DESIGN OF A MANUAL TANK DRIVE SYSTEM FOR A MOBILE SCAFFOLDING UNIT

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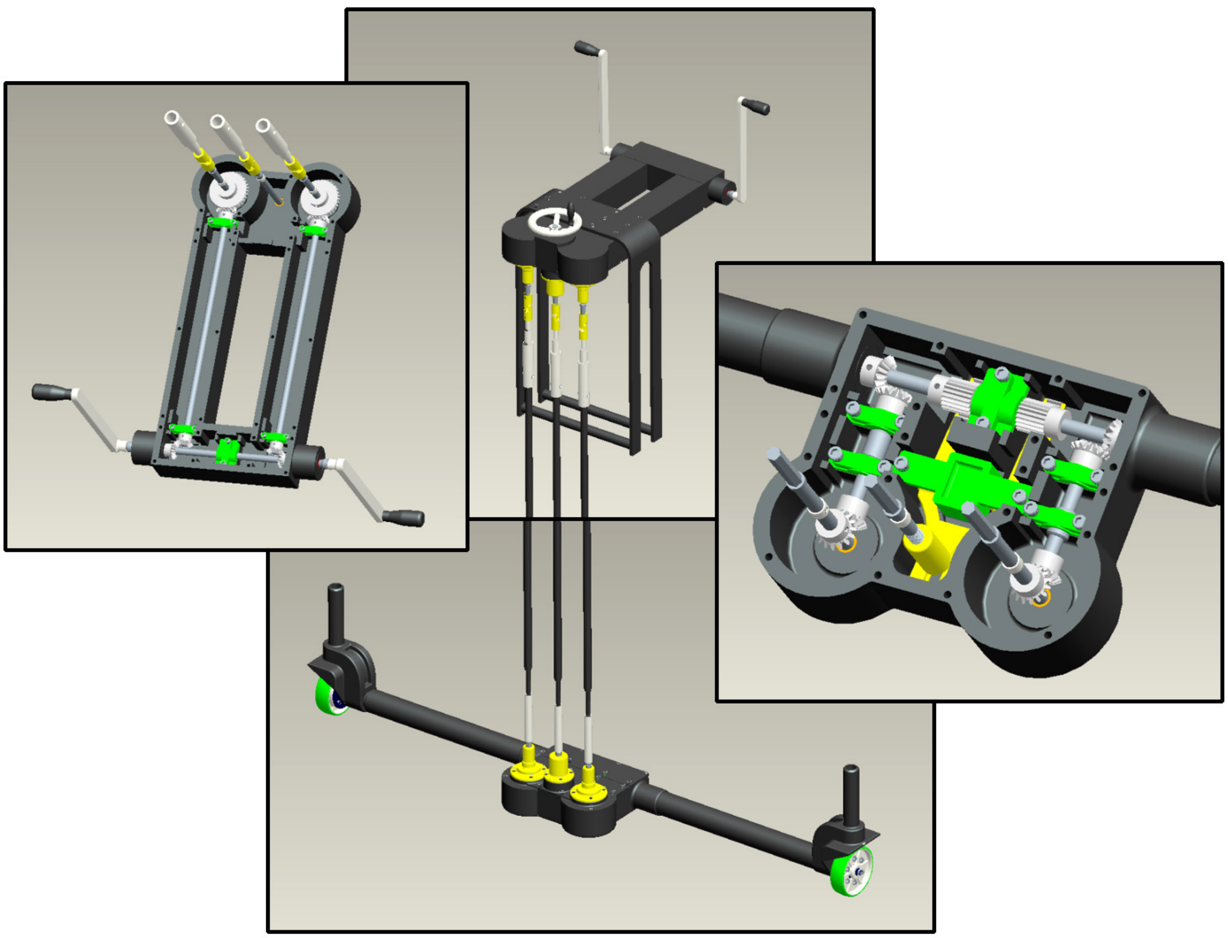

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EXECUTIVE SUMMARY

This report presents the design of a manual tank drive system designed to address the following problem; Mobile scaffolding units allow work to be carried out on elevated platforms and are mounted on lockable wheels so that they may be repositioned. If a single worker is utilizing a mobile scaffolding unit and needs to reposition the unit the worker must repeatedly descend to the ground to reposition the unit. If the type of work being carried out requires frequent repositioning of the scaffolding unit this procedure is impractical for the worker. The problem at hand was how to enable the worker to safely reposition the scaffolding unit from the elevated platform. It was important that the worker be able to move, steer, and lock the scaffolding unit in accordance with relevant OSHA standards. It was also important that the existing features of the scaffolding unit were preserved.

The drive system designed to address this problem consists of three parts; the *chassis assembly*, the *sky shafts*, and the *input assembly*. The chassis assembly replaces two of the four freely rotating casters on a scaffolding unit with two wheels fixed in the same direction and connected to a gearbox. Motion is transmitted to each wheel through the gearbox from a set of drive shafts referred to as *sky shafts*. The sky shafts travel up the side of the scaffolding unit to the input assembly and are composed of multiple sections that are pinned together. This allows the sky shafts to change in length if the scaffolding unit changes in height. The input assembly transfers motion from two manual hand cranks to the sky shafts and, subsequently, to the wheels. This allows the two wheels to be driven in the style of a tank where one wheel moves faster than or in the opposite direction of the other in order to steer. The entire drive system has a power ratio of two to one effectively doubling the input torque at the hand cranks and halving the rotational speed of the hand cranks. With a rotational input of approximately 50 rpm a forward speed of approximately 6 inches per second can be achieved. With an input torque of approximately 175 ft-lbf the maximum required torque at the wheels of 350 ft-lbf can be achieved. In addition to the two previously mentioned, a third sky shaft is connected to a hand wheel at the input assembly and actuates a locking mechanism in the gearbox of the chassis assembly. This effectively allows the scaffolding unit to be secured in place when it is not in motion. It cannot, however, act as a brake in the event of a runaway.

The design was based entirely on the maximum torque required at the wheels to overcome the effects of static friction and initiate movement of the scaffolding unit. Critical assumptions were made concerning the weight and dimensions of the scaffolding unit, from which the maximum required torque and the gear ratios were determined. The detail design of the critical drive system parts was confirmed and revised through Finite Element Analysis. In most of the analyses the total design factor exceeded a value of six with most being several multiples higher. The exceptions to this total design factor involved the presence of stress concentrations on some of the parts or the simulation of loadings that are more severe than those likely to be encountered in practice. The principal advantages of the design include the ability to disassemble the drive system as well as to disengage the sky shafts from the gearbox so that the scaffolding may be moved from the ground in a traditional manner. The principal disadvantages of the design include the neglect of shock and fatigue effects and the 66 pound weight of the input assembly that must be lifted to the elevated platform during assembly of the scaffolding unit and drive system. Overall, the design successfully addressed and solved the problem described.

INTRODUCTION

This report presents the design of a manual tank drive system for a mobile scaffolding unit. This introduction provides a description of the problem addressed by the design.

Problem Description

Scaffolding units allow work to be carried out on platforms at elevated heights and can be disassembled and reassembled at different work sites. Mobile scaffolding units are mounted on lockable wheels so that they may be repositioned. Depending on the height and footprint of a scaffolding unit it may also incorporate outriggers to prevent it from tipping over. If a single worker is utilizing a mobile scaffolding unit and needs to reposition the unit the worker must descend to the ground, unlock the wheels, reposition the unit, lock the wheels, and ascend to the platform. If the type of work being carried out requires frequent repositioning of the scaffolding unit this procedure is impractical for the worker. The problem addressed by the design was how to enable the worker to safely reposition the scaffolding unit from the elevated platform. It was important that the worker be able to move, steer, and lock the scaffolding unit. It was also important that the existing features of the scaffolding unit were preserved, such as its ability to be disassembled and its ability to be relocated in a traditional manner by a worker on the ground.

Problem Background

The problem described may be encountered whenever a mobile scaffolding unit is employed for relatively quick work over a large area and it is undesirable to task extra workers with pushing the unit around. Examples might include hanging or focusing lighting instruments in a theater or conducting work like painting or electrical installation across an expansive ceiling. Research found no products currently on the market for adapting an existing mobile scaffolding unit for movement by the worker from the elevated platform. While there are many OSHA and ANSI standards relating to scaffolding and elevated platforms there are a few standards of particular relevance to the problem described. According to OSHA 1926.452(w)(2) scaffold casters and wheels must be locked to prevent movement of the scaffold while it is being used in a stationary manner. According to OSHA 1926.452(w)(6)(i) and (ii) “employees shall not be allowed to ride on scaffolds unless the surface on which the scaffold is being moved is within 3 degrees of level and the height to base width ratio of the scaffold during movement is two to one or less.” Finally, according to OSHA 1926.452(w)(6)(iv) “when power systems are used, the propelling force is applied to directly to the wheels, and does not produce a speed in excess of 1 foot per second.” The requirements contained within these OSHA standards have important implications for design used to address the problem described.

Project Scope

Given the various aspects of the problem described the scope of the project had to be limited in order for the design to reach completion. The project focused on achieving movement of a scaffolding unit via two wheels driven tank style from the elevated platform of a scaffolding unit the other two wheels being standard freely rotating casters. The project also focused on being able to adequately lock the driven wheels from the elevated platform. The project did not address the subject of outriggers as mentioned in the OSHA requirements on height to base width ratio. The responsibility of properly employing outriggers, depending on the scaffolding height, was left to the worker. Additional aspects and implications of the project scope will be discussed in the advantages and disadvantages of the design, which is presented and described in detail in the following sections.

THE DESIGN

This section discusses the design of the manual tank drive system created to address the problem described in the introduction, which will begin with a detailed description of the design. The initial assumptions, constraints, and preliminary calculations that led to the design will then be described. Finally, the results of the FEA carried out on the critical parts will be presented.

Overview

The design of the manual tank drive system consists of three main parts. The first, referred to as the *chassis assembly*, replaces the two wheels on the narrow side of a scaffolding unit with a rectangular foot print. The chassis assembly is shown in Figure 1. The vertical posts above each wheel in Figure 1 are inserted into the vertical tubes of the scaffolding unit after its existing wheels have been removed. Gravity holds the scaffolding down on the vertical posts securing the chassis assembly in place. The chassis assembly consists of two wheels connected to a gearbox that is mounted halfway between them. The gearbox transmits motion to the wheels from the second part of the drive system, referred to as the *sky shafts*.

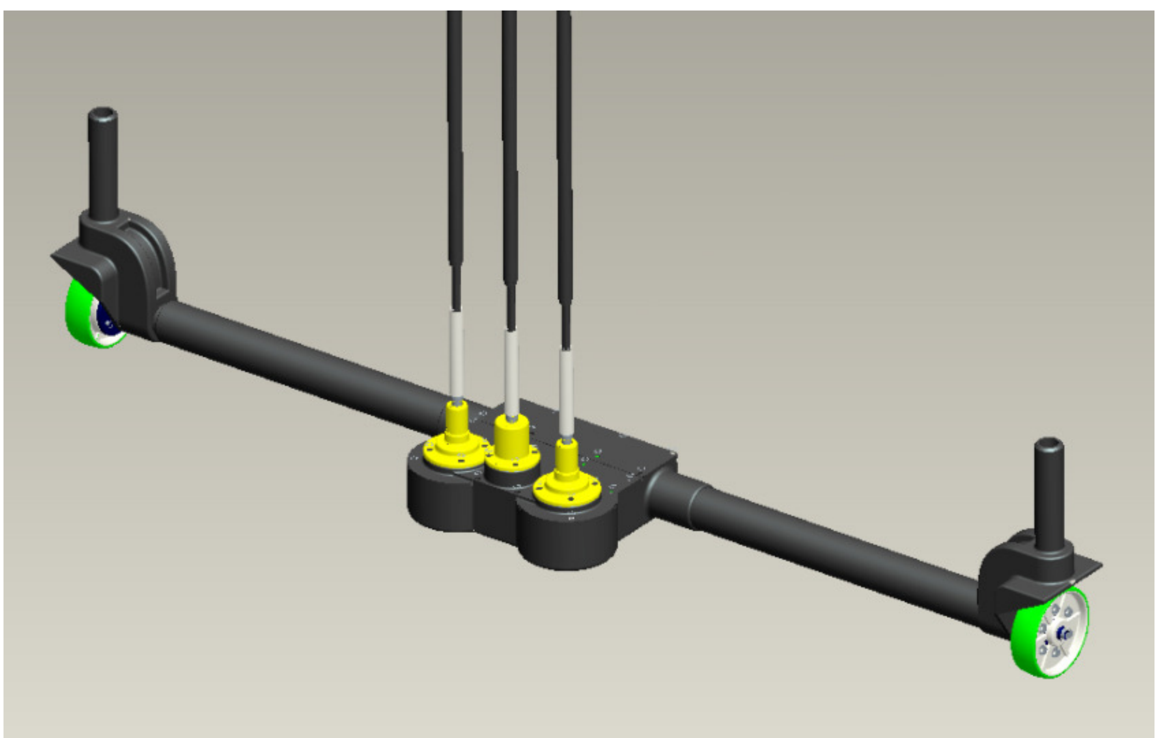

Figure 1 – Chassis Assembly

The sky shafts consist of three modular drive shafts that can be shortened or lengthened depending on the height of the scaffolding unit. The two outside sky shafts transmit motion directly to the two wheels of the chassis assembly while the center sky shaft actuates a locking mechanism inside the gearbox of the chassis assembly allowing the scaffolding unit to be locked securely in place. The third part of the drive system is the *input assembly*, shown in Figure 2. The motion from the two outside sky shafts is transferred through the input assembly to two hand cranks, which allow the worker to manually input power. From the point of view of the worker the right hand crank drives the right sky shaft and subsequently the right wheel and the left hand crank drives the left sky shaft and subsequently the left wheel. This is referred to as a tank drive system because in order to turn the scaffolding unit one wheel must be driven faster than or in the opposite direction of the other wheel. The wheels themselves are not rotated in order to steer. The center sky shaft is transferred to a small hand wheel which allows the worker to actuate the locking mechanism in the gearbox of the chassis assembly down at the ground. The large mounting bracket seen in Figure 2 allows the input assembly to be slid over the tubes at the top of the scaffolding unit that are parallel to the ground. As long as the bracket slides over at least two of the scaffolding tubes the input assembly is secured in place without the need for fasteners.

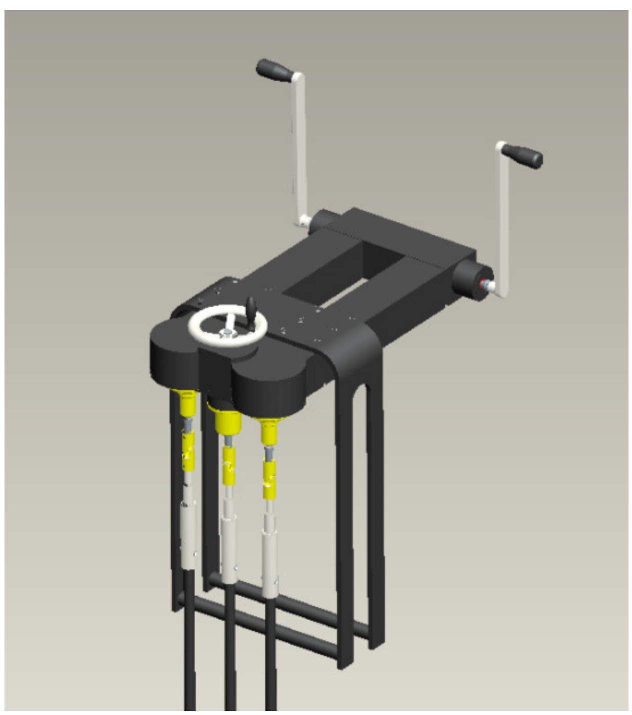

Figure 2 – Input Assembly

Input Assembly

The mechanism of the input assembly, shown in Figure 3, is mounted within a solid aluminum crankbox housing. Each hand crank is mounted to a crank axle via a press fit and set screw. The crank axles run through needle roller bearings (used throughout the design) and are fitted with gears that mesh in one to one ratios with gears fitted on the longer transverse shafts seen in Figure 3. Gears fitted to the opposite ends of the transverse shafts mesh in two to one ratios with gears fitted to the vertical shafts protruding from the crankbox housing. This effectively creates a power ratio in which the input torque is doubled while the input speed is halved. The vertical shafts terminate in single joint universals and couplers designed to connect to the sky shafts. The center vertical shaft seen in Figure 3 originates from the hand wheel mounted on the top of the crankbox housing and also terminates in a single joint universal and a coupler. The universals were included on the vertical shafts for two reasons. First, they allow for slight misalignment between the input assembly and the chassis assembly. Second, they allow the sky shafts to be angled away from the gearbox of the chassis assembly when they are disconnected. This will be discussed further in the following section on the sky shafts.

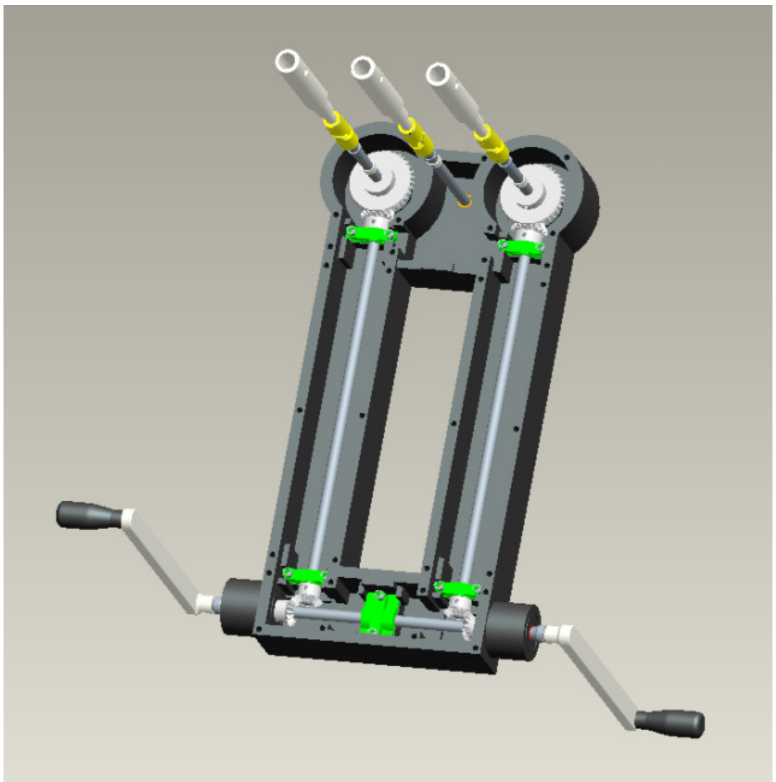

Figure 3 – Input Assembly Mechanism

Sky Shafts

Each sky shaft is a modular drive shaft that can be lengthened or shortened by adding or removing sections. This allows for a variable height of the scaffolding unit. Each section of sky shaft has a male and female end and is connected to the next as shown in Figure 4 using a pin. In an identical manner a pin is used to connect the sky shaft to the coupler of the input assembly, as in Figure 2. The section of sky shaft that connects to the gearbox of the chassis assembly has a unique design. This section has two male ends, one with the usual circular shape for connection to the next sky shaft section and one with a hexagonal shape that lines up with the hexagonal shafts protruding from the gearbox of the chassis assembly, as seen in Figure 5. Before lining up the hexagonal sky shaft end with the hexagonal gearbox shaft a hexagonal coupler is slid onto the sky shaft. Once lined up, the coupler is slid across the joint between the sky shaft and the gearbox shaft. This system allows for quick disconnect of the sky shafts from the gearbox of the chassis assembly. This is important because it is necessary to disconnect the input assembly from the wheels when the scaffolding unit is moved by workers on the ground, so as to avoid the hand cranks from spinning rapidly during movement. To keep the sky shafts out of the way during movement they may be angled at the single joint universals and tied to the tubes of the scaffolding unit. For a more detailed look at the sky shaft design refer to Assembly #3 and Detail #12 in *Appendix A-1: Design Drawings*.

Figure 4 – Sky Shaft Pin Connections

Chassis and Gearbox

As described in the overview, the chassis assembly replaces the two wheels of a scaffolding unit with a pair of wheels that are connected to a gearbox. The wheels are driven through the gearbox using the motion of the sky shafts originating from the worker at the input assembly. The wheel, shown in Figure 6, is mounted to a hub with six bolts. The hub is press fit onto an axle than runs through a structural tube to the gearbox. The gearbox, shown in Figure 5, serves as a structural connection between the structural tubes running from each wheel. Just behind the wheel a structural bracket is mounted to the structural tube that transfers the weight of the scaffolding unit from the vertical post seen in Figure 6 to the axle of the wheel.

