Spring 2020

Redesign and Analysis for Landing Gear Components

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Landing Gear Drag Brace Redesign

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Department of Mechanical Engineering

Honors Research Project

Submitted to

The Honors College

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Scott Sawyer
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Dean, Honors College

Note:

Due to Covid-19 and the Ohio Stay at Home order, Collins Aerospace employees were directed to work from home if possible until the end of May. Due to this, I am not able to get a physical signature for Paul Wang. Attached is an email from Paul containing his title and that he read and approved of my report.

You forwarded this message on 5/1/2020 3:48 PM.

From: Wang, Xiaobo Collins
To: Clarke, Daniel Collins
Cc:
Subject: RE: SD Report

Dan,

Paul Wang

Staff Engineer 1032 Program stress Lead

I am the reader of SD report. I approve this report.

Regards,

Paul Wang - Staff Engineer 1032 Stress lead -Landing Systems

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computer. Your cooperation is greatly appreciated. [8-pt Arial plain]

Abstract

Collins Aerospace has been working on a DoD project designing the landing gear for a future military aircraft. This project and report focus on the design, analysis, and redesign of the Nose Gear Drag Brace assembly. The landing gear is considered one of the main structural components on an aircraft. While the landing gear may only account for a small percentage of the aircraft's total weight, it supports enormous loads and has to endure high stress during takeoff, landing, and ground operations. The gear may endure tension, compression, torsion, shear, and bending. All of these factors must be taken into consideration and analyzed during the design process of a landing gear.

Landing gear design is extremely iterative, and as will be seen in this report, multiple revisions of individual components as well as entire assemblies are made before the final design is released to manufacturing. As critical of a component as the Drag Brace is, this most definitely applies here. This report is going to walk through the steps it takes to design and then redesign the Drag Brace assembly, with a focus on the primary components such as the Upper and Lower Drag Braces, the Toggle, the Link, and the Spindle Pins. Also discussed heavily is the actual structural analysis of these parts, as this is perhaps the most critical aspect of the design phase. The parts are analyzed utilizing FEA to apply the actual loads they will see during operation. The FEA results help stress analysts to spot high stress locations as well as bending and deflection levels. Based on these results, effective redesign can occur.

Please note that due to the fact that this is a Military program, all proprietary/technical data has to be left out in order to be used. This means not many actual loads, dimensions, or calculations can be shown. This includes any identifying features in CAD models as well. All CAD models are going to be simplified due to this. As much detail has been provided to display the credible design concept and process without infringing on Collins Aerospace technical data policies.

Acknowledgements:
I would like to thank Collins Aerospace for allowing me to use my work for my Senior Design project. I would also like to thank my co-workers and mentors for their assistance on this project and all of the engineering knowledge I have gained from them. Paul Wang has been my biggest mentor during my time at Collins. All of the technical skills I have learned from him on the stress side of things will be carried on throughout the rest of my career.

Table of Contents:

1.0) <u>Introduction:</u>

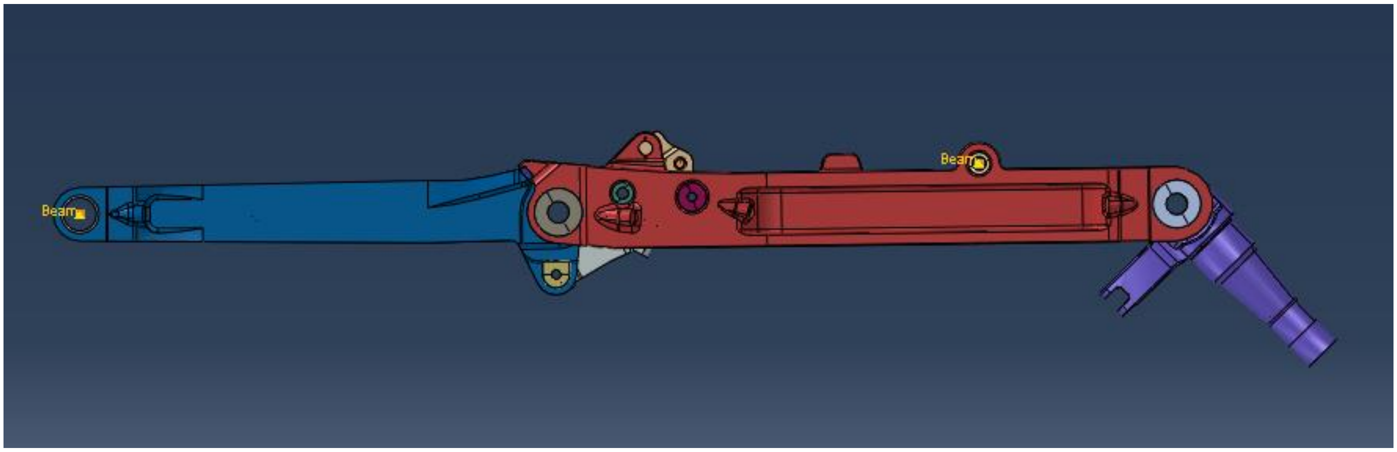
As stated previously, this landing gear is being designed for a military aircraft. This presents some unique challenges as often times; military designs have more requests but very strict design parameters. The gears need to be extremely strong and durable, but remain very light weight relative to the aircraft weight itself. Requirements tend to change as well since no aircraft is designed in one step. It is quite iterative. Collins Aerospace was given both weight and volume requirements by the customer for the landing gear design. The Drag Brace on an aircraft landing gear is extremely critical to the function of the entire gear and as such, needs to be design to a standard that reflects its importance. This leads to very intensive design and stress analysis work which will be seen throughout this report.

1.1) <u>Drag Brace Function:</u>

The primary function of the Drag Brace is to ensure that the gear remains extended during landing and ground operations. The Drag Brace for this gear is complicated, multi part design, with one end attached to the aircraft structure while the lower end is attached to the shock strut. During ground operations, the Drag Brace apex joint is moved below the loading line and the stop pad feature is reacted to prevent buckling, effectively locking out the gear. There is a secondary locking system utilizing a spring built into the brace that acts as a redundant system. The design of this gear allows for the brace to fold and be stored inside the aircraft when it is retracted. As the gear retracts the brace folds in the plane to reduce volume taken up.

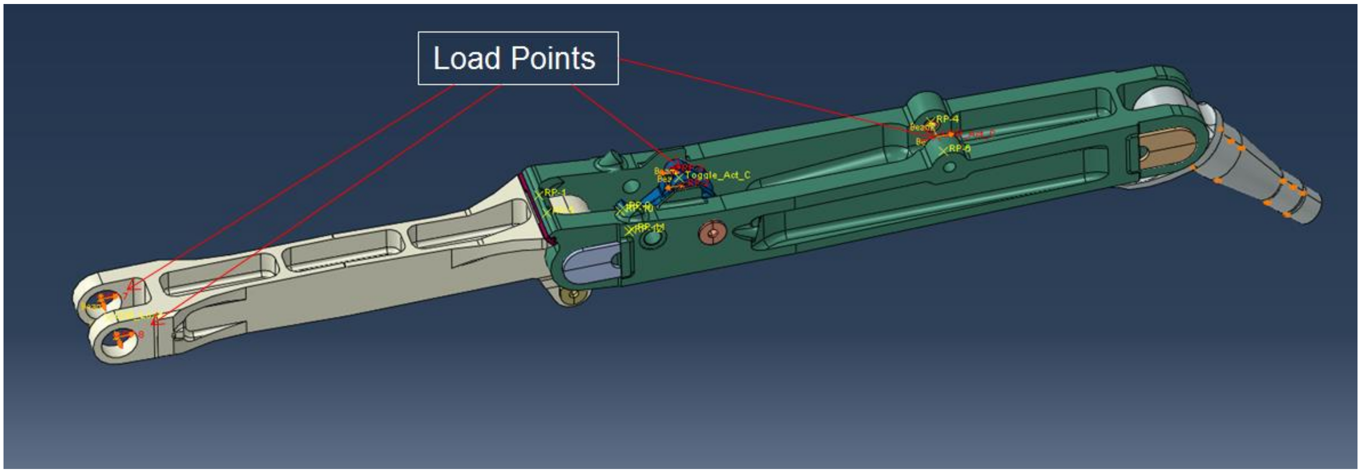
When on the ground, landing gears often utilize ground lock systems to ensure that the gear remains extended. Normally, ground locks are used during maintenance or while repairs take place. These can be as simple as a pin that has to be manually inserted in a joint to prevent any movement of components. In the case of the drag brace, it is a pin that prevents the release of the down lock mechanism. Another feature of this drag brace design is that during emergency extension, the brace is able to extend due to gravity alone and does not require any hydraulic power or air loads. This ensure that if a system fails, the brace can still fully extend and lock out the gear, allowing the aircraft to still land safely.

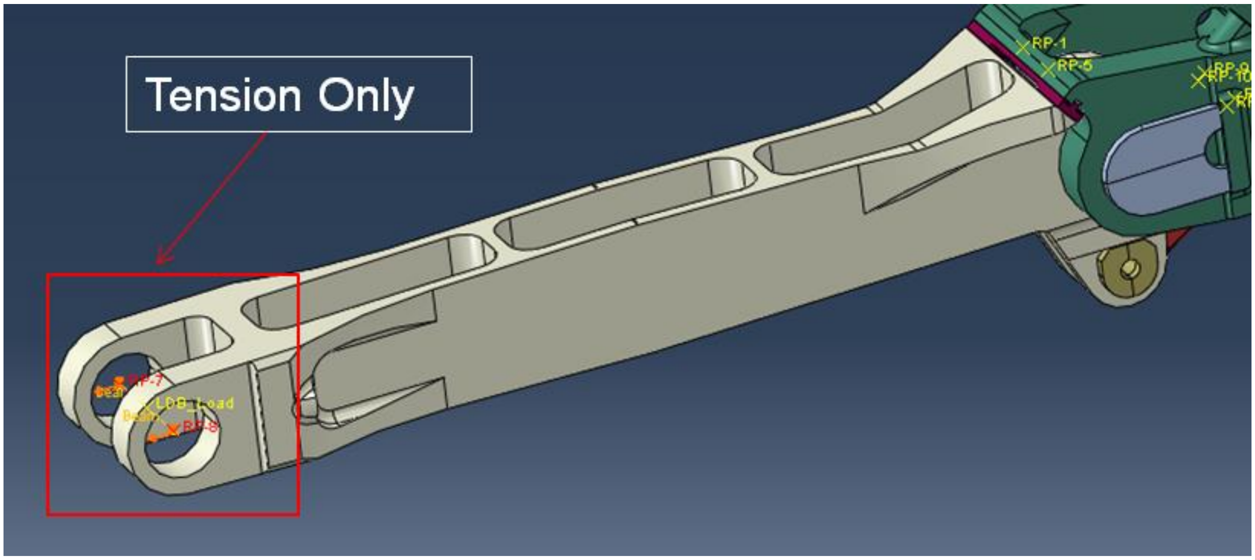
2.0) Initial Design:

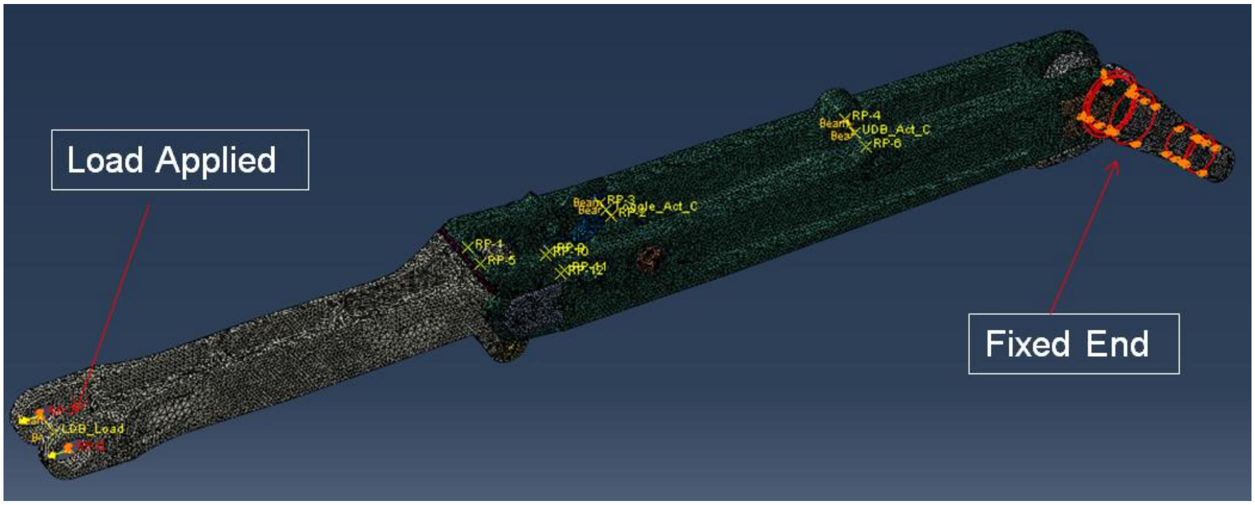


The figure above contains the design of the first Drag Brace model. This model was built in Abaqus. I was able to utilize this model to run FEA and determine if and what components needed modified given the loading conditions that would be observed in operation. The lower spindle pin/joint was not included in this model.

2.1) Loading Conditions and Boundary Conditions:







As seen above, a load and moment were each applied on the center points in the Lower Drag Brace lugs. A local coordinate system was created at the center point of the lower joint with X in the direction of the brace center line, Y following the axial direction of the lug, and Z in the downward direction. The Boundary Condition is applied to the lug center points and fixes those points which are coupled to the bushing IDs in the Y and Z directions. This BC is based on the local coordinate system described previously. Rotation about any axis is left unchecked as that is not a concern for this model. The Upper spindle pin is fixed from moving which essentially keeps the model ends in place.

A force was also applied on the Upper Drag Brace and Toggle to simulate the spring force from the actuator. These forces and moments are what the gear will see in service. Multiple cases were run with varying moments and also cases where the brace is only subject to tension or compression. This is to simulate all the load cases provided by the customer that allow the gear to be designed to the actual conditions it will face. Both static and fatigue conditions were checked.

2.2) Conditions Run:

There are three positional conditions that need checked; max over center, min over center, and nominal over center. The smallest sized shim is the minimum over center, the nominal shim is the nominal over center, and the max sized shim is the max over center.

