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Hendrickson Lift Kit

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Abstract

The purpose of this senior design project is to develop a lift kit for Hendrickson's light weight, optimized suspension system called the ULTRAA-K®. A lift kit can suspend one of the trailers axles from the road when the trailer is in the unloaded state and not in need of the extra weight capacity. This will increase the life of the tire, provide cost savings for trailer fleets, and reduce the environmental waste of worn-out tires. Hendrickson has lift kits available for other products, so the focus of this design project will be to redesign the front mounting bracket to be compatible with the ULTRAA-K system. While ensuring the design is compatible, it must also be designed to safely transfer confidential loads specified by Hendrickson's research and development department. With the help of Creo Simulate Live, structural analysis through simulation will be performed prior to physical validation to optimize the design. The results of the validation will be benchmarked against current lift kits, and this will serve as proof of concept for further development of an ULTRAA-K lift kit.

Contents

1. Introduction

This project focusses on developing a lift kit that is compatible with Hendrickson's ULTRAA-K® trailer suspension system. The ULTRAA-K suspension system is one of Hendrickson's newer product lines that has grown in popularity over the past decade. Hendrickson would like to convert customers from older suspension systems to ULTRAA-K, but to do so they need to provide the same options as the old systems. Lift kits are an option on the older suspension systems that the ULTRAA-K would benefit from. A lift kit provides the trailer operator the ability to lift the front most axle on the trailer suspension. The purpose of this is to reduce wear on the tire when the trailer is unloaded and not in need of the full carrying capacity.

The target market for this product will be trailer fleets that regularly travel long distances without any cargo. With modern supply chain management, this happens less and less, but for the fleets where this still occurs, purchasing a lift kit to extend tire life provides significant cost savings. Looking at other lift kits on the market with similar applications, Hendrickson's under-beam lift (UBL) 401 provides a great benchmark in terms of functionality. Refer to figure 1 below for the important components in the system. In this project, we will be reusing the UBL 401 components highlighted in red, with slight changes in position. Because these components can be reused, the scope of the project has been narrowed down to focus on redesigning the front bracket highlighted in green. The reusable components along with the ULTRAA-K hangers determine the location of the bracket.

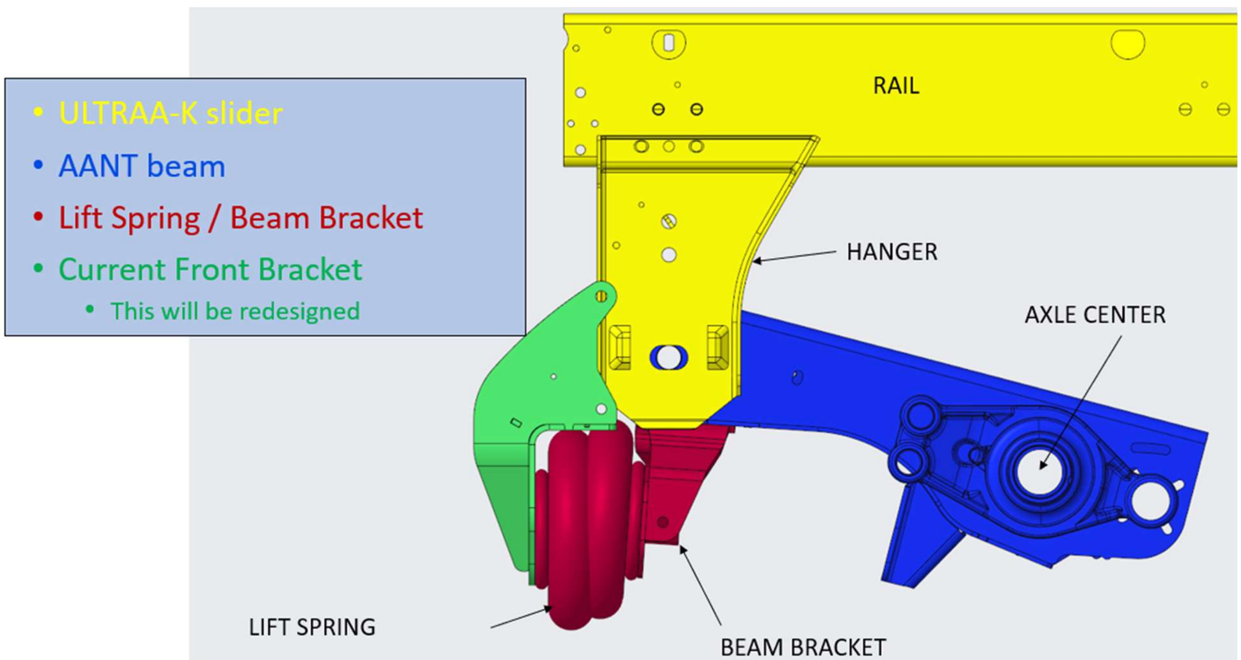


Figure 1 shows the important components in the system. The focus of this project will be redesigning the UBL 401 bracket (highlighted in green) to interface with all the other components seen above.

Hendrickson has a rich history in the trailer suspension market and has developed multiple different lift kits in the past from which inspiration has been taken for this project. What makes this lift kit novel is that the ULTRAA-K system has been optimized for weight and strength, so the available mounting surfaces have been greatly reduced. The new lift kit is required to bolt onto the ULTRAA-K using existing mounting points, meaning no modifications can be made to the main structure. It is also expected to safely transfer a specific load to simulate raising one of the axles. This specific load has been defined at

Hendrickson as the maximum force the axle will regularly see in dynamic motion. The lift kit will also be tested at the ultimate force which is to simulate worst case scenario. All these tests have been performed on Hendrickson's UBL 401, so the performance of the new lift kit can be benchmarked against UBL 401's performance. Due to confidentiality reasons, Hendrickson is unable to disclose certain values deemed proprietary information; instead, variables will be used when applicable. In summary, the metrics for success of this senior design project are to bolt onto the existing ULTRAA-K hangers without modification to the hangers and to react loads of suspension during normal use and ultimate without failure or excessive deformation. Weight and cost of the bracket will not be completely overlooked, but being in the proof-of-concept stage, the design needs to be proven before the time and effort is spent on optimization. The outcome of the project was not a complete success because not all of the metrics for success were achieved. The bracket just fell short in lift force and allowable deflection, but the results from testing of the first design will aid in the improvement of the design for the second iteration.

2. Technical Chapters

2.1 Codes & Standards

An ULTRAA-K lift kit would be used on class 8 vehicles which are federally regulated. While there are some regulations pertaining to lift axle systems, there are none that will need to be considered for this project. Title 49 lays out some specifications and standards for when lift axle systems should be used, but not the actual functions or dimensions. With Hendrickson being the leader in the industry, they have developed internal specifications and standards that their lift kits will be evaluated to. These standards have been developed from decades of research and development at Hendrickson and have allowed Hendrickson to become the leader in air-ride suspension systems.

Other standards and specifications that must be considered are material properties. Hendrickson's products are typically made out of grade 50 or grade 80 steel and it is important to understand the material properties of these materials established in ASTM A572. Referencing the ASTM standards also allows the bracket to be designed to a specific stress value while minimizing weight and cost.

2.2 Preliminary Design

Using the position of the older lift kit, UBL 401, the location of the new lift kit was determined. The pivot point of the integrated axle, narrow top-mount (AANT) beam was used as a reference point to position the lift air spring. The location of the lift air spring will then determine the location of the front bracket.

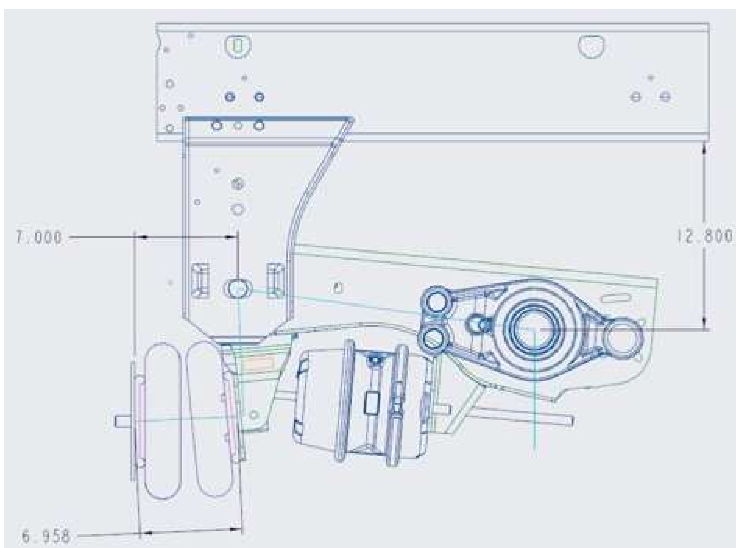


Figure 2 above displays the position of the lift air spring as well as the beam-side bracket from the UBL 401 ki.t

The front bracket needs to transfer the loads of the lifted axle to the hanger and rail of the suspension system. Looking at Figure 1, the lift kit functions by inflating the lift spring to around 100 psi,. The front bracket is secured rigidly, and the force of the lift bag is transferred through the red beam bracket, which causes the blue AANT beam to rotate upwards.

