CEI ER-20-071
Date: 16 July 2020

Cassady Engineering, Inc. (CEI)
Engineering Report

SUBJECT: Lugger Cargo Securement Analysis

OBJECTIVE:

To determine compliance to 49CFR 393.102 (Cargo Securement Devices) for the Ace 120-RC-50 Lugger Hoist.

SUMMARY:

Title 49 393.102 sets forth minimum performance criteria for cargo securement in terms of both the breaking strength of the securement devices and their working load limits. In summary, the devices must be shown to not break when the load is subjected to a forward acceleration of 0.8g, a rearward acceleration of 0.5g, or a lateral of 0.5g, applied separately. Additionally, the devices' working load limits must not be exceeded under accelerations of 0.435g forward, 0.5g rearward, or 0.25g lateral.

The Ace design includes hydraulically operated arms (left and right) that manipulate the container through the use of chain slings integrated with dump keys. Hydraulic contact cylinders in each arm are retracted or extended to interact with the dump keys, depending on whether the desired operation is to dump the container contents or to set the container on the ground level. When the container is placed in the bed for transportation, the contact cylinders are extended into contact with the container side walls adjacent to the dump keys. This contact has the effect of constraining the container in the forward, rearward, and lateral directions. The purpose of this study is to determine whether this method of constraint satisfies the cargo securement performance requirements of 393.102.

Loads for all six cases were calculated based on the specified accelerations, the maximum loaded container weight, and conservative (low) friction calculations where the load rests on the bed floor wear strips. Resulting stresses were then calculated for the affected components (arms, cylinders, chains, container welds). The ultimate material strength of any affected component was then compared to its calculated stress in order to determine compliance to the

breaking strength requirements. For the working load requirements, calculated stresses were compared to material strengths representing a reasonable safety factor below any given material's ultimate strength.

RESULTS:

The applicable components of the Ace 120-Rc-50 exceed the performance requirements for cargo securement set forth in 393.102. Detailed supporting analyses and figures are attached.

Prepared By ______________________

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<u>ANALYSIS</u>

Figures 1 and 2 give the overall configuration of the truck and container. Figure 3 defines the components and geometry in a side view. Maximum container mass is 50,000 lb. The container rests on steel wear strips on the bed of the floor. A conservatively low number for static friction coefficient for steel-on-steel is the lubricated number, at 0.16.

Forward direction:

The breaking strength requirement is for 0.8g,

(0.8g)(50,000 lb) = 40,000 lbf load forward

Friction force is at least (.16)(50,000 lb) = 8,000 lbf

So the forward restraints must have a breaking strength that will react no more than

40,000 lbf – 8,000 lbf = 32,000 lbf.

Forward motion is resisted by the 2.5 inch diameter contact cylinder bearing on the 4-inch A36 channel which is fully fillet welded to the container wall on both legs and is 24.5 inches long. These welds, at a conservatively small effective area of 80% x .25 inch fillet depth, will fail ultimately at

(.8)(.25 inch)(24.5 inch)(2 legs)(36,000 psi) = 352,800 lbf

And 2 channels left and right give

(2)(352,800 lbf) = 705,600 lbf.

Therefore the welds would see 32,000 lbf/705,600 lbf = 4.5% of their failure load in the 0.8g forward case, easily satisfying the breaking strength requirement of 393.102(a)(1)(i).

And the working load limit requirement of 0.435g forward would subject these welds to

(0.435g/0.8g)(4.5%) = 2.4% of their failure load. This is certainly below what we will consider the working load limit of the steel channel and its welds, so 393.102(a)(2)(i) is satisfied.

The other component that should be assessed in this load case is the shaft of the contact cylinder, which is in near full shear due to the support design where it projects out of the arm. These shafts are made of 1045 steel with a tensile strength of 100,000 psi and a diameter of 2.5 inches, so have a shear strength of

$(5/8)(\pi)(2.5^2)/4(100,000 \text{ psi}) = 306,795$ lbf

And with two cylinders this is (2)(306,795) = 613,590 lbf.

So the shafts would see 32,000/613,590 = 5.2% of their failure load in the 0.8g forward case and .435/.8(5.2) = 2.8% of their failure load in the .435g case, again easily satisfying both 393.102(a)(1)(i) and 393.102(a)(2)(i).

Rearward direction:

Both the breaking strength and working load requirements are for 0.5g in this direction.