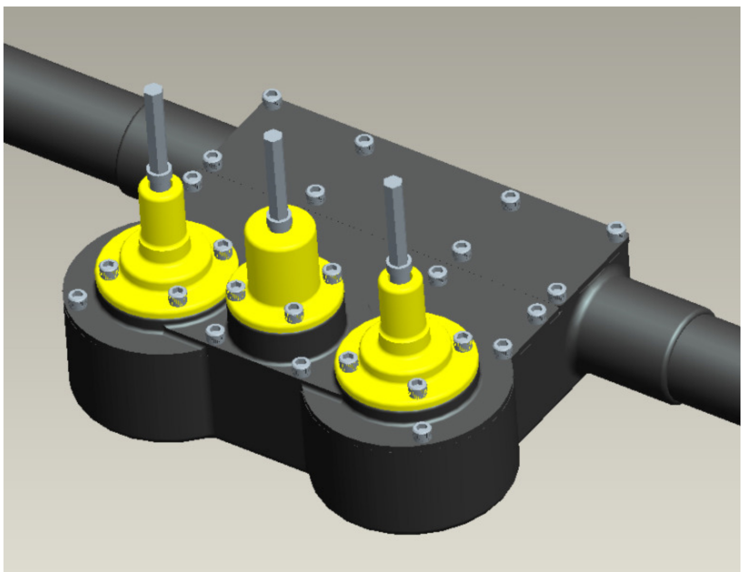

Figure 5 – Gearbox

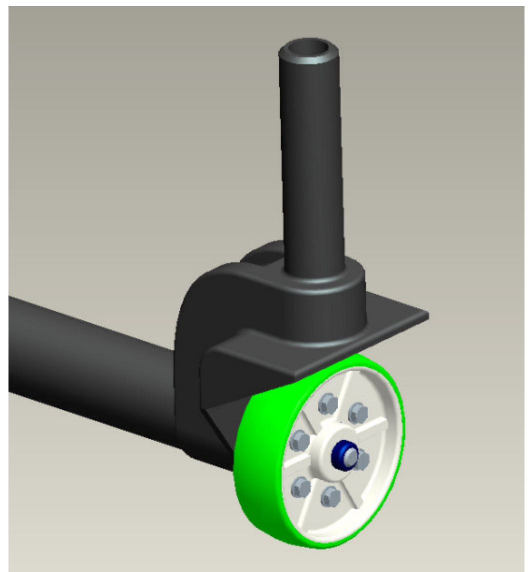

Figure 6 – Wheel Bracket

Like the crankbox mechanism, the gearbox mechanism, shown in Figure 7, is mounted within a solid aluminum housing. The two outside vertical shafts of the gearbox, which are connected directly to the sky shafts, are fitted with gears that mesh in one to one ratios with gears fitted on two short transverse shafts. This one to one ratio effectively preserves the two to one power ratio established at the input assembly. The other end of the short transverse shafts are fitted with gears that mesh in one to one ratios with gears mounted on the wheel axles, again maintaining the two to one power ratio established at the input assembly. The yellow parts shown in Figure 7, the center vertical shaft that connects to the center sky shaft, and the extra gear on each of the wheel axles, comprise the locking mechanism, which is shown in Figure 8.

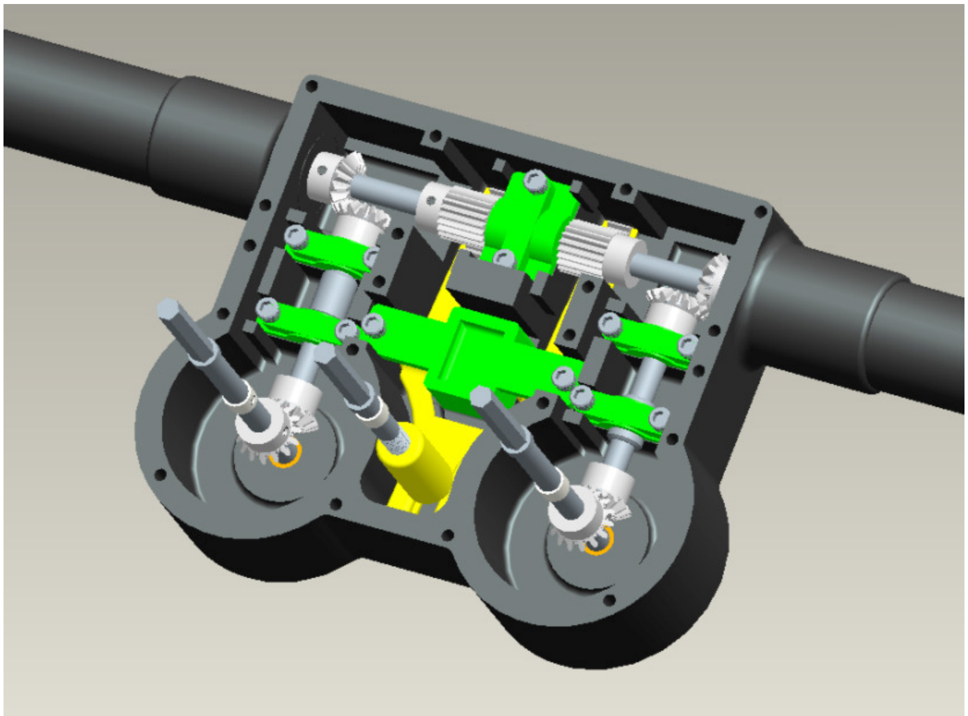

Figure 7 – Gearbox Mechanism

In Figure 8 all of the parts of the gearbox except for the parts of the locking mechanism have been hidden. Note the difference in orientation between Figure 7 and Figure 8. The center vertical shaft in the gearbox has a hexagonal end which, as previously described, connects through a coupler to the sky shaft. The other end is effectively a ½-13 UNC threaded rod that meshes with the threads on the cylindrical actuator seen in Figure 8. The vertical shaft is also fitted with a collar that maintains its position as it is rotated. This effectively causes the actuator to move up and down when the vertical shaft, the sky shaft, and the hand wheel of the input assembly are rotated. The actuator fits into the slot on a fork shaped locking lever. Movement of the actuator causes the lever to rotate about its axle. The end of the locking lever is fitted with a gear rack that meshes with spur gears on the wheel axles when the actuator is moved downward into the gearbox. When the gears are meshed the wheel axles are prevented from turning which effectively locks the scaffolding unit in place. It is important to note that the mechanism shown in Figure 8 is only intended to be engaged or disengaged when the scaffolding unit is not moving. An attempt by a worker to use the locking mechanism as a brake (during movement of the scaffolding unit) could cause serious damage to the components of the locking mechanism.

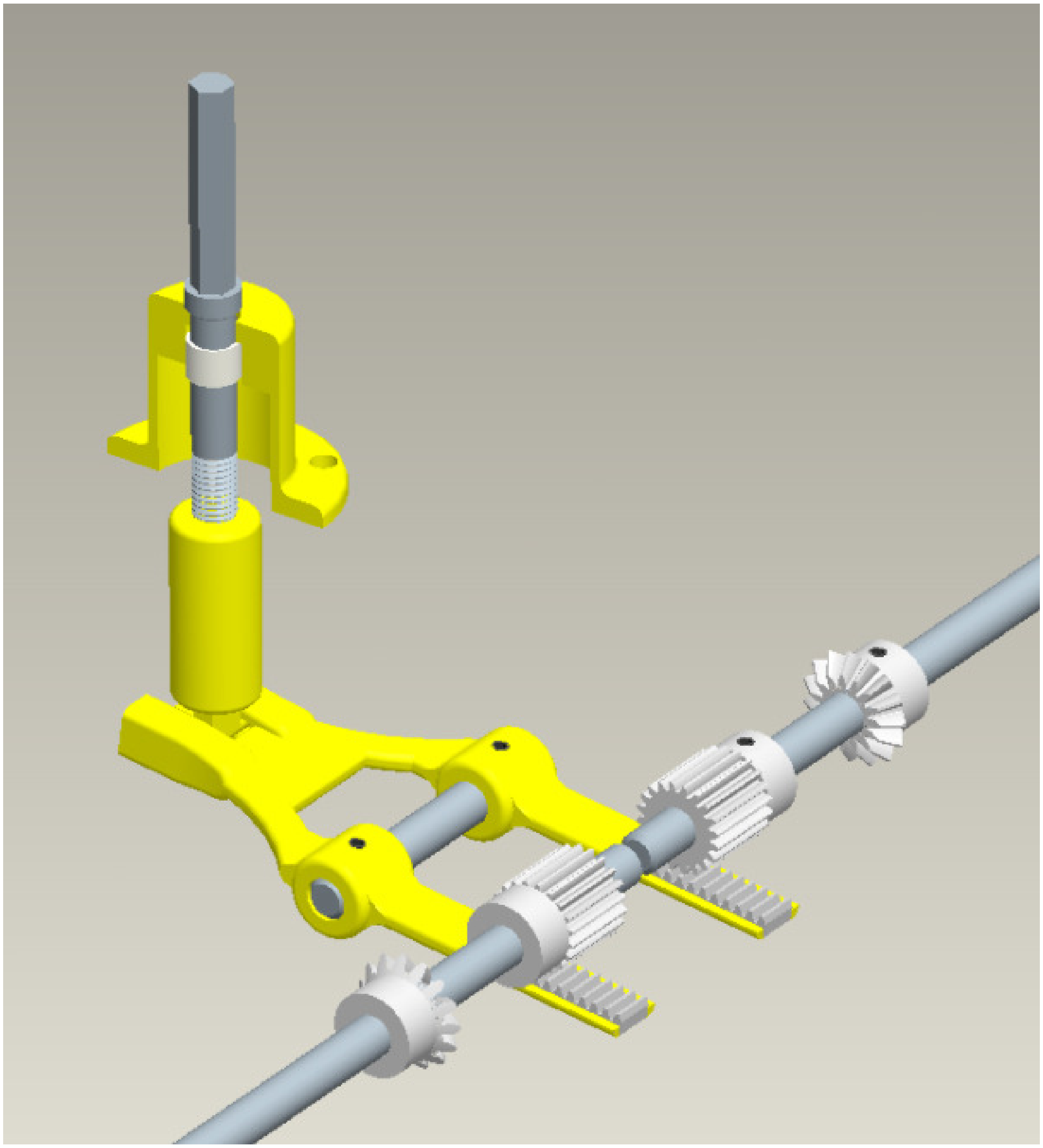

Figure 8 – Locking Mechanism

This concludes the detailed description of the design. The initial assumptions, constraints, and preliminary calculations that led to the design will be described next, followed by the results of the FEA carried out on the critical parts. For a more detailed look at the design refer to the assembly and detail drawings included in *Appendix A-1: Design Drawings*.

Assumptions and Calculations

Given the variation of mobile scaffolding units on the market and the applications in which they are used it was necessary to make critical assumptions about the scaffolding unit on which the design was based. As shown in Table 1, the maximum weight of the scaffolding unit was assumed to be 750 pounds. This assumption roughly accounted for the possibility that the scaffolding unit could be constructed of either aluminum or steel and could be as much as 20 feet in height. The maximum load assumed for each deck of the scaffolding was a typical 500 pounds. The maximum number of decks was assumed to be four, which allowed for two decks to compose the highest platform with two decks serving as intermediate platforms between the highest platform and the ground. Assuming even distribution over the four wheels of the scaffolding unit the maximum weight on each wheel was calculated, as shown in Table 1.

Table 1 – Calculation of Maximum Torque Required to Initiate Movement

A. Weight on each scaffold wheel

Scaffold Weight	750.00	Pounds
Maximum Load per Scaffold Deck	500.00	Pounds
Maximum Number of Decks	4	Quantity
Weight on Each Scaffold Wheel	687.50	Pounds

B. Torque to move a wheel

Coefficient of Static Friction Between Floor and Wheels	0.40	Unitless
Frictional Force Between Floor and Wheels	275.00	Pounds
Maximum Radius of Wheels	2.50	Inches
Torque at Wheel to Initiate Movement of Wheel	687.50	Inch Pounds
	57.29	Foot Pounds

C. Torque to rotate scaffold about center of the width

Width of Scaffold	5.00	Feet
Length of Scaffold	10.00	Feet
Distance from Center of Width to Opposite Corners	10.31	Feet
Moment About Center to Initiate Rotation	4209.64	Foot Pounds
Forces at Each Wheel Composing the Above Moment	1683.85	Pounds
Torque at Wheel to Initiate Rotation About Center	4209.64	Inch Pounds
	350.80	Foot Pounds

With the maximum weight on each wheel calculated it was then necessary to make critical assumptions concerning the wheels. The wheel radius was assumed to be 2.5 inches while the coefficient of static friction between the floor and the wheels was assumed to be about 0.4. This coefficient assumes that the wheels are composed of a tough material with a smooth surface, such as urethane, and that they sit on a smooth and level surface. Using the simple relationship between normal force and frictional force the 57 ft-lbf torque needed to initiate rotation of a single wheel was calculated, as shown in Table 1.

In order to determine the maximum torque required at the drive wheels of the scaffold it was necessary to identify the situation in which the frictional forces at the wheels would have the greatest effect on resisting the initiation of movement. The maximum torque required at the drive wheels was based entirely on the torque needed to overcome the effects of static friction because the effects of rolling friction would be significantly less once the scaffolding unit achieved movement. It was determined that the frictional forces at the wheels would have the greatest effect on resisting the initiation of movement when attempting to initiate rotation about the center point between the two drive wheels. The torque required to initiate rotation was calculated to be approximately 350 ft-lbf, as shown in Table 1. The equations used for the calculations summarized in Table 1 can be found in *Appendix A-3: Torque Calculations*.

With the maximum torque at the drive wheels calculated it was possible to determine the gear ratios that were required given a specific input torque at the hand cranks. The crank lever arm and maximum force to be exerted by the worker were selected to achieve a crank torque that would be a simple multiple of the required maximum torque at the drive wheels. This was done in parallel with the determination of the gear ratios employed in the input assembly mechanism and the gearbox of the chassis assembly. Details concerning these calculations and the trade offs between torque and forward speed can be found in *Appendix A-3: Torque Calculations* and *Appendix A-4: Gearing Calculations*. It was eventually determined that a total ratio of two to one would be employed to effectively double the torque input by the worker and halve the rotational speed of the hand cranks. As previously described, this ratio was achieved in the input assembly mechanism between the transverse shafts and the vertical shafts while all other gear ratios in the design remained one to one. It was also found that the maximum forward speed of the scaffolding unit had to be sacrificed for the ability to achieve the required maximum torque. With the total ratio of two to one a maximum rotational input speed of 60 rpm resulted in a forward speed of about 8 inches per second. Given a more realistic rotational input speed the forward speed of the scaffolding unit was around 6 inches per second. While this was only a third of the forward speed originally hoped for it was considered acceptable because it is still practical for conducting work, makes the overall movement of the scaffolding unit more safe by limiting the maximum forward speed achievable, and abides by the OSHA standards for forward speed.

FEA Results

In order to confirm and revise the detailed design of the various drive system parts Finite Element Analysis was carried out on the most critical of those parts. Table 3 lists the analyses carried out and the results of those analyses. Detailed results for each analysis can be found in *Appendix A-2: FEA Analyses*. Most of the parts required the application of at least the maximum torque required to initiate movement of the scaffolding unit. In an effort to include an initial design factor prior to the FEA the maximum torque was multiplied by a factor of ten, this is shown in the torque column of Table 3. To apply this torque in PRO/*Mechanica* cylindrical coordinate systems were added to the parts and forces were applied in the theta direction of those coordinate systems. The radius of each part and the resulting theta force required to create the 3500 ft-lbf torque are shown in Table 3. The loadings for many of the structural parts deviated from the theta force technique and are described in the loading notes of Table 3.

Table 2 – FEA Results

No.	Analysis	Radius (in)	Torque	θ Force (lbf)	Material	Yield (psi)	FEA Max (psi)	Design Factor	Total Factor
1	RushGears B1218-2	1.5	3500	194	AISI 4130	52200	1560	33.46	**43.46**
2	RushGears M1215B	1.25	3500	233	AISI 4130	52200	2252	23.18	**33.18**
3	RushGears B1218-2	3	3500	97	AISI 4130	52200	908	57.49	**67.49**
4	Gearbox Transverse Shaft	0.25	3500	1167	AISI 1040	72500	4768	15.21	**25.21**
5	Sky Shaft Lower Section	0.5	3500	583	2024-T4	42000	7226	5.81	**15.81**
6	Sky Shaft Upper Section	0.5	3500	583	2024-T4	42000	1627	25.81	**35.81**
7	Sky Shaft Coupler	0.75	1750	194	440A SS	51300	39300	1.31	**6.31**
8	Sky Shaft Pin	0.375	3500	778	440A SS	51300	32770	1.57	**11.57**
9	Wheel	1.25	3500	233	6061-T6	40000	684	58.48	**68.48**
10	Wheel Hub	1.25	3500	233	6061-T6	40000	5281	7.57	**17.57**
11	Gearbox Housing	n/a	n/a	n/a	6061-T6	40000	**26840**	**1.49**	n/a
12	Wheel Bracket	n/a	n/a	n/a	6061-T6	40000	3054	**13.10**	n/a
13	Chassis Assembly	n/a	n/a	n/a	6061-T6	40000	**24210**	**1.65**	n/a
14	Locking Gear	0.5	3500	583	AISI 4130	52200	25906	2.01	**12.01**
15	Locking Lever	n/a	3500	n/a	AISI 1040	72500	**70103**	**1.03**	**11.03**
16	Locking Lever Actuator	n/a	3500	n/a	440A SS	51300	11490	4.46	**14.46**
17	Input Assembly	n/a	n/a	n/a	6061-T6	40000	**36910**	**1.08**	n/a
18	Crank	n/a	n/a	n/a	AISI 1040	72500	**4870**	**14.89**	n/a

Loading Notes

11	1374 lbf applied downward with 1683 lbf applied each side to create moment
12	687 lbf applied downward with 1683 lbf applied to simulate moment
13	687 lbf applied downward with 1683 lbf applied each side to create moment
15	583 lbf applied across gear teeth toward axle
16	583 lbf applied upward (assuming all force from the locking gear is transferred across the lever)
17	1000 lbf applied downward between crank handles
18	150 lbf applied downward on handle

Summarized in Table 3 are also the maximum Von Mises stresses, the design factors based on the yield stresses of the materials, and the total design factors taking into account the factor of ten multiplying the original maximum torque. The maximum stresses shown in red indicate that they were accepted as the maximum stresses even though there may have been significantly higher stress concentrations that could not be eliminated given the nature of the analysis or the design of the part. Acceptance of the values in red indicate that the basic design of the part was appropriate but further revision of the detailed design is necessary to eliminate stress concentrations. The detailed FEA results for the analyses in question can be investigated in *Appendix A-2: FEA Analyses*.

In general the design factors resulting from the FEA were quite acceptable. With the exception of analyses 11, 13,15, and 17 all of the design factors exceeded a value of six. It is important to note that in analysis 11 the forces applied to the gearbox would not likely be encountered in practice. The forces applied simulated the effect of applying maximum torque to the wheels while the gearbox was fixed from moving. In practice it is unlikely that the gearbox would ever be fixed from moving. The same conclusions apply to analysis 13, which simulated the same effect as analysis 11 but on the gearbox and axle tubes instead of the gearbox alone. Analysis 15 simulated the effect of transferring all of the maximum torque from the spur gears on the wheel axles to the teeth of the gear rack on the locking lever. This situation would only occur in practice if the maximum torque were accidentally applied at the hand cranks with the locking mechanism engaged. This obviously should be avoided but could occur by accident so additional revision of the locking lever mechanism could be conducted to improve the results. Finally, analysis 17 simulated a weight of 1000 lbf being applied to the top of the crankbox housing between the two hand cranks. A force of this kind is also not very likely to occur in practice unless a worker were to shockingly apply their body weight to the housing. With the exception of these four analyses the design factor results were generally quite good.

It is important to remember on what the design, and subsequently the loads applied in the FEA, are based; the maximum torque required to initiate rotation of the scaffolding unit about the point directly between the drive wheels. The design does not take into account gross negligence on the part of the operator, which could lead to shock loads being applied to the chassis assembly or the sky shafts in the event of a collision of the scaffolding unit with a fixed object. Shock loads could also result from the operator attempting to start or stop movement of the hand cranks in a very sudden manner. Fatigue was also neglected in the design due mainly to the extremely low revolutions per minute experienced by all of the rotating parts and the low accumulation rate of stress cycles under intended operating conditions. The various advantages and disadvantages of the design will be discussed in further detail in the next section.