With the location of the lift spring known, preliminary force and moment calculations were completed to understand the magnitude of the reaction forces. These forces heavily influenced the initial geometry during concept generation.

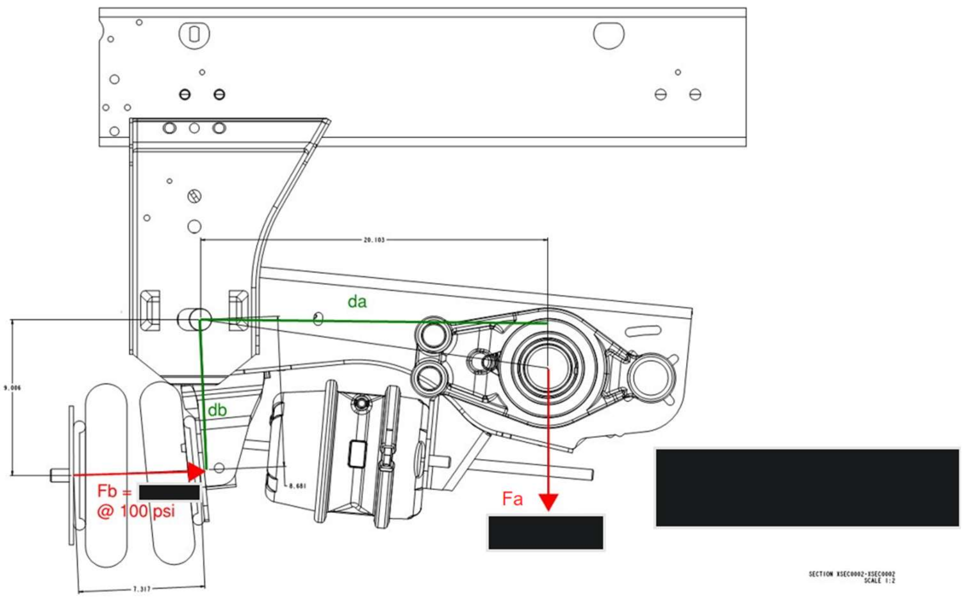
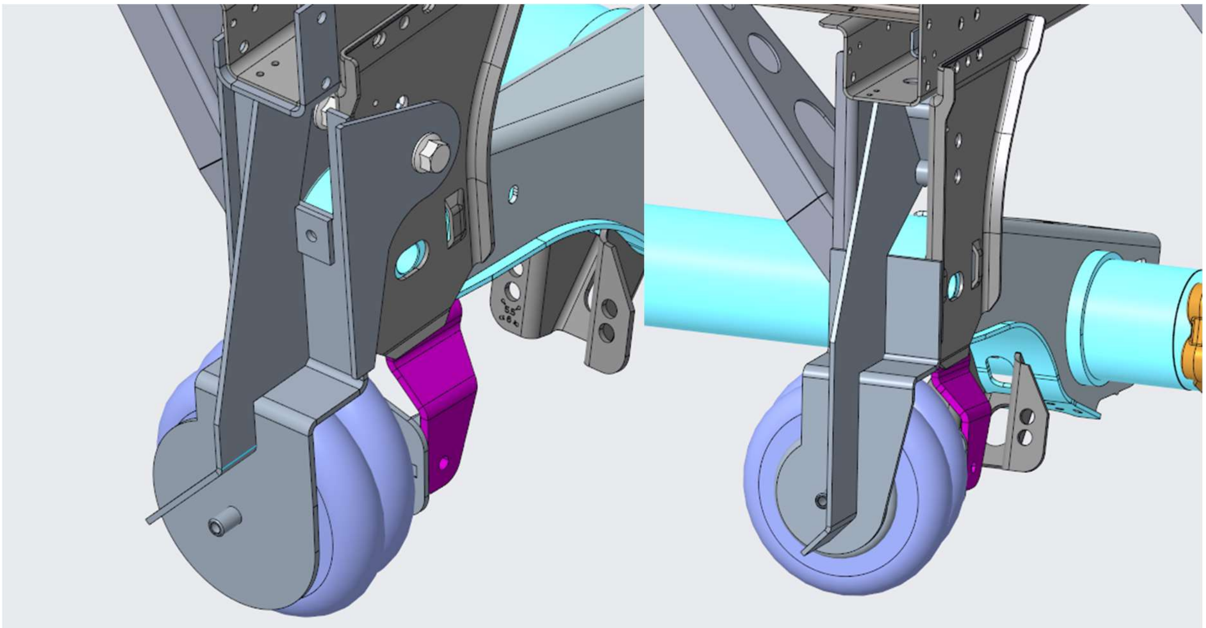


Figure 3 displays the location and variables for the predicted forces acting through the suspension and the lift kit.

The force of Fa applied down at the axle is equivalent to the dynamic load of the heaviest wheel-end options. Through testing, Hendrickson has determined Fa as the required upward force provided by the lift kit to maintain the axles position in the lifted state during use. Knowing the position of the lift kit air bag and the minimal operating pressure, the resulting forces can be determined from confidential load curves provided by Firestone. In the worst case, the upward force at the axle provided by both the driver and curb side lift is 1.6 times the required lifting force. When evaluating the stresses seen in the bracket using FEA, the reaction force of Fb, which Hendrickson has also determined through testing, will be applied to the interface of the bracket and the lift spring.

While weight, cost, and ease of manufacturing will be focused on in the future, this lift kit will not be optimized for weight or cost at this time because the first design and prototype will serve as a proof of concept. This does not mean that these factors will be ignored. Weight will be minimized by targeting approximately 297 MPa as the maximum stress in Creo Simulate Live. The max stress value was gathered from another lift kit made from grade 50 steel material. Targeting a specific stress value will avoid overbuilding the bracket with no regard to weight. Cost will be taken into consideration by avoiding complex geometry which could greatly increase price if ever taken to production. Avoiding complex geometry and adding interface features for components that need to be welded, will make the prototype easier to manufacture.

The approach taken for designing the bracket was to first establish the known components in the system. These include the ULTRAA-K slider, the AANT axle beam weldment, the UBL 401 beam-side bracket, and the C-23114 air spring. After establishing the positions of these components, concept generation began with both hand sketches and rough 3D models.


Figures 4 & 5 display two of the initial 3D concepts that were generated.

During the concept generation phase, the big challenge was finding which of the existing holes in the ULTRAA-K would sufficiently support the load being transferred through the bracket. It happened that the ¾" hole circled in figure 6 was favored to be the main mounting point of the lift kit, so it was suggested that force calculations be completed to ensure that the bolt would not fail in shear. Below, the setup can be seen with the general bracket shape, the force vector applied to the bracket, the reaction force, and the ¾" bolt location in question.

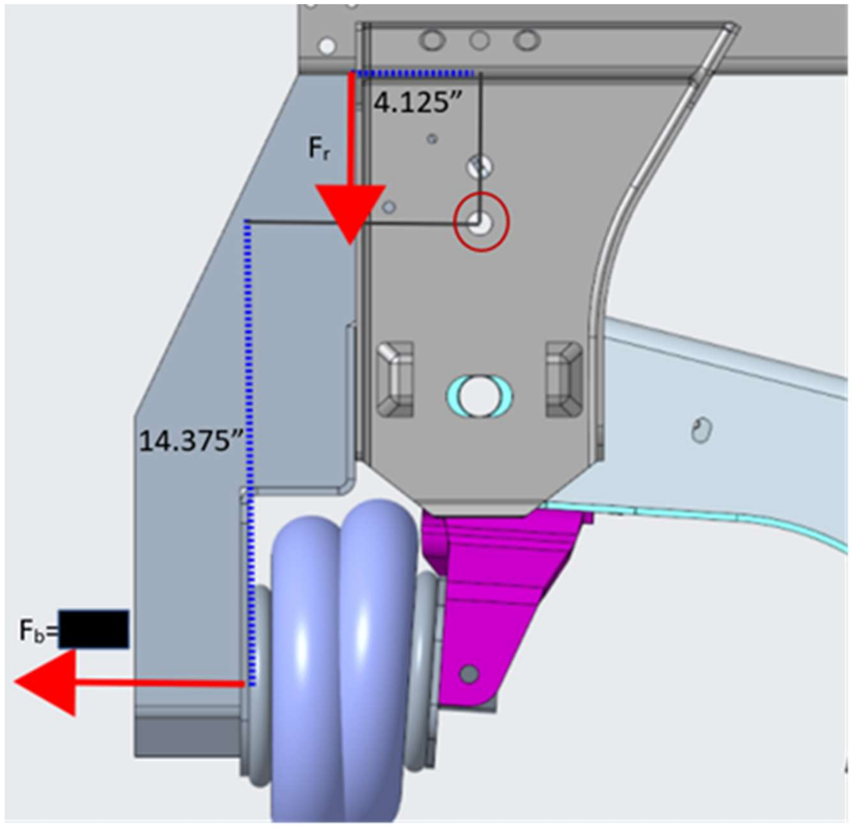


Figure 6 above shows the applied and reaction force vectors, the moment arm, and the moment center circled in red. While the bracket geometry changed in the future, this provides a worst-case reaction force at the ¾” bolt that can be used to ensure the bolt is capable.