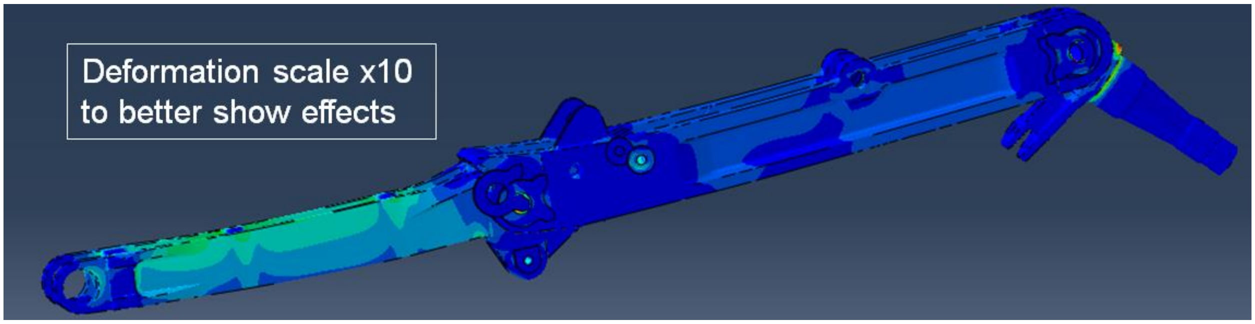
Max Over Center: Positive + Negative Moments

Min Over Center: Positive + Negative Moments

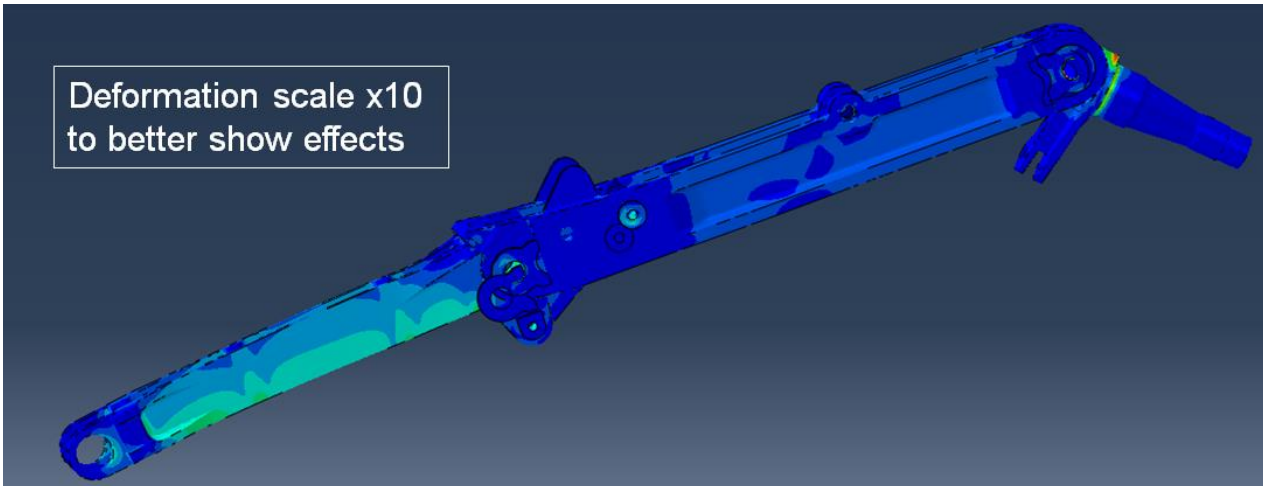
Nominal Over Center: Tension only

2.3) Results:

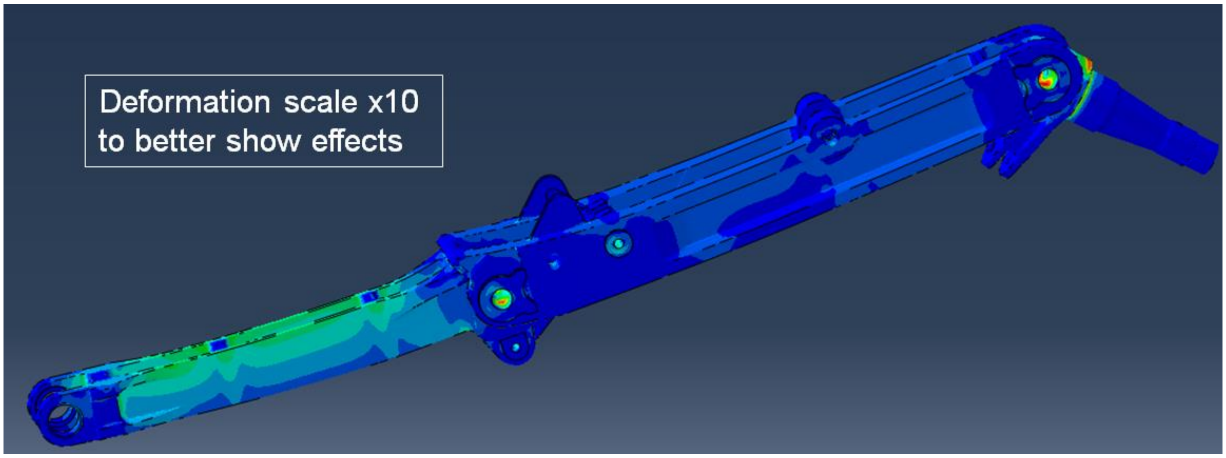
Minimum Over Center-Negative Moment Applied



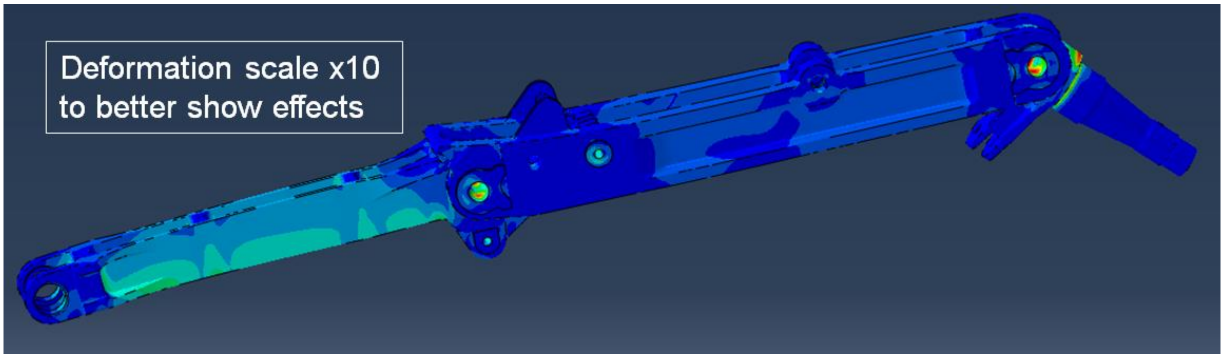
Minimum Over Center-Positive Moment Applied



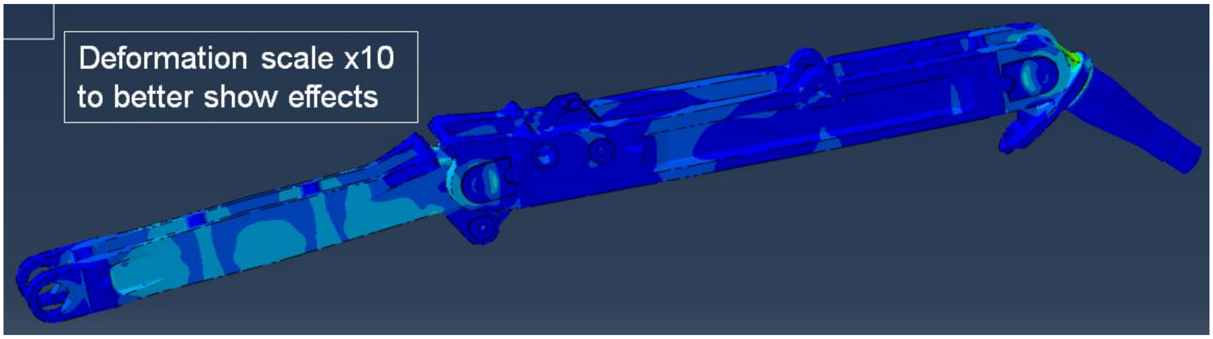
Maximum Over Center-Negative Moment Applied



Maximum Over Center-Positive Moment Applied



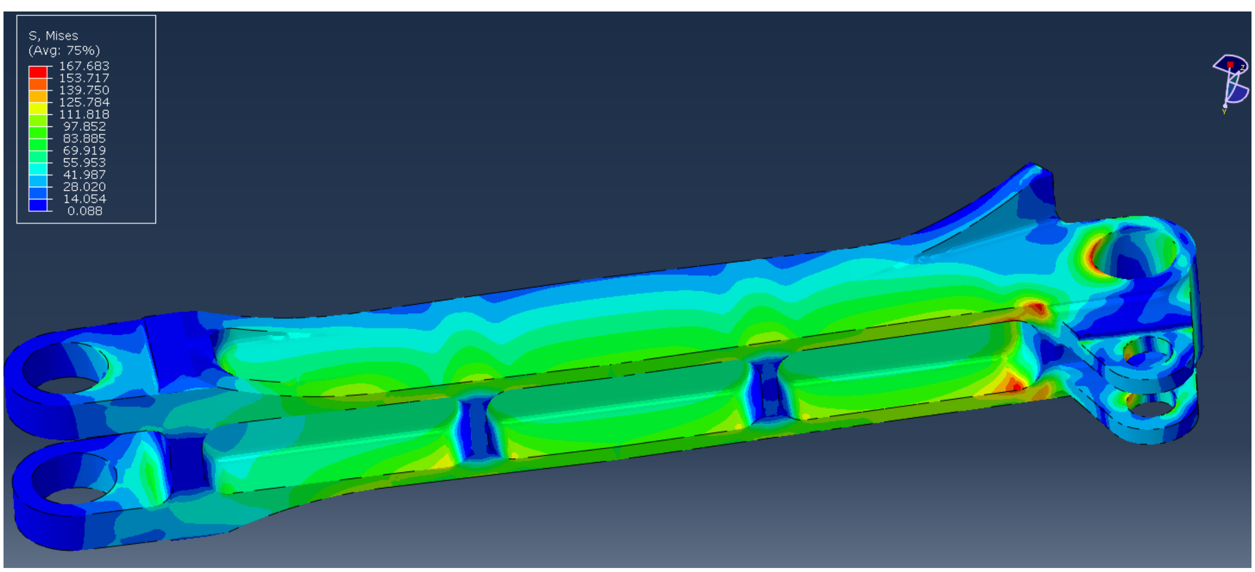
Tension Only



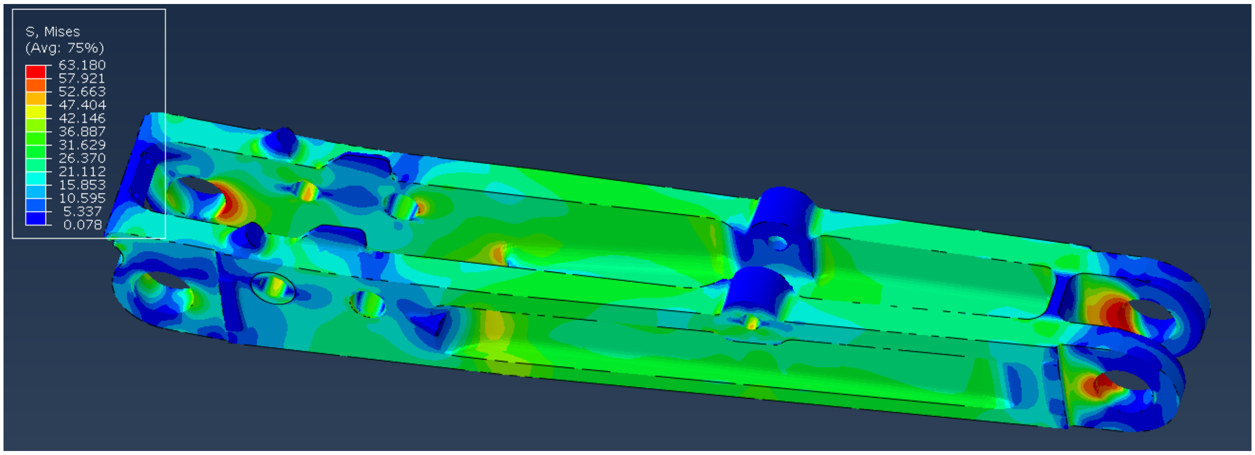
When a positive moment is applied on the Lower Brace lugs, the brace deflects and bends upwards. When a negative moment is applied it does the opposite and bends downwards. Tension on the lower lugs causes the braces to pull apart, with contact holding them together. While I cannot go into the actual deflection values due to the technical nature of this project, we can see from the deflection plots where the brace deflects most. In each case, it is always the Apex joint location, or center of the entire brace assembly. Due to how the brace is designed, this does make sense but we have to ensure that the deflection is not too great that it causes damage to any components.

After running the FEA for these various conditions, both stresses and displacements were checked and analyzed. Based on the results, several key components needed to be modified. Both the Upper and Lower Drag Brace needed to have some material added, as there were some high stress areas that potentially lead to damage over time.

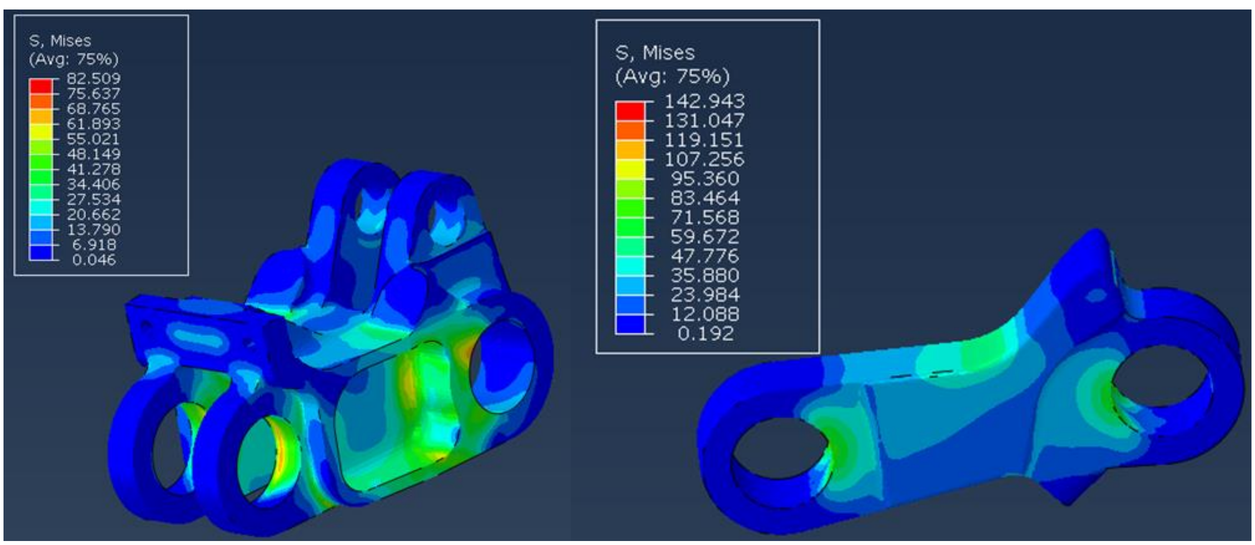
The figure below shows the stress on the Lower Drag Brace in the most critical case. The max stress is 170 ksi and while the part is made of a steel alloy with a much higher ultimate strength (280 ksi), some areas need reinforced. Where the plot is red are some of the areas of concern.



The following figure shows the most critical cases stress plot of the Upper Drag Brace. This component is made of an Aluminum alloy with a much lower ultimate strength.



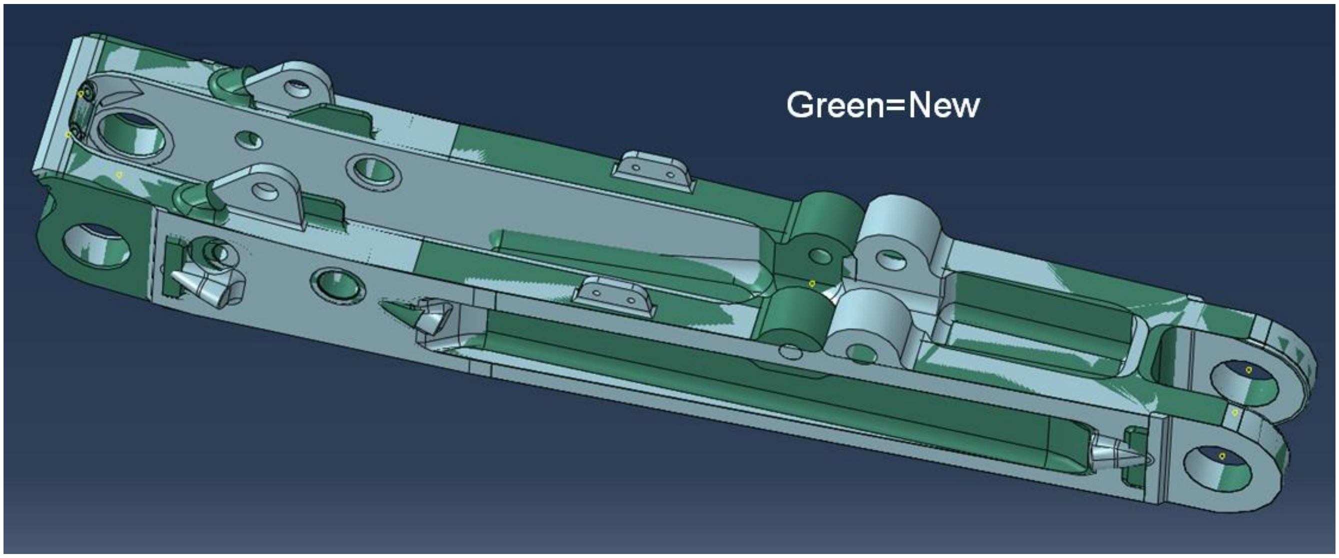
As can be seen above, the max stress is around 63 ksi, which is nearly the same as the materials ultimate strength. While the analysis is very conservative from the start, clearly some modifications to this component needed to be made. The lugs are some areas where the stress is highest and material will be added.