DISCUSSION

This section discusses the advantages and disadvantages of the design just described. While the design could be decomposed in great detail only the most significant advantages and disadvantages of the design will be addressed here.

Advantages

There are many advantages to the design of the manual tank drive system presented in the previous section. Most importantly, the design fulfills the basic requirements of enabling movement of a scaffolding unit via two wheels driven tank style from the elevated platform. Though it could be argued that the propelling force is not applied directly to the wheels because it is input at the elevated platform it is certainly transferred directly to the wheels of the scaffolding unit, as required by OSHA 1926.452(w)(6)(iv). Even with the most energetic cranking of the hand cranks it would be difficult for a worker to exceed the 1 foot per second speed requirement specified in the same OSHA standard. In keeping with OSHA 1926.452(w)(2) the drive wheels may be locked from the elevated platform when it is being used in a stationary manner.

One particular advantage of the design is its ability to be disassembled along with the scaffolding unit itself. The sky shaft sections can be easily dismantled, the input assembly lowered to the ground, and the chassis assembly removed once the rest of the scaffolding unit has been disassembled. The design of the connections between the sky shafts and the gearbox of the chassis assembly is also advantageous because it allows the sky shafts to be easily disconnected. This is important because it allows the scaffolding unit to be pushed in a traditional manner from the ground without causing the hand cranks to spin wildly during the movement. It should also be noted that a simple tool could be devised to allow a worker to engage the locking mechanism of the gearbox while on the ground. This would allow the wheels of the chassis assembly to be easily locked when the scaffolding is being utilized in a traditional manner. Finally, the design of the connections between the chassis assembly and the input assembly and the scaffolding unit are especially advantageous because they are achieved without the need for fasteners.

Disadvantages

Just as there are many advantages to the design described there are also many disadvantages. The effects of stress concentrations on some of the parts and the neglect of shock and fatigue, both discussed in the section on FEA, are certainly disadvantages of the design. One important disadvantage is the approximately 66 pound weight of the input assembly. Though still manageable this weight could be significantly reduced to enable an easier, safer assembly of the manual tank drive system. The 56 pound weight of the chassis assembly is comparable to that of the input assembly but not critical because it does not need to be lifted as does the input assembly. The weight of the chassis assembly can be attributed mostly to the design of the crankbox housing, which calls for a particularly massive quantity of solid aluminum. This follows for the gearbox of the chassis assembly as well. Revision of the detailed design for both of these parts could greatly reduce the weight and subsequent cost of the raw materials and manufacturing.

There are a couple disadvantages regarding the implementation of the sky shafts. In the design no provisions have been made to protect the sky shafts from bending due to accidental collision with objects or from instability caused by especially long length. The single joint universals may also not provide adequate play in the alignment between the input assembly and the chassis assembly, a double joint might be more desirable. Though the chassis assembly does not require fasteners to secure it to the scaffolding in the design they may prove to be necessary in practice depending on how easily the assembly can be slid sideways across the scaffolding tubes. If sliding of this kind were to occur it could cause damage to the sections of the sky shafts.

While the locking mechanism achieves its purpose there are some important disadvantages associated with it, the primary one being that it cannot be employed as a brake in the event of a runaway. In the current design the teeth of the locking gear or the gear rack on the locking lever could potentially shear off if used in an attempt to stop a moving scaffolding unit. Another important consideration regarding the locking mechanism are the implications of OSHA 1926.452(w)(2) that all of the four scaffolding wheels should be locked when the scaffolding unit is being used in a stationary manner. The design only allows for locking of the two wheels associated with the manual tank drive system and not the other two.

CONCLUSION

This report has presented the design of a manual tank drive system for a mobile scaffolding unit. The problem addressed by this design was described along with pertinent background information. The overall design and each of its parts were then described in detail, along with the critical assumptions, calculations, and analyses relating to it. Finally, the advantages and disadvantages of the design were discussed.

Summary

The manual tank drive system presented consists of three parts (the *chassis assembly*, sky *shafts*, and *input assembly*) that allow a worker to move and lock a mobile scaffolding unit from its elevated platform. The drive system has a collective power ratio of two to one that effectively doubles the input torque and halves the input speed of the hand cranks. The detail design of the critical drive system parts was confirmed and revised through Finite Element Analysis in PRO/*Mechanica*. In most of the analyses the total design factor exceeded a value of six. Reasons for the exceptions to this total design factor were discussed and involved the presence of stress concentrations on some of the parts or the simulation of loadings that may not actually be encountered in practice. The principal advantages of the design include the ability to disassemble the drive system as well as to disengage the sky shafts so that the scaffolding may be moved in a traditional manner. The principal disadvantages of the design include the neglect of shock and fatigue effects and the weight of the input assembly that must be lifted to the elevated platform during assembly of the scaffolding unit and drive system. To summarize, the design successfully addressed and solved the problem described.

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"Allegheny Ludlum Martensitic Stainless Steel Type 440A, Annealed."
"Alclad Aluminum 2024-T4, T351."
"Aluminum 6061-T6; 6061-T651."
"AISI 1015 Steel, cold drawn."
"AISI 1015 Steel, mock carburized at 915 deg C for 8 hours, 775 deg C reheat, water quenched, 175 deg C temper, 13 mm round."
"AISI 1040 Steel, oil quenched from 855 deg C, 540 deg C temper, 13 mm."
"AISI 4130 Steel, annealed at 865 deg C."
"AISI E 52100 Steel."

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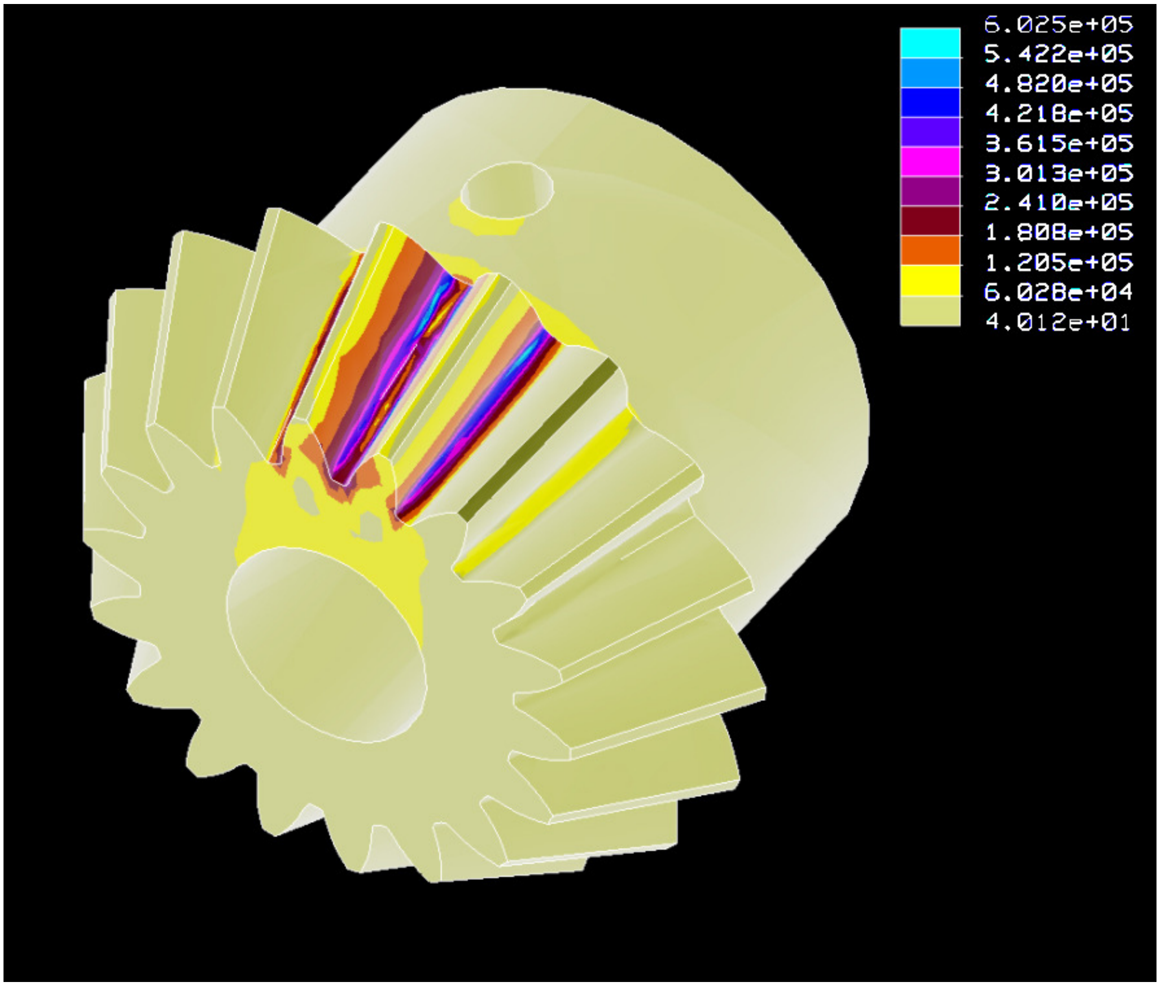
APPENDIX A-1: DESIGN DRAWINGS

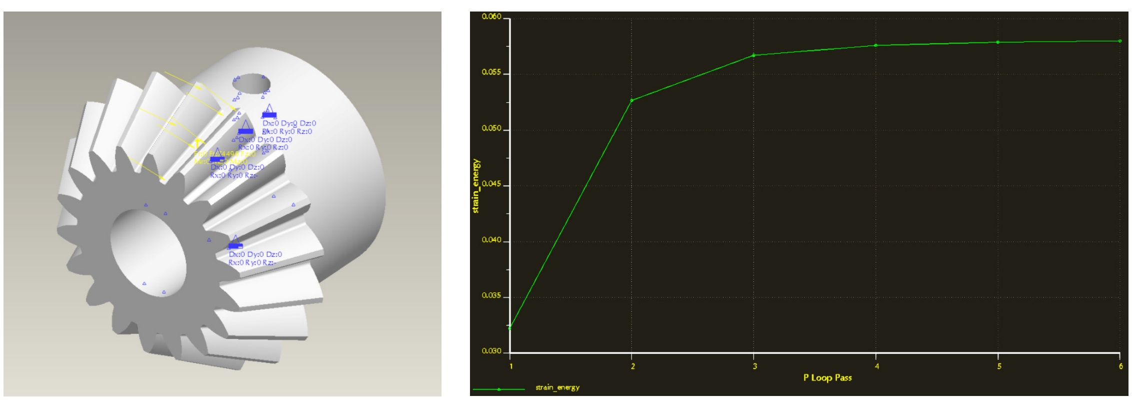
This appendix contains the assembly and detail drawings documenting the design. Each assembly drawing includes a Bill of Materials identifying the subsequent drawing number for each item in the assembly. A drawing number of A1 through A8 refers to an assembly drawing. A drawing number of D1 through D14 refers to a detail drawing. Drawings of off-the-shelf standard parts and only slightly modified standard parts have not been included in this appendix. Standard parts and any applicable modifications are listed and described in the Bill of Materials on each assembly drawing.

APPENDIX A-2: FEA ANALYSES

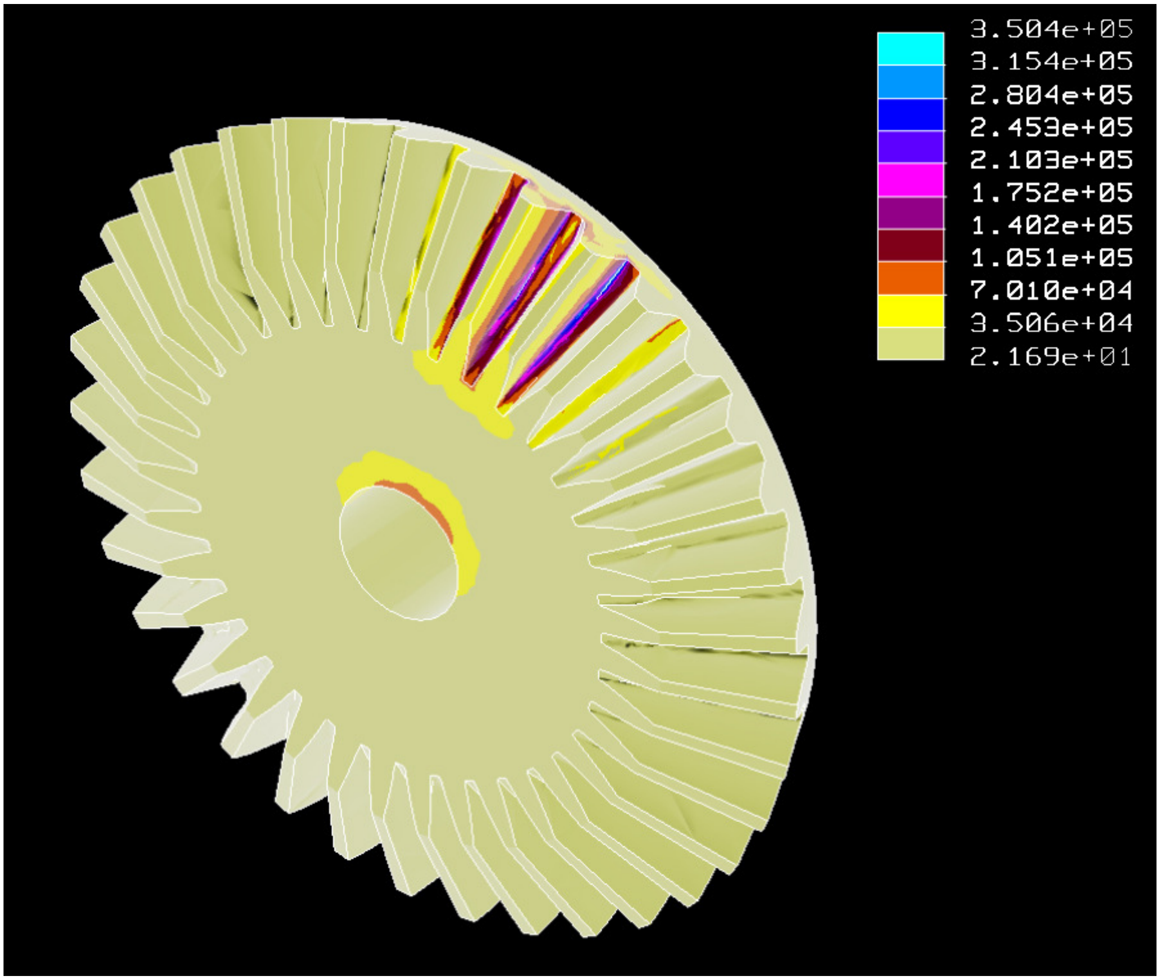
This appendix contains the Von Mises stress results from each of the FEA analyses carried out during the design. Screenshots of the PRO/*Mechanica* loads and constraints and a strain energy convergence plot accompany each stress fringe plot. Note that in Figures 1-4, 21-22, 25-28, and 29-30 the units of stress and strain energy are $lbm/(in^2\text{-}sec^2)$ and $in^2\text{-}lbm/sec^2$ respectively, in all other figures the units are lbf/in^2 and lbf-in respectively.



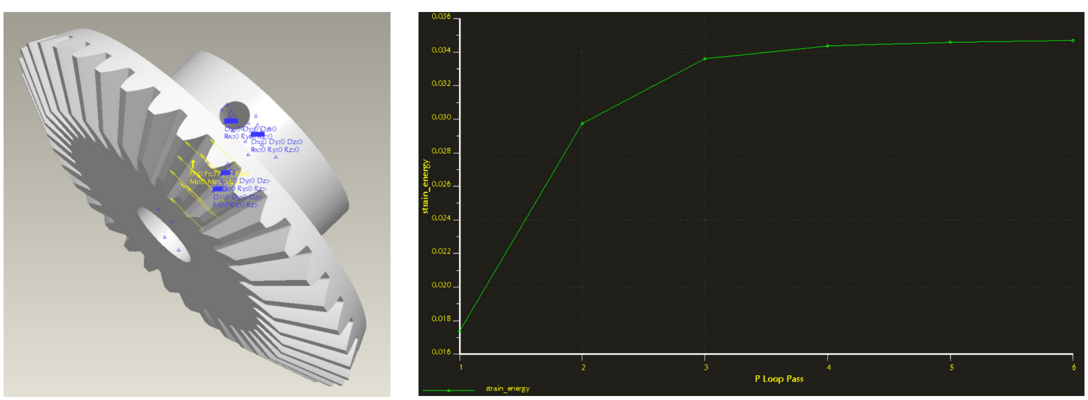
Appendix A-2 Figure 1 – RushGears B1218-2 Von Mises Stress



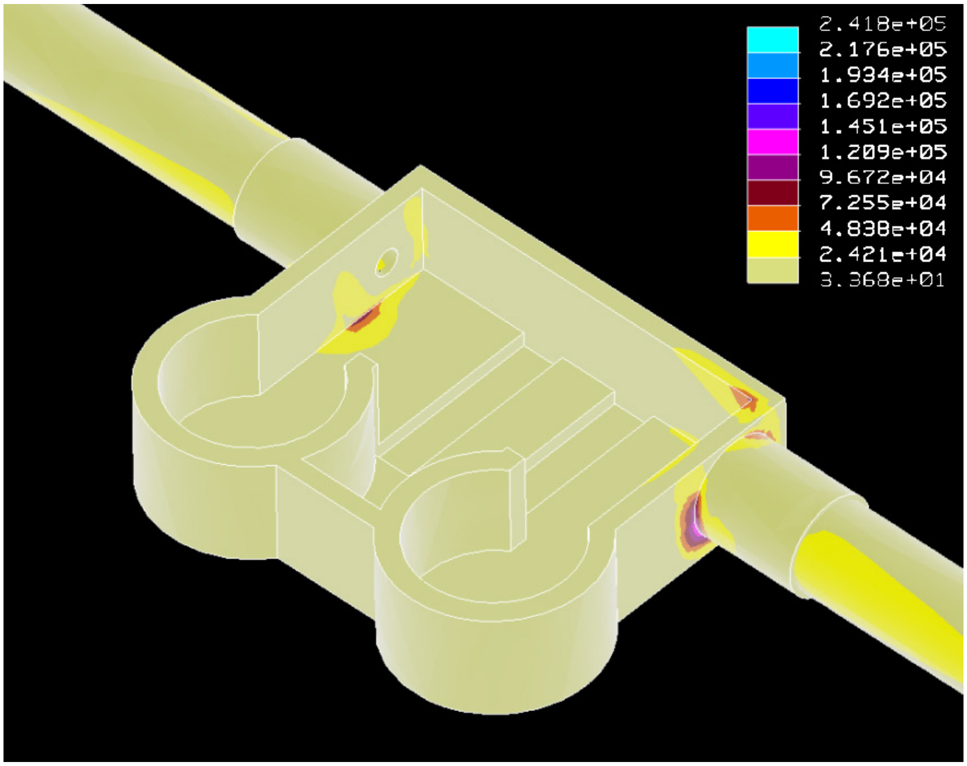
Appendix A-2 Figure 2 – RushGears B1218-2 Loading and Convergence



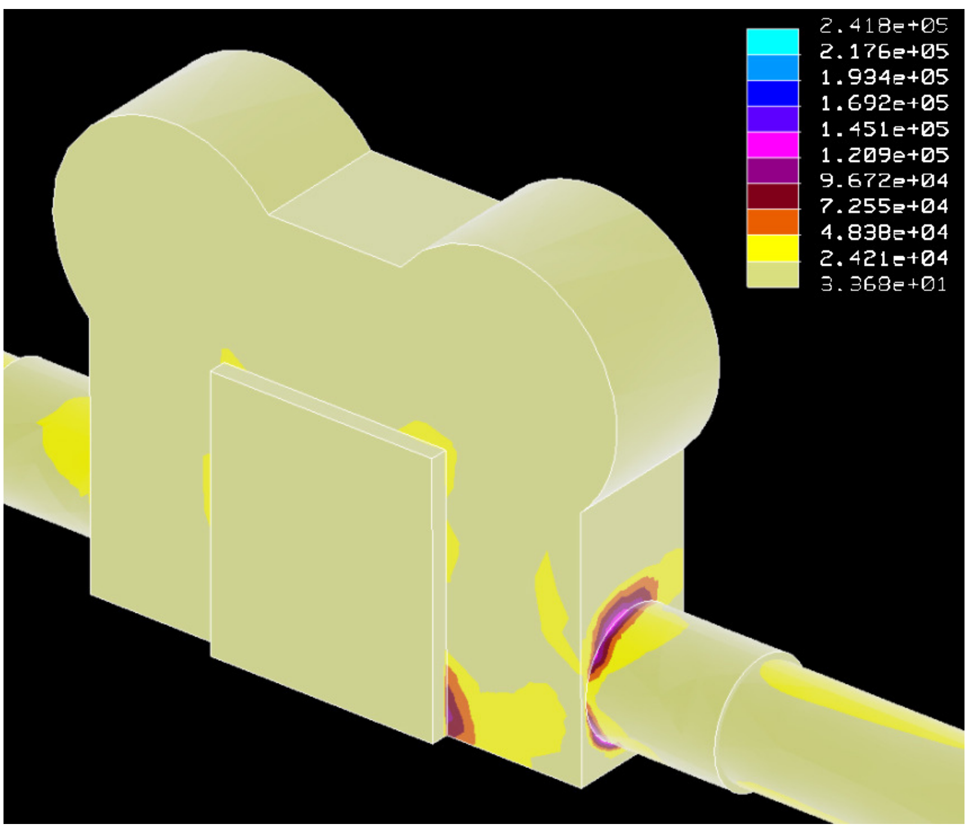
Appendix A-2 Figure 3 – RushGears B1236-2 Von Mises Stress