Specific values could not be included in this report, but the general equations for the moment and resulting force calculations can be found below:

$$F_r = \frac{F_b * 14.375}{4.125}$$

Reaction force at bolt:

$$F = \sqrt{F_r^2 + F_b^2}$$

The shear calculations can be found below:

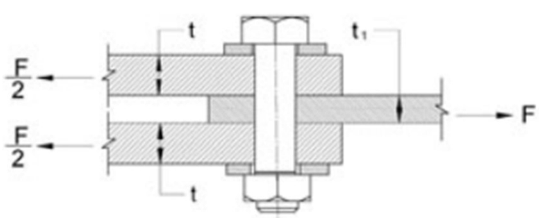


Figure 7 displays a diagram along with variables used in a double shear calculation.

t = 0.19” t_1 = 3.66” D = 0.75”

Bearing Stress: $\sigma_B = \frac{F}{t_1 D} = \frac{F}{(3.66)(0.75)}$ $\sigma_{B,max} = \frac{F/2}{tD} = \frac{F/2}{(0.19)(0.75)}$

Shear Stress: $\tau = \frac{2F}{\pi D^2}$

Looking at a grade 8, ¾" fastener, the yield stress is 130 ksi, which provides a factor of safety greater than 2 for this application. Now knowing that the ¾" bolt holes are a viable option, development for concepts that mounted on that hole moved forward.

2.3 Expanded Design

After three weeks of initial concept generation and a couple solid concepts were generated, a design review with the Slider and Suspensions group was held to get more feedback. The two concepts found in images 5 and 6 were taken to the design review where each was evaluated. After discussing the benefits and shortcomings of each, it was decided to focus on concept number two because it connects on the inside of the hanger. This was desired because the geometry outside the hanger makes it difficult to achieve a substantial connection between the hanger and the lift kit bracket. Other changes to improve the design were discussed. These included: extending the bracket all the way up the hanger face, connecting to the ¼" bolt holes on the hanger, add a second support bracket.

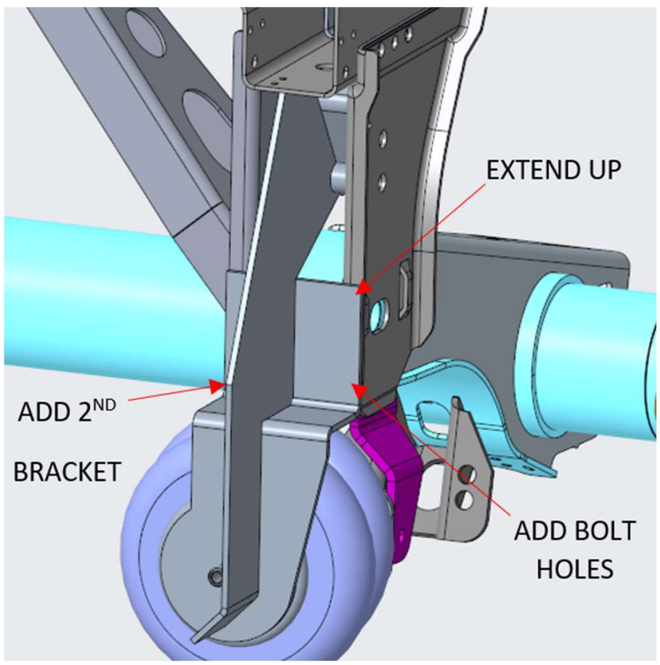


Figure 8 shows the chosen design along with the changes to be made.

After one of the bi-weekly meetings with Dave Peters, it became clear that FEA was needed to provide better reasoning for design decisions. Using FEA would justify bracket geometry such as bends and thicknesses. While making the changes discussed, Creo Simulate Live was used to evaluate how the geometry updates affected the stresses. As previously mentioned, the target maximum stress is 297 MPa, but any value below the yield stress of 345 MPa will be accepted. This phase of design took a significant amount time investment because many iterations were developed. While Creo Simulate Live does not provide very sophisticated models, it allows for stresses to be observed almost instantly after a design change. By changing one aspect of the design, the resulting stress was observed, and the design change could instantly be said to improve or worsen the strength of the structure. The benchmark lift kit for another suspension system can be seen below along with some of the iterations.

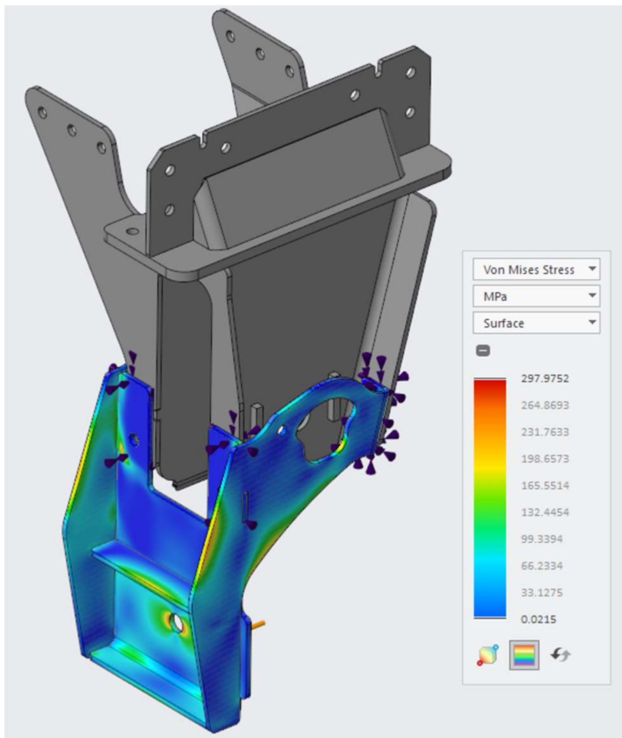


Figure 9 shows the benchmark lift kit used when evaluating the stresses present in the bracket. The maximum stress seen is 298 MPa which is significantly below the yield of material which is 345 MPa.

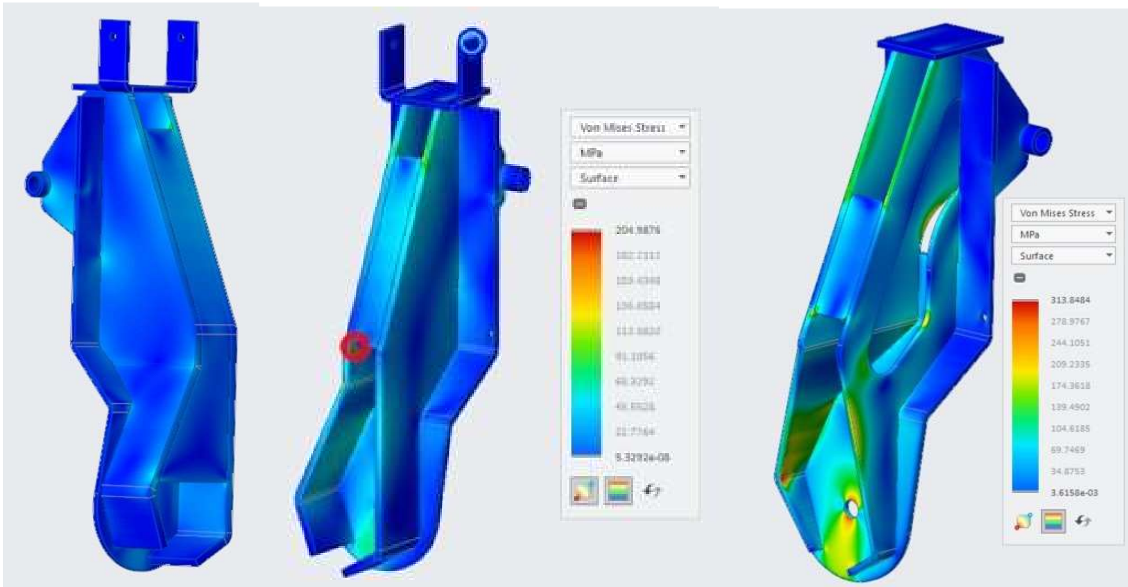


Figure 10 shows a few of the iterations in Creo Simulate. Geometry was tweaked until stress was optimized.