Neither the Toggle or Link had any stress concerns in their original designs but there were some sizing issues that came about as a result of customer requirements changing so these components do change as well. Both are made of steel alloys and can handle much greater load than they saw in the first iteration assembly.

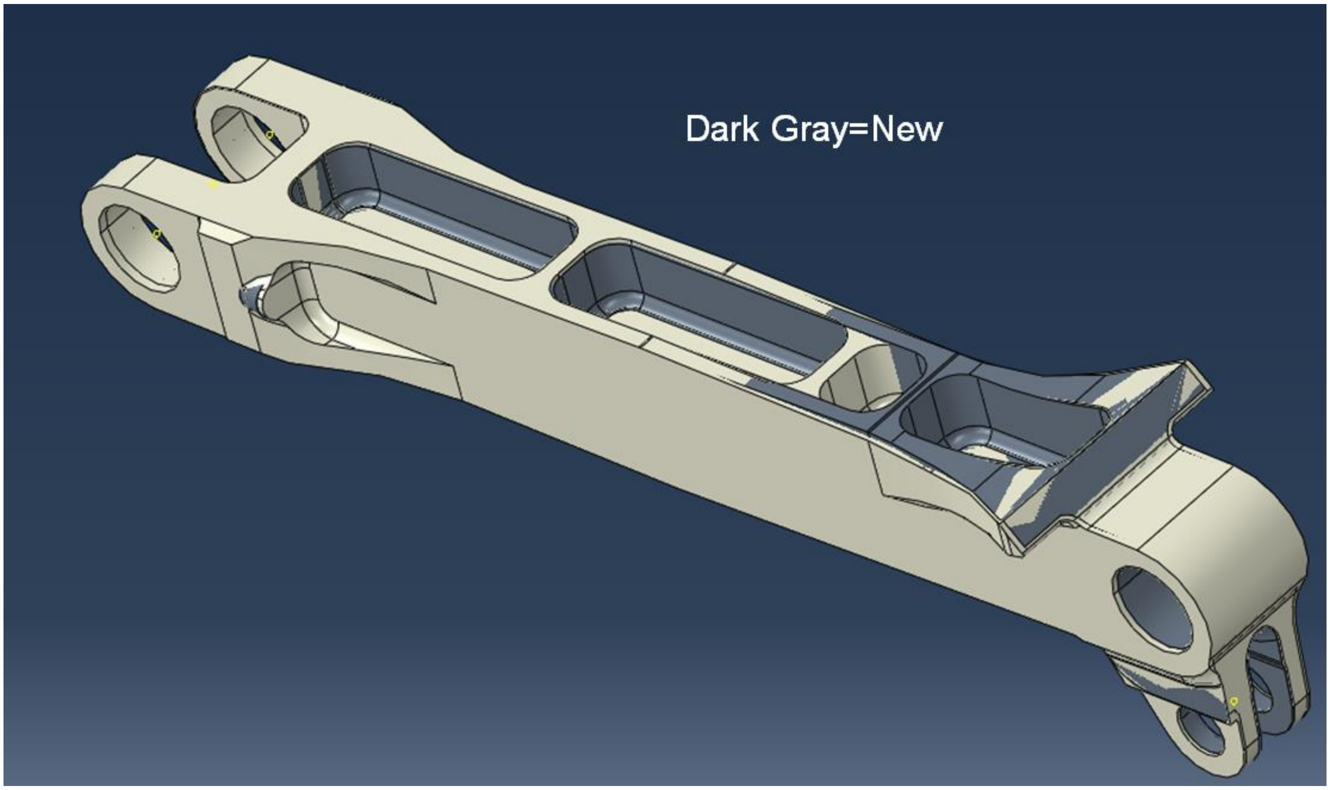
3.0) Redesign

Upper Drag Brace



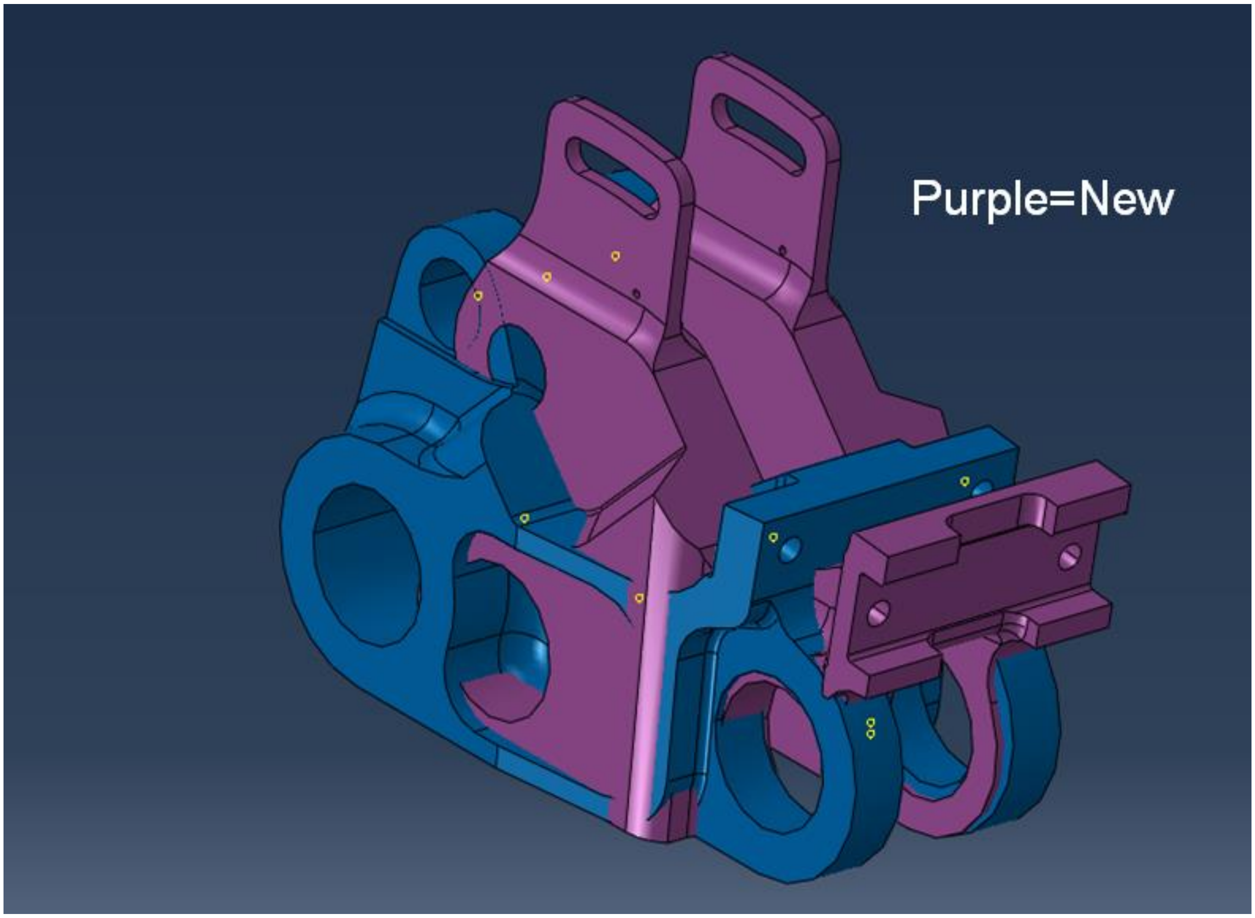
As discussed in the previous section, there were stress concerns around the lugs and also in some of the pockets. The green model is the new design and it is laid on top of the old model to clearly see the differences in designs. The two lugs in the center were shifted towards the Apex joint to account for a customer request (over center range adjustment). Material was added around the Apex lug and in some of the pockets. On the outside pocket, it is clear where a good deal of material is. That helps to alleviate some of the stress concerns and icnreases the stiffness of the brace so it does not deflect too much. The overall weight of the Upper brace only went up roughly one pound with the added material. In aircraft landing systems, a single pound is actually quite a big increase and those slight changes tend to add up quick.

Lower Drag Brace



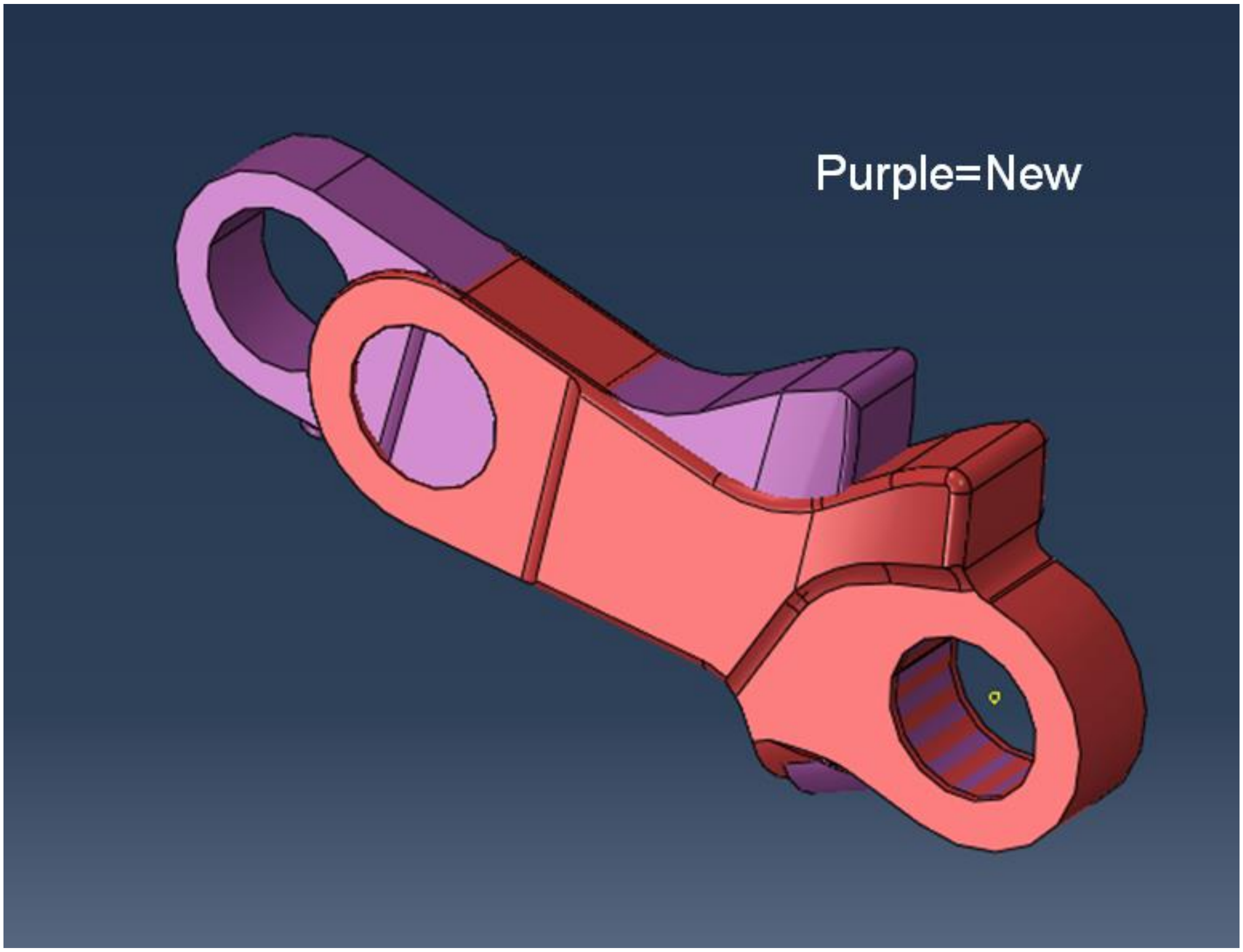
The above image also has the redesigned Lower Drag Brace laid over top of the old design. As we can see, the lugs were thickened and material was added in the pockets to create a thicker wall. The center pocket was also lengthened to account for the same changes. The pocket near the Apex lug was reduced in length as well. The design changes here help to reduce stress and increase stiffness. Despite the changes and added material, the overall volume of the part increased by only 2 cubic inches and the weight only went up a quarter of a pound. This very small increase in size and weight was worth the added stability.

Toggle



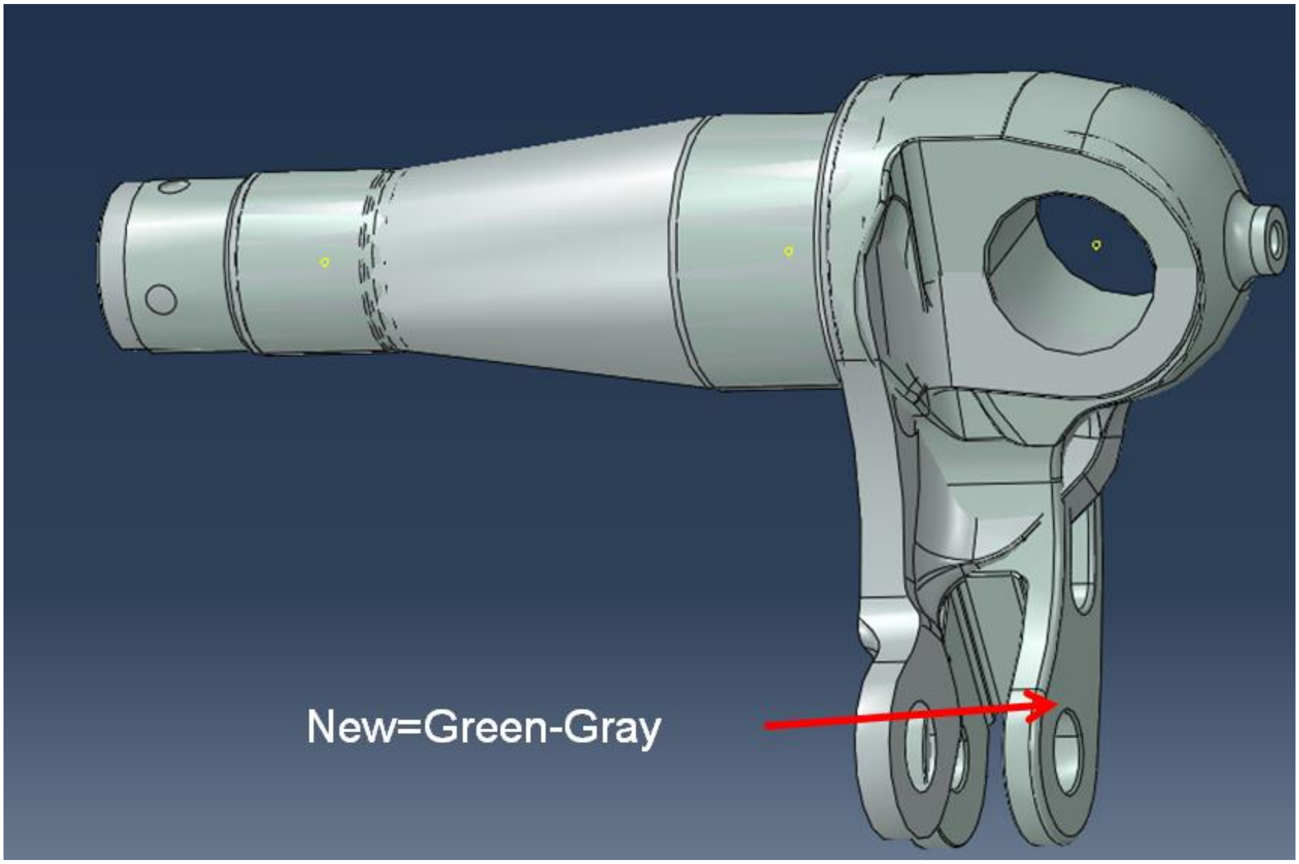
The Toggle underwent a great deal of redesign work. This was not due to any stress concerns but related directly to the over center range change the customer requested. This meant that the toggle-link assembly had to be shortened to account for a smaller volume. The Toggle was shortened down and the lug on the left side of the part in the model moved towards the rear. Brackets were also added at the top where sensors would be attached. The upper lugs were pushed back a bit and that is where the down lock assembly attaches.