(0.5g)(50,000 lb) = 25,000 lbf load rearward

Again, friction force is at least (.16)(50,000 lb) = 8,000 lbf

So the rearward restraints must have a breaking strength that will react no more than

25,000 lbf – 8,000 lbf = 17,000 lbf.

Rearward motion is resisted by the 2.5 -inch diameter contact cylinder shaft bearing on the dump key. The dump key is constrained by a 1.75-inch diameter pin at its lower end and by tension in the chain. The x-component of chain tension reacts the 17,000 lbf force so

17,000 lbf/2 sides = Tx = Tcos50° where T is the chain tension. Refer to Figure 3 for this geometry.

Solving T = 17,000/2/cos50° = 13,224 lbf.

The chain is ½ inch Grade 100 which has a minimum yield strength of 100,000 psi and a rated working load capacity of 15,000 lbf.

13,224 lbf < 15,000 lbf thus satisfying 393.102(a)(2)(ii) – working load, rearward direction.

As to the chain's breaking strength, we will conservatively use the material yield point giving it a strength of

(π(.5^2)/4)(2 legs per link)(100,000 psi) = 39,269 lbf.

13,225 lbf < 39,269 lbf thus satisfying 393.102(a)(1)(ii) – breaking strength, rearward direction.

Using chain tension of 13,224 lbf, we can look at the dump key's lower pin. It will see a shear stress of

13,224 lbf/π/(1.75 inch^2)(4) = 5,498 psi.

As mild steel, the pin has a shear stress capability of at least 5/8(58,000 psi) = 36,250 psi, so at a stress of 5,498 psi we will consider it to be loaded both well below its working load limit and its breaking strength, satisfying 393.102(a)(2)(ii) and 393.102(a)(1)(ii).

Lateral direction:

In this direction, the breaking strength requirement is for 0.5g and the working load is 0.25g.

Looking at the higher load (0.5g):

(0.5g)(50,000 lb) = 25,000 lbf load lateral

Again, friction force is at least (.16)(50,000 lb) = 8,000 lbf

So the lateral restraints must have a breaking strength that will react no more than

25,000 lbf – 8,000 lbf = 17,000 lbf.

Lateral motion is resisted by the arm assemblies acting as cantilever beams fixed at their lower end pivots, connected to one another at top by the 3-inch diameter cross bar, and loaded through just one contact cylinder located 61.9 inches above the fixation point. Refer to Figure 4 where the arm is shown in blue.

Using 3D CAD files supplied by Ace, we constructed a model for this case and subjected it to loads using a linear static analysis program. Figure 5 shows the model with the fixations shown in green and the 17,000 lbf lateral load applied at one contact cylinder mount (magenta arrows).

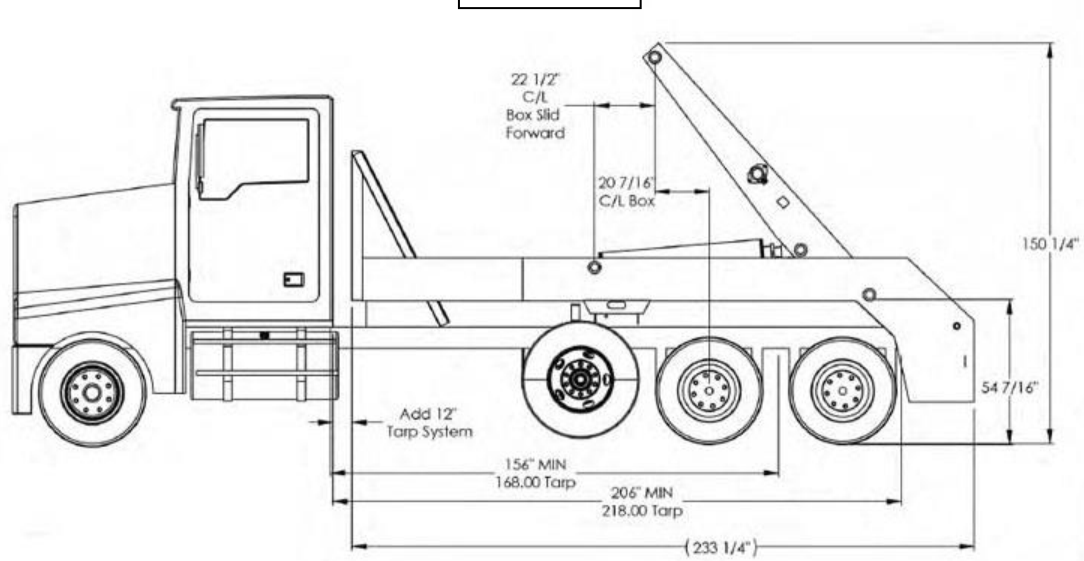
The analysis results give a maximum stress of 49,000 psi, located near the arm pivot points. This value is comfortably below the material's tensile strength of 70,000 psi. The arms are constructed of ASTM A572 Grade 50 steel plate with tensile and yield strengths of 70,000 psi and 50,000 psi respectively.