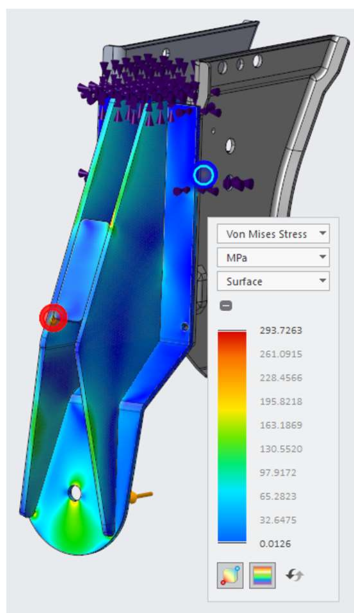


Figure 11 shows the latest iteration of the bracket that was taken to the second design review. The geometry of this bracket was developed through human iteration to minimize stress.

The stresses seen in the latest version of the bracket were approximately 294 MPa which is lower than both the target stress and yield stress. With the stress and deformation validated through Creo Simulate Live, the next step is to prototype and validate the design through physical testing.

2.4 Prototyping

The majority of Hendrickson's products are made from sheet metal and that is how this prototype would be made as well. The individual components were to be cut by a laser, then formed by a break press if

needed, and finally welded together. The final assembly is seen in figure # and the individual parts can be found in the appendix.

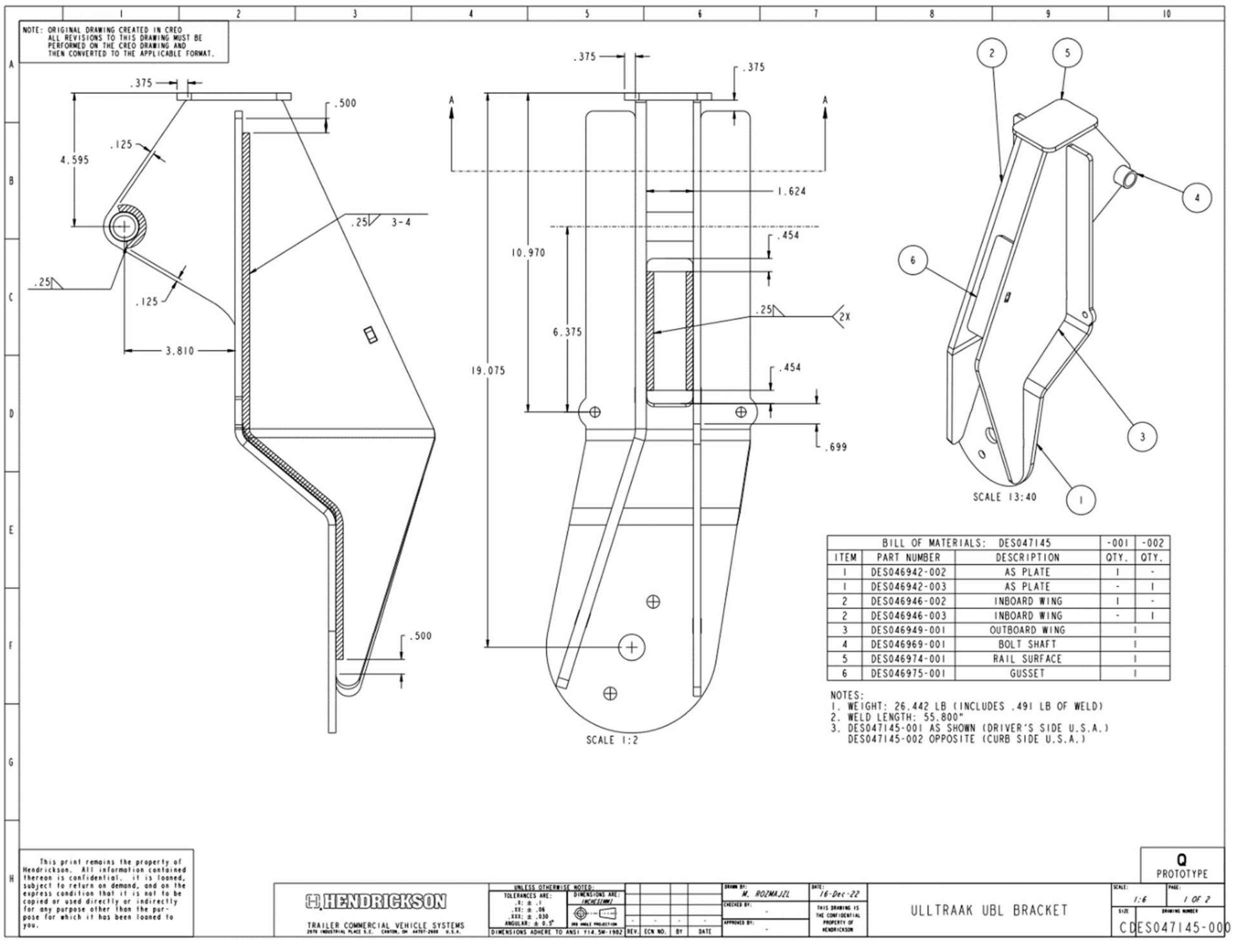


Figure 12 displays the full assembly drawing for the prototype.

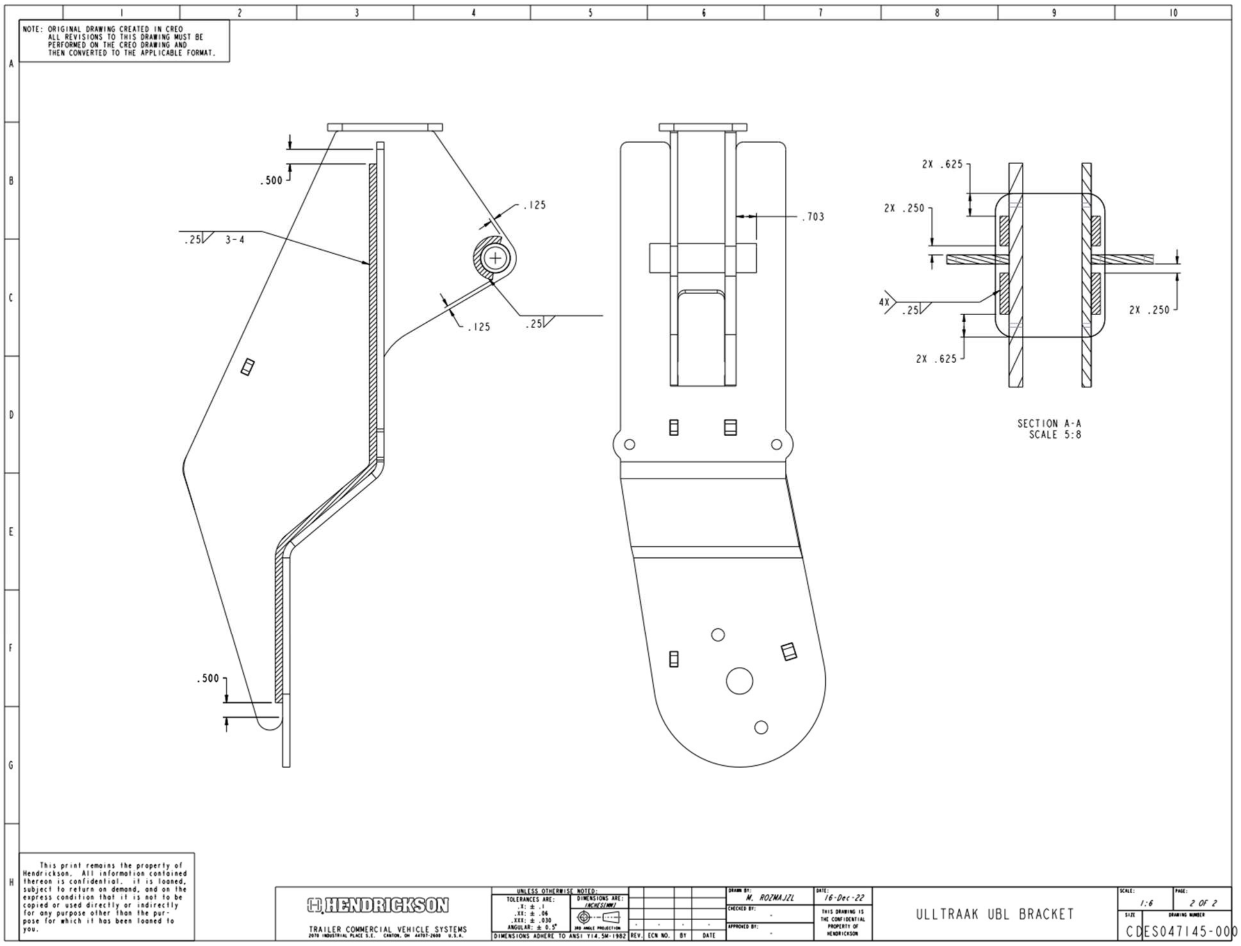


Figure 13 displays the full assembly drawing for the prototype.

A left-hand and right-hand version of the bracket was created, because there would be one present on each side of the suspension. Below is what the final prototyped brackets looked like.