Link



The Link design did not change drastically. The main difference is the length. The Link shortened several inches to account for the same design change that the Toggle faced. Again, there was no stress or deflection concern so the part remained relatively the same other than the length being changed.

<u>Spindle Pins</u>



The Upper Spindle Pin is what attaches the Drag Brace to the aircraft airframe. While it is a critical part, that is not the focus of my project as we are looking at the braces themselves more so than any pins. It underwent some small design changes along with the other components but nothing significant. The Lower Spindle Pin attaches the Drag Brace to the landing gear Cylinder. Again, this is a critical part but was actually left out of my project as I was able to simulate the entire joint utilizing boundary conditions, couplings, and connectors.

3.1.1) Contact/Interactions:

Contact Definition Name	Type	Separation	Sliding	Discretization	Property	Adjust	Surface Smoothing
Contact_1	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	None
Contact_2	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_3	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_4	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_5	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_6	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_7	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_8	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_9	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_10	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_11	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_12	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_13	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_14	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_15	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_16	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_17	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_18	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_19	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_20	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_21	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_22	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_23	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_24	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_25	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_26	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_27	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic

Contact Definition Name	Type	Separation	Sliding	Discretization	Property	Adjust	Surface Smoothing
Contact_28	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_29	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_30	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_31	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_32	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_33	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_34	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_35	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_36	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_37	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_38	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_39	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_40	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_41	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_42	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_43	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_44	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_45	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_46	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_47	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_48	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_49	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_50	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_51	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_52	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_53	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_54	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_55	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_56	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_57	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic

Contact Definition Name	Type	Separation	Sliding	Discretization	Property	Adjust	Surface Smoothing
Contact_58	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_59	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_60	Interaction	Yes	Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_61	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_62	Interaction		Finite	Surf-Surf	Hard-Contact	Off	Automatic
Contact_63	Tie	-	-	Surf-Surf	-	On	-
Contact_64	Tie	-	-	Surf-Surf	-	On	-
Contact_65	Tie	-	-	Surf-Surf	-	On	-
Contact_66	Tie	-	-	Surf-Surf	-	On	-
Contact_67	Tie	-	-	Surf-Surf	-	On	-
Contact_68	Tie	-	-	Surf-Surf	-	On	-
Contact_69	Tie	-	-	Surf-Surf	-	On	-
Contact_70	Tie	-	-	Surf-Surf	-	On	-
Contact_71	Tie	-	-	Surf-Surf	-	On	-
Contact_72	Tie	-	-	Surf-Surf	-	On	-
Contact_73	Tie	-	-	Surf-Surf	-	On	-
Contact_74	Tie	-	-	Surf-Surf	-	On	-
Contact_75	Tie	-	-	Surf-Surf	-	On	-
Contact_76	Tie	-	-	Surf-Surf	-	On	-
Contact_77	Tie	-	-	Surf-Surf	-	On	-
Contact_78	Tie	-	-	Surf-Surf	-	On	-
Contact_79	Tie	-	-	Surf-Surf	-	On	-
Contact_80	Tie	-	-	Surf-Surf	-	On	-
Contact_81	Tie	-	-	Surf-Surf	-	On	-
Contact_82	Tie	-	-	Surf-Surf	-	On	-
Contact_83	Tie	-	-	Surf-Surf	-	On	-
Contact_84	Tie	-	-	Surf-Surf	-	On	-

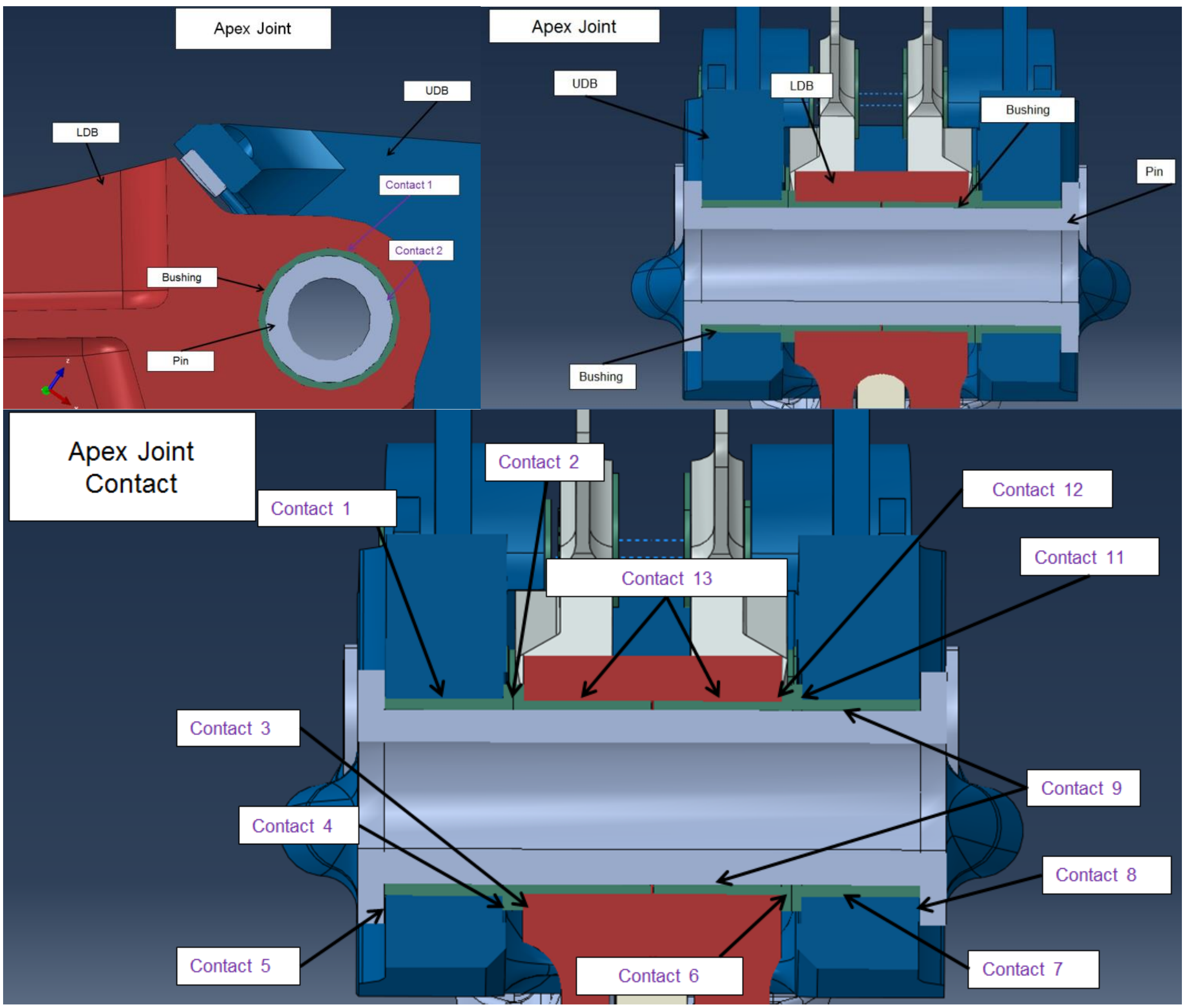
This table shows the various contact and constraints that are present in the model. These have to be set up in the FEA model to ensure that the model functions and acts like it would in real world operations. There are a mixture of contacts and constraints used. Tie constraints are used when we want to simulate two parts joining as one. Normally ties are used to simulate threated contact surfaces such as the threaded end of a bolt and a nut. They are also used between bushing ODs and Lug IDs in some instances. The property section defines the friction coefficient between contact surfaces. There are several different friction coefficients used in this model depending on what type of contact it is. For example, pin and bushing contacts have a lower coefficient than lug to bushing contacts. These tables really are to show just how complex this model is and how much has to be accounted for during the analysis.

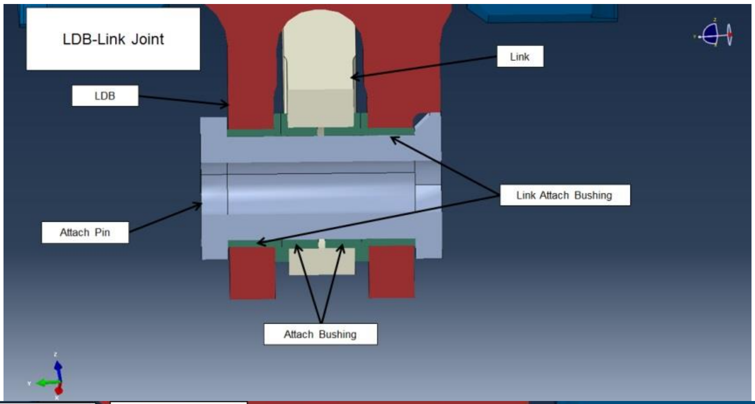
3.1.2) Material Properties:

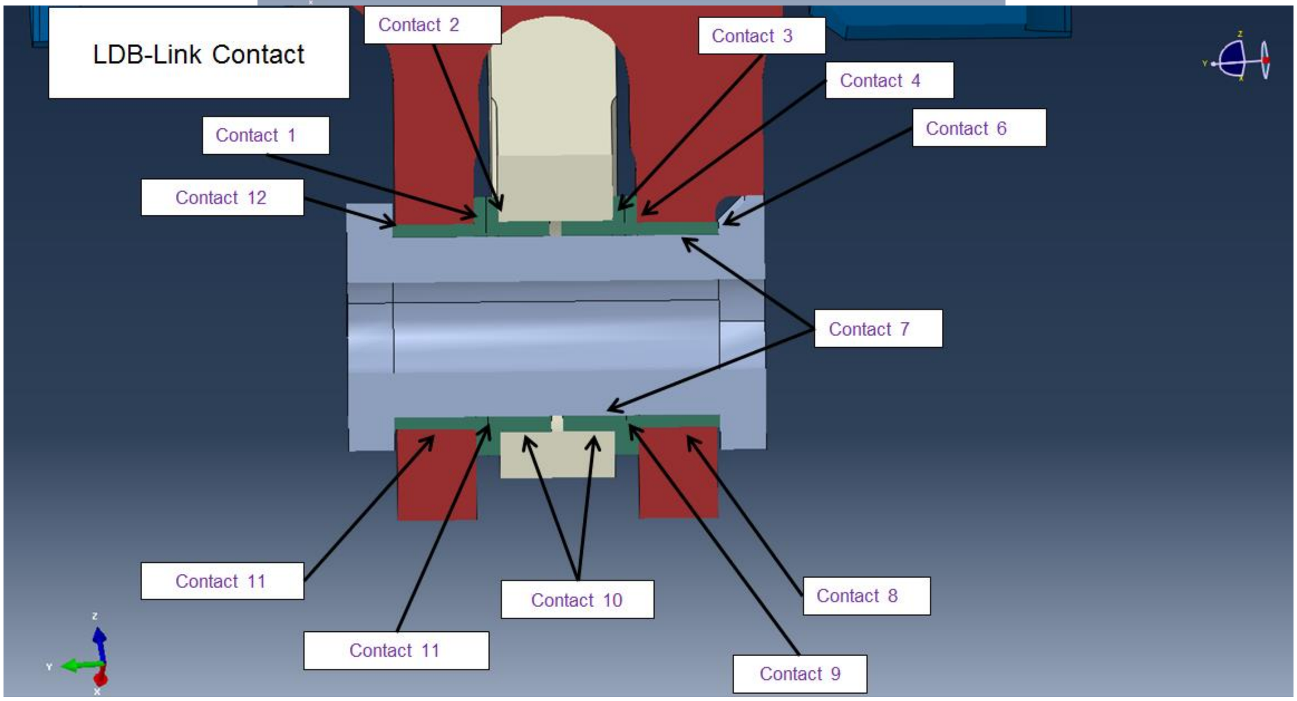
Material	E (ksi)	v	Plasticity
Aluminum Nickel Bronze	17500	0.27	N
NL Ult 300M Steel	29000	0.32	Y
Ult 300M Steel	29000	0.32	N
NL Ult 15-5h Steel	28500	0.27	Y
NL Ult 7075-T7351 Aluminum	10300	0.33	Y
NL Ult Ph13-8 Steel	28300	0.28	Y

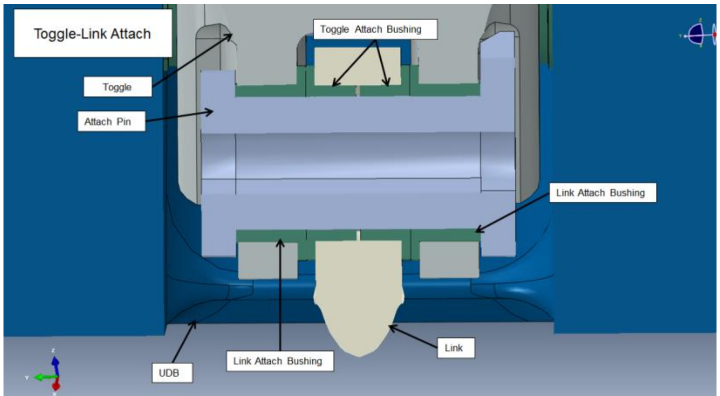
There are 84 contacts or ties in the final FEA model. There are also numerous couplings used.

