THE UBER WHEEL: DESIGN AND CONSTRUCTION OF A CONTINUOUSLY VARIABLE TANGENTIAL VELOCITY (CVTV) WHEEL SYSTEM

A Major Qualifying Project Report

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Abstract

The primary objective of this project was to design and produce a continuously variable transmission for a mobile robot platform. The innovative approach was to develop a system that could continuously vary the tangential velocity of a wheel without changing its overall angular velocity or diameter. A prototype CVTV, "Uber Wheel," was developed, as well as an optimized control system to automate ratio changes based on system demand. The prototype Uber Wheel and control system were tested using a custom made dynamometer and changes were made resulting in a final design. Success was based on performance criteria which included dynamic response to varying load and input conditions.

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*Due to unavoidable personal team issues these sections will be submitted at a later date.

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Introduction

The team's advisor, Professor Ken Stafford, had developed a concept for a new form of continuously variable transmission called a continuously variable tangential velocity (CVTV) system. He had worked with a former graduate student to prove the concept of the design, but an actual prototype had never come to fruition. Professor Stafford requested that the team design and develop a prototype of the CVTV System. The basic concept of the CVTV System is a "wheel" that is capable of changing its tangential velocity at any point without changing its overall angular velocity or radius.

The goal of this project was to produce a functional prototype CVTV System. The system had to be tangible and work according to all of the team's design specifications. The system had to have the ability to continuously vary the tangential velocity of a wheel without changing its overall angular velocity or diameter. This would result in the ability to continuously change the drive train's gear ratio by a factor yet to be determined while maintaining stability throughout all operating conditions. Additionally, the CVTV System had to be autonomous. That is, the CVTV System had to determine the most effective ratio for the system's current situation and react accordingly without additional user input or direct control.

This project contained elements from all three major disciplines of Robotics Engineering. Mechanical design was initially emphasized to produce the physical prototype. Control algorithms were integrated with the system to insure proper functionality of the wheel under all operating conditions. The sensors and the electrical work required to properly build the CVTV system facilitated automatic shifting, and responded according to the user's input.

Background

Continuously Variable Transmissions

A continuously variable transmission (CVT) is a transmission that can continuously change through an infinite number of effective gear ratios between its upper and lower extremes. What separates this from other transmissions is its lack of discrete gears. The CVT allows for the input shaft to maintain a constant angular velocity while continuously varying the output velocities. CVTs are used in many applications in the world today and can be seen in ATVs, automotive vehicles, and agricultural vehicles.

Automatic Transmission Shifting

The CVTV system needed to react automatically to the demands placed on it by user input or the environment. To best understand how other systems evaluate demand and react, the group took a look into the algorithms used in current automatic transmissions. "In most traditional automatic transmission, gear selections are determined based on the shift patterns of the vehicle speed and engine throttle opening" (Xi, Xiangyang, & Yanfang, 2009). Automatic transmissions rely on an onboard computer to analyze how the driver is driving and to determine when to shift. Since a CVT does not have discrete gears its shifting can instead be optimized to allow the motors to run at optimal efficiency or power. The graph below shows an acceleration curve for a Porsche 968 with a 6-speed transmission. Each gear is marked on the curve, and discontinuities can be seen between each gear. These discontinuities occur when the motor is disengaged from the transmission in order to allow the transmission to shift. A CVT eliminates these discontinuities because there are no discrete gears to shift between.

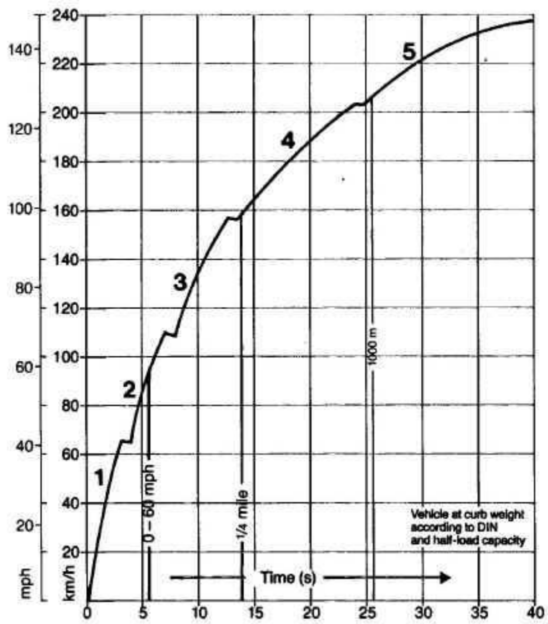

Figure 1: The acceleration curve of a 6-speed transmission.