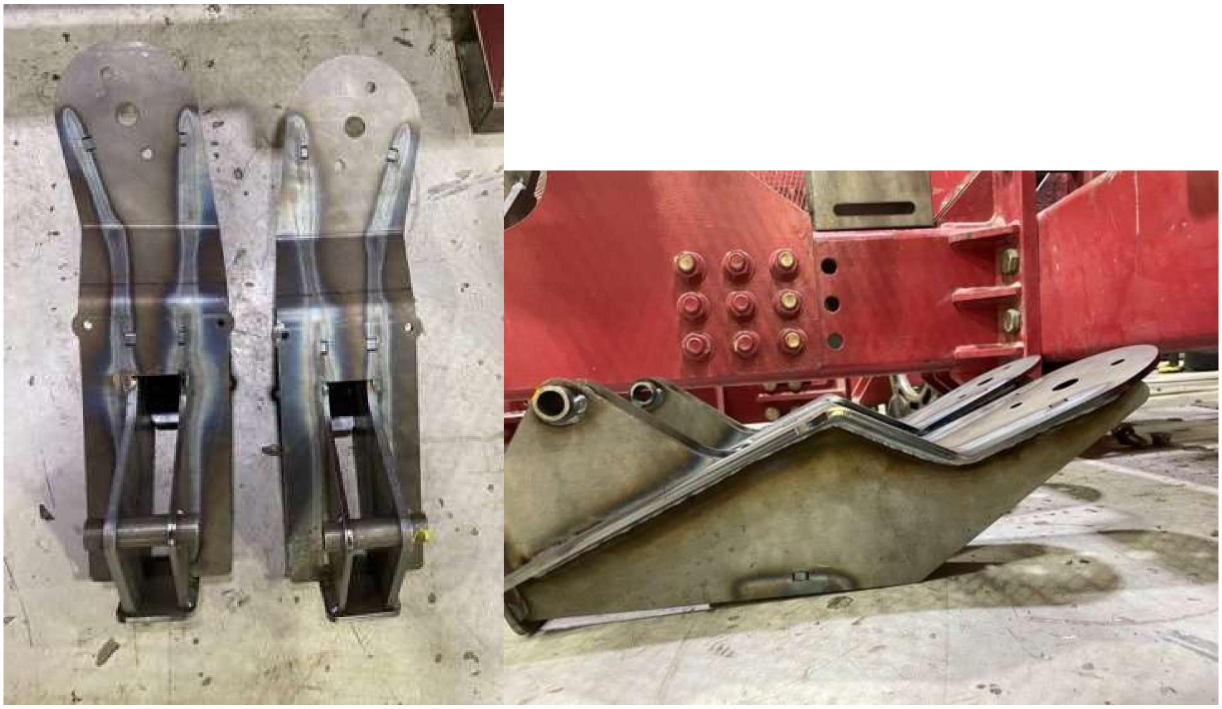


Figure 14 displays the fabricated brackets for the initial prototype.

2.5 Testing

While prototyping was underway, preparation for testing had begun. The procedure for lift kit testing is relatively routine for Hendrickson, so there were standards to follow. The research and development procedure for lift kit testing consists of a lift force test, an ultimate test, and a fatigue test. The lift force test determines how much upward force through the axle is generated by the lift kit. The ultimate test inflates the lift kit air bags to maximum pressure while also in the most stress inducing suspension orientation. The fatigue test runs the lift kit so the suspension articulates to the raised position, and then is released to the down position. The fatigue test will run until there is a significant failure in the component. All tests would be run in the same test stand.

Figure 15 displays the test stand to be used for all ULTRAA-K lift kit testing

The first test ran was the lift force test. The force results from this test were slightly lower than the predicted lift forces. The difference between the predicted and resultant might be attributed to the deflection present in the bracket under load. If the deflection is significant enough, the lift bags will provide less force. Using the C-23114 air spring, the lift force was about 1.53 times the dynamic load of the suspension. The initial calculations were predicted to be 1.6 times the dynamic load, so the difference is not too far off. However, Hendrickson usually targets a higher lift force of about 1.7-1.9 times the dynamic load of the suspension. In order to achieve those loads, the lift force test was run again with a new air spring C-35689, which provides greater force at the same displacement and psi. When this was done, the lift force was increased only slightly to 1.59 times the dynamic load. For further testing, it was determined that this lift force would suffice, but should be increased in the future by changing bracket geometry to minimize deflection.

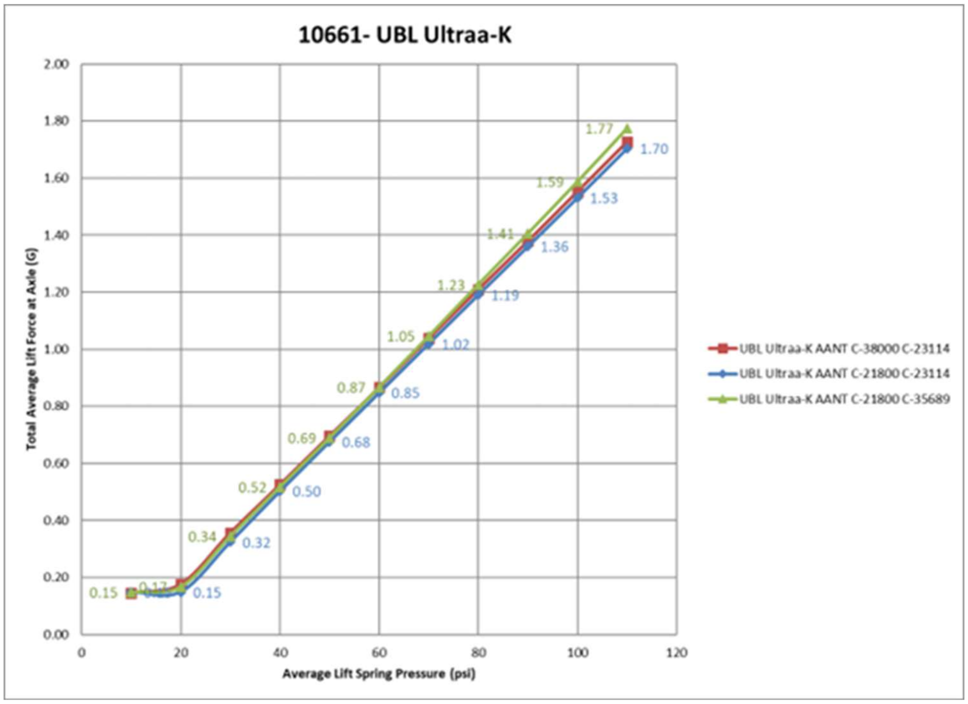


Figure 16 displays the values for lift force that were obtained through testing. The red, squared data points can be ignored.

For ultimate testing, the ride air bags were installed, and testing was ready to begin quickly thereafter. In this test, the lift kit air bags were inflated to a maximum pressure. After that, the ride air bags were inflated until the axle was as low as it would ever be in any real-world application. This puts extreme force on the lift kit bracket and will provide an understanding of how the bracket performs in the worst case possible. During the test, the lift kit air bag reached around 180 psi of pressure and one of the grade 8, 5/16” fasteners snapped off the bracket. Despite the fastener failing, the majority of the load was being transferred through other contact surfaces, so the bracket did not fail. While the bracket did not fail during the ultimate test, the deflection of the bracket was significant enough to raise some concern. Figure 18 contains displacement data for both the front bracket and the beam side bracket.

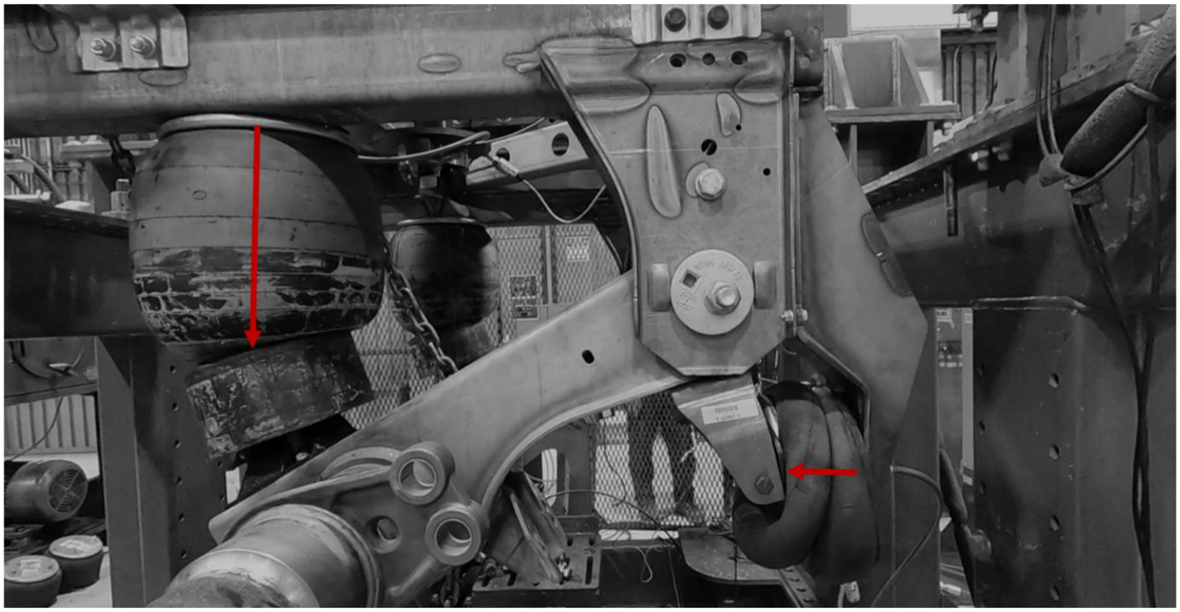


Figure 17 displays the suspension and lift kit during the ultimate test along with the force vectors of the air springs. Deflection is hard to see just by looking, so string pots were connected to locations of interest. The data below was recorded on these string potentiometers.

