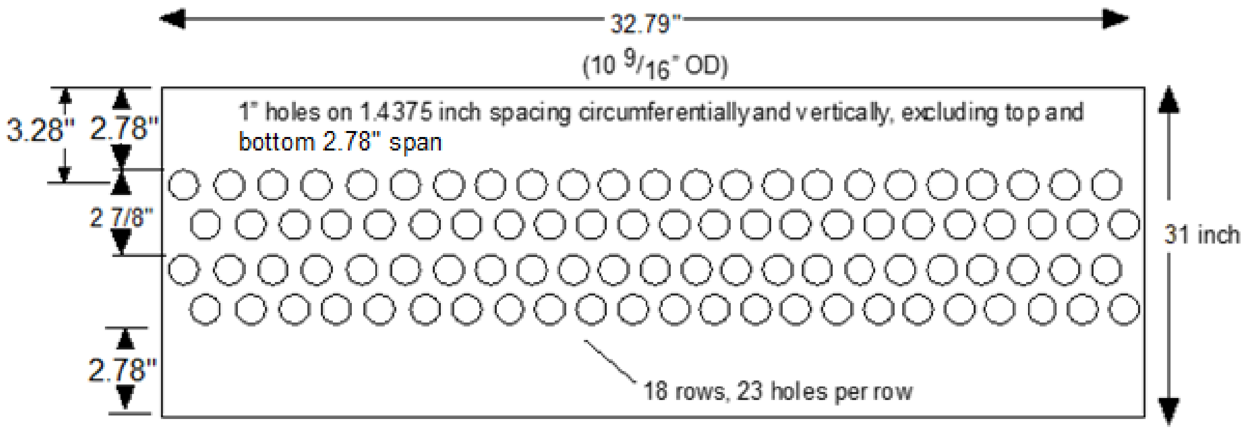


Figure 6-3 Outer Carrier Body Suggested “Lightening” Holes

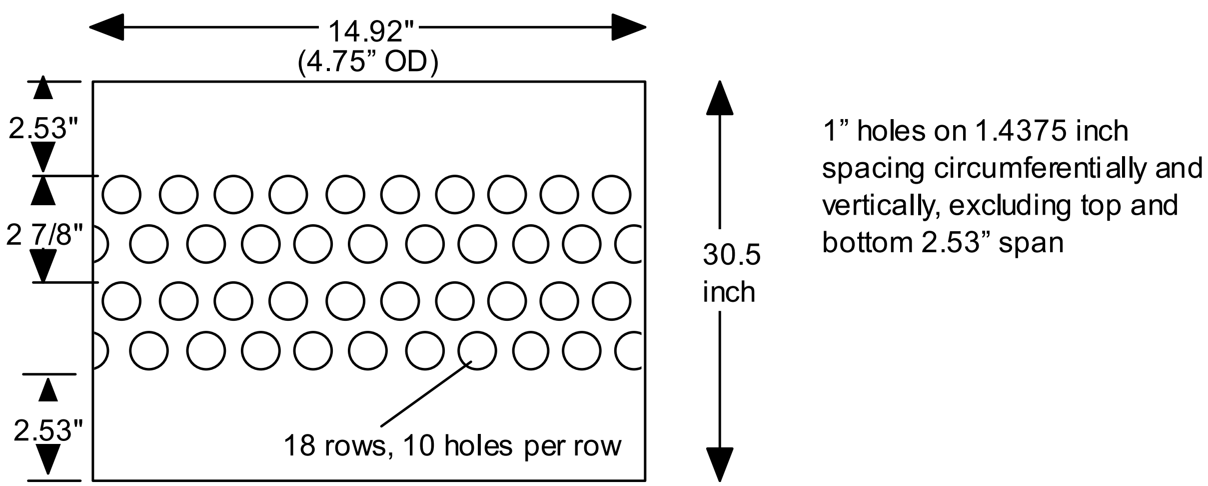


Figure 6-4 Inner Carrier Body Suggested “Lightening” Holes

6.1.7 *Summary of Material and Size Options*

The following tables summarize the size and material options for the carrier lift bail components.