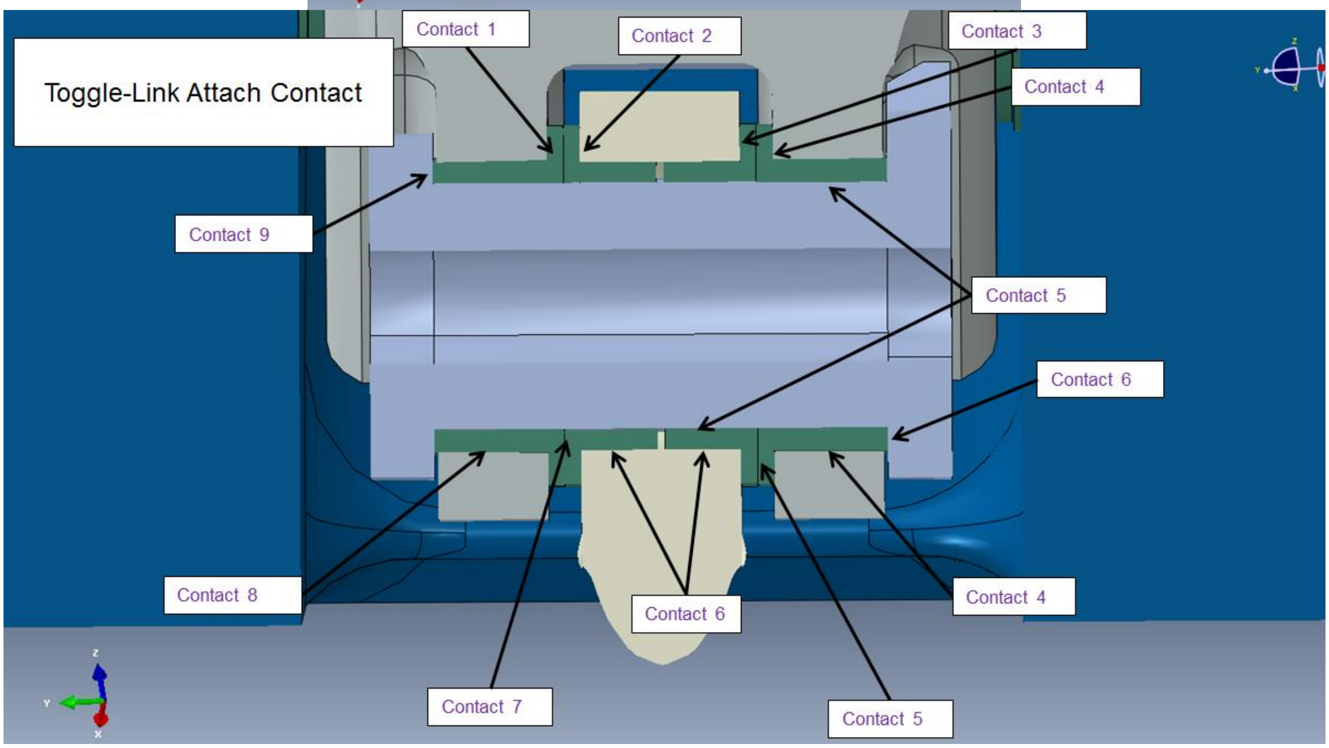
3.1.3) Joint Set Up:

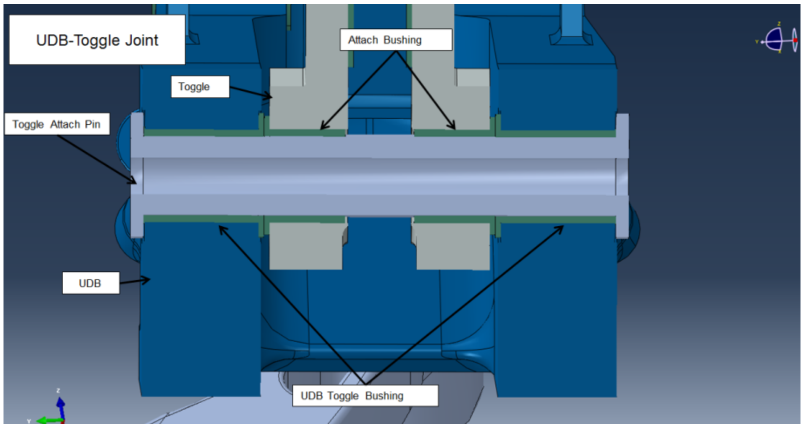


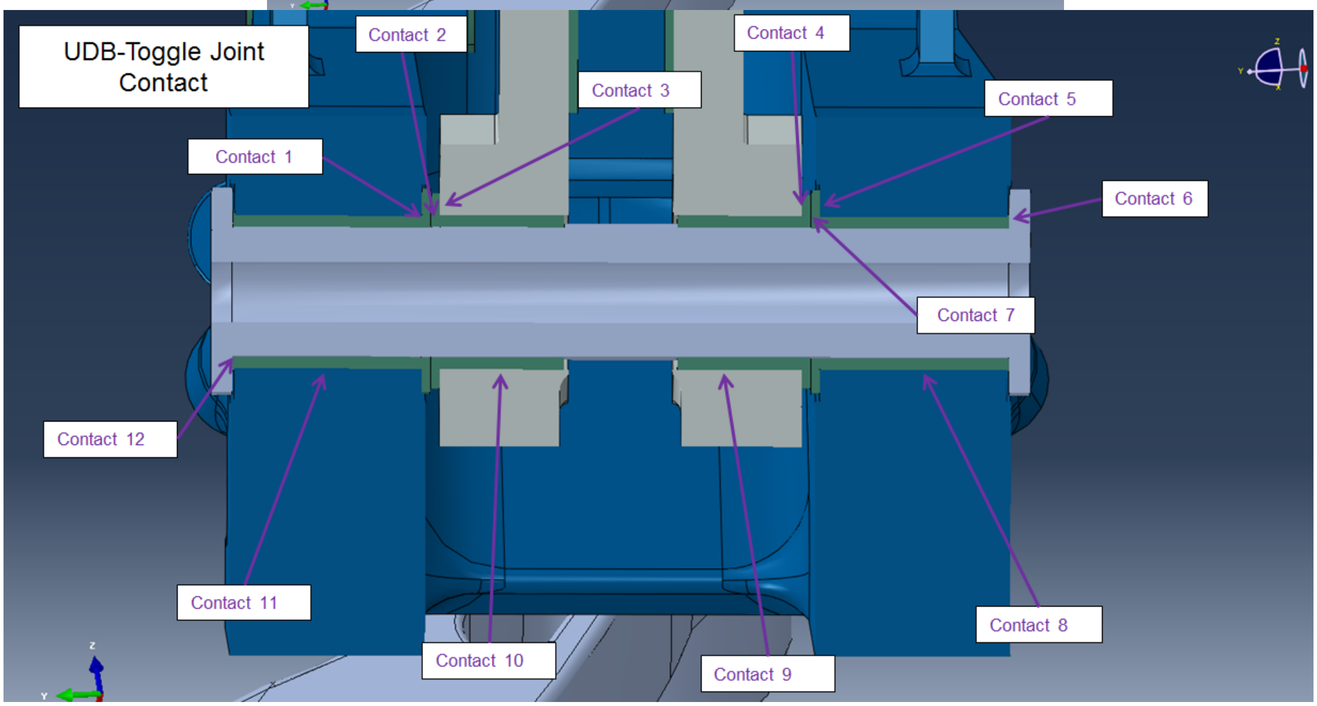

LDB-Link Joint
Link
LDB
Link Attach Bushing
Attach Pin
Attach Bushing

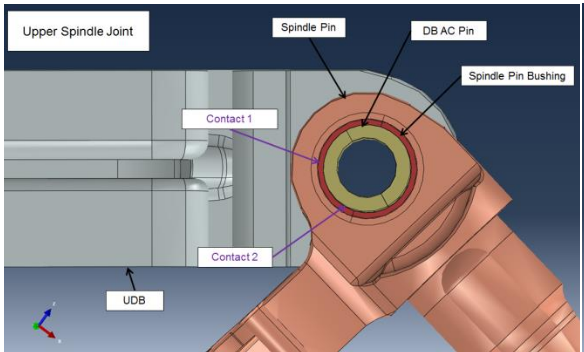

LDB-Link Contact
Contact 2
Contact 3
Contact 4
Contact 6
Contact 1
Contact 12
Contact 7
Contact 11
Contact 10
Contact 8
Contact 11
Contact 9

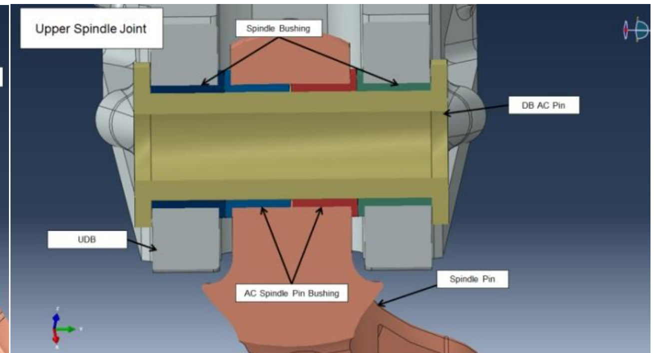

Toggle-Link Attach
Toggle Attach Bushing
Toggle
Attach Pin
Link Attach Bushing
Link
Link Attach Bushing
UDB

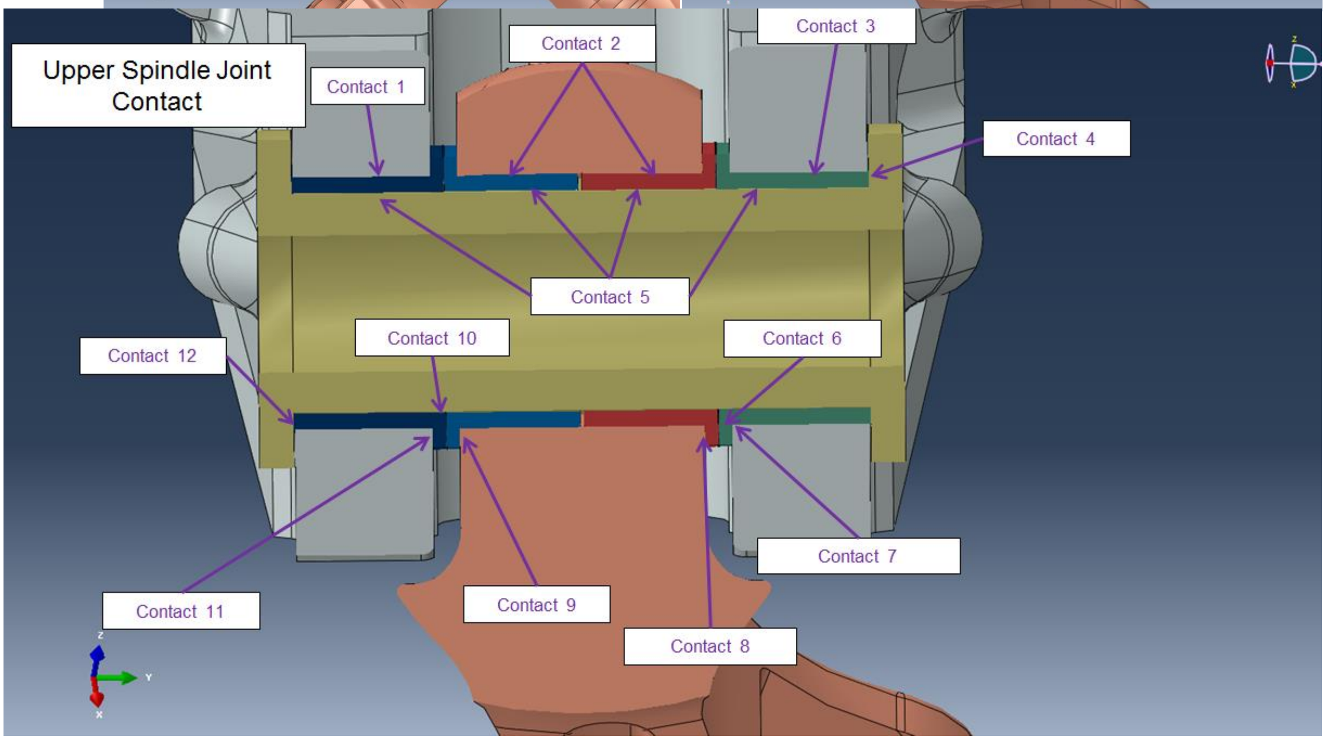

Toggle-Link Attach Contact
Contact 1
Contact 2
Contact 3
Contact 4
Contact 9
Contact 5
Contact 6
Contact 8
Contact 6
Contact 4
Contact 7
Contact 5

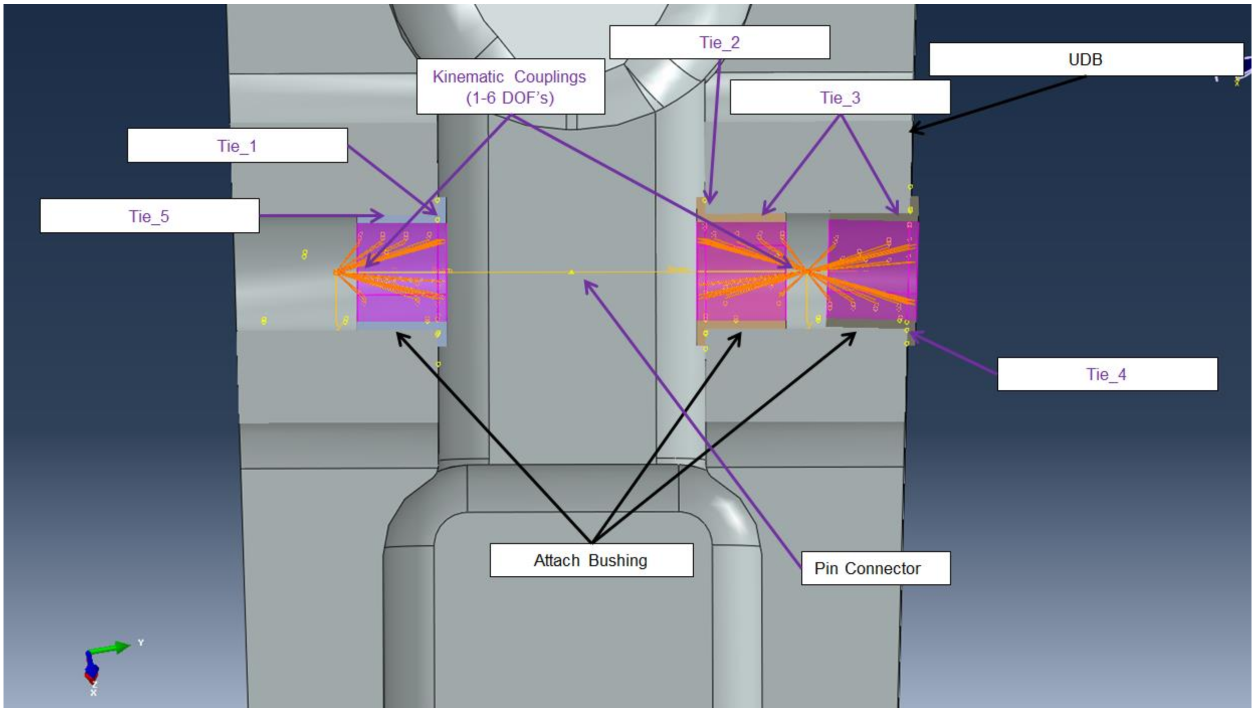

UDB-Toggle Joint
Attach Bushing
Toggle
Toggle Attach Pin
UDB
UDB Toggle Bushing

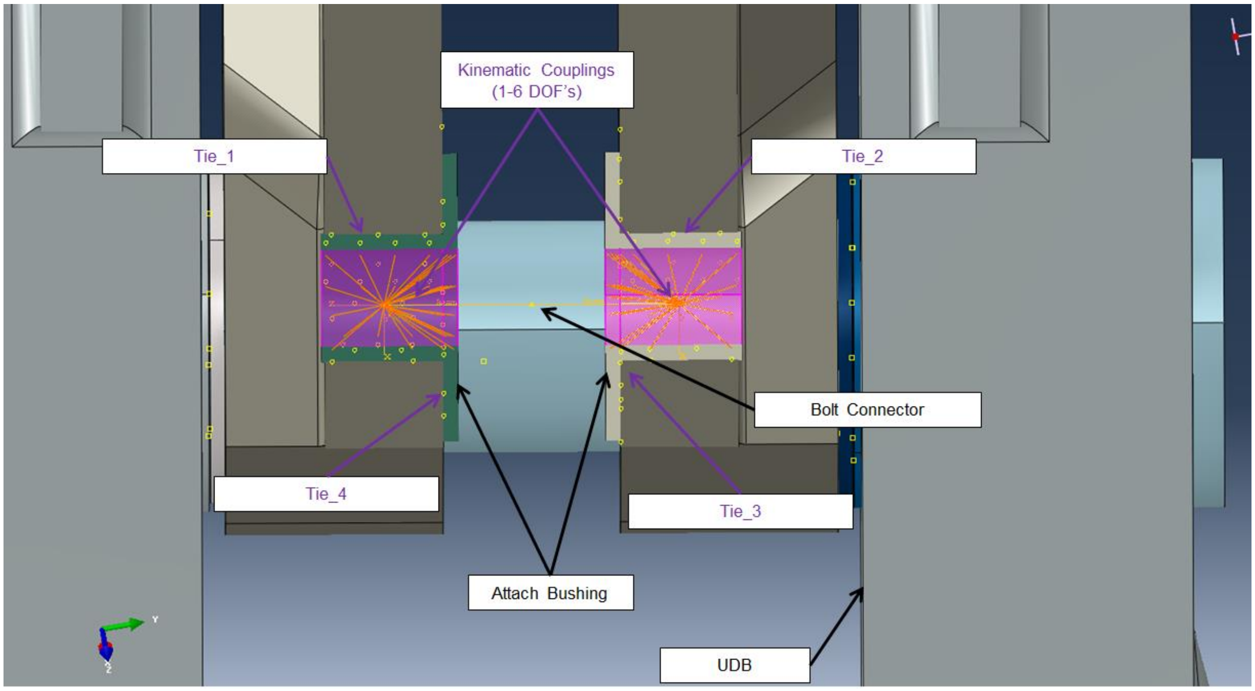

UDB-Toggle Joint
Contact
Contact 1
Contact 2
Contact 3
Contact 4
Contact 5
Contact 6
Contact 7
Contact 8
Contact 9
Contact 10
Contact 11
Contact 12