	Ultimate test (with bolts)			Lift spring 120 psi at bumper contact (bolts removed)		
Location	Start of test	at RH	at Rebound	Start of test	At Bumper contact	end of test
Hanger bracket(inch)	0"	0.38"	0.732"	0.339"	0.621"	.395"
Beam bracket(inch)	0"	0.28"	0.59"	0.25"	0.422"	0.25"
lift bag pressure(psi)	0	144	183	0	120	0
Air spring pressure(psi)	0	29	83	0	0	0

Figure 18 displays the deflection of the hanger-side bracket the beam-side bracket along with the pressure seen in the lift kit air bags and the suspension air bags.

2.6 Analysis

At the time of writing this report, the first lift force and ultimate tests were complete. After observing the results from the two tests, Hendrickson decided to make modifications to the design of the bracket before performing further lift force, ultimate, and fatigue tests.

Lift Force:

When discussing the results of the lift force test, the main concern was that there was not enough upward force generated through the axle. The design was predicted to produce an upward force of 1.6 times the dynamic load of the axle. Testing shows the bracket produced 1.53 times the dynamic load. Swapping out the lift air spring to a more powerful one brought that number up to 1.59. As the results were discussed, it became clear that the amount of lift force should be in the 1.7 to 1.9 range. This target number was not made clear at the beginning of the project and should have been used as a target in the metrics for success. In order to achieve this new target, there are two changes that should be made.

One design change to improve lift force is to reduce deflection of the bracket. Reducing deflection is achieved by stiffening up the bracket either by increasing material thickness, increasing material grade, or improving the bracket interface with the suspension system

The other design change to improve lift force is to modify the geometry so the ends of the lift air spring are closer together. The C-23114 and C-35689 Firestone air springs provide greater lift force when the ends of the spring are closer together. By decreasing the distance between spring ends by one inch, the force in the spring increases by about 500 lbs.

The first step that will be taken to improve the lift force is to add a 1” spacer to the bracket which will provide a more optimal spring end-to-end distance force achieving target lift force. This will be an easy change and won’t require a complete rebuild of the prototype, so this is the optimal design change. In the future, the bracket will be redesigned to capture the one-inch adjustment, and efforts will be made to improve the bracket’s resistance to deflection.

Ultimate:

The results of the ultimate test provided a better idea of just how much force is being exerted on the bracket in the worst-case scenario. When the force calculations were performed near the beginning of the project, the force produced by the bag was capped at the maximum supplied pressure. When calculating the forces exerted during the worst-case, the results from the ultimate test were needed. The pressure of the lift bag during the ultimate test was nearly 180 psi. The force curves don’t go beyond 120 psi so the force was extrapolated at the specific deflection seen during the ultimate test. The maximum force present in the lift bag during the ultimate test was nearly 8750 lb. This was much higher than the force used in preliminary force calculations, so the force calculations will be revisited, and the bracket will be modified to accommodate the new force.

The ultimate test also made it obvious just how much deflection was occurring. At its worst, the bracket deflected 0.732”. The standard deflection for other lift kits that Hendrickson offers is less than 0.5”. While not specifically captured in the metrics for success, the target deflection of 0.5” should be included in the metrics for success as the project continues.

3. Conclusion

Looking back, the original metrics for success were that the bracket bolts onto the existing ULTRAA-K hangers without modification to the hangers. The other metric was that the bracket reacts the loads of suspension during normal and worst-case use without failure or excessive deformation. Based on the metrics for success, the ULTRAA-K lift kit that was developed during this senior design project was mostly a success. While the bracket successfully reacted the ultimate load during testing, deflection was a serious problem that needs to be addressed in future versions of the bracket. As an industry project, the goal was to prove the ULTRAA-K lift kit as a concept that can be developed further upon in the future. The results from this design project have proven the concept and it will be further developed at Hendrickson.

Project Success Scoring – Table 1

Metric for success	Success level (1-10)	Reasoning
Bolts onto ULTRAA-K without modification to the suspension	10	No issue attaching bracket to suspension.
Reacts load of the suspension without significant deformation	5	Deformation was greater than expected. Almost 3/4" of deflection in the bracket. Should be closer to 3/8"
Provides adequate lift force	7	Lift force was just short of target loads. Can be improved by changing geometry and decreasing deflection

Table 1 displays the self-assigned level of success for the Hendrickson Lift Kit senior design project.

4. References

"Innovation Built In." *Hendrickson International*, https://www.hendrickson-intl.com/.

Ohio Department of Transportation, Ohio Department of Transportation, https://www.transportation.ohio.gov/working/permits/special-hauling-permits/resources/vehicle-configuration.

"PART 393 - PARTS AND ACCESSORIES NECESSARY FOR SAFE OPERATION." *Federal Register :: Request Access*, https://www.ecfr.gov/current/title-49/subtitle-B/chapter-III/subchapter-B/part-393#393.207.

"Standards by Category - Standards Products - Standards & Publications - Products & Services." *ASTM International - Standards Worldwide*, https://www.astm.org/products-services/standards-and-publications/standards/standards-category-list.html?utm_source=public-website&utm_medium=click&utm_campaign=homepage-ad.