Table 6-5 Tube Options for Inner and Outer Carrier Bails

	Style	**Material**	**Do (in)**	**Di (in)**	**Wall T (inch)**	**Req'd Sec Mod** (in^3)	**Actual Sec Mod** (in^3)	**Section Area** (in^2)	**Reduction**
Outer Carrier Lift Bar (5/8" existing)	Solid	6061-T6	0.625	0	~	0.0095	0.0240	0.307	~
	Solid	6061-T6	0.50	0	~	0.0095	0.0123	0.196	36%
	Tube	6061-T6	0.625	0.5	0.0625	0.0109	0.0142	0.110	64%
	Solid	6063-T5	0.625	0	~	0.0190	0.0240	0.307	~
	Tube	6063-T5	0.625	0.375	0.125	0.0219	0.0209	0.196	36%
Inner Carrier Lift Bar (3/8" existing)	Solid	6061-T6	0.375	0	~	0.0025	0.0052	0.110	~
	Solid	6061-T6	0.30	0	~	0.0025	0.0027	0.071	36%
	Tube	6061-T6	0.375	0.25	0.0625	0.0029	0.0042	0.061	44%
	Solid	6063-T5	0.375	0	~	0.0049	0.0052	0.110	~
	Tube	6063-T5	0.375	NA	NA	0.0056	Tube not practical		

Table 6-6 Tube Options for Inner and Outer Carrier Pivot Bars

	Style	**Material**	**Do (in)**	**Di (in)**	**Wall T (inch)**	**Req'd Sec Mod** (in^3)	**Actual Sec Mod** (in^3)	**Section Area** (in^2)
Outer Carrier Pivot Bar (3/4" existing)	Solid	6061-T6	0.75	0	~	0.0052	0.0414	0.442
	Solid	6061-T6	0.375	0	~	0.0052	0.0052	0.110
	Tube	6061-T6	0.75	0.625	0.0635	0.0060	0.0214	0.135
	Solid	6063-T5	0.75	0	~	0.0190	0.0414	0.442
	Tube	6063-T5	0.75	0.5	0.125	0.0219	0.0332	0.245
Inner Carrier Pivot Bar (3/8" existing)	Solid	6061-T6	0.375	0	~	0.0022	0.0052	0.110
	Solid	6061-T6	0.3	0	~	0.0022	0.0027	0.071
	Tube	6061-T6	0.375	0.25	0.0625	0.0025	0.0042	0.061
	Solid	6063-T5	0.375	0	~	0.0035	0.0052	0.110
	Tube	6063-T5	0.375	0.25	0.0625	0.0040	0.0042	0.061

7.0 Conclusions

The analysis documents that the inner and outer carrier assemblies and lifting bails described on drawings C-CM-L-0016 and C-CM-L-0017 meet Site Standard 1060 based stress criteria for the rated lift load In the current configuration with ⅝-inch bail size on the outer carrier and ⅜-inch bail size on the inner carrier (AA6061-T6 material), the demand/allowable ratios are 47% for the outer carrier and 48% for the inner carrier.

All results and conclusions in this analysis are based on there being inconsequential fluid weight added to the HFIR and carrier as the assembly is lifted out of water. The 1.25 load factor used in this analysis allows for some additional load (25% of 115 lbs is ~ 3 gallons, assuming no additional dynamics are contemporary)

<u>Bail Alternatives:</u>
AA6063-T5: This material can be used. Most member sizes need to remain per current drawings (See Table 7-1)
Table 7-1 shows minimum part dimensions for various aluminum materials with the volume reduction in parenthesis for that part.

Table 7-1 Alternate Member Sizes for HFIR Carrier Lift Bails with Part Volume Reductions [1]