Dynamometers

In order to test the Uber Wheel, the team intended to build a simple dynamometer. A dynamometer, commonly referred to as a dyno, is a device which is used to test the performance of engines and vehicles. Engine and chassis dynos are the most common and are categorized by their location on the system being tested. Engine dynos are placed directly on the output of an engine, while chassis dynos are attached to the wheel or wheels of a vehicle. Dynos are then further categorized into “brake” or “inertial” load systems. Inertial loaded systems do not allow for variable loads and would not provide the group with any valuable tests.

To measure the system’s torque and power, a dyno must apply a resistive force. This resistive force “absorbs” the energy from the system and converts it to another form of energy, most often heat. If the heat produced from the system is not dissipated quickly enough the dyno

will not function properly, making the cooling system one of the most important parts, but also the most expensive.

The dissipated energy from the driving wheel could be used to run an electric DC generator with a controllable magnetic resistive load. DC generator dynamometers do not allow for quick unloading of the applied resistive forces without expensive capacitors and software and do not allow for accurate acceleration control. These dynamometers are best used for steady state testing.

Eddy current brakes provide a resistive magnetic force. The rotor on the drum of the dyno would be made out of magnetic metal and driven inside the magnetic field of a solenoid. Because the magnetic field generated by the solenoid is created from an electric power supply it can be changed extremely fast, allowing for near instantaneous control of the applied load. Although there is no frictional force, the high amount of energy in the coils of the solenoid would melt if not cooled. These systems generally cost upwards of $50,000.

The most simple of all dynamometers uses a brake similar to that on a vehicle to apply a load to the drum. This system cannot operate for long periods of time at high loads because air is the only medium to dissipate heat and the brake or brake pad would melt. The resistive force can be calculated with the coefficient of friction from the brake pad and the angular velocity at which the rotor is turning. For testing the CVTV system this will be the most practical solution, requiring few parts and no expensive cooling system. (Bergeron, 2001)

Similar to using regular vehicle brakes, water cooled brakes use a radiator to dissipate the generated heat. Adding a water cooling system to a dynamometer greatly increased the price but allows for longer tests at higher velocities.

Water brakes use an enclosed chamber with a fan inside of it. To create a resistive force, water is pumped into the chamber with the fan making it harder to turn with more water. The water level in the chamber is controlled using an intake and an outtake valve. Because these systems do not require complicated separate cooling devices, they can handle high power with a very small system. (Simmons, 2010)