5. Appendix

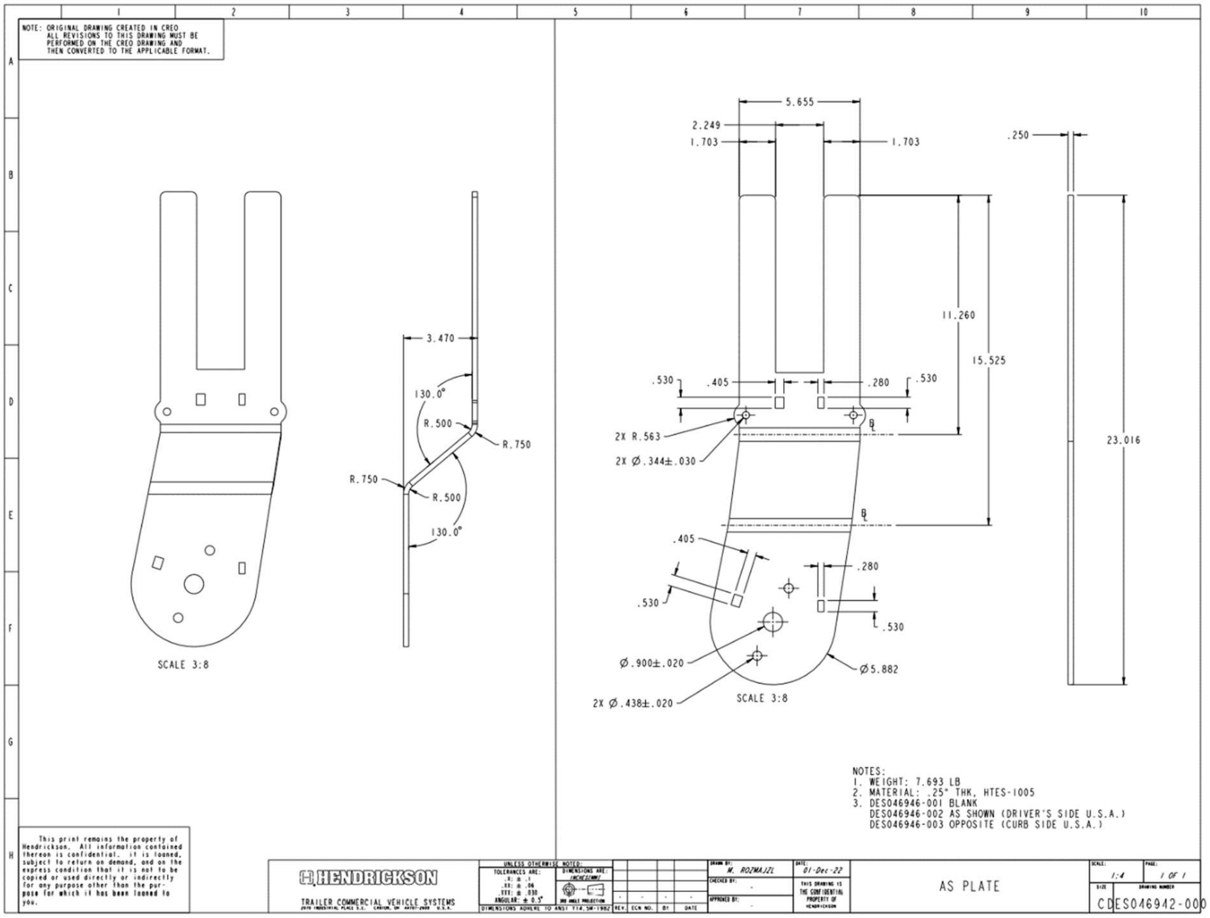


Figure 19 displays the air spring plate drawing for the prototype

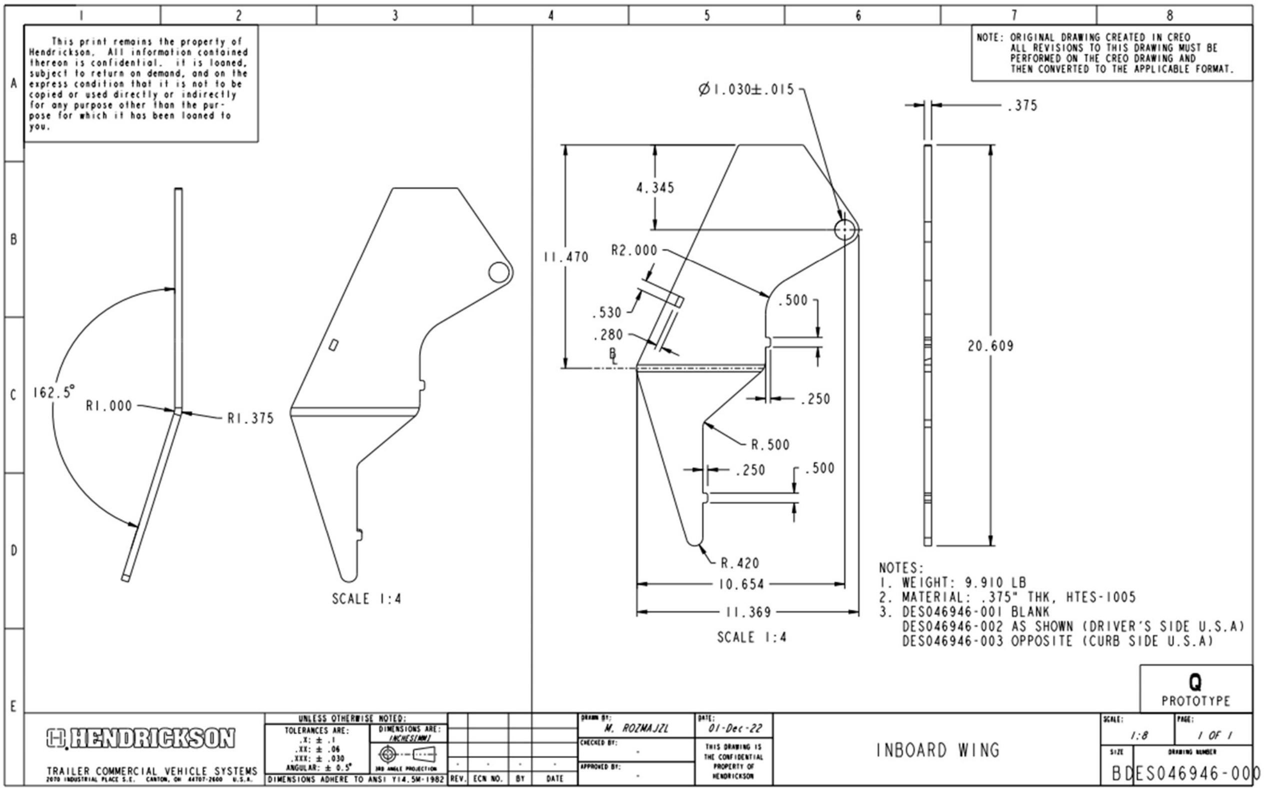


Figure 20 displays the inboard wing drawing for the prototype.

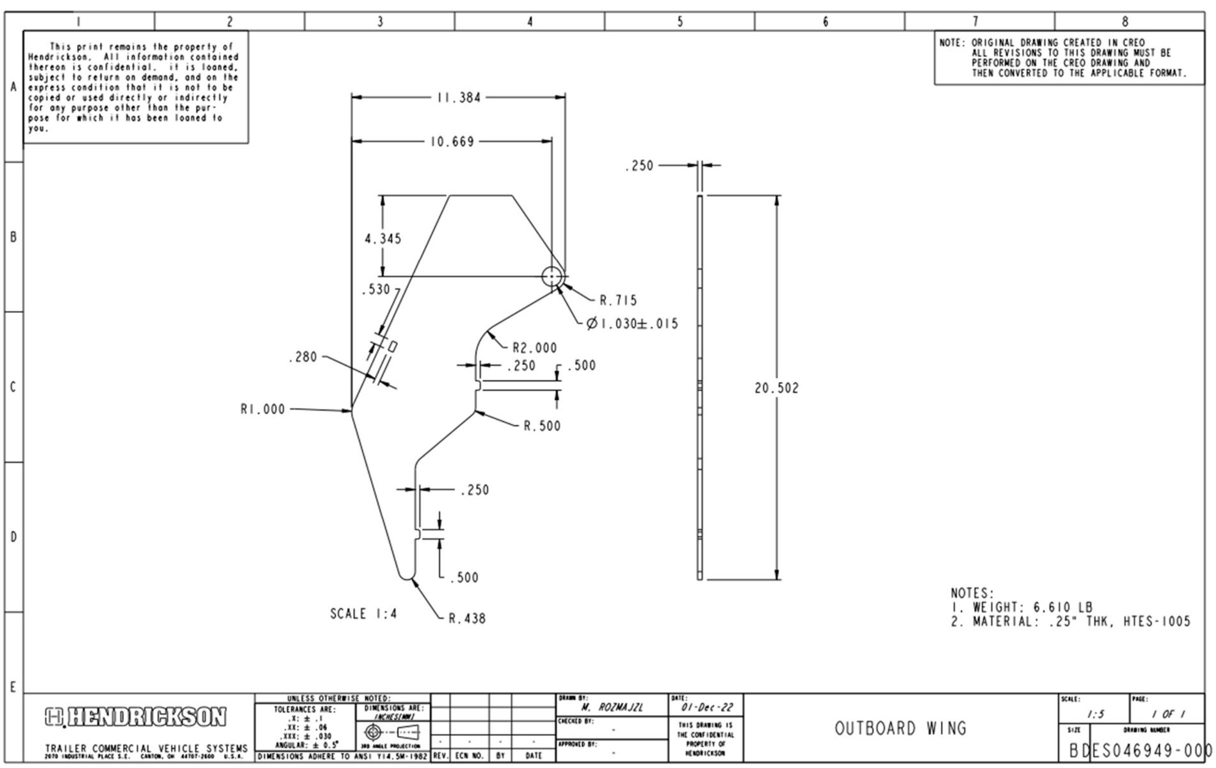


Figure 21 displays the outboard wing drawing for the prototype.