Figures 6 and 7 are graphical representations of the stresses and deflections for this case. Lateral load breaking strength is thus satisfied - 393.102(a)(1)(iii).

As for 392.102(a)(2)(iii) lateral working load limit, the model was re-run with a force of 17,000/2 = 8,500 lbf to represent that case. Figures are not repeated for this case. Maximum stress seen was again near the arm pivots and had a value of 24,600 psi, well below the yield point of 50,000 psi, satisfying the lateral/working load requirement.

Figure 1.

Figure 2.



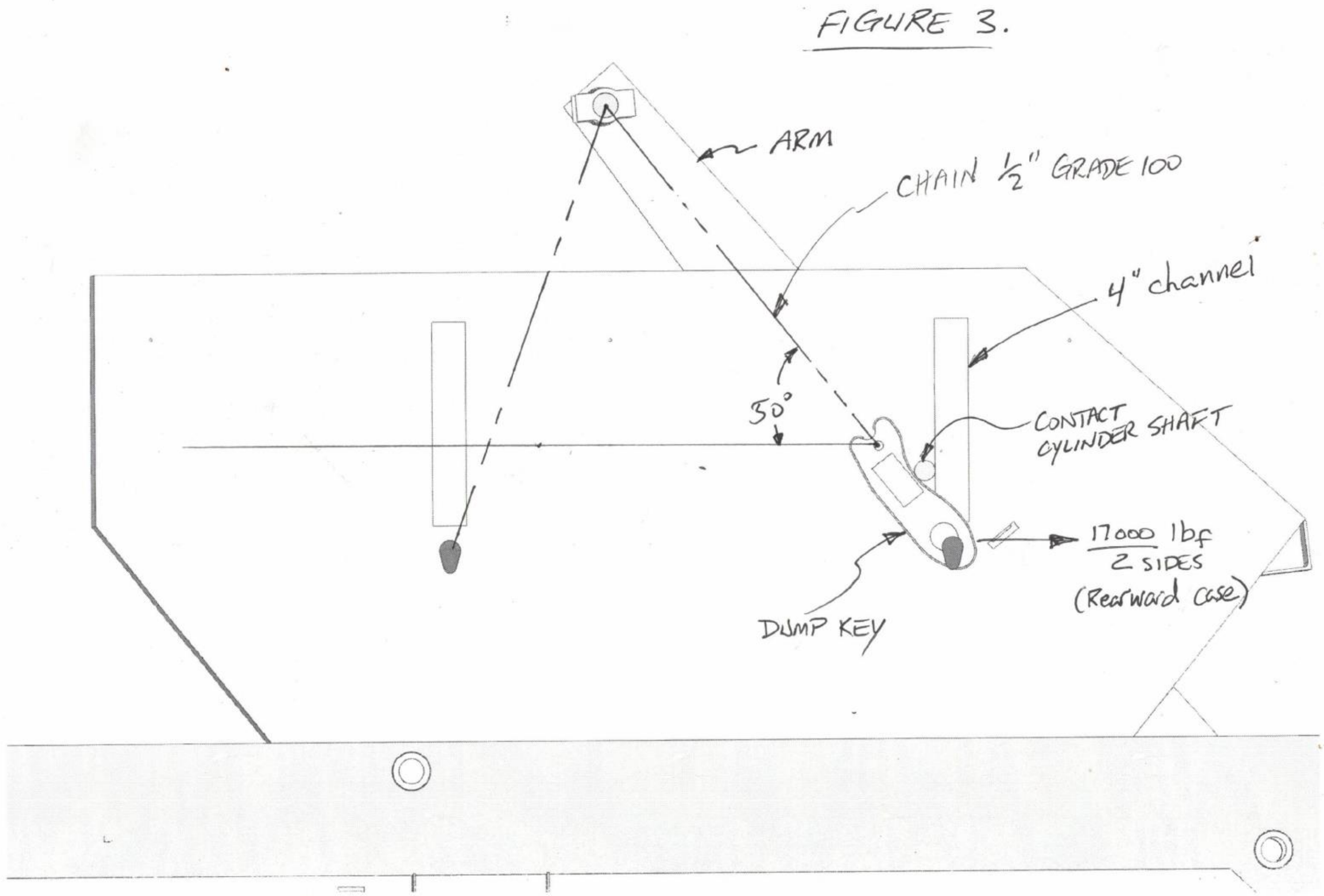


Figure 3. Side View,
Components and Geometry

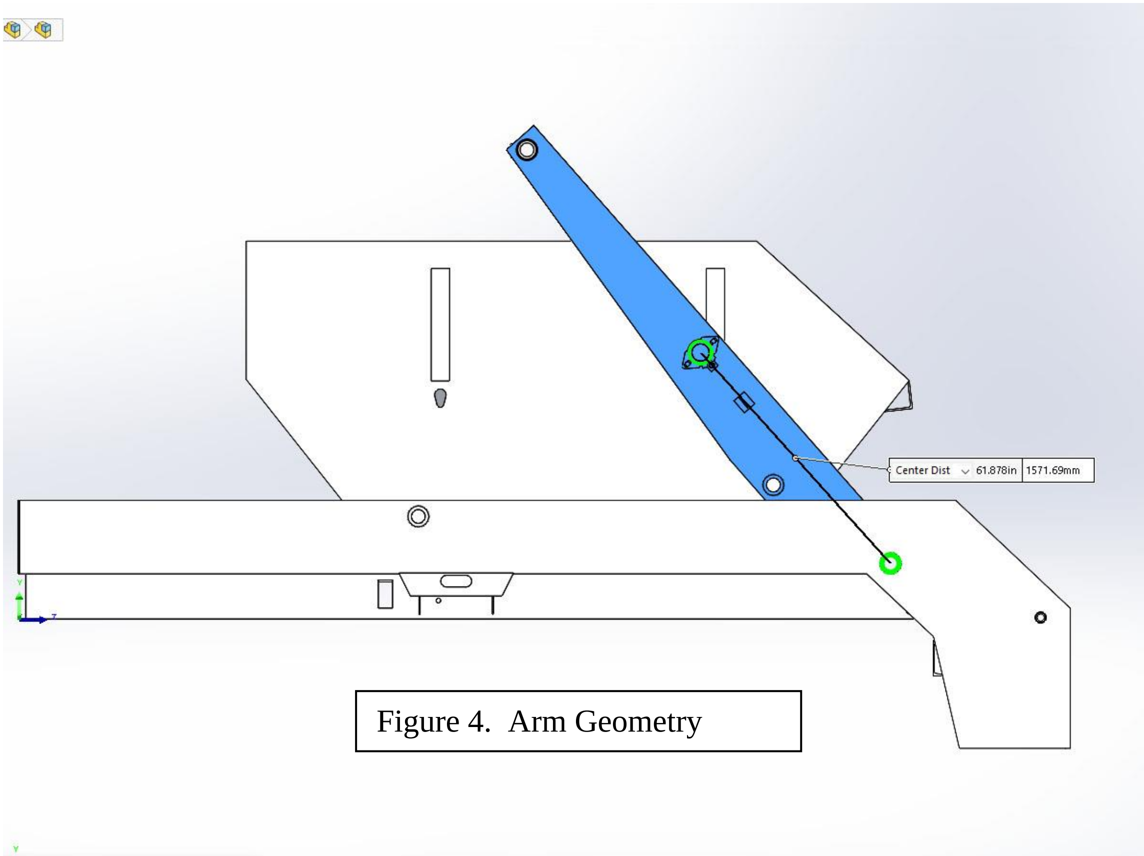


Figure 4. Arm Geometry