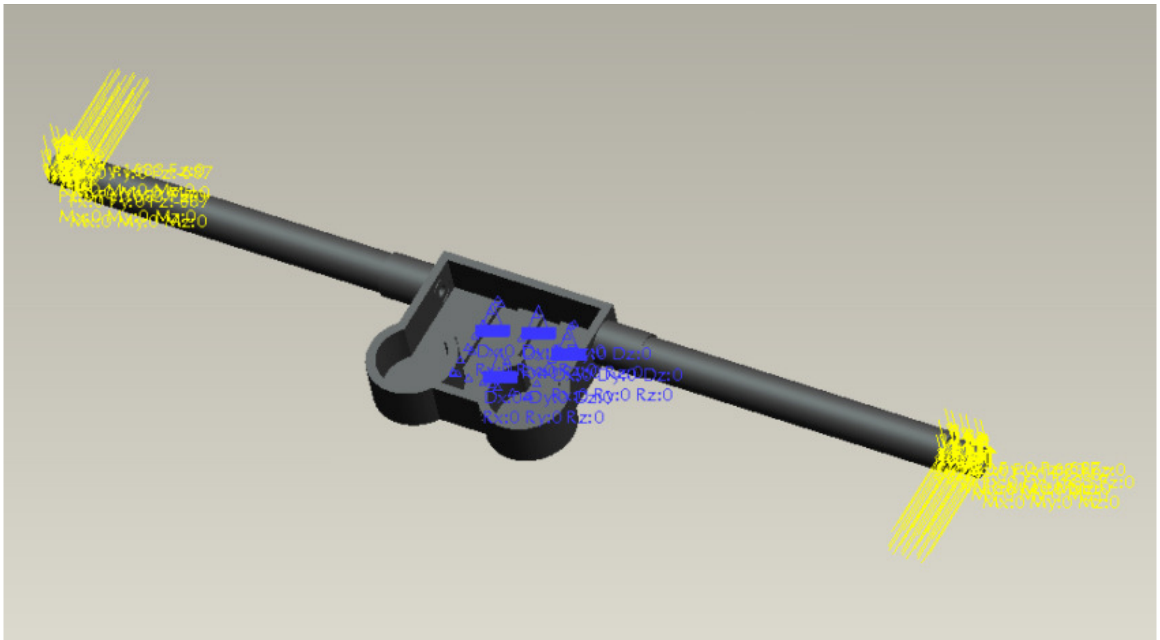
Appendix A-2 Figure 4 – RushGears B1236-2 Loading and Convergence



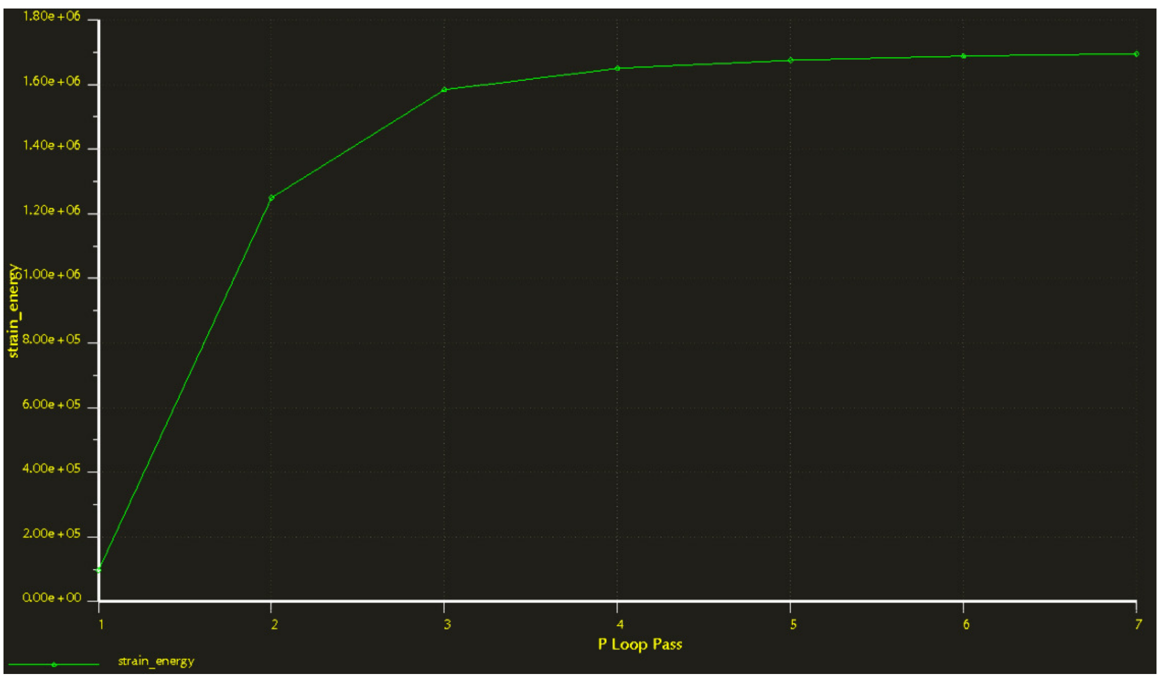
Appendix A-2 Figure 5 – Chassis Assembly Von Mises Stress



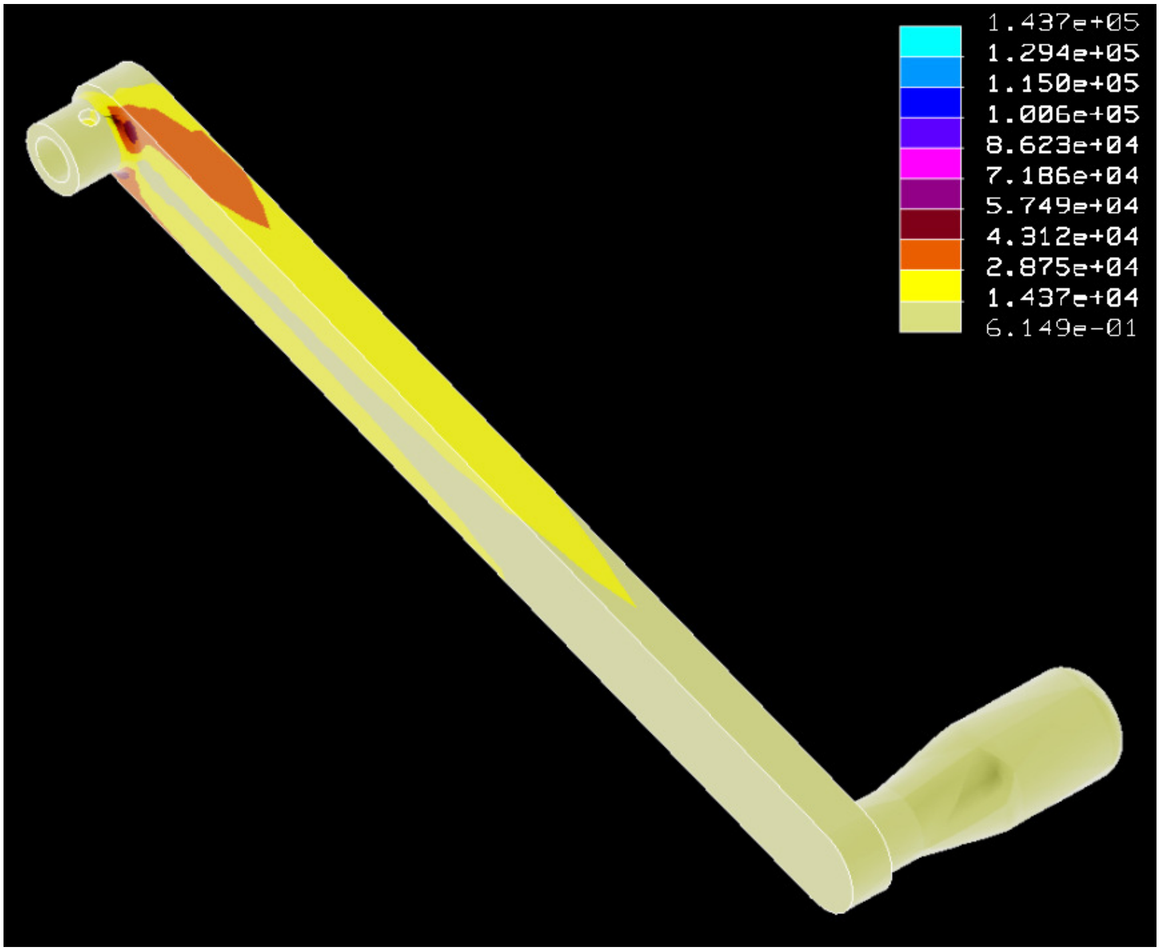
Appendix A-2 Figure 6 – Chassis Assembly Von Mises Stress



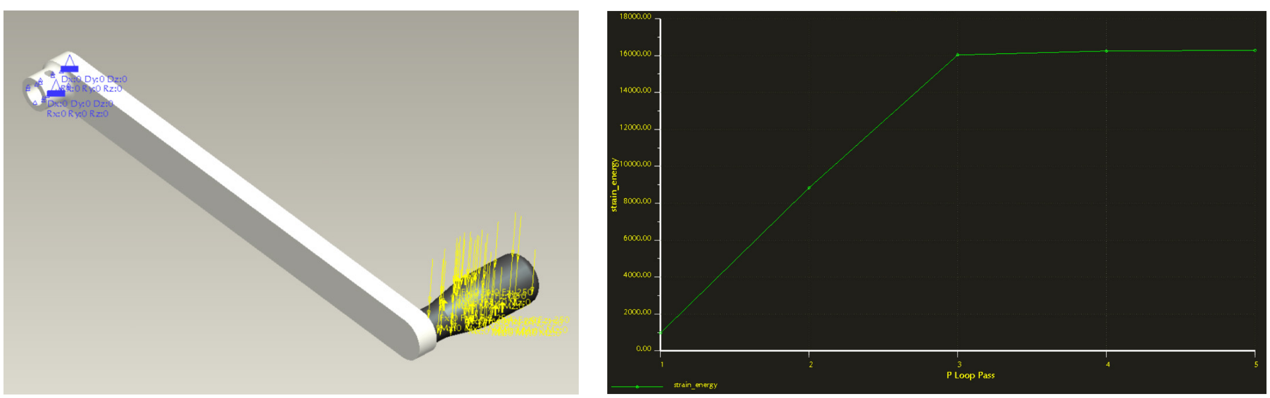
Appendix A-2 Figure 7 – Chassis Assembly Loading



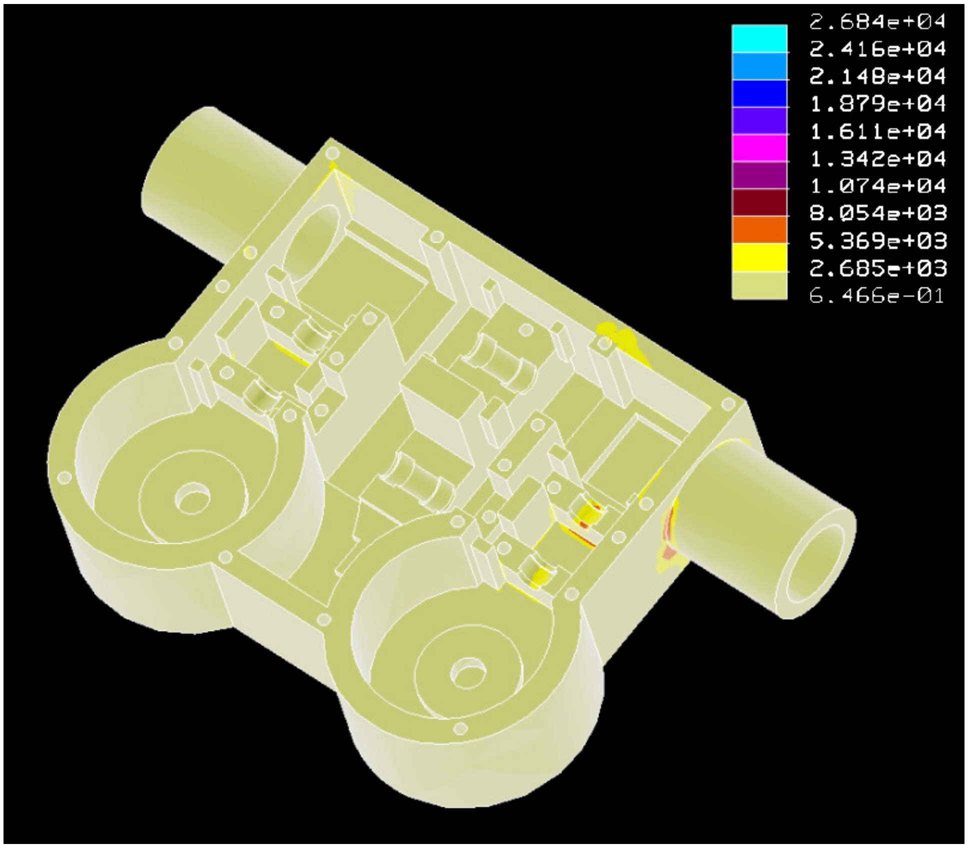
Appendix A-2 Figure 8 – Chassis Assembly Convergence



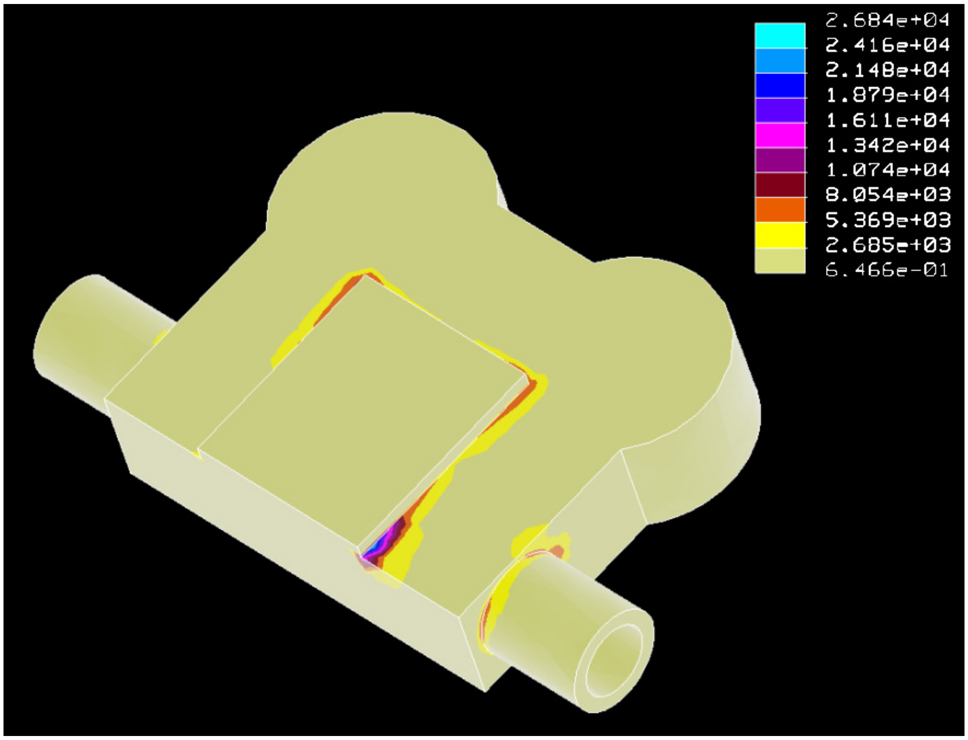
Appendix A-2 Figure 9 – Crank Von Mises Stress



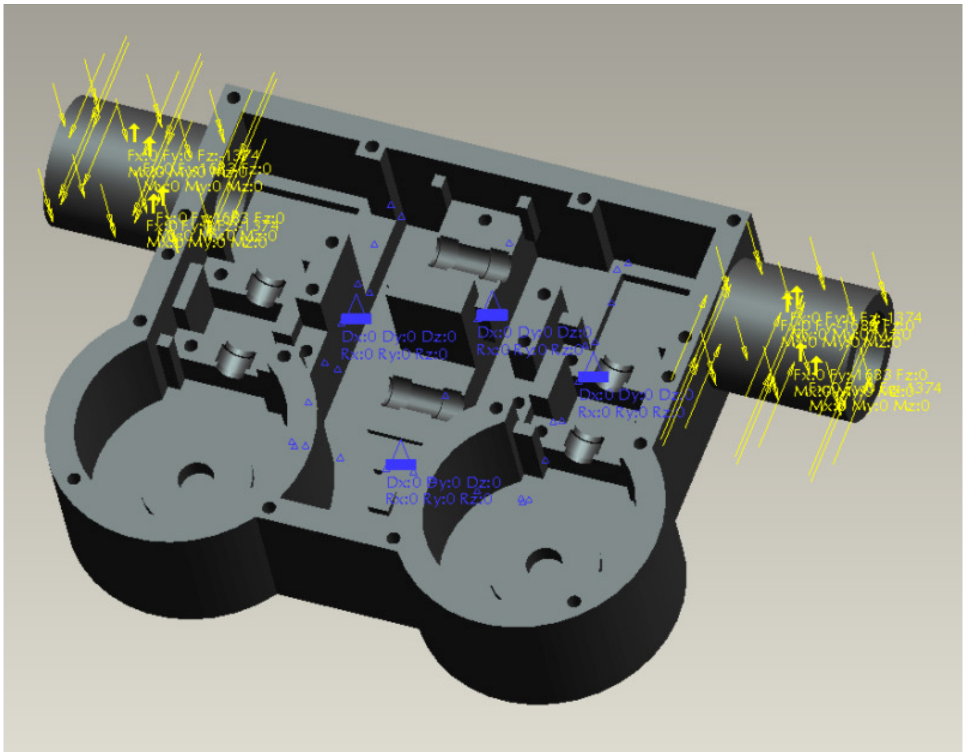
Appendix A-2 Figure 10 – Crank Loading and Convergence



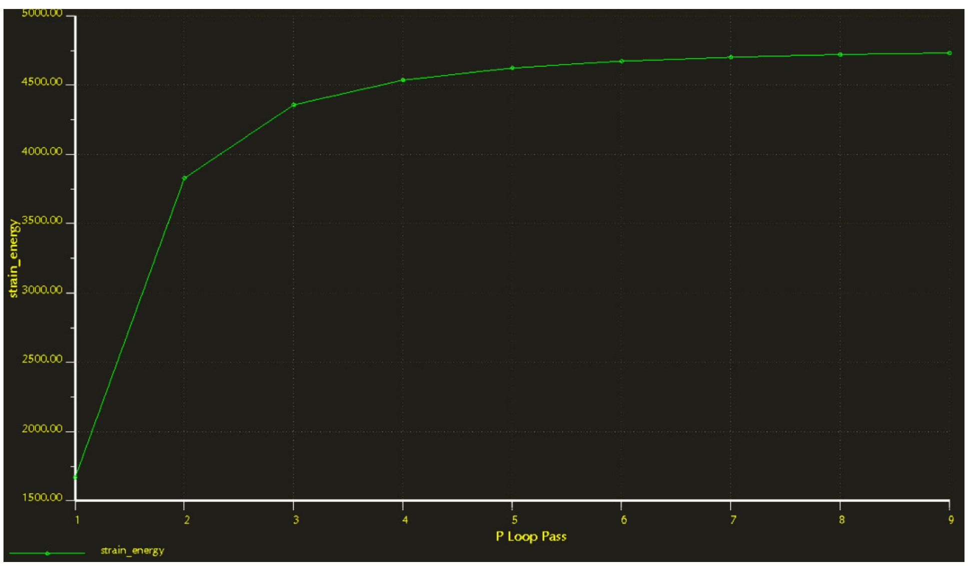
Appendix A-2 Figure 11 – Gearbox Housing Von Mises Stress