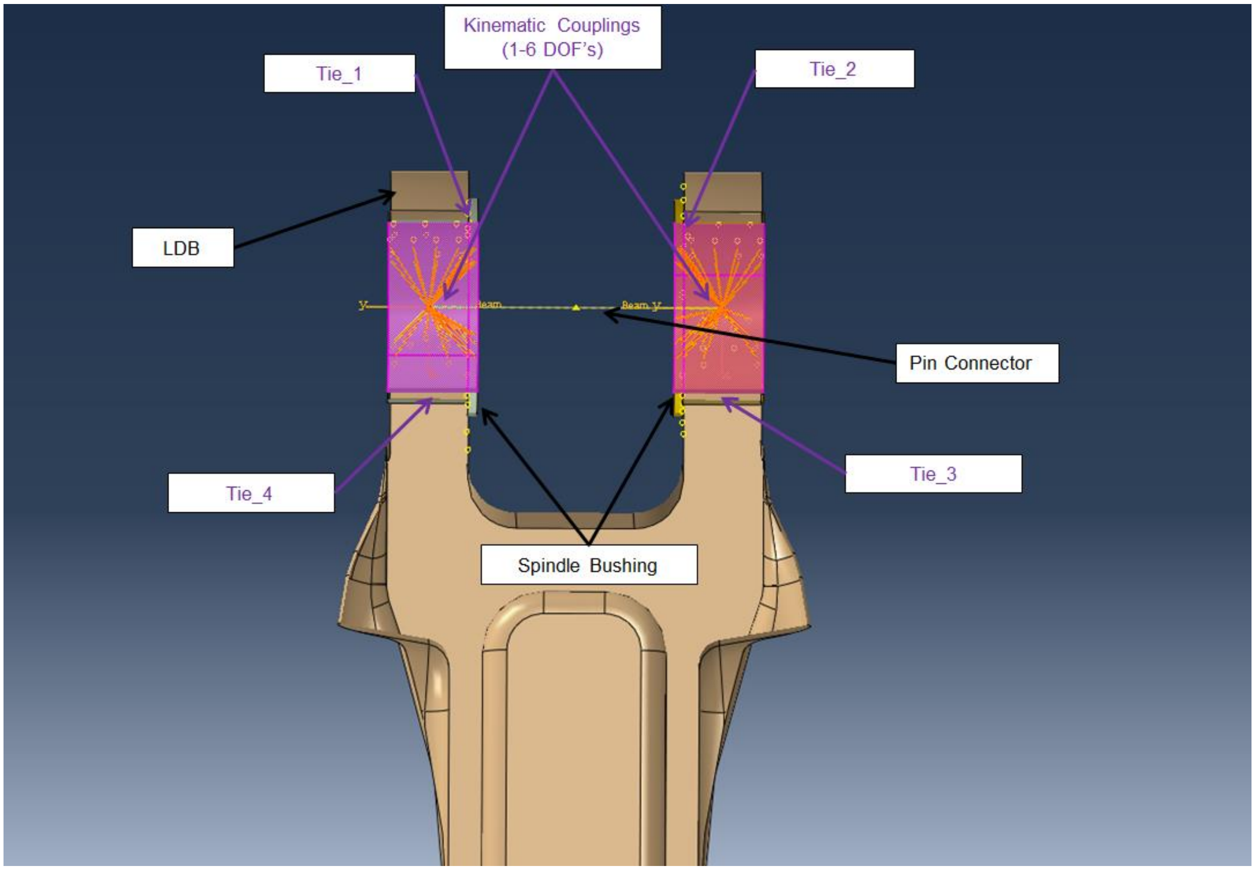

Upper Spindle Joint
Spindle Pin
DB AC Pin
Spindle Pin Bushing
Contact 1
Contact 2
UDB


Upper Spindle Joint
Spindle Bushing
DB AC Pin
UDB
AC Spindle Pin Bushing
Spindle Pin

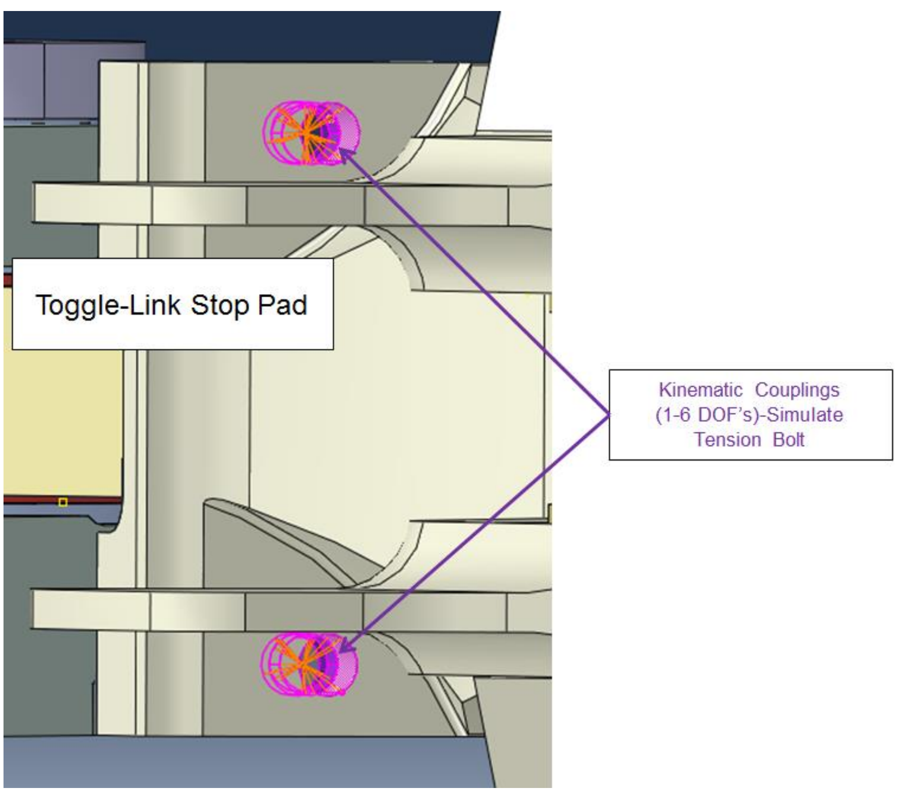

Upper Spindle Joint Contact
Contact 1
Contact 2
Contact 3
Contact 4
Contact 5
Contact 6
Contact 7
Contact 8
Contact 9
Contact 10
Contact 11
Contact 12


Tie_2
UDB
Kinematic Couplings
(1-6 DOF's)
Tie_3
Tie_1
Tie_5
Tie_4
Attach Bushing
Pin Connector


Kinematic Couplings
(1-6 DOF's)
Tie_1
Tie_2
Bolt Connector
Tie_4
Tie_3
Attach Bushing
UDB



Utilized a beam connector and kinematic couplings to simulate sold pin



Rather than solid bolts, kinematic couplings used to prevent movement.

The above figures go through each critical joint and show the contact and constraint set up. In FEA, correctly setting up contact is very important or the model will not give accurate results. Inaccurate results are useless. As can be seen, the model is very complex and has many contacts and constraints but there are also five full joints in the model as well as various partial joints. While you get very accurate results with all the contacts that are actually present in the model, it also slows down run time and greatly increases computational time. That is why these jobs are normally submitted to offsite servers that shorten run time.

3.2) Stop Pad Design:

The stop pads carry out a critical role in the function of the Drag Brace during takeoff, landing, and ground operations. These react the load that the Brace to prevent buckling. The stop pads are where contact occurs between certain components thus locking the gear out. There are pads between the upper and lower braces and then also between the toggle and link. I cannot go into too much detail with how this system functions as this is Collins proprietary data.

Upper-Lower Drag Brace Stop Pad

Curved Stop Pad	Lower Drag Brace
$\nu_1 := 0.32$	$\nu_2 := 0.32$
$E_1 := 20900$	$E_2 := 29000$
$R_1 := 3$	$R_2 := 9.9E{+}99$

$f_{sec} := 16.082063\text{kip}$

$f := f_{sec}$

Length of Contact $L_1 := 2 \cdot 1.364\text{in} = 2.728\,\text{in}$

$$a := \left[\left(\frac{1-\nu_1^{\,2}}{E_1}\right) + \left[\frac{\left(1-\nu_2^{\,2}\right)}{E_2}\right]\right] \qquad a = 7.39 \times 10^{-5}$$

$$\frac{1}{R_1} + \frac{1}{R_2} = 0.333$$

half width of rectangular contact area $b := 0.040792839$ in

Max contact pressure $P_{max} := 92.00121867$ ksi

$FCY_{SP} := 146$ ksi $\qquad FCY_{LDB} := 230$ ksi

$$MS_{SP} := \left(\frac{146}{92}\right) - 1 = 0.587 \qquad MS_{LDB} := \left(\frac{230}{92}\right) - 1 = 1.5$$

$F_{ax} := 127.7$ kips

$$F_{ax\_lim} := \frac{F_{ax}}{1.3} = 98.231 \text{ kips}$$

$d_1 := 0.43\,\text{in}$ overcenter after deflection

$$F_{sec} := \frac{\left(F_{ax} \cdot d_1\right)}{2.625} = 20.918 \text{ kips}$$

Width of contact area on each side of pad = 1.36 in

Height of contact area of pad = 0.720 in

Radius of curved pad $R_1 = 3$ in

Distance from center of radius to flat surface of pad = 2.789 in

Pad Thickness $t := 3 - 2.789 = 0.211$ in

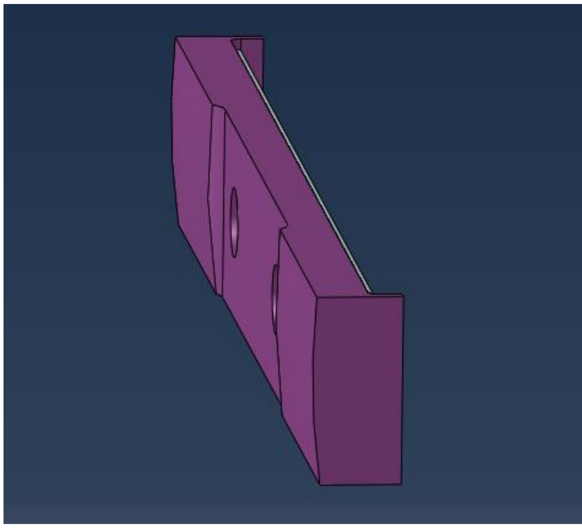
Hertz Contact radius $b = 0.041$ in

Contact Diameter $2 \cdot b = 0.082$ in

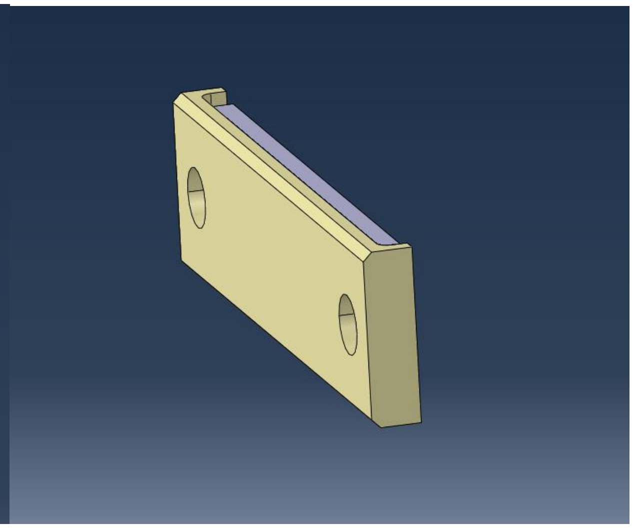
a) $t = 0.211$ in
5* Hertz Contact Radius = 0.204 in
t > 5* Hertz Contact Radius

b) Pad width = L = 2.728 in
6* Hertz Contact Diameter = 0.490 in
Pad width > 6* Contact Diameter

c) Pad height = 0.7175
3* Contact diameter from extreme contact center location = 0.25
Pad Height > 3* Contact diameter



Curved Stop Pad



Flat Stop Pad

Link-Toggle Stop Pad

$F_{stop} := 5.385$ kips

Width of Contact area-link = 0.6171 in

Height of Contact area-flat pad = 0.69 in

Flat Pad

$\nu_{1b} := 0.32$

$E_{1b} := 20900$ ksi

$R_{1b} := 9.9E+99$

Link

$\nu_{2b} := 0.28$

$E_{2b} := 28300$ ksi

$R_{2b} := 4$

$F_{stop} = 5.385$ kip

Contact Length L = link contact area width = 0.6171 in

$$a_2 := \left[\left(\frac{1-\nu_{1b}^{\ 2}}{E_{1b}}\right)+\left[\frac{\left(1-\nu_{2b}^{\ 2}\right)}{E_{2b}}\right]\right] \qquad a_2 = 7.551 \times 10^{-5}$$

$$\frac{1}{R_{1b}}+\frac{1}{R_{2b}} = 0.25$$

b (1/2 width of contact area) = 0.058 in

$P_{max.b} := 95.9\text{ksi}$

$$MS_{FlatPad} := \left(\frac{146}{95.9}\right) - 1 = 0.522 \qquad MS_{Link} := \left(\frac{200}{95.9}\right) - 1 = 1.086$$

$$f_{padbearing} := \frac{F_{stop}}{[(2\cdot.058)\cdot.6171]} = 75.227 \text{ ksi}$$