	Inner Carrier	**Outer Carrier**
Main Lift Bar (existing is 3/8” inner, 5/8” outer)	6061-T6: 0.30 inch Solid Bar (36%) 6063-T5: 0.375 inch Solid Bar (0%) 6061-T6: 3/8” OD x 1/16” thk (44%) 6063-T5: No Tube option	6061-T6: ½ - inch Solid Bar (36%) 6063-T5: 0.58 inch Solid Bar (~0) 6061-T6: 5/8” OD x 1/16” thk (64%) 6063-T5: 5/8” OD x 1/8” thk (36%)
Pivot Bar (existing is 3/8” inner, 3/4” outer)	6061-T6: 0.30 inch Solid Bar (36%) 6063-T5: 0.33 inch Solid Bar 6063-T5: 3/8” OD x 1/16” thk (44%)	6061-T6: 0.38 inch Solid Bar (75%) 6063-T5: 0.48 inch Solid Bar 6063-T5: ¾” OD x 1/8” thk (44%)
Bail to Pivot Welds	1/8 fillet, all around (a 45 degree span still gets a reduced weld, e.g. seal weld) (no change from current design)	1/8 fillet, all around (no specified change, except credited weld is full circle)
Carrier Body	Retaining Ring and Carrier Body can be switched to 6063-T5 Material for both inner and outer carrier. The carrier body is already 1/16” and not readily thinned. However, perforations can be added to reduce volume by up to 50%.	

[1] Where 6063-T5 is listed, 6063-T52 may also be used.

High strength aluminum material options are limited for the current bail design, since the current design involves a welded design. The welding results in a loss of temper to aluminum and thus low strength regardless of whether the material was originally T4, T5, T6 or higher. Fully utilizing high temper strength would require replacing weld details with non-welded construction.

8.0 References

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Appendix A

Attachment A: FEA Inputs

```
*HEADING
  Model OF 5/8 inch bent bar lifting bail
****
*NODE,NSET=NALL
  1, -4.0,  0.0, -1.06
  2, -4.0,  0.4419, -0.6181
  5, -4.0,  0.7495, -0.3105
  9, -4.0,  1.4491, 0.0
  29,-4.0,  9.125, 0.0
  35,-3.505,10.32, 0.0
  45,-1.195,12.63, 0.0
  52, 0.0,  13.125, 0.0
  59, 1.195,12.63, 0.0
  69, 3.505,10.32, 0.0
  75, 4.0,  9.125, 0.0
  95, 4.0,  1.4491, 0.0
  99, 4.0,  0.7495,-0.3105
 102, 4.0,  0.4419, -0.6181
 103, 4.0,  0.00, -1.06
*NGEN,NSET=NALL
2,5
9,29
35,45
59,69
75,95
99,102
*ngen, line=c, nset=nall
 5, 9,1,, -4.0, 1.4491, -1.06
29,35,1,,-2.31, 9.125, 0.0
45,52,1,,  0.0, 11.435, 0.0
52,59,1,,  0.0, 11.435, 0.0
69,75,1,, 2.31, 9.125, 0.0
95,99,1,,  4.0, 1.4491, -1.06
***
*************
*NODE,NSET=NALL
 201, -4.375,  0.0, -1.06
 202,  -3.625,  0.0, -1.06
 203, 3.625,  0.00, -1.06
 204, 4.375,  0.00, -1.06
*element,type=b31, elset=ehook2
201, 201, 1
202, 1, 202
203, 203, 103
204, 103, 204
*element,type=b31,elset=ehook
1,1,2
102, 102,103
**************
*element,type=b31,elset=ebail
2,2,3
*elgen,elset=ebail
2,101,1,1
*********************************************************************
*beam SECTION,ELSET=ehook,section=circ,MATERIAL=Malum
0.3749
0,0,1
*beam SECTION,ELSET=ebail,section=circ,MATERIAL=Malum
0.3125
```

```
0,0,1
*beam SECTION,ELSET=ehook2,section=circ,MATERIAL=Malum
0.625
0,1,0
*MATERIAL,NAME=Malum
*ELASTIC
10100000,0.3
*DENSITY
 7.3E-4
*NSET,NSET=NHOLD
1,103
*BOUNDARY
*** use 2,3 for no friction,  use 1,3 for friction
NHOLD,1,3
*** node 52 is the lift point, top center.  DOF 2 is left free, for load application
52,1,1
52,3,3
*************************************************************************************
*RESTART,WRITE
****************
*** Lift Load
*STEP
*STATIC
*CLOAD
51,2, 112.15
51,3, 9.05
53,2, 112.15
53,3, 9.05
*output,field, variable=preselect
*output,field
*element output, elset=ebail
sf
*element output, elset=ehook
sf
*node output,nset=nall
U
*NODE PRINT,NSET=NHOLD
RF
*EL PRINT,ELSET=Ebail

Sf
*END STEP
```

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