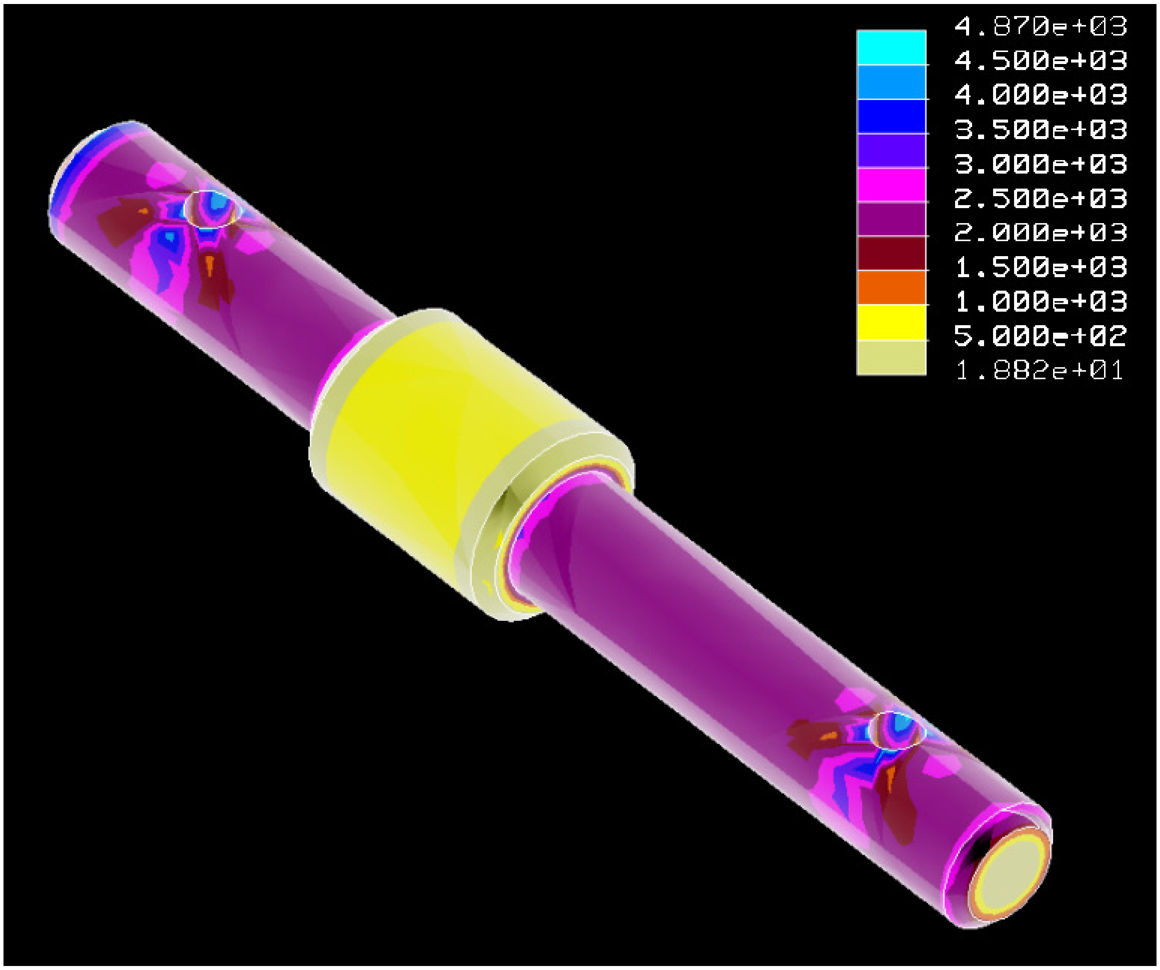
Appendix A-2 Figure 12 – Gearbox Housing Von Mises Stress



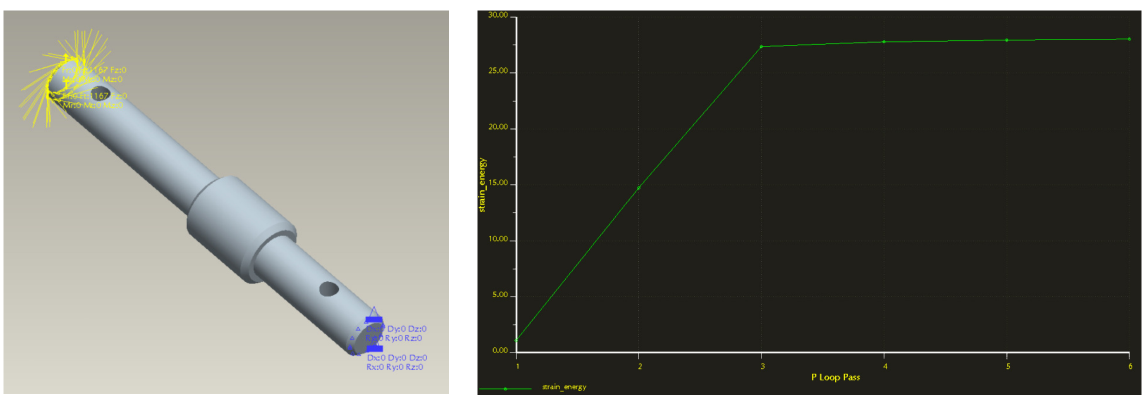
Appendix A-2 Figure 13 – Gearbox Housing Loading



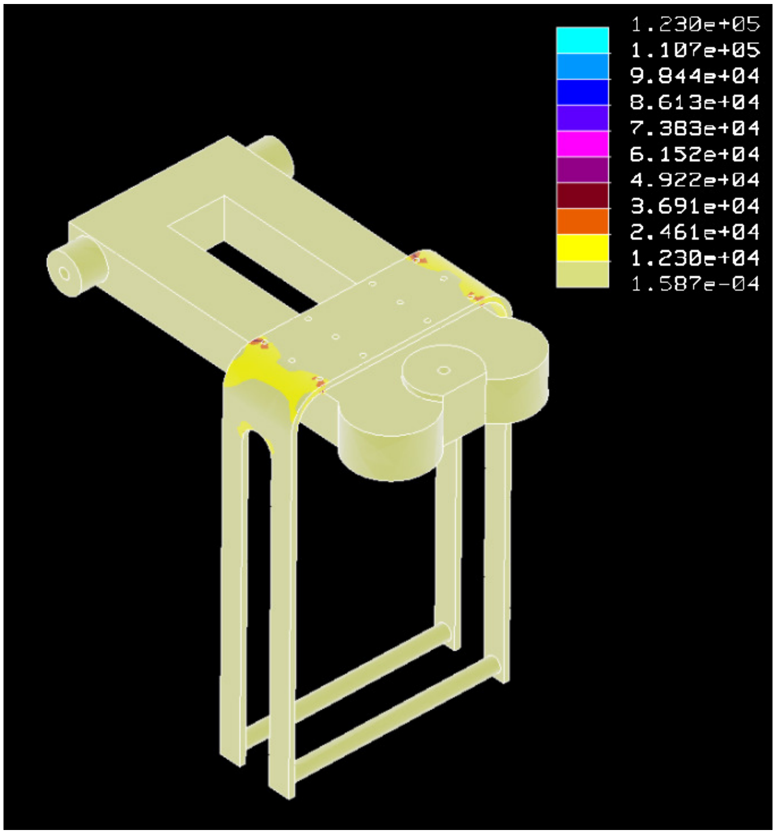
Appendix A-2 Figure 14 – Gearbox Housing Convergence



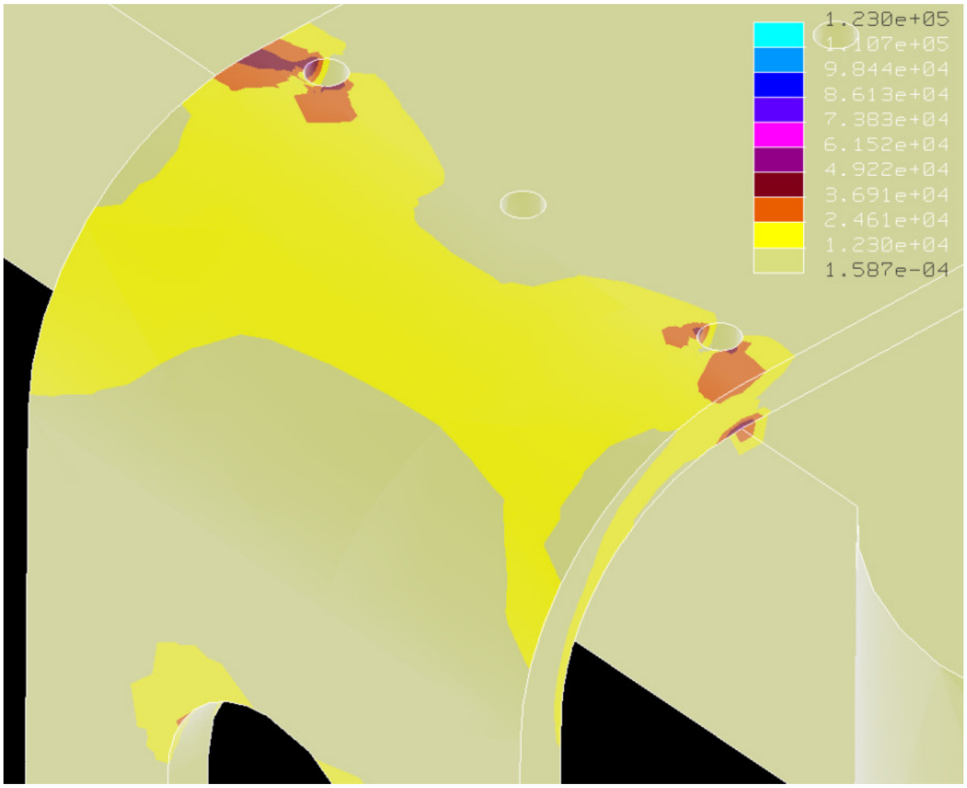
Appendix A-2 Figure 15 – Gearbox Transverse Shaft Von Mises Stress



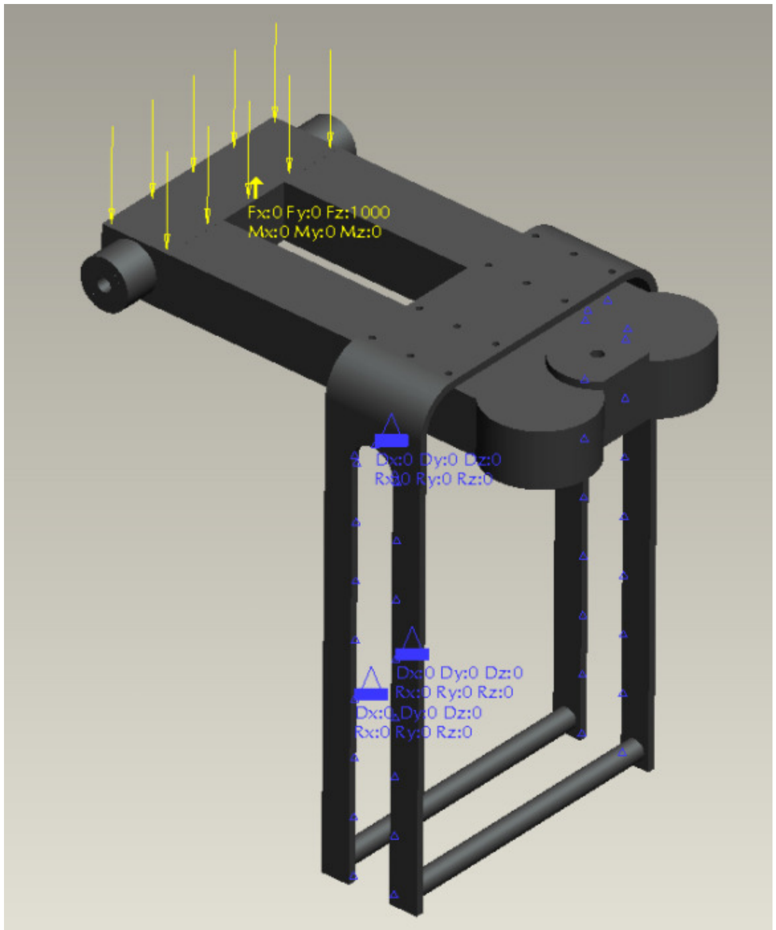
Appendix A-2 Figure 16 – Gearbox Transverse Shaft Loading and Convergence



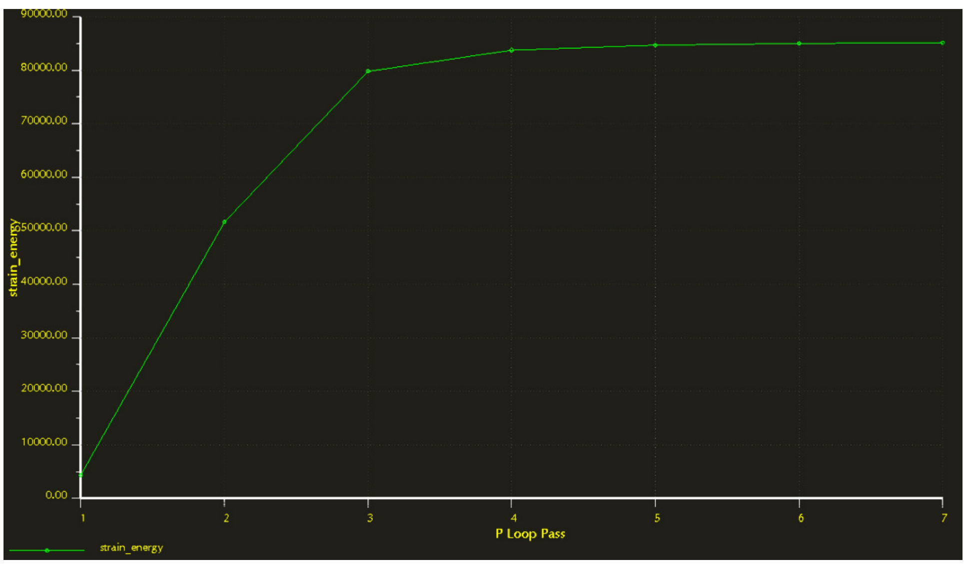
Appendix A-2 Figure 17 – Input Assembly Von Mises Stress



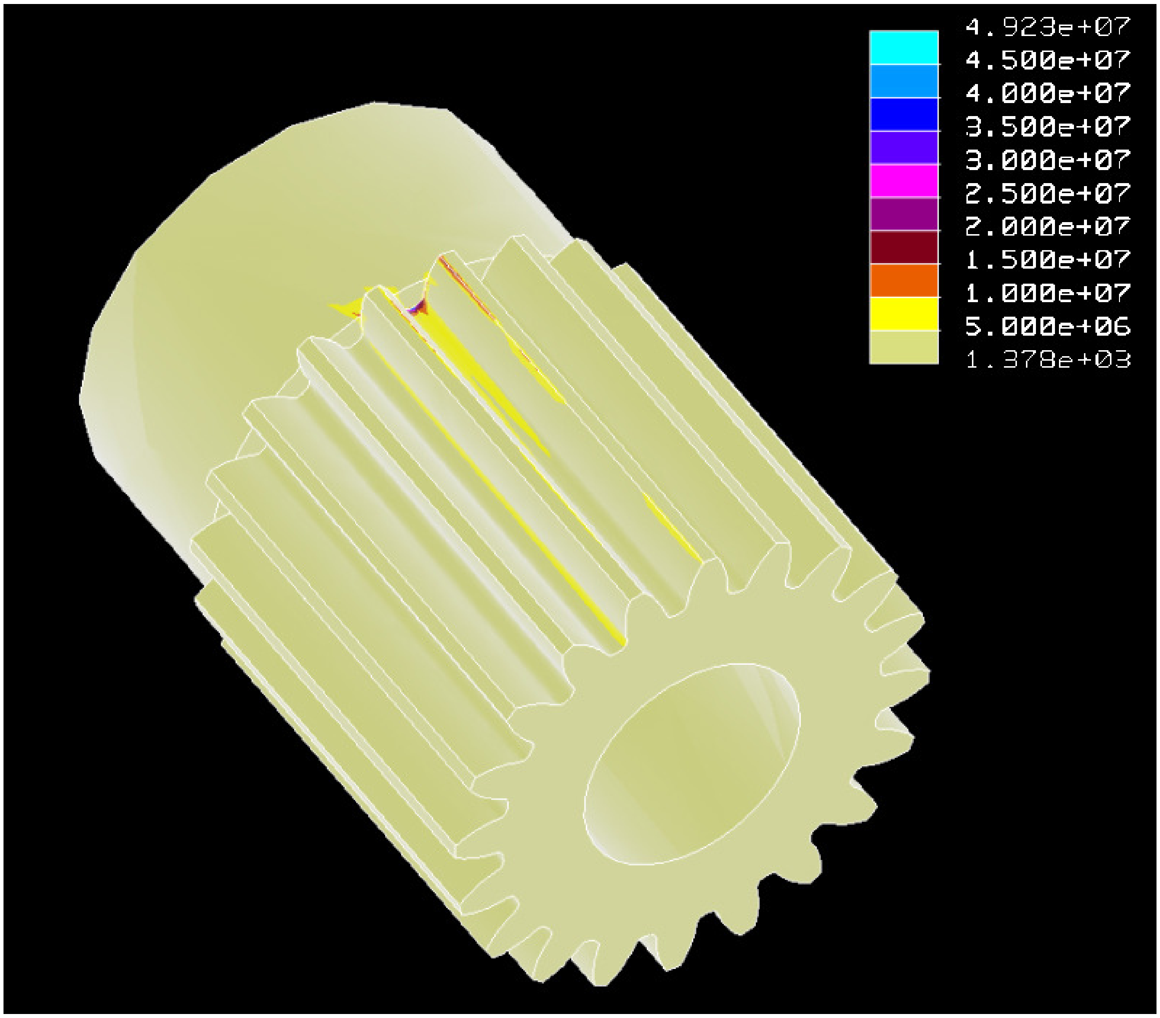
Appendix A-2 Figure 18 – Input Assembly Von Mises Stress



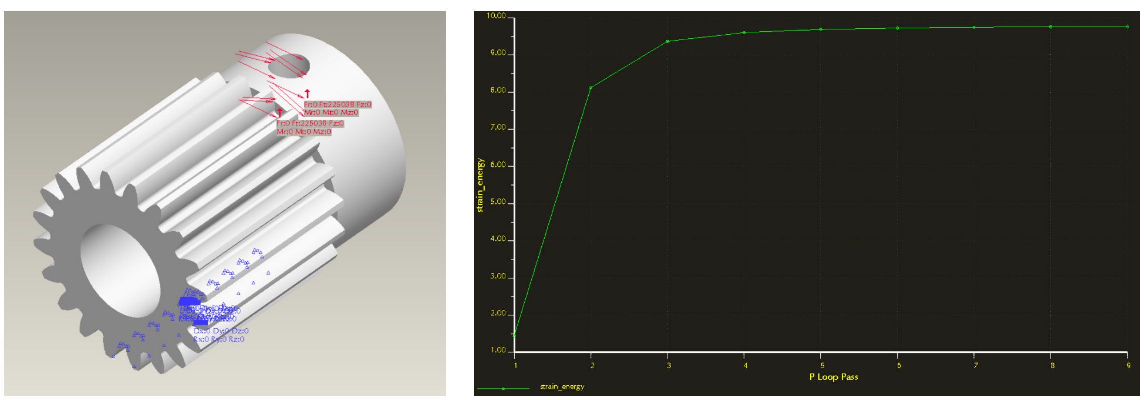
Appendix A-2 Figure 19 – Input Assembly Loading