Bearing Allowable = 161 ksi

$$MS_{bearing} := \left(\frac{161}{75.227}\right) - 1 = 1.14$$

Hertz Contact Radius = b = 0.058 in

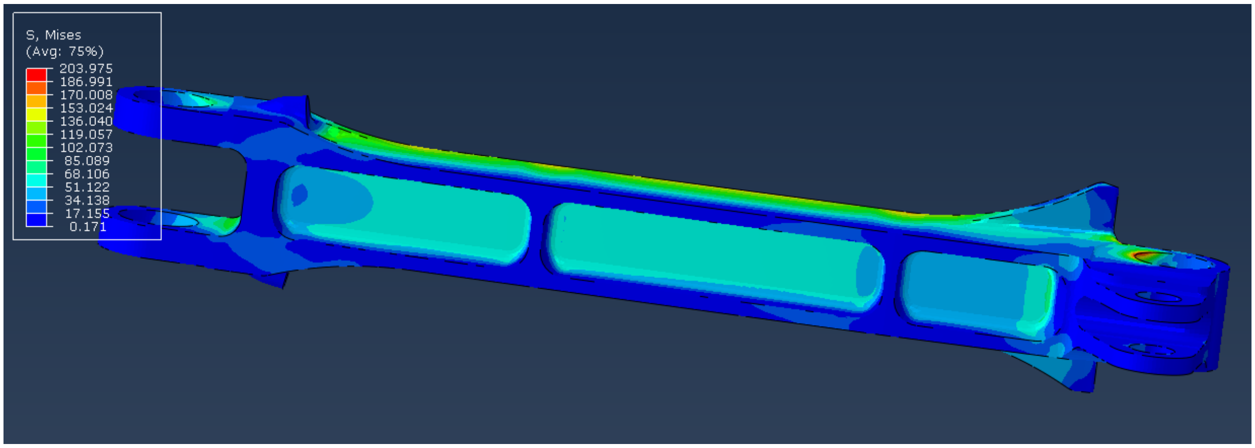
Contact Diameter = 2b = 0.116 in

a) Pad Thickness t = 0.5 in
3* Hertz Contact Radius = 0.174 in
t < 3* Hertz Contact Radius

b) Pad Width = L = 0.617 in
6* Contact Diameter = 0.695 in
3* Contact Diameter < Pad Width < 6* Contact Diameter

c) Pad Height = 0.69 in
3* Contact Diameter from extreme center location = 0.348 in
Pad Height > 3* Contact Diameter

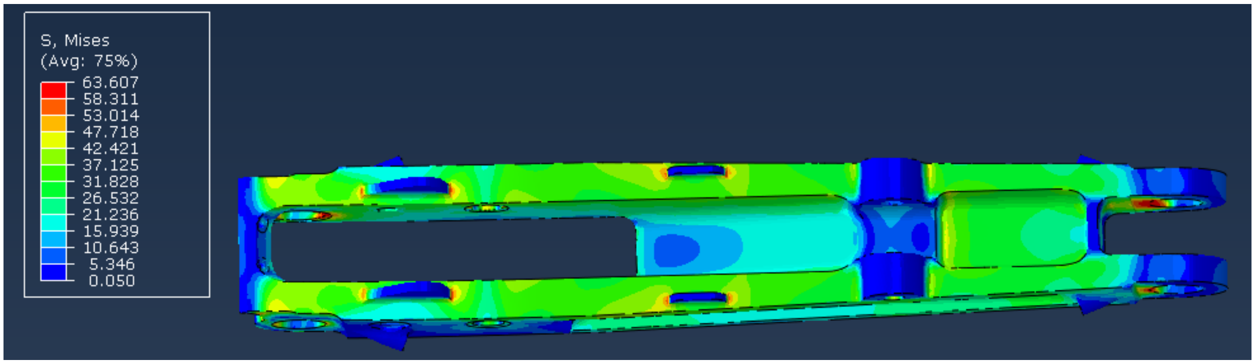
3.3) Results:



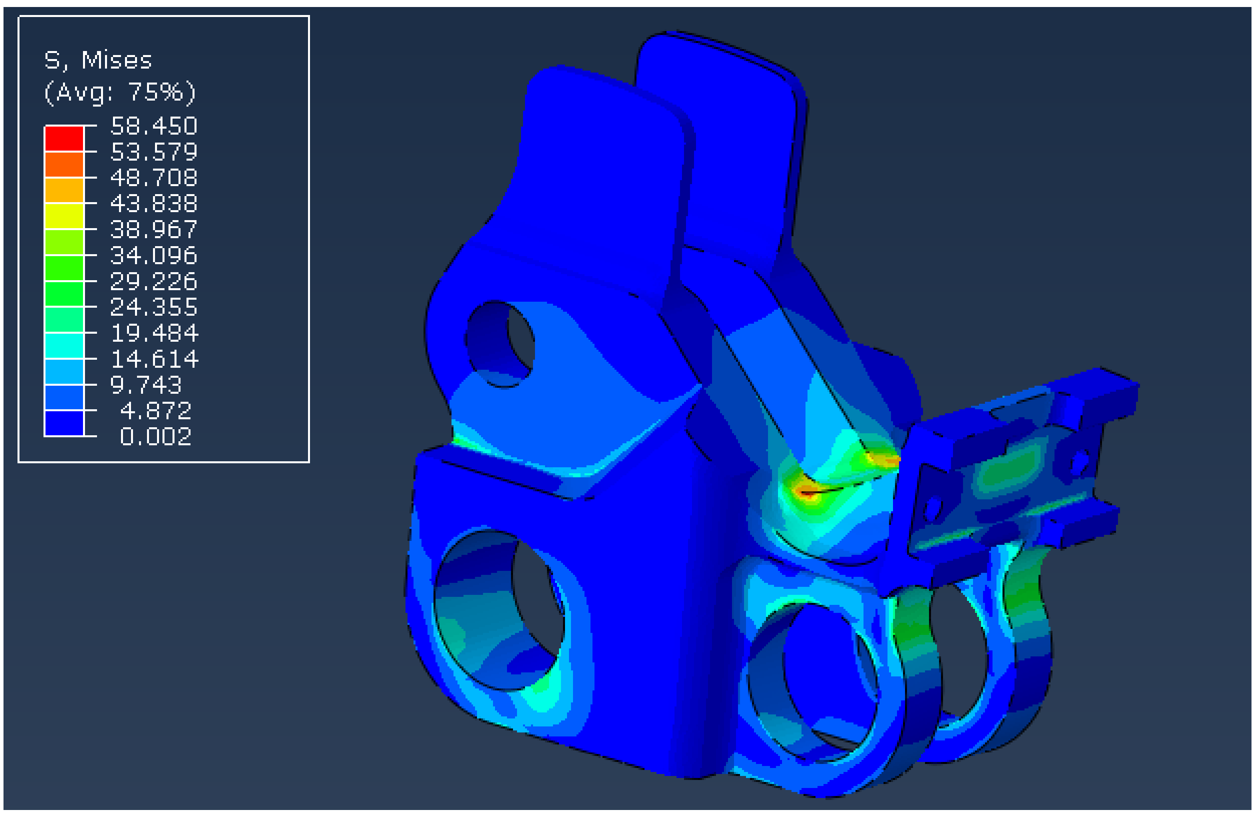
The above figure is the redesigned Lower Drag Brace. The stress levels in critical areas have been reduced enough to be comfortable with. Reinforcing certain areas and increasing the wall thickness with minimal weight gain allowed for this. The overall stress did go up, but that is a contact stress that was determined to not be a real stress. Thus, we can ignore this.

Section cuts of the Lower Brace were also taken at critical locations to check the strain. This was done for the test lab to detemrine where strain gauges need to be placed during actual test conditions. The strain was not significant but we need to make surethat the FEA, hand calcs, and actual test data all correlate.

MS = (280 ksi / 204 ksi) -1 = 0.373 Ultimate

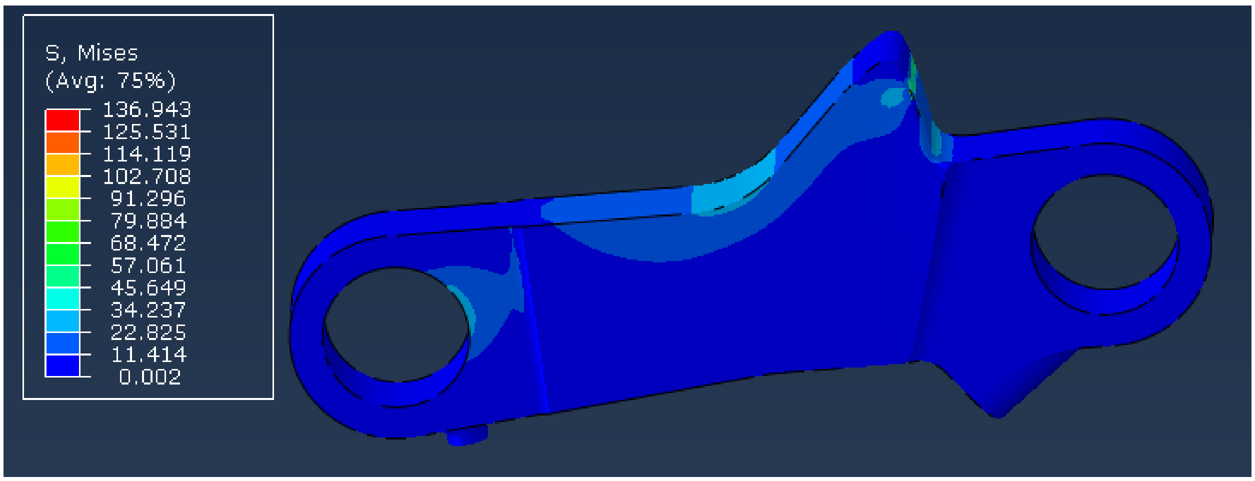


Material was also added to the pocket on the Upper Drag Brace and the lugs were thickened a small amount. As we can see, the high stress areas were reduced and the real stress levels are not very high relative to the material of the brace. The upper lugs see the highest stress but it is still below the ultimate strength of Aluminum (66ksi) at ultimate load conditions. Also, there is some contact stress again that gets ignored.



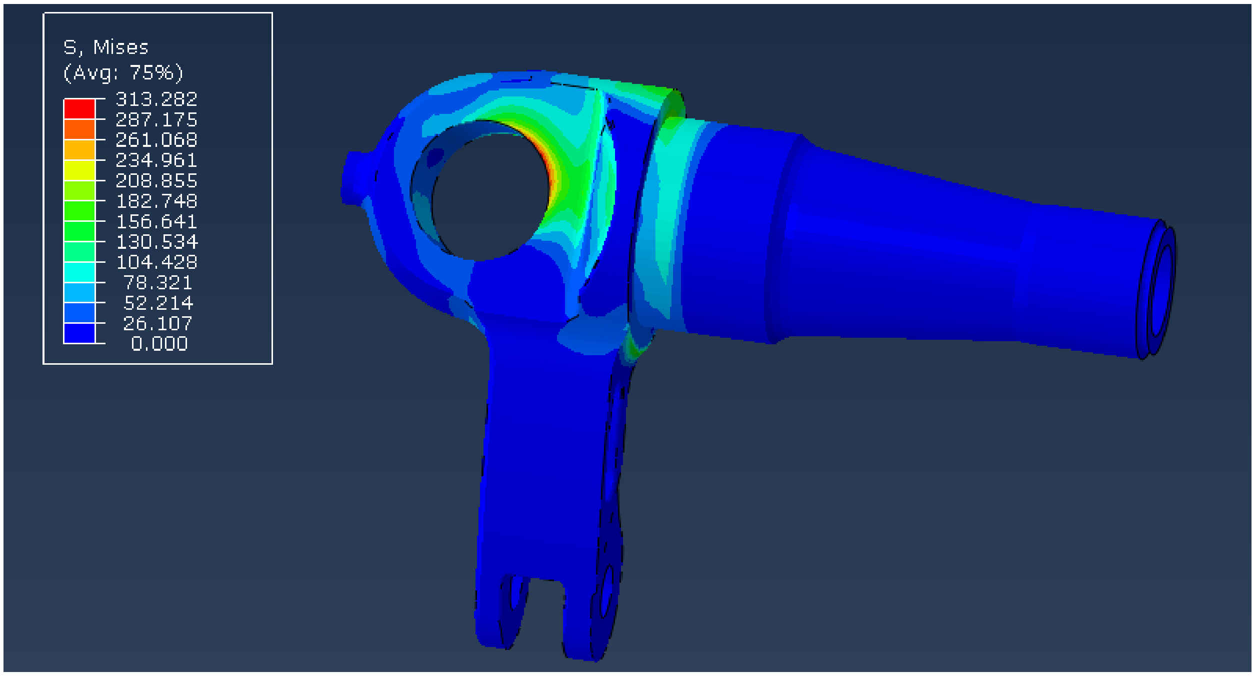
While there was not a stress concern for the Toggle in the initial design, due to the changes made, it did need checked again. The stress remained well below the ultimate strength of the material. Stress levels actually decreased in the new design. Weight also decreased.

MS = (201 ksi / 59 ksi) – 1 = 2.41 Ultimate



There was not a stress concern for the link either and the stress distribution plot above shows only a small stress as expected. Based on the stress seen, there were high margins again.

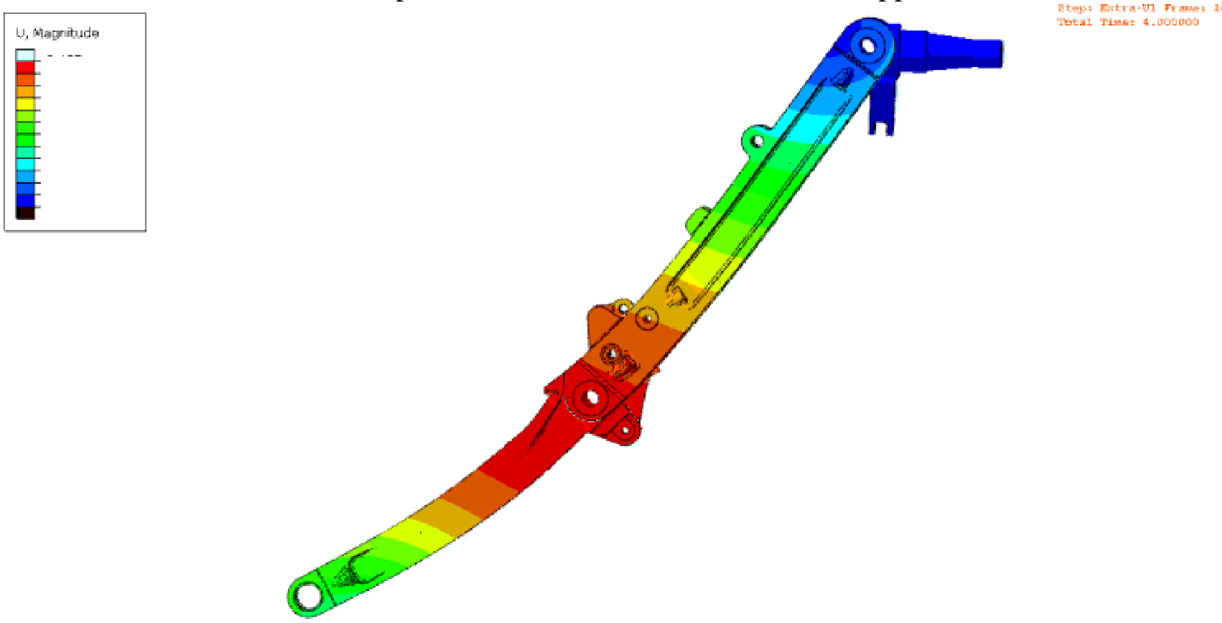
MS = (201 ksi / 137 ksi) – 1= 0.467



The above plot shows the stress plot for the Upper Spindle Pin. The only stress that exceeds this components ultimate strength was determined to be a contact stress that does not actually exist. Otherwise, stress remains acceptable. This area was further tested with what are known as submodels. Utilizing global model result files with a specific, small scale model of just a local area; the Upper Spindle Joint for example, we were able to determine the actual stress, deflection, and strain in this area.

After running these submodels and obtaining the local results, the part was approved in this current design.