DC Motor Characteristics

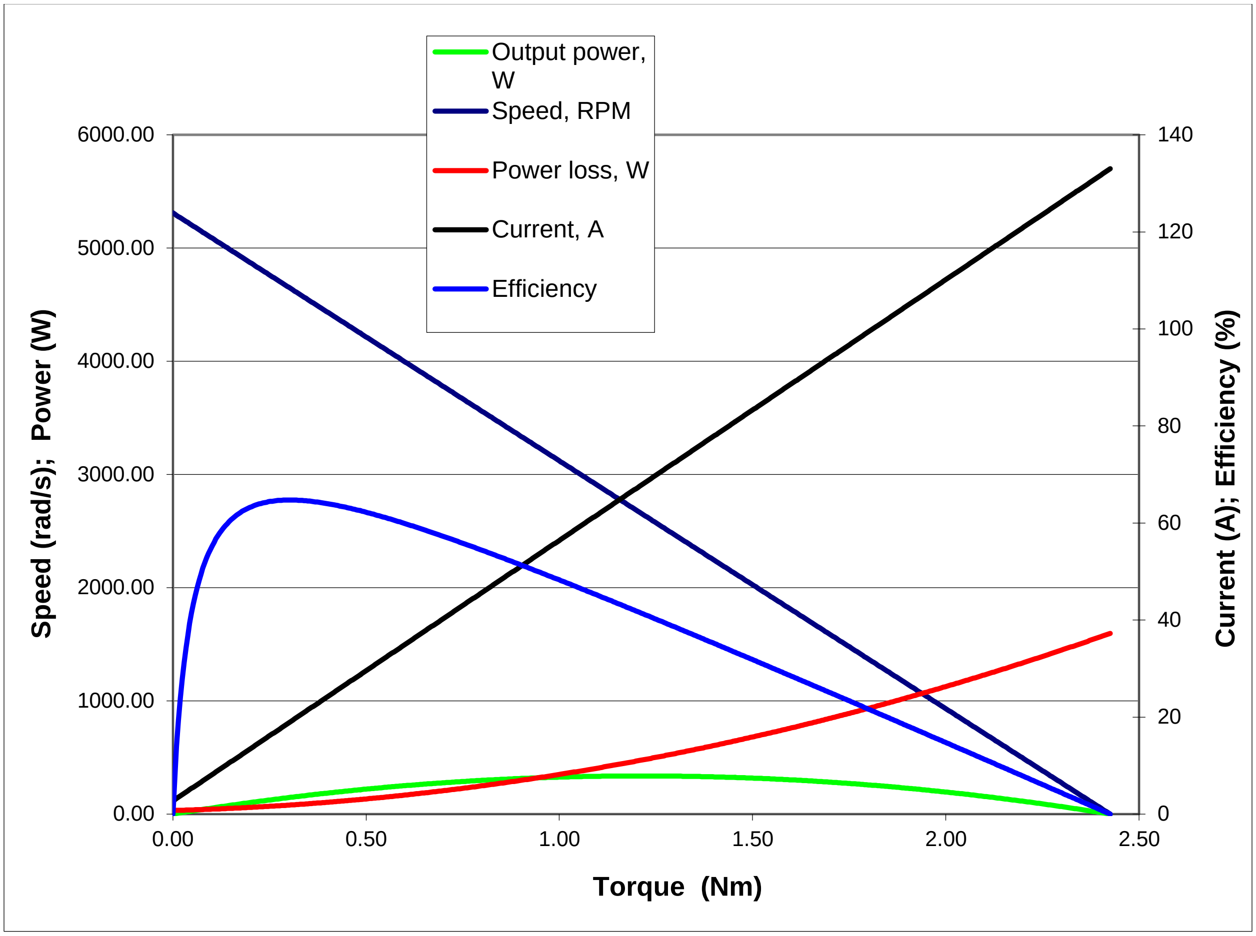

Figure 2: Motor Curve for the CIM Motor

The CIM motor is a 12 volt DC motor that is commonly used in the drivetrains of FIRST robots. Figure 2 shows the motor curve of the CIM motor. Most permanent magnet DC motors have a motor curve that looks similar to this. The line angling down from left to right is the speed of the motor when running at 12 volts. The line angling up from left to right is the current draw of the motor when running at 12 volts. The curved line sloping from left to right below the rpm line denotes the efficiency of the motor based on how much torque the motor is developing. The line curving up below the current line denotes the power lost by the motor to heat and

friction as a function of output torque. Finally, the line running along the bottom of the graph shows the maximum power output of the motor also based on output torque.

In most applications, it is desirable to operate most DC motors at an output torque requirement (and related RPM) that allows the output to range from maximum efficiency to maximum power. This allows the motor to run at an efficient and powerful condition that can be tailored to the demands of the motor's function. If a motor would be running continuously for long periods of time, an RPM that allows the motor to run at maximum efficiency would be optimal. Conversely, in a situation in which a motor needs to generate the maximum power possible, an RPM that generates that maximum power is desirable. A DC motor generates its maximum torque at stall, or 0 rpm. Operating motors at this point is detrimental to the motors and is not recommended. Instead, running the motor within the optimal range and producing the required torque via a reduction is recommended.