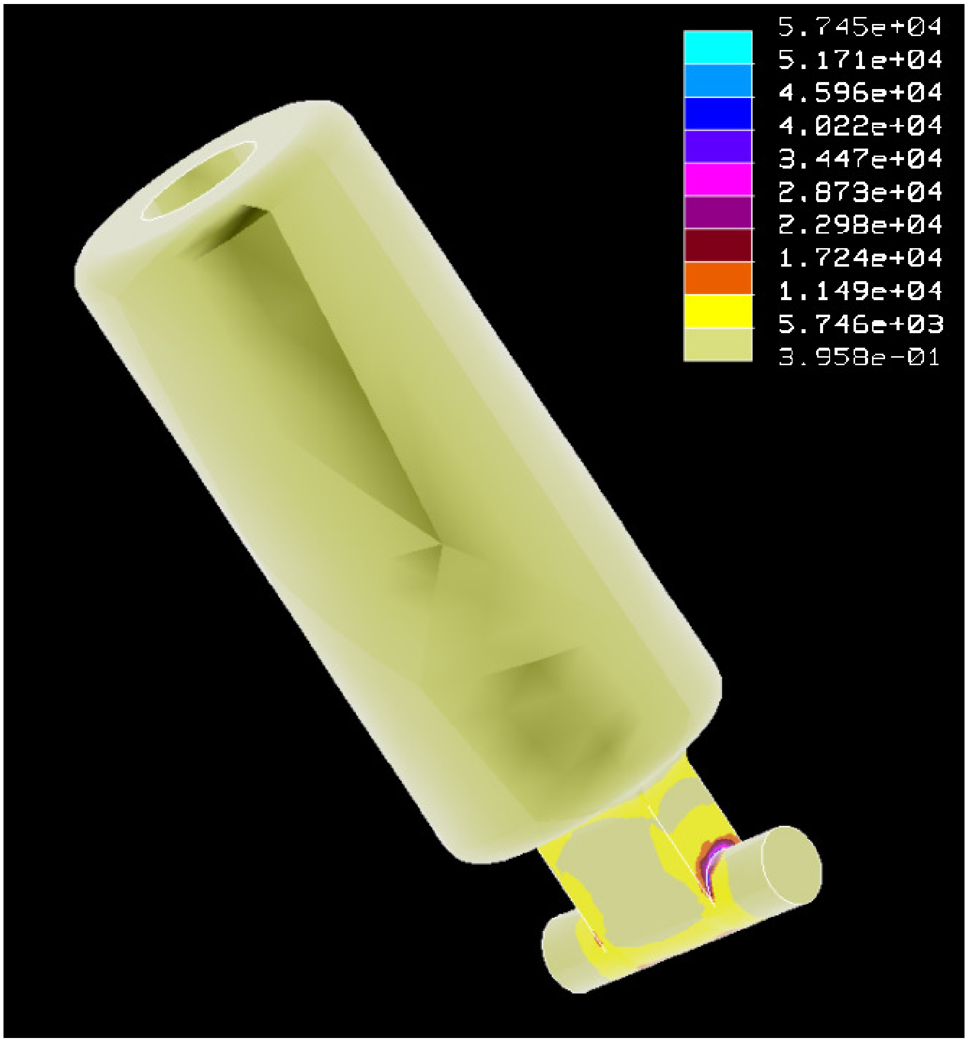
Appendix A-2 Figure 20 – Input Assembly Convergence



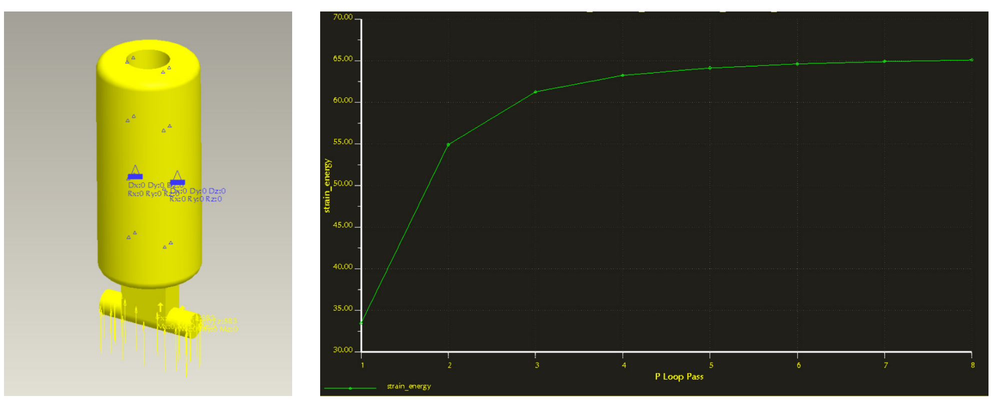
Appendix A-2 Figure 21 – Locking Gear Von Mises Stress



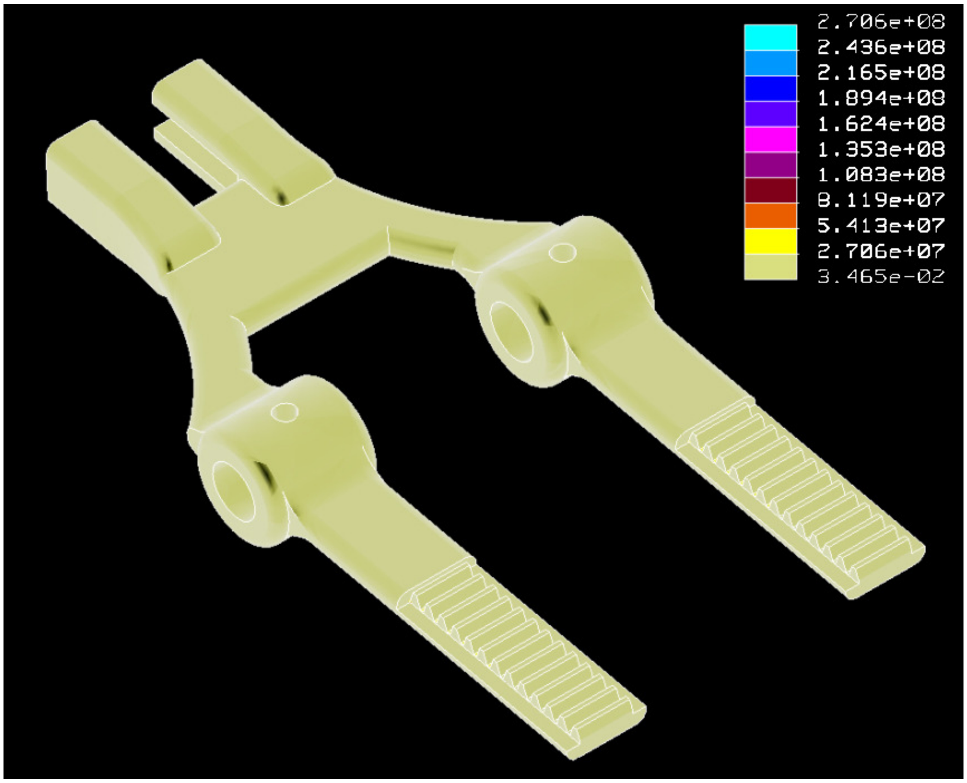
Appendix A-2 Figure 22 – Locking Gear Loading and Convergence



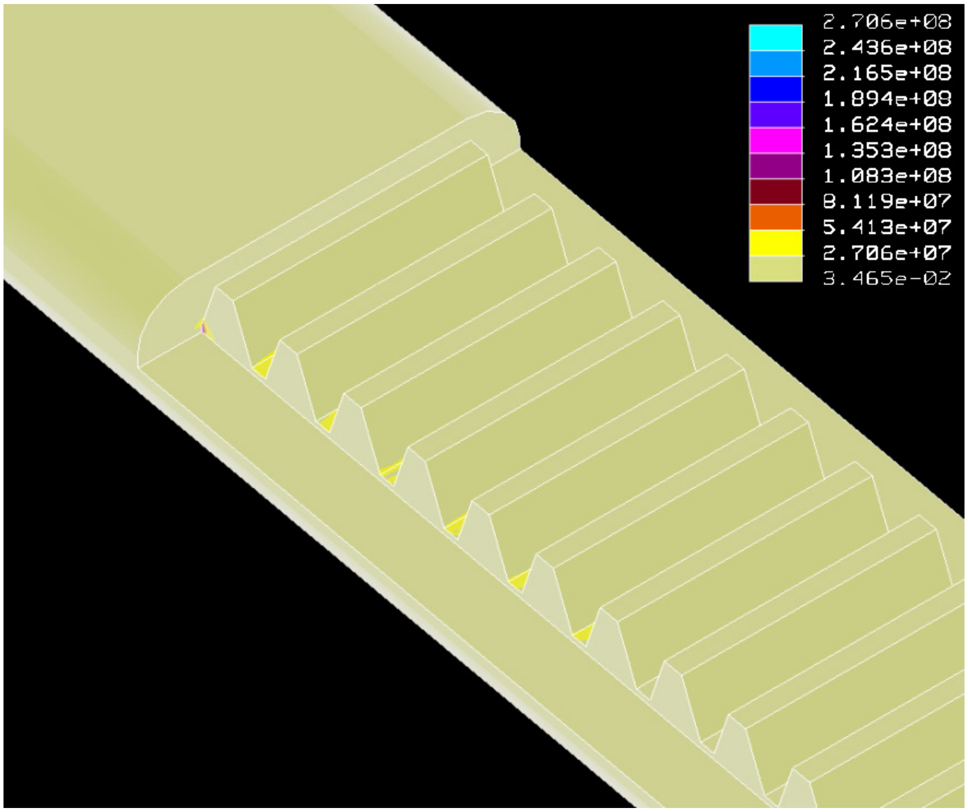
Appendix A-2 Figure 23 – Locking Lever Actuator Von Mises Stress



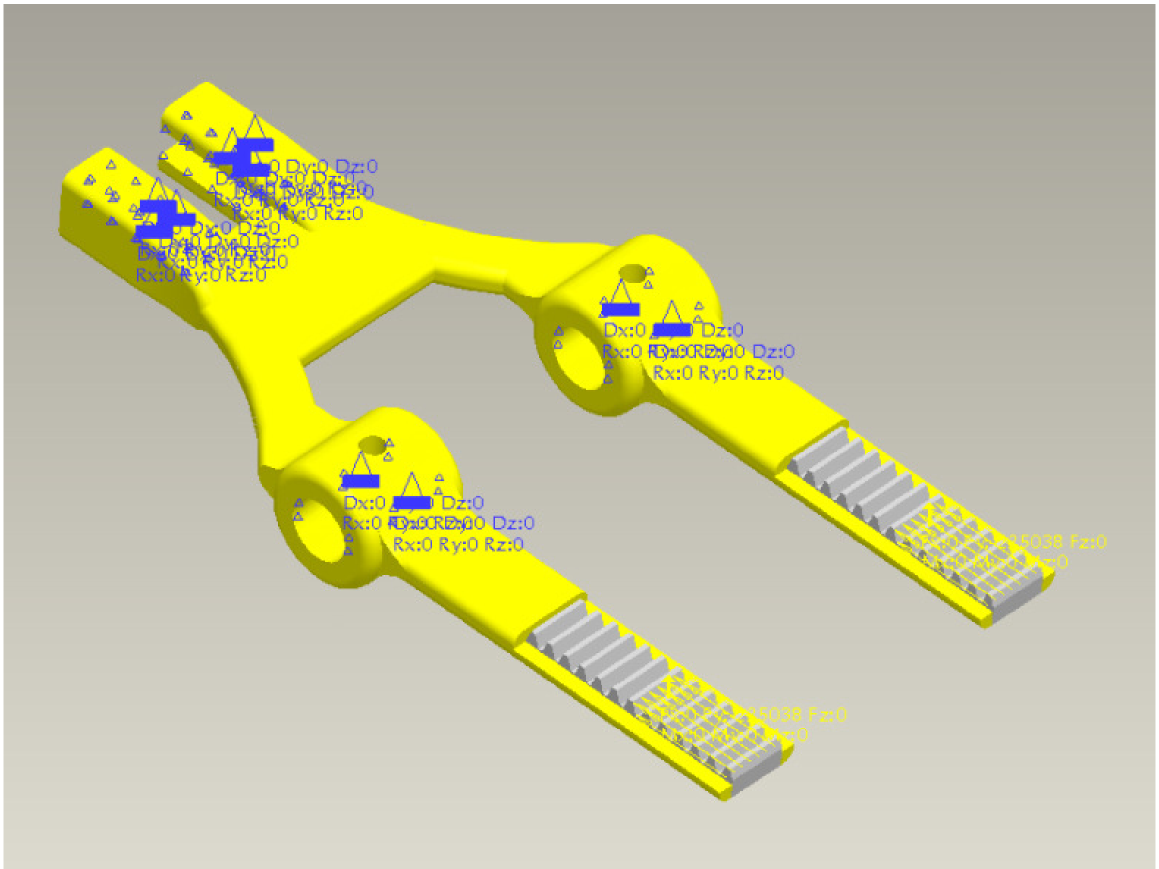
Appendix A-2 Figure 24 – Locking Lever Actuator Loading and Convergence



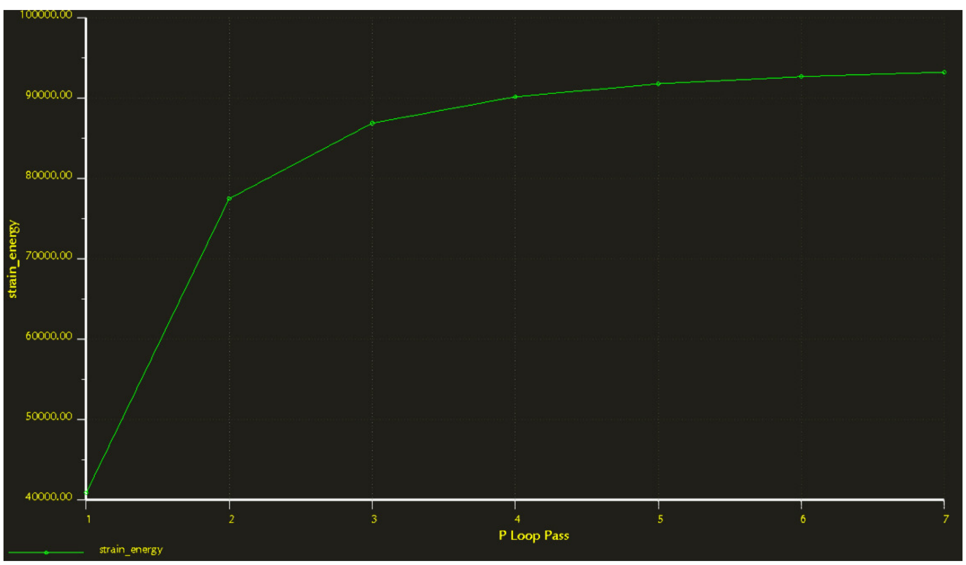
Appendix A-2 Figure 25 – Locking Lever Von Mises Stress



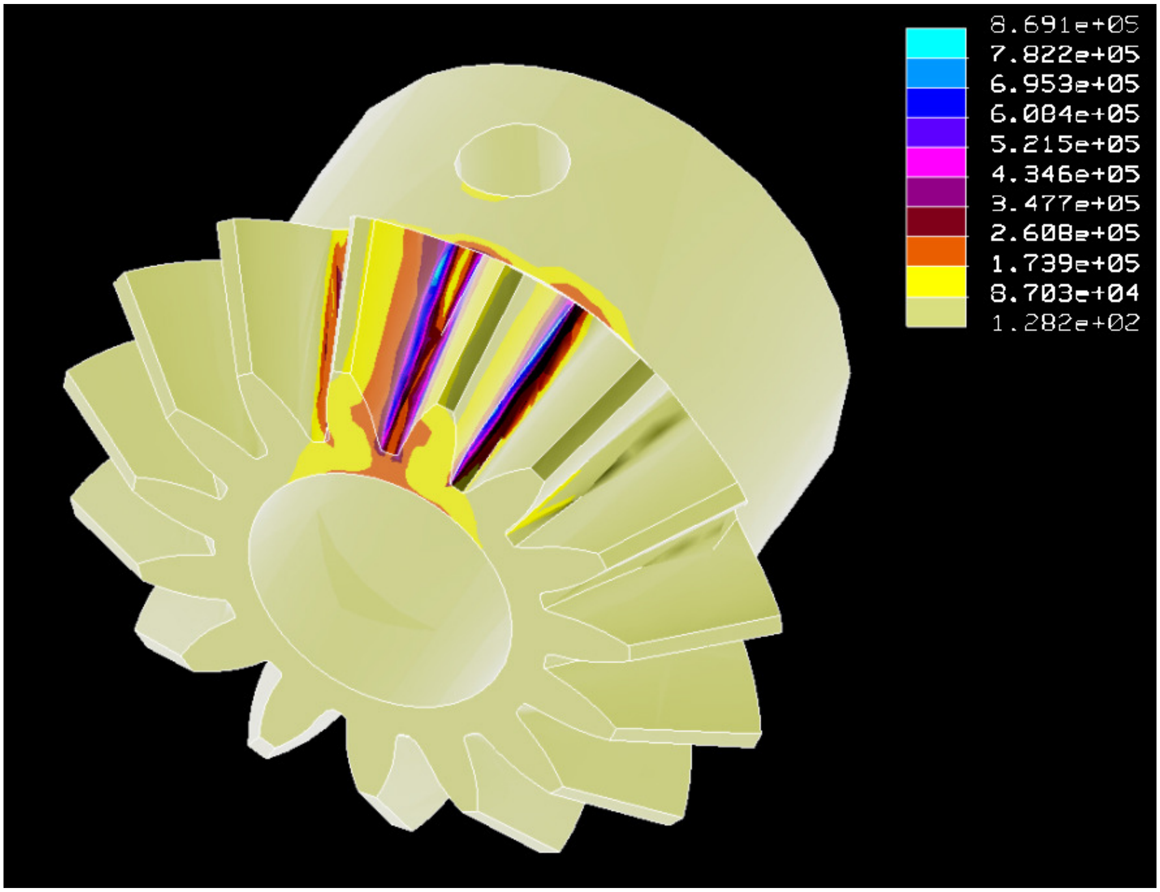
Appendix A-2 Figure 26 – Locking Lever Von Mises Stress



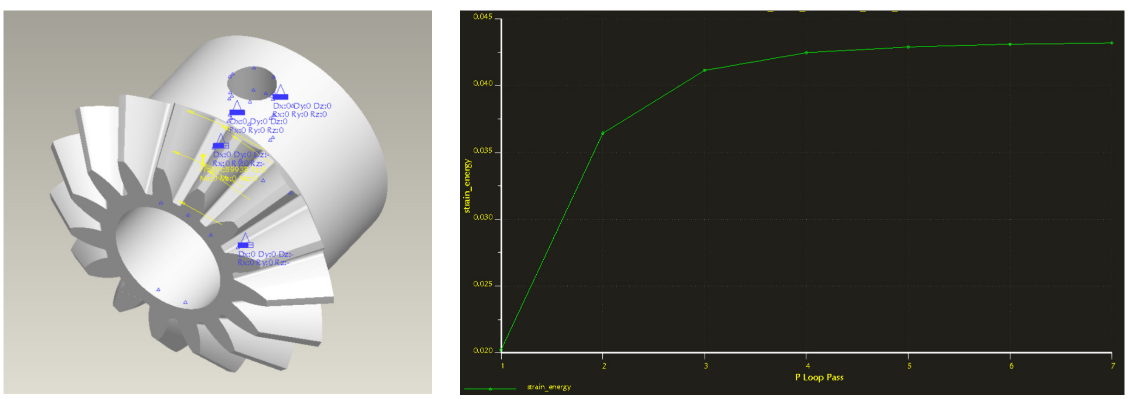
Appendix A-2 Figure 27 – Locking Lever Loading



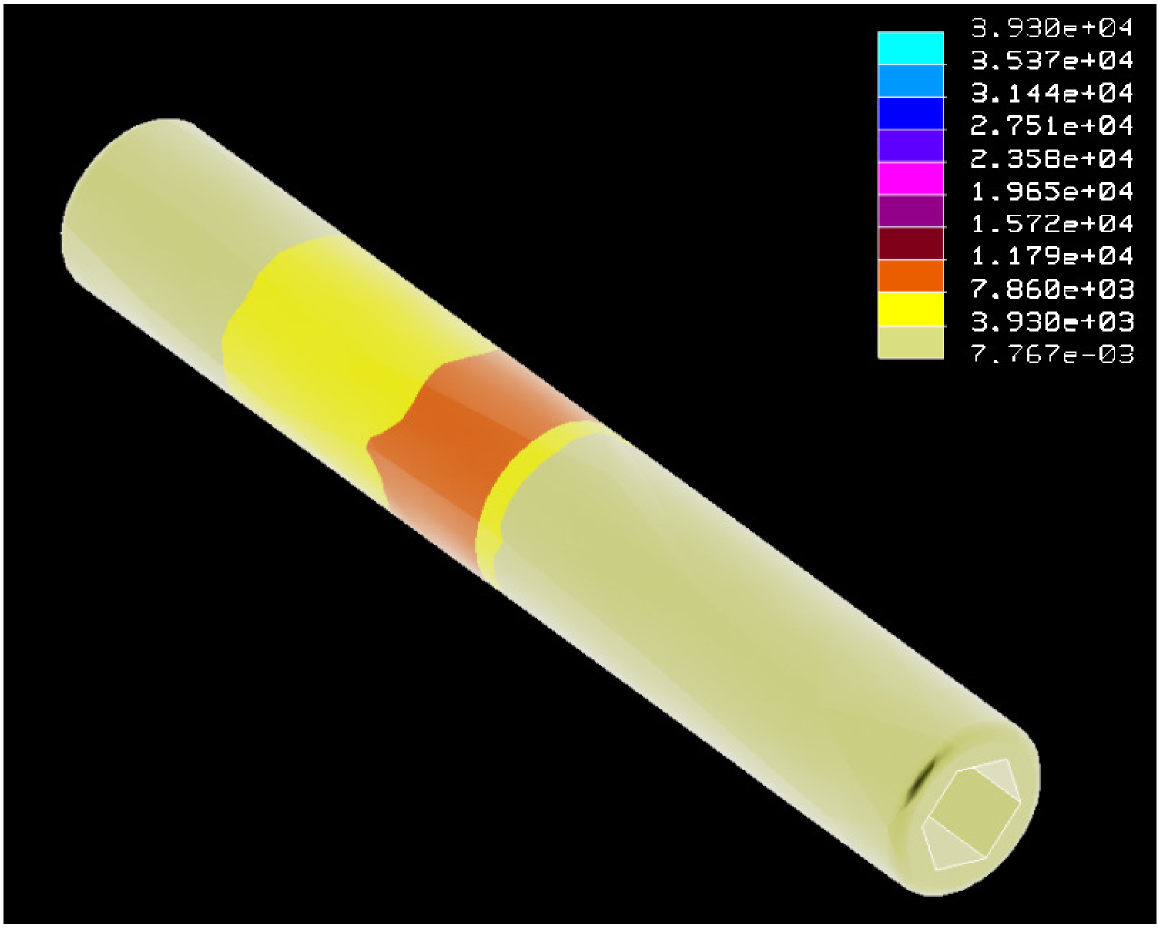
Appendix A-2 Figure 28 – Locking Lever Convergence