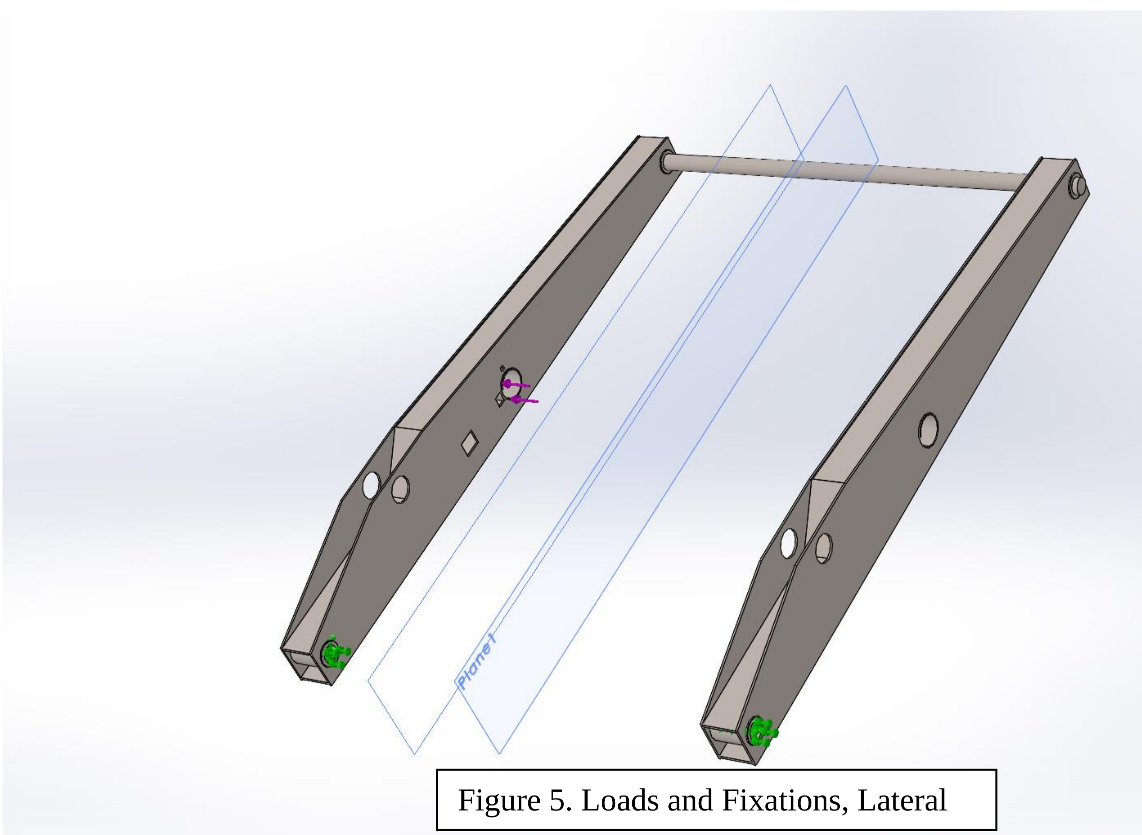


Figure 5. Loads and Fixations, Lateral

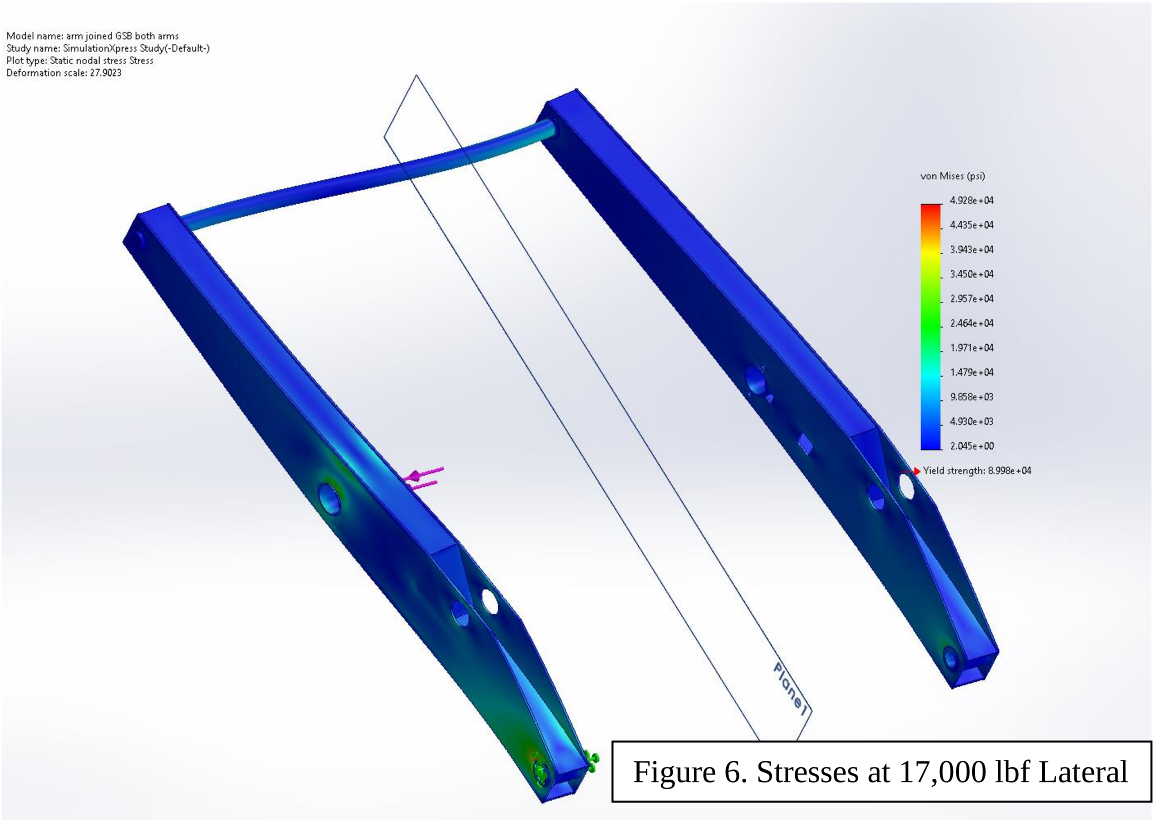


Figure 6. Stresses at 17,000 lbf Lateral

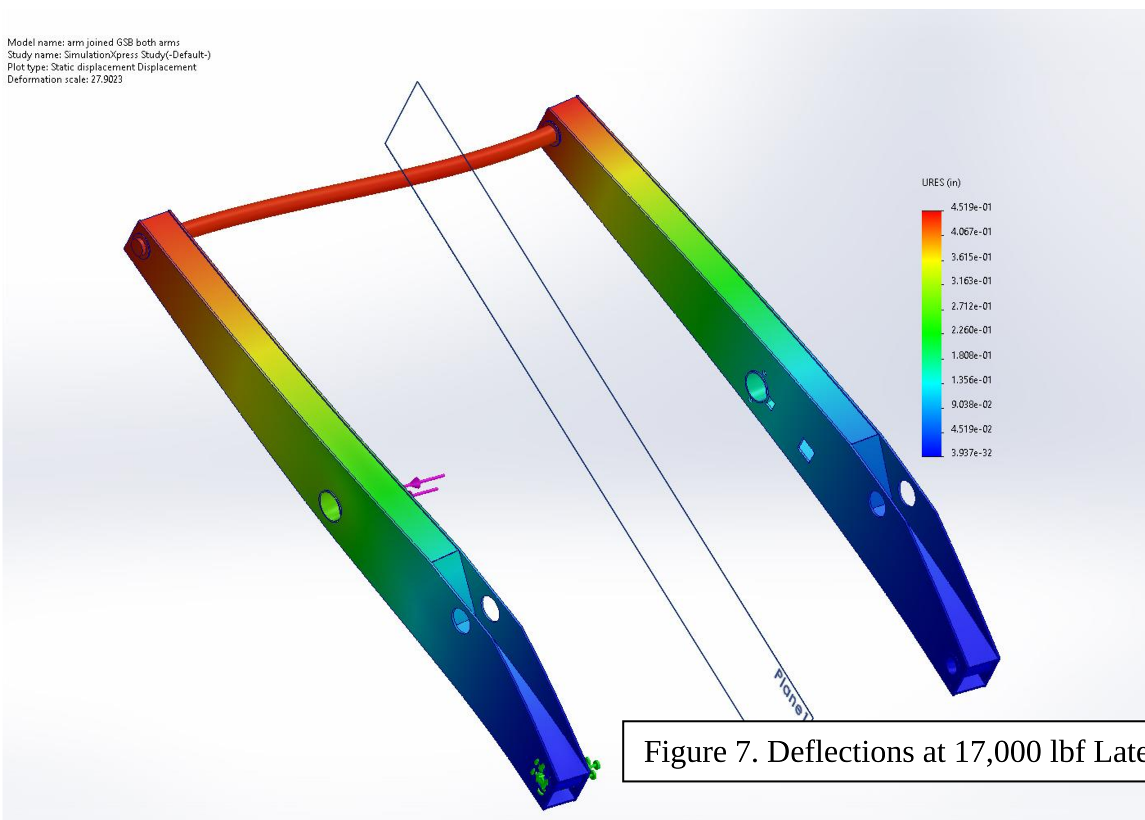


Figure 7. Deflections at 17,000 lbf Lateral