Robotics Platform

The team decided that building a robotic platform would be difficult without a predetermined set of guidelines. As a result, the team decided to build the CVTV system to FIRST Robotics Competition (FRC) specifications. The FRC is a well-established robotics program with a set of standards that are very familiar. Only motors supplied by FIRST in their Kit of Parts can be used. This did not adversely affect the team's design process as the motors supplied by FIRST were more than sufficient to perform the tasks required of them. Additionally, the team's electrical component choices were limited because of the battery requirements that FIRST had put in place. Only 12V batteries were permitted, but 12V systems are common enough that this was not a deterrent. Additionally, in the event that an opportunity to use the CVTV Wheel on an FRC robot arose, it would provide a great environment in which to demonstrate the design. The robot on which the CVTV Wheel might be utilized would be built by WPI/Massachusetts Academy of Math and Science Team 190. The team goes to several competitions across the country each year, competes in hundreds of matches, and faces hundreds of different competitors. This large testing base would allow the team to collect data that would help in future iterations of the CVTV System.

Goal Statement

Design and produce a prototype CVTV system capable of continuously varying the tangential velocity of a wheel without changing its overall angular velocity or diameter.

Functional Requirements

Performance	• Robot must produce a max speed of at least 15 ft./sec • Robot must produce a minimum speed of 6.75 ft./sec* • DC Motor should operate with a current draw less than 40 Amps • DC Motor should run at a desired balance between max efficiency and max power. *with motors at selected operating point (RPM/Torque)
Control	• Must be capable of autonomously determining an optimum ratio based on system demand.
Maintainability	• Must be robust • Must be easily maintainable
Size Constraints	• Must fit within a 10in x 8in x 8in envelope • Have a 6 inch diameter "wheel"
Manufacturability	• Must be made in accordance with FIRST rules

Table 1: Functional Requirements

Design Process and Initial Designs

The team decided to call the version of CVTV System that it developed The Uber Wheel. The following sections will describe the decisions made in its development. However, in order to understand the decisions made by the team, it is important to fully understand the mechanical operation of The Uber Wheel.