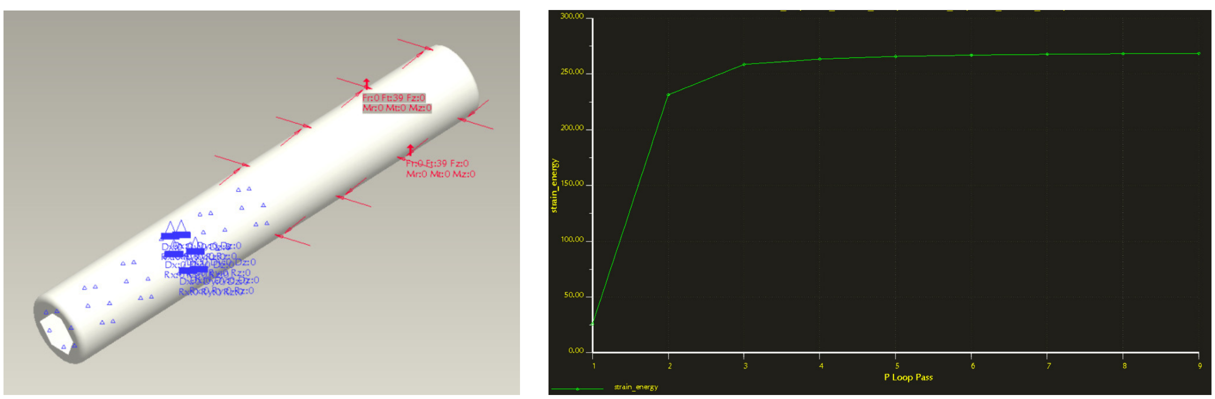
Appendix A-2 Figure 29 – RushGears M1215B Von Mises Stress



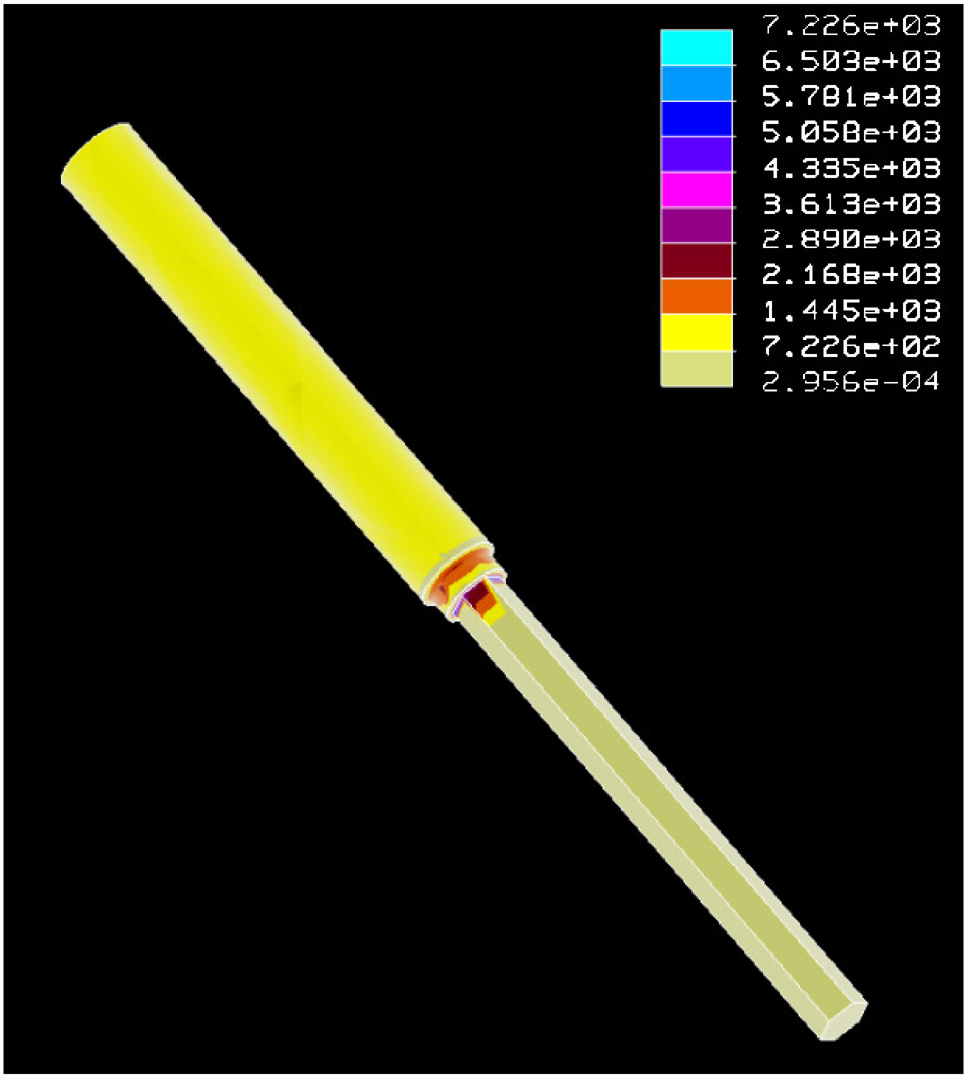
Appendix A-2 Figure 30 – RushGears M1215B Loading and Convergence



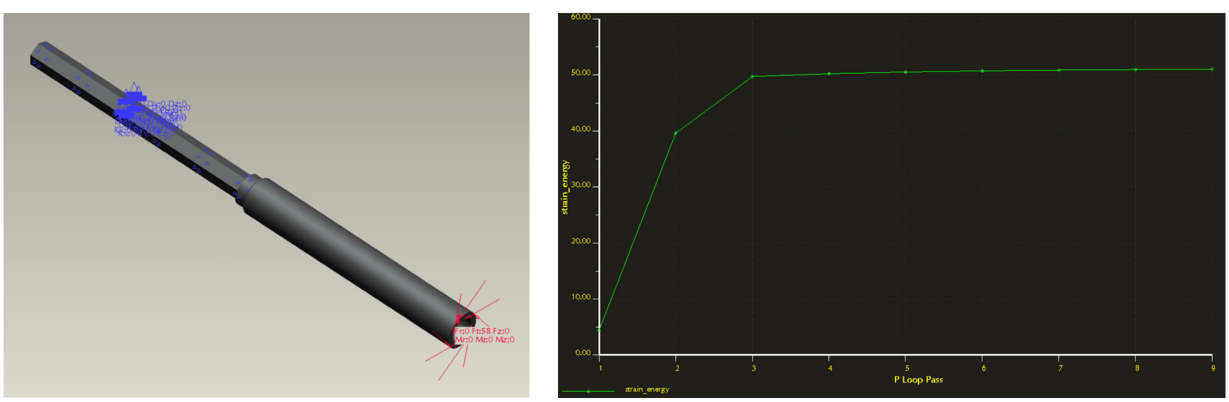
Appendix A-2 Figure 31 – Sky Shaft Coupler Von Mises Stress



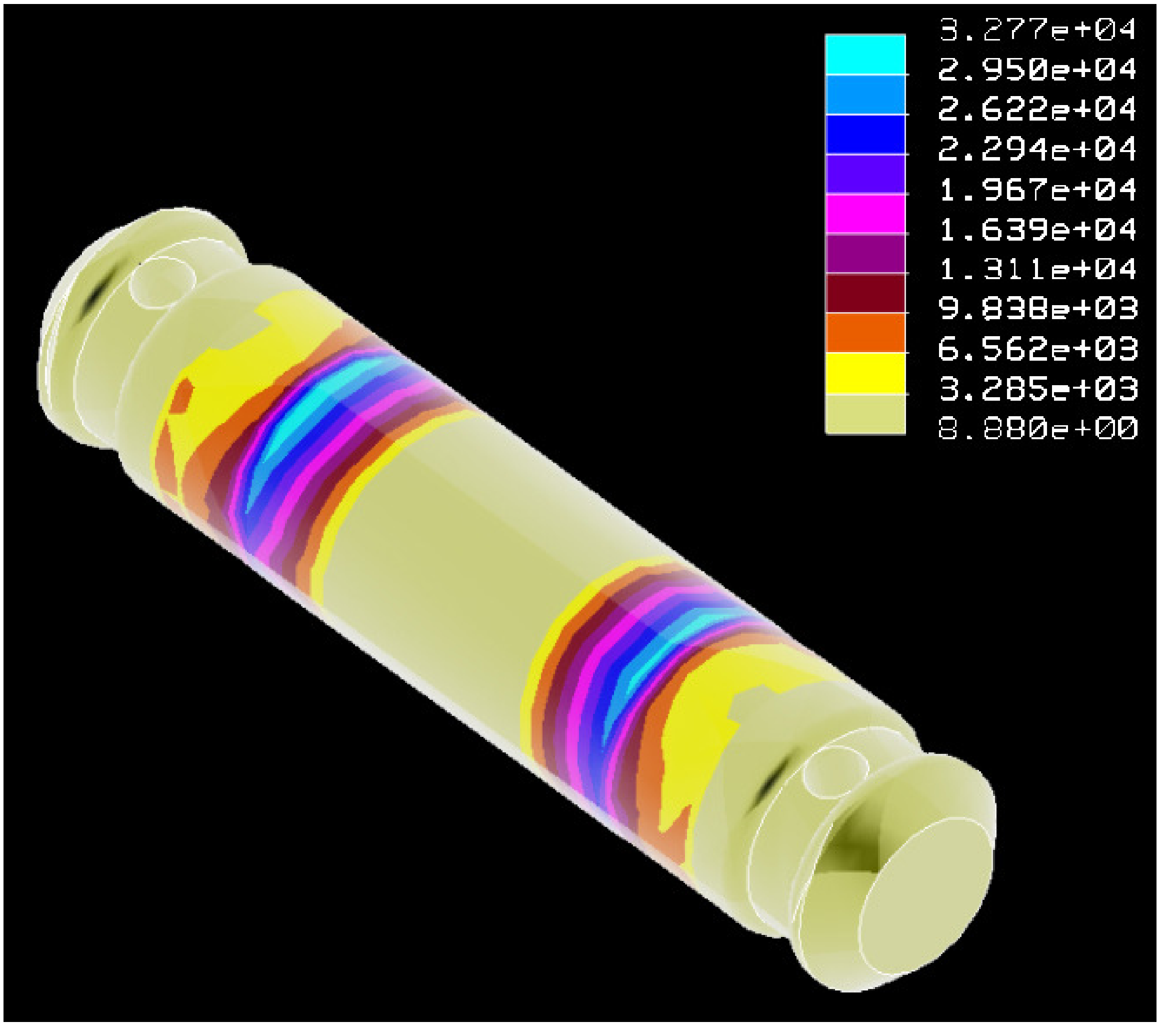
Appendix A-2 Figure 32 – Sky Shaft Coupler Loading and Convergence



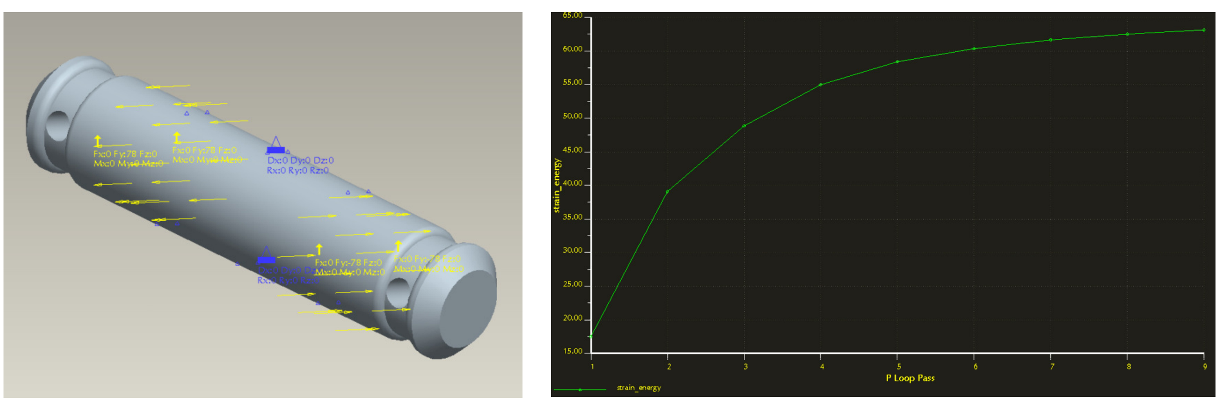
Appendix A-2 Figure 33 – Sky Shaft Lower Section Von Mises Stress



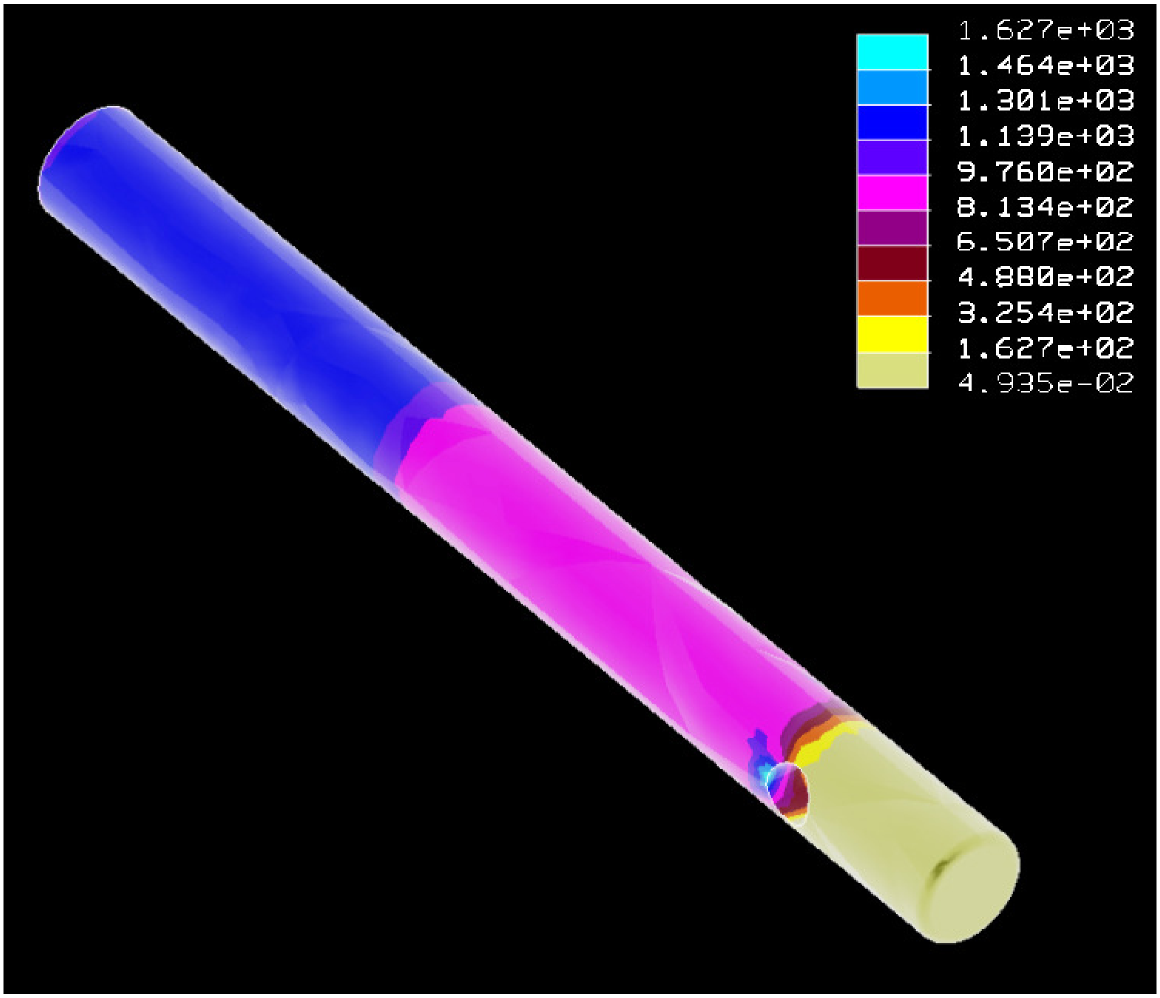
Appendix A-2 Figure 34 – Sky Shaft Lower Section Loading and Convergence



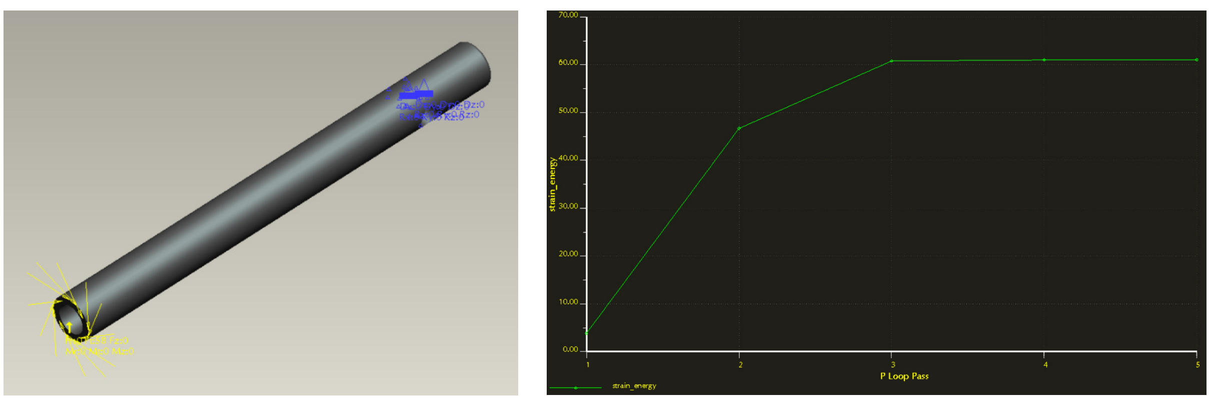
Appendix A-2 Figure 35 – Sky Shaft Pin Von Mises Stress