Nominal Over Center with Compressive Load and Positive Moment applied



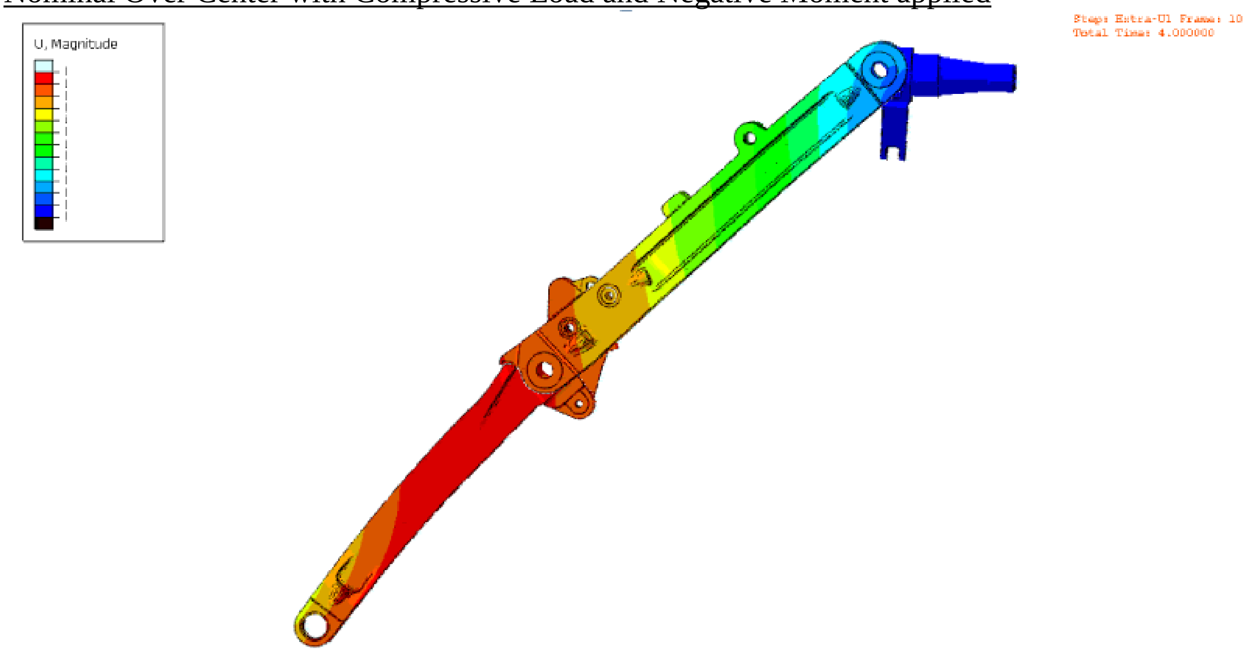
This condition was run with a moment and force applied on the Lower Brace lug center points evenly distributed between the two points. This is the same load and boundary condition set up as in the initial revision of this model. Multiple load steps were included in the FEA, those being Stabilization, Limit, Ultimate, and Extra Ultimate (150 % Ultimate load). The purpose of the stabilization step is to close any gaps among parts and actually start contact. It is just a small percent of the ultimate load, normally 10-20 %, which helps to establish contact. The model is then put through Limit, Ultimate, and Extra Ultimate load levels to ensure that it can survive the full spectrum of loading it will see plus additional load so that is designed with built in margins.

Depending on the load condition, signs may have changed but the absolute value of the applied force or moment remained the same. The force at ultimate level was 125 kips split between two load points so about 62 kips per lug. The applied moment at ultimate was 22 inch – kips, also split in half and applied at each lug. For this first condition, the load was compressive so negative and the moment was positive.

The critical location for this model is the Apex joint; the joint that holds the Upper and Lower Drag Braces together. Deflection is the primary concern for this area. From the FEA results, we see that the max deflection is somewhat high relative to Collins stress guidelines but still an acceptable value. The Apex center deflection can be calculated based on the following equation:

Deflection at Apex Center = Over Center + FEA max deflection

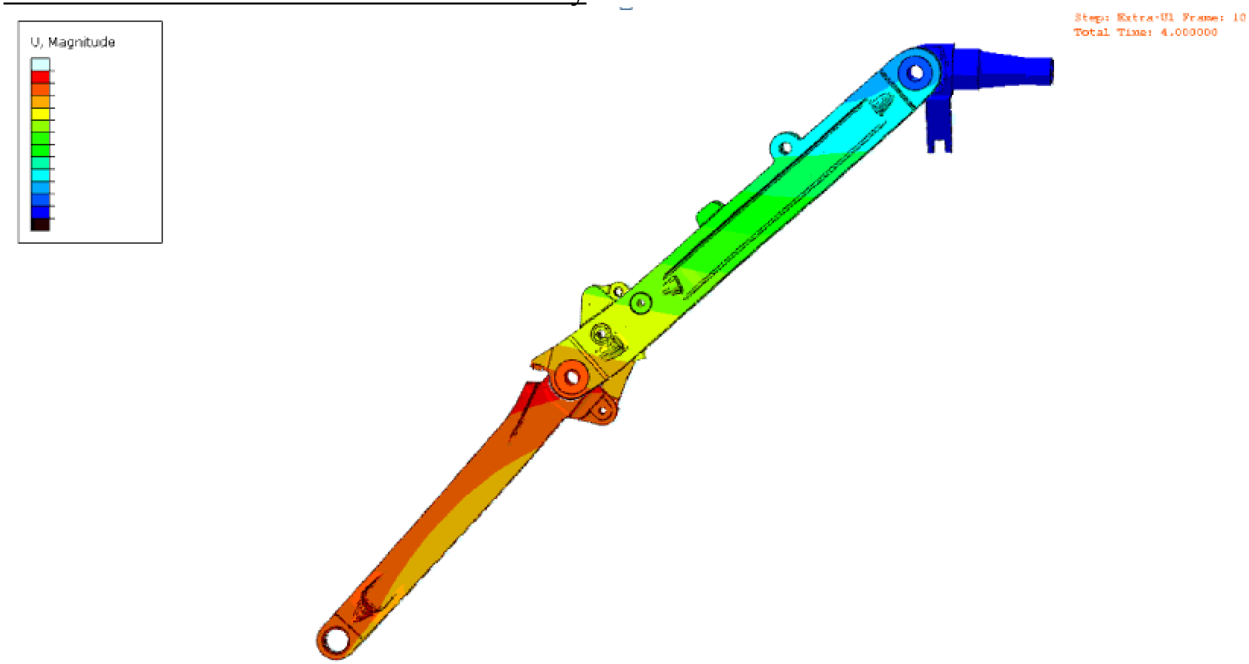
<u>Nominal Over Center with Compressive Load and Negative Moment applied</u>



Under these loading conditions, the model sees a negative compressive force and a negative moment split between the two Lower Brace lug center points. These values are the same as the previous condition. The max deflection at the apex center was not that significant in this case. Again, the main concern is the Apex Center deflection and using the equation:

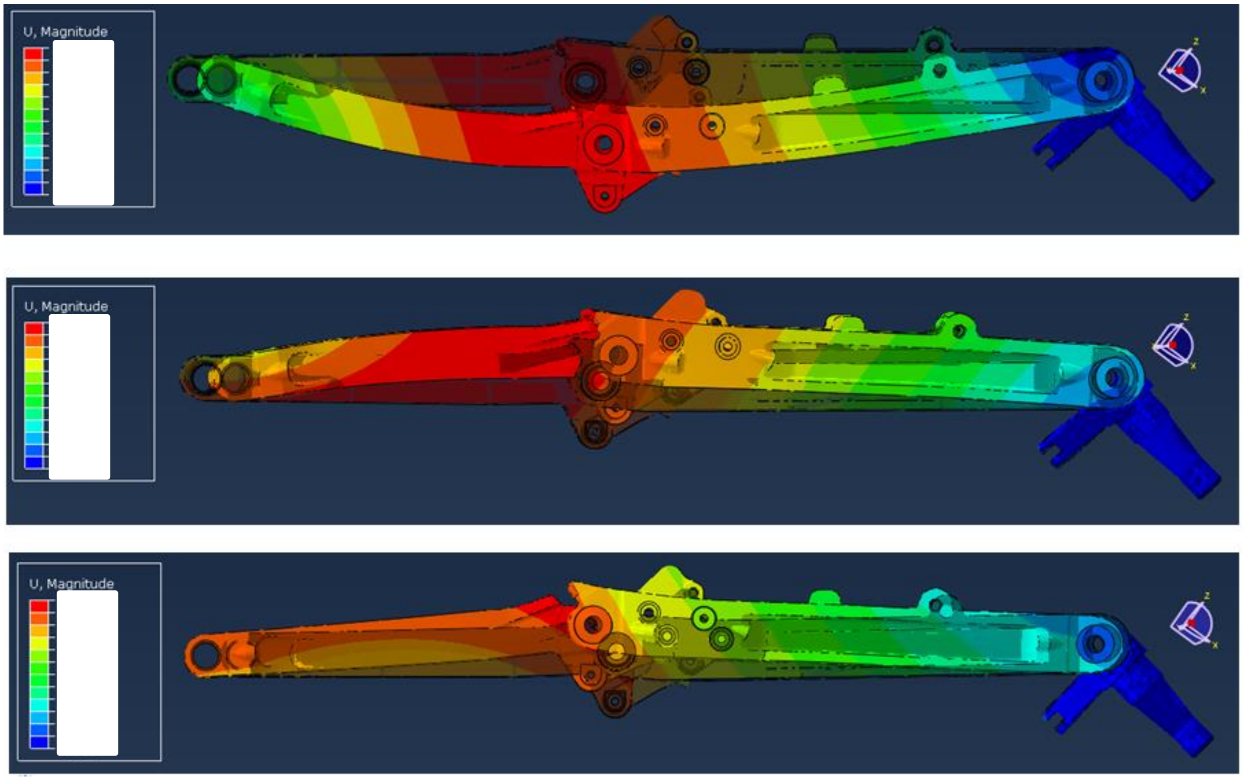
Deflection at Apex Center = Over Center + FEA max deflection

Nominal Over Center with Tensile Load only



This condition is a bit different from the other tested as there is purely tension load applied. The same method of splitting the load and applying it between the LDB lugs is used, resulting in a force of 62 kips applied on each lug, but in the positive direction. This causes a pulling effect on the lower brace which is quite obvious in the above figure. This is a critical case to look at as the Apex Joint is what holds the entire assembly together. Using the same equation to calculate total deflection gives the value needed to see whether it is acceptable or not. Max deflection remains under half an inch which is more than acceptable.

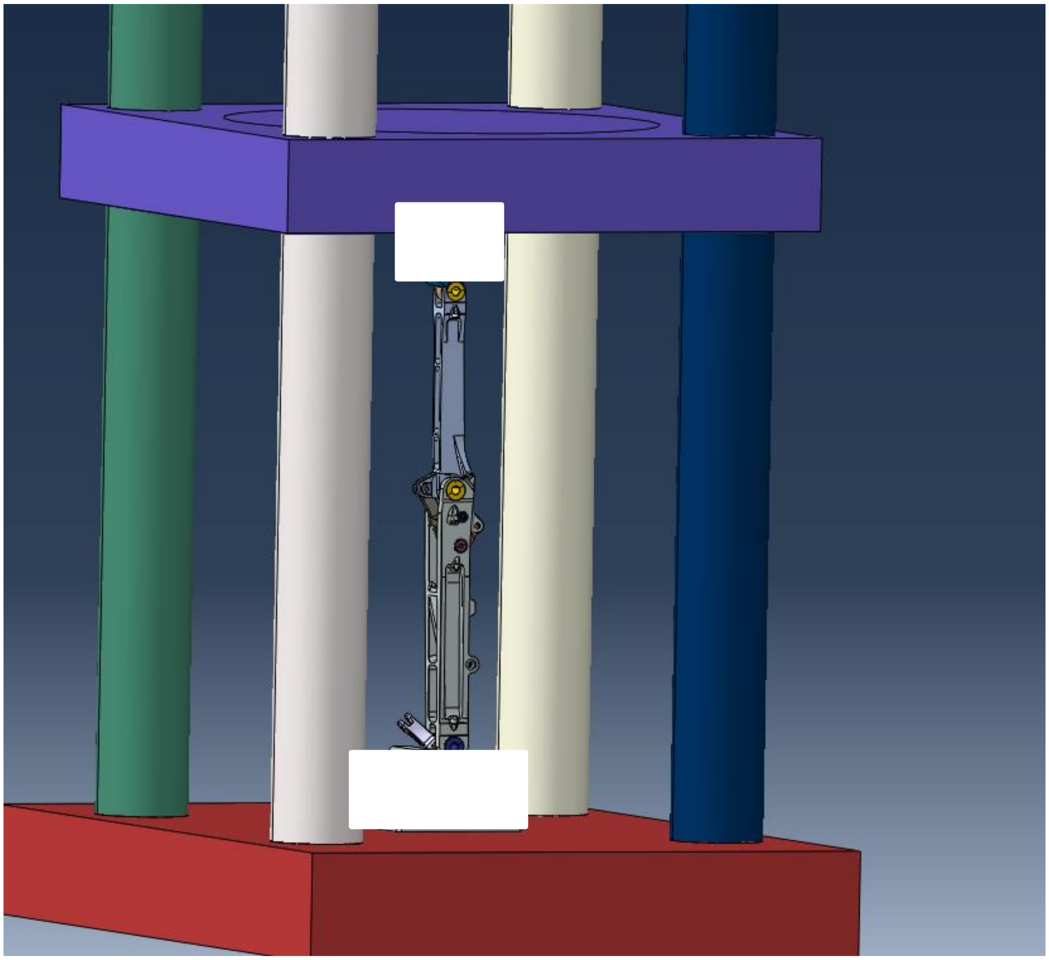
Deflection at Apex Center = Over Center + FEA max deflection



The above figure is a comparison of the three cases and their respective deflections at ultimate conditions. When analyzing the new revision Drag Brace model, it was decided that only the nominal over center position would be looked at. This was because the previous iterations showed that it was the most critical of the three over center positions.

4.0) Looking Forward

As stated before, the Drag Brace is moving to the test phase next. Over the course of working on this project, manufacturing of components has begun and the physical testing is planned. The stress group here has to support our test facility in Canada with FEA models and some other structural analysis.



I am in the process of building a model that has the entire Drag Brace model as well as all of the test hardware that will be installed during the actual testing process. There are several tests that will be performed including a drop test of the Brace. The test fixture components need to be checked that they will pass certain loading conditions that will be experienced during testing. I have to compile some data from my FEA results that will be passed on to the test engineers including displacements at certain locations and max deflection of some components. There are a variety of reasons that so much work has to be done before actually testing one of which is that various sensors and gauges need to be placed on the gear to measure data.

This is what I will continue to work on until I eventually have to leave for Officer Candidate School for the Navy. It will be the culmination of many months' work and a great technical experience to have gone through and ended my time at Collins Aerospace with.

5.0) Conclusions

After going through the initial design phase, the analysis phase, and the redesign phase, manufacturing of the parts could begin. Once the entire Drag Brace is manufactured, assembly can begin at the test lab and the physical testing can begin. We are currently entering this phase, as support for the test lab with FEA models, as well as MRB support is being provided. Oftentimes during manufacturing, individual parts will be created with small defects. Sometimes, these defects are not critical and the part can still be used, whether as a spare or for test purposes. CAD models of these incorrect parts are developed then FEA can be run on them to determine if they are usable or not. Currently, that is where this program is at and we are gearing up for testing.

By the end of this project, each component of the Drag Brace assembly had been heavily modified. While stress concerns generally drive design, weight starts to come into play. When looking at the Upper and Lower Brace, the large pockets in the side of the model are primarily for weight savings purpose. If parts can be designed using less material and still pass stress requirements then that is the most optimal design. Each main component in the Drag Brace assembly was designed in that manner and after going through multiple phases, each was determined to be sufficient given the requirements. All of the parts were designed to a point that stress, deflection, and strain were within tolerable limits. FEA was the most effective way to see the effects that certain design changes caused on the part. It is difficult to design components that need to be extremely strong while limiting weight, but utilizing FEA, Catia, and classical hand calculations, effective designs were able to be created.

6.0) References

-Young, Warren Clarence., et al. Roarks Formulas for Stress and Strain. McGraw-Hill, 2012.
-Collins Aerospace Internal engineering manuals
-Customer documents