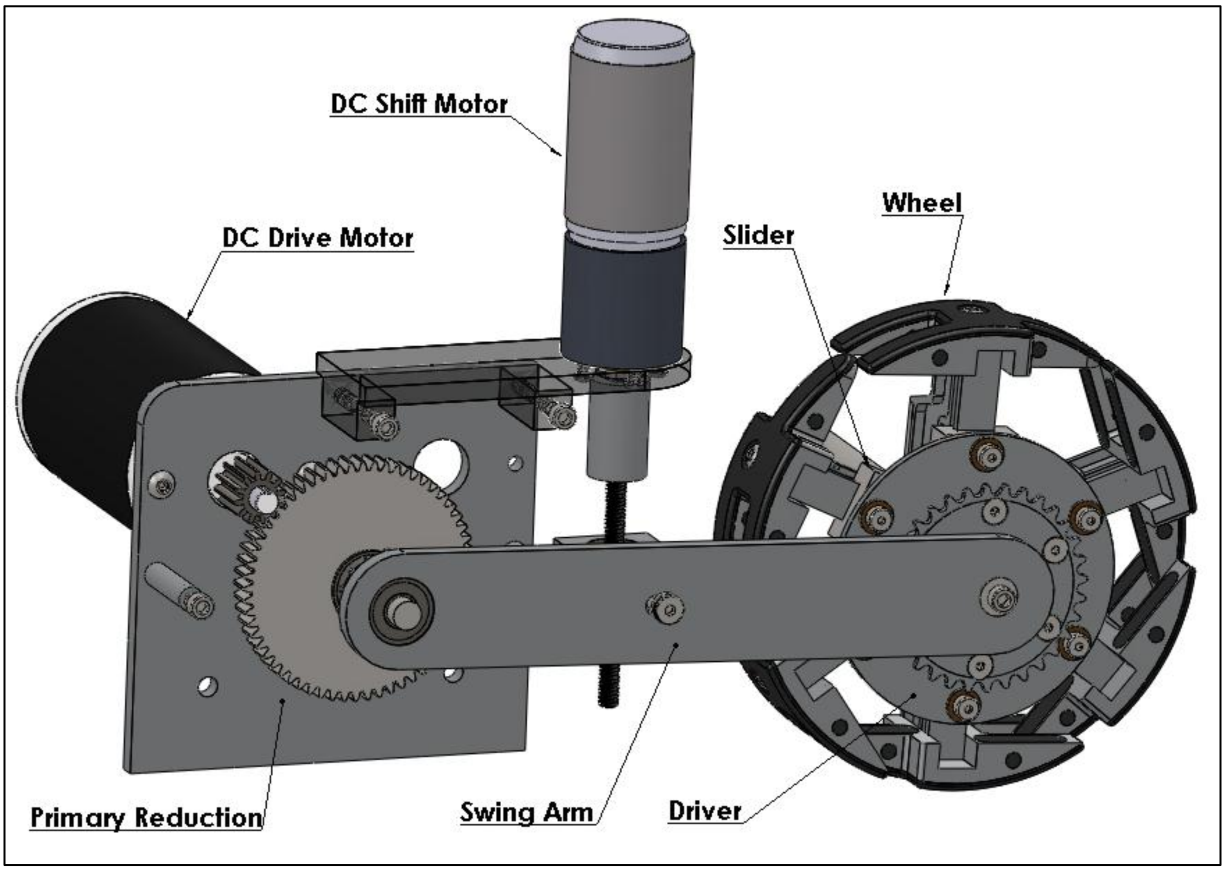

Figure 3: Labeled Diagram of the Uber Wheel

The Uber Wheel is composed of four main components: the primary reduction, the swing arm, the driver, and the wheel. The primary reduction is a traditional gearbox used to reduce the output speed of the DC drive motor to a workable speed. The swing arm pivots about the output shaft of the primary reduction and controls the position of the driver. The driver

consists of a sprocket driven by roller chain that is powered from the output shaft of the primary reduction. Coupled to the sprocket is a disc with six evenly spaced pivoting sliders. Each slider interfaces with a spoke of the wheel. The wheel can be viewed as a wheel with six spokes that has been divided radially. Each spoke has its own section of the wheel attached rigidly to it and all spokes rotate independently about the same fixed axle. A labeled diagram can be seen in Figure 3.

It is important to note that the axle of the driver and the axle of the wheel are not the same and, despite the fact that they can be collinear, are separate. In order to change the overall ratio of The Uber Wheel, the driver is moved either up or down. When the driver's axle is aligned with the wheel's fixed axle, The Uber Wheel acts as a traditional six inch diameter wheel. However, as the driver's axle is moved either above or below the wheel's axle, the sliders on the driver get farther from and closer to the surface of the wheel. This causes a change in the mechanical advantage, or ratio, of the system.

Mechanical Design

Having chosen FIRST Robotics as a platform on which to build The Uber Wheel, the team designed the system as if it was to be utilized on the Team 190 robot. This meant that the system was to be used in conjunction with many other systems on Team 190's final competition robot, potentially including pneumatics, end effectors, controllers, and other electrical equipment. Thus, it was important to confine The Uber Wheel to a 10in x 8in x 8in space. FIRST Robotics competitions are fast paced, making it imperative that The Uber Wheel be robust as well as easily maintainable. This would reduce the amount of repair work needed on

The Uber Wheel during competition as well as expedite it in the event that repair work was necessary.

The motor most frequently used in FIRST robot drivetrains is the CIM motor. This motor was chosen as the primary drive motor for the CVTV System because it is the most powerful motor in the FIRST Robotics Kit of Parts as well as one of the most robust. Instead of using moving air to cool the motor, the CIM motor uses its thermal mass to remain within operating temperatures. This allows the CIM motor to withstand stalling longer than other motors in the Kit of Parts. The Uber Wheel is a form of continuously variable transmission which, when used correctly, will allow the CIM motor to run at peak efficiency. The CIM motor runs at peak efficiency when operating at 4646 rpm. However, the CIM motor produces peak power when operating at 2655 rpm. The team decided that a balance of power and efficiency (i.e. An operating rpm between the max efficiency rpm and the max output power rpm) was optimal for a FIRST robot and selected a desired operating speed of 3186 rpm. However, directly driving a six inch wheel at these speeds would result in a maximum robot speed of over 100 feet per second as well as incredibly slow acceleration and braking rates. To resolve this issue, a primary reduction was developed to both reduce the output speed of the motor and increase its torque output for better acceleration and braking.