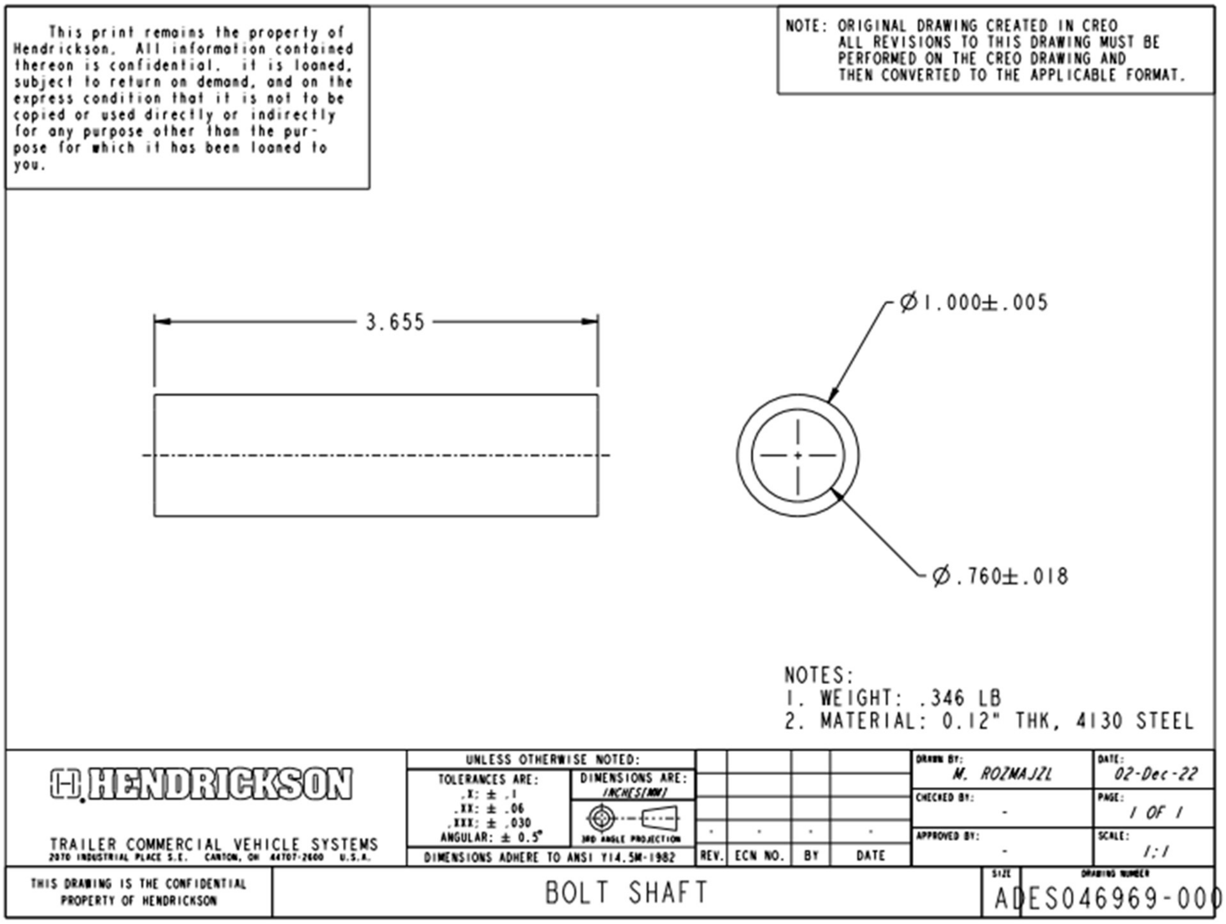


Figure 22 displays the bolt shaft drawing for the prototype.

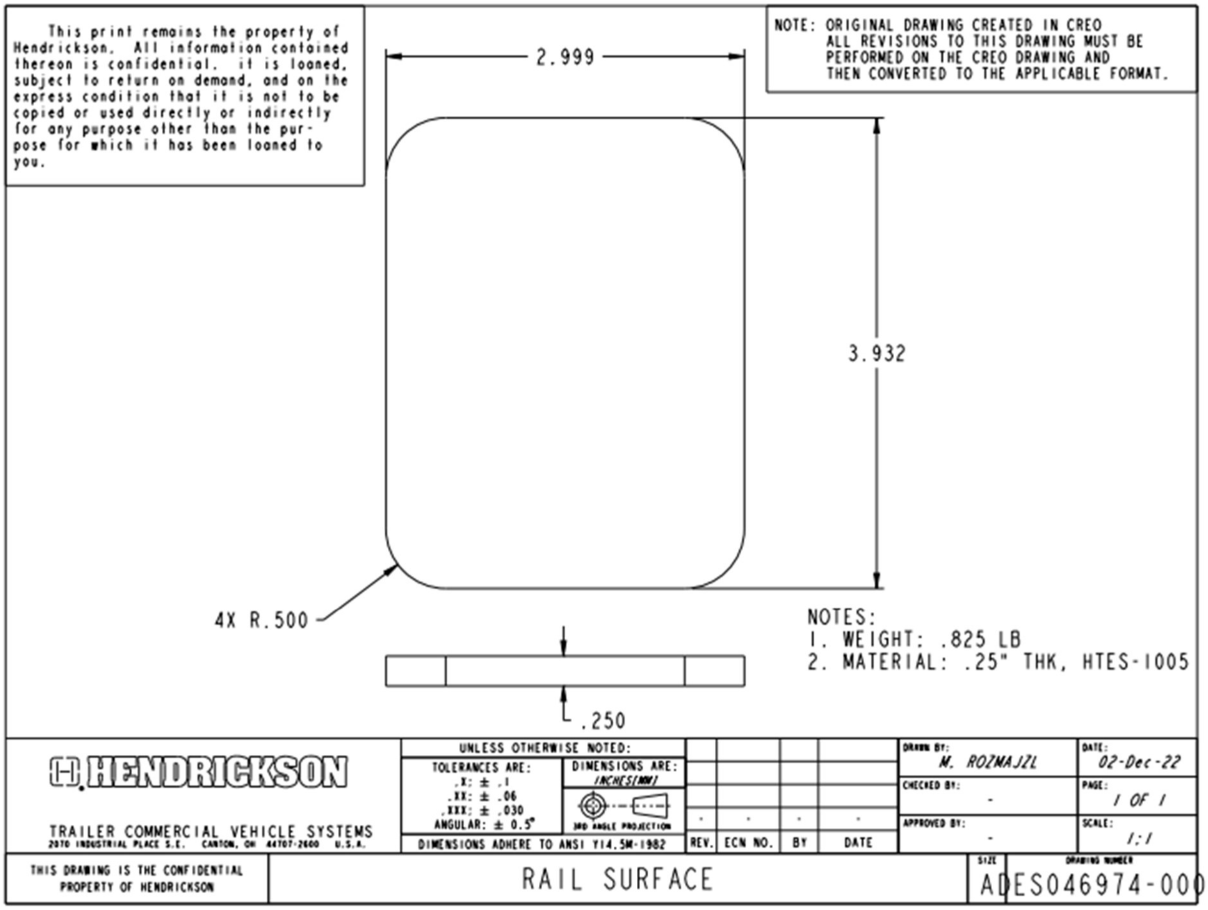


Figure 23 displays the rail surface drawing for the prototype.

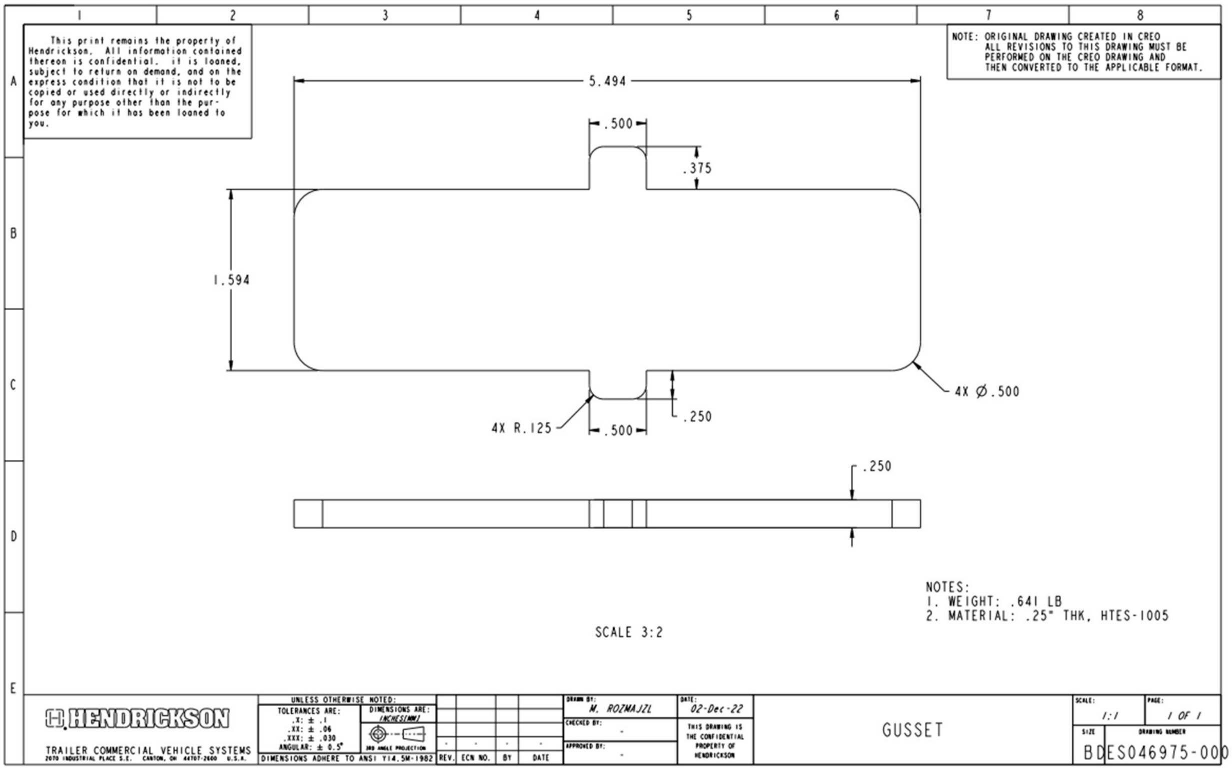


Figure 24 displays the gusset drawing for the prototype.