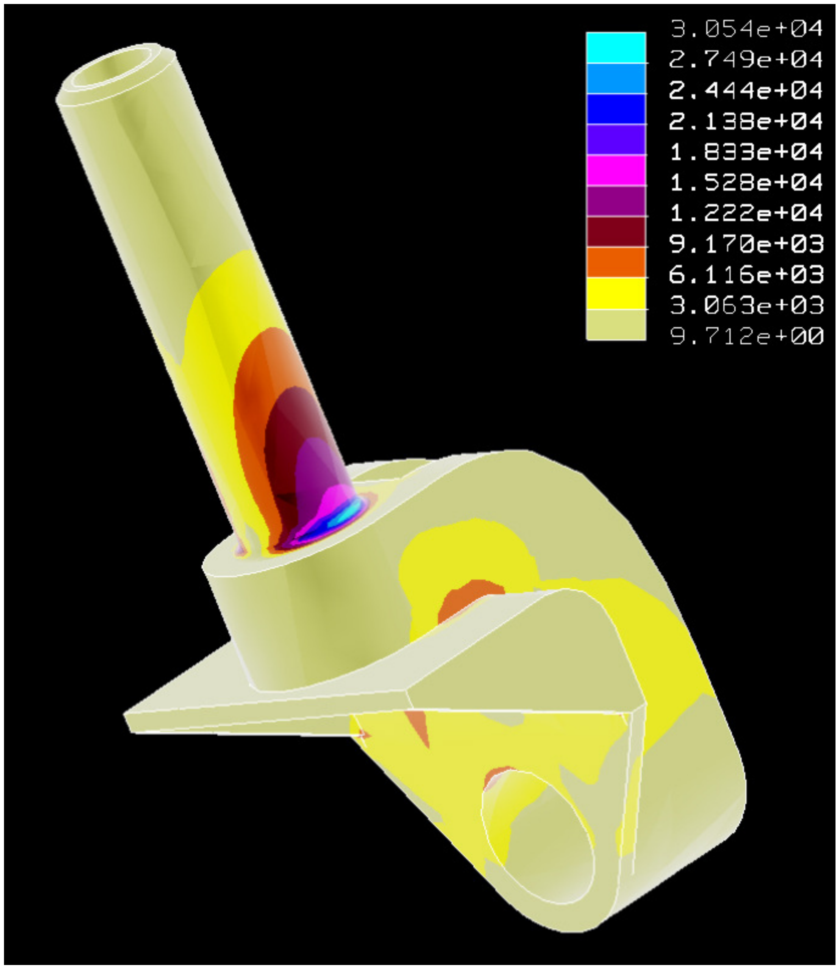
Appendix A-2 Figure 36 – Sky Shaft Pin Loading and Convergence



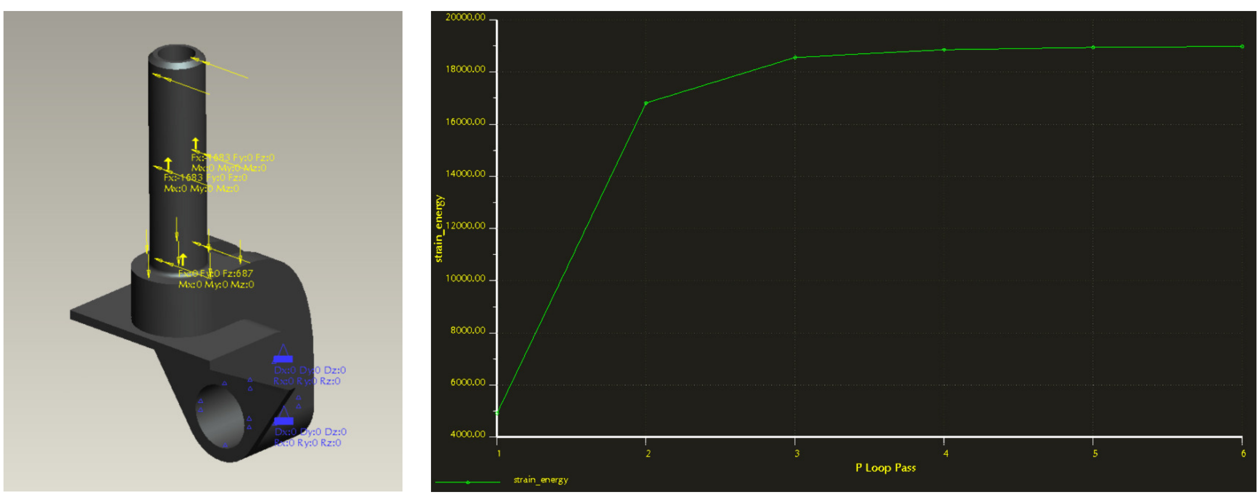
Appendix A-2 Figure 37 – Sky Shaft Upper Section Von Mises Stress



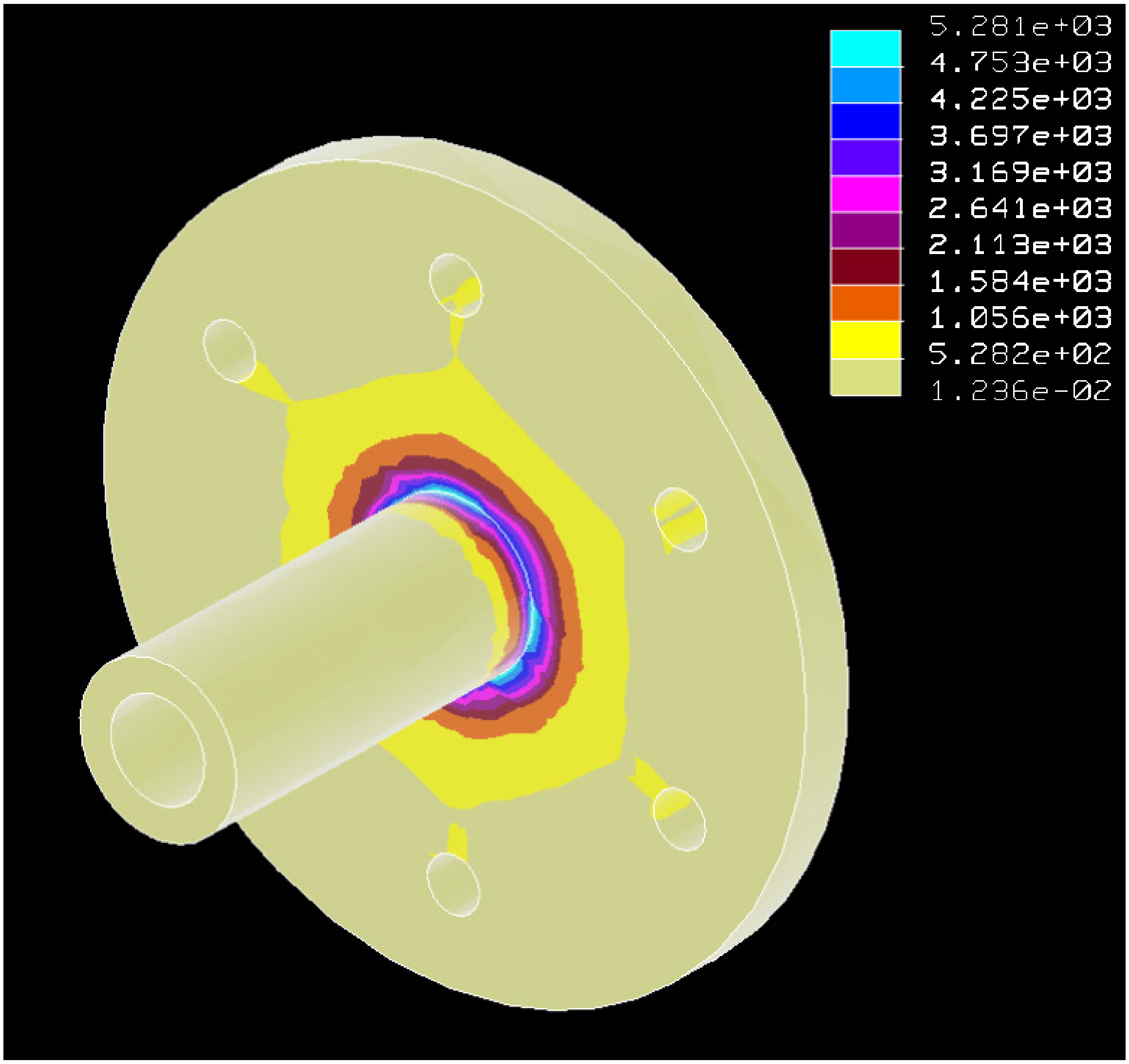
Appendix A-2 Figure 38 – Sky Shaft Upper Section Loading and Convergence



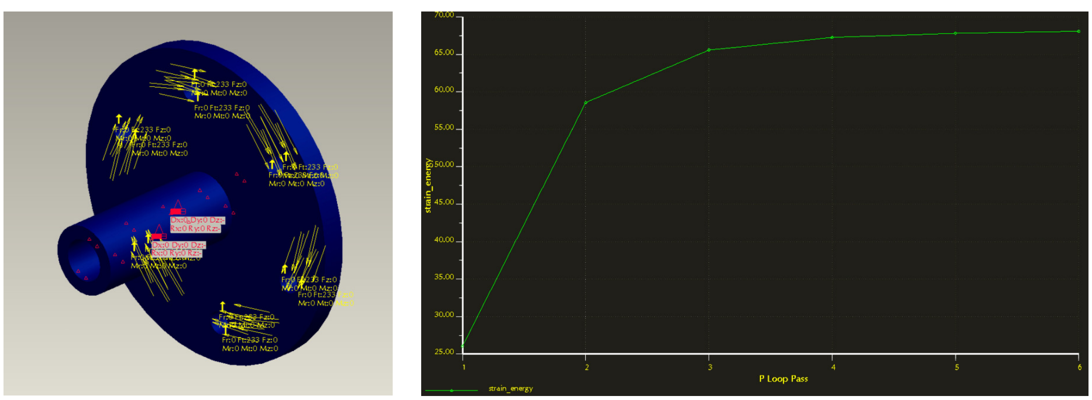
Appendix A-2 Figure 39 – Wheel Bracket Von Mises Stress



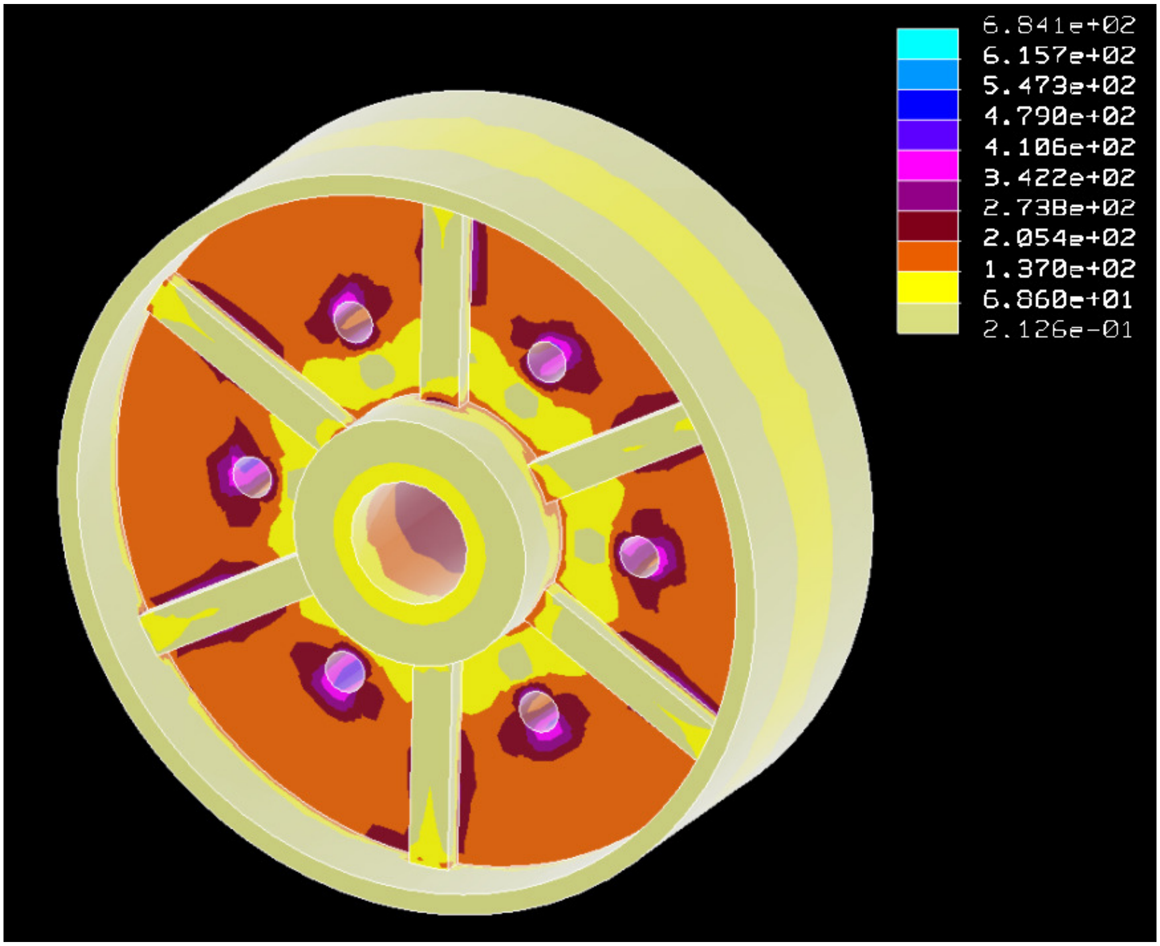
Appendix A-2 Figure 40 – Wheel Bracket Loading and Convergence



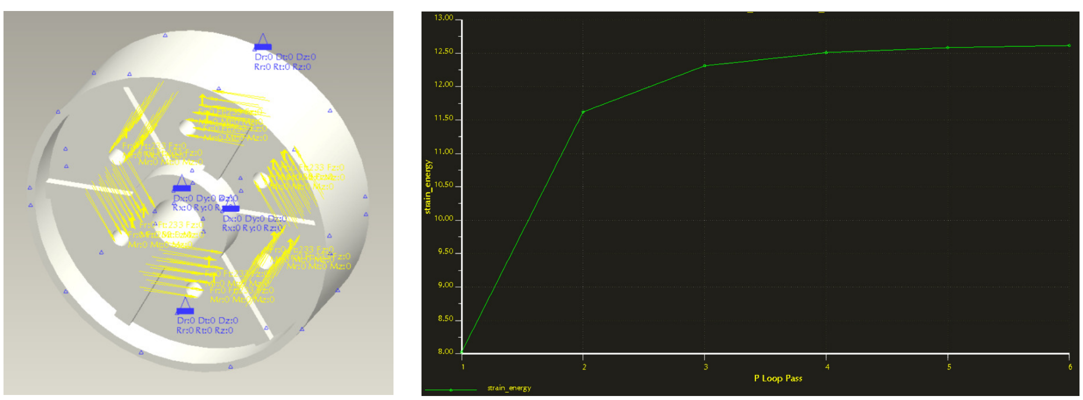
Appendix A-2 Figure 41 – Wheel Hub Von Mises Stress



Appendix A-2 Figure 42 – Wheel Bracket Loading and Convergence



Appendix A-2 Figure 43 – Wheel Von Mises Stress

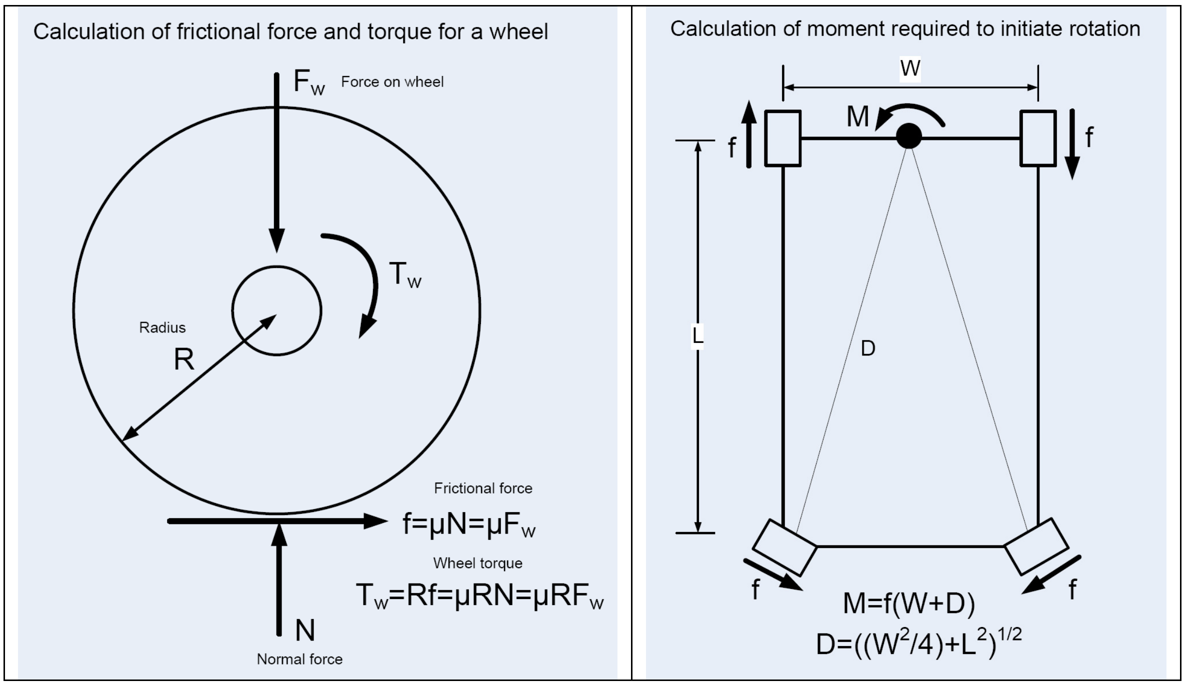


Appendix A-2 Figure 44 – Wheel Loading and Convergence

APPENDIX A-3: TORQUE CALCULATIONS

This appendix contains the diagrams, equations, and spreadsheet used to calculate the maximum torque required at the drive wheels given assumptions about the weight and dimensions of the mobile scaffolding unit.

Equations used in the following spreadsheet



Excel spreadsheet used for calculations

A. Weight on each scaffold wheel

Scaffold Weight	750.00	Pounds
Maximum Load per Scaffold Deck	500.00	Pounds
Maximum Number of Decks	4	Quantity
Weight on Each Scaffold Wheel	687.50	Pounds

B. Torque to move a wheel

Coefficient of Static Friction Between Floor and Wheels	0.40	Unitless
Frictional Force Between Floor and Wheels	275.00	Pounds
Maximum Radius of Wheels	2.50	Inches
Torque at Wheel to Initiate Movement of Wheel	687.50	Inch Pounds
	57.29	Foot Pounds

C. Torque to rotate scaffold about center of the width

Width of Scaffold	5.00	Feet
Length of Scaffold	10.00	Feet
Distance from Center of Width to Opposite Corners	10.31	Feet
Moment About Center to Initiate Rotation	4209.64	Foot Pounds
Forces at Each Wheel Composing the Above Moment	1683.85	Pounds
Torque at Wheel to Initiate Rotation About Center	4209.64	Inch Pounds
	350.80	Foot Pounds

D. Torque to rotate scaffold about one drive wheel

Distance between Corners	11.18	Feet
Moment About Drive Wheel to Initiate Rotation	7199.59	Foot Pounds
Force at Wheel to Create Above Moment	1439.92	Pounds
Torque at Wheel to Initiate Rotation About Drive Wheel	3599.80	Inch Pounds
	299.98	Foot Pounds

E. Torque to move scaffold forward or backward

Force Required to Initiate Forward Movement	1100.00	Pounds
Force at Wheel to Initiate Forward Movement	550.00	Pounds
Torque at Wheel to Initiate Forward Movement	1375.00	Inch Pounds
	114.58	Foot Pounds

F. Maximum intended wheel, crank, and shaft speeds

Maximum Intended Forward Speed of Scaffold	2.50	Feet / Sec
	30.00	Inches / Sec
Maximum Intended Angular Speed of Wheel	12.00	Rad / Sec
	114.59	Rev / Min
Maximum Intended Angular Speed of Crank	1.30	Rev / Sec
	8.17	Rad / Sec
	78.00	Rev / Min
Maximum Intended Angular Speed of Modular Drive Shaft	0.70	Rev / Sec
	4.40	Rad / Sec
	42.00	Rev / Min

G. Crank torque

Crank lever arm	11.00	Inches
Maximum force to be exerted by operator	190.00	Pounds
Maximum intended torque generated by crank	2090.00	Inch Pounds
	174.17	Foot Pounds

APPENDIX A-4: GEARING CALCULATIONS

This appendix includes the spreadsheet used to analyze gearing ratios and the effects of those ratios on input and output torque and speed.

Achieving Target Torque to Initiate Movement

Step	Input Torque (ft-lbs)	Output	To	Input	Ratio	Output Torque (ft-lbs)
Crankbox	**175**	1	To	1	1	175
Driveshaft	175	2	To	1	2	350
Gearbox	350	1	To	1	1	**350**
						Target: 350

Achieving Target Maximum Speed

Step	Input Speed (rpm)	Output	To	Input	Ratio	Output Speed (rpm)
Crankbox	**60**	1	To	1	1	60
Driveshaft	60	2	To	1	2	30
Gearbox	30	1	To	1	1	**30.00**
						Target: 95

Radius of Wheels (in)
2.5
Resulting Speed (in/s)
7.85

Conclusion: Without relaxing the maximum load assumptions a lower top speed must be tolerated and a higher input torque to initiate movement must be tolerated.