During a FIRST Robotics competition match there can be up to six 150 pound robots on the competition field at once. Therefore, a competitive robot is one that can be fast and agile on the field. Unfortunately, because of the tradeoff between output speed and output torque, a fast robot struggles to win a pushing match with another robot if one occurs. A transmission allows the robot to be both fast and strong by changing the ratio between the drive motors and the wheels. An informal survey of students and mentors of the WPI / Massachusetts Academy of

Math and Science FIRST Team 190 was conducted to determine the desired minimum and maximum operating speed for a robot during a FIRST Robotics competition match. As shown in the Functional Requirements, it was agreed that a maximum speed of 15 feet per second would allow the robot to be one of the fastest on the field, while a minimum speed of 6.75 feet per second would allow the robot to win most pushing matches.

In order to achieve the required speeds, The Uber Wheel had to be capable of an overall ratio of 2:1. This would allow the CIM motor to operate within our selected range for most of the match and, once The Uber Wheel had reached its maximum ratio, operate above that range to achieve 15 feet per second. Because the torque generated from the CIM motor is applied to The Uber Wheel at the point at which a slider contacts its respective spoke as a force, the amount of force that can be generated at the surface of the wheel is dependent on where the slider contacts that spoke. Each individual spoke can be viewed as a Class III lever in which the force is imparted by the slider and the load is imparted by the frictional force between the surface of the wheel and the ground (Figure 4).

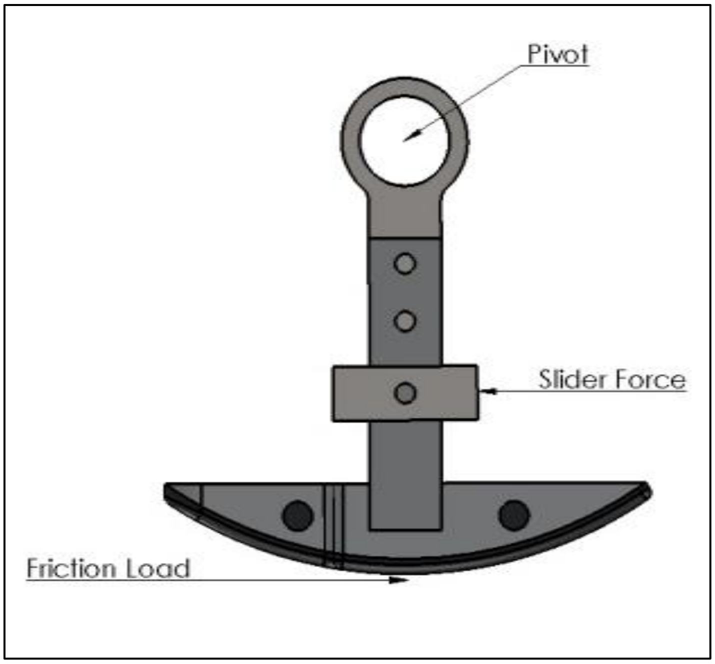

Figure 4: Spoke as a Class III lever

The ratio can then be calculated based on how the slider's distance from the surface of the wheel changes when the driver is at its highest and lowest points. The only spoke that can interact with the environment is the one that is touching the ground. Thus, it was only necessary to calculate the distances for the spoke that was touching the ground. The Uber Wheel was designed such that when the driver is at its highest point the distance between the slider and surface of the wheel is two inches. Also, when the driver is at its lowest point, the distance between the slider and surface of the wheel is one inch. This results in a ratio of 2:1.

Spokes

The spokes proved to be the most challenging component of The Uber Wheel to design. After determining the diameter of the system's wheel, it became evident that the size of the system would limit the number of spokes. Except for when The Uber Wheel is at a ratio of 1:1, the angular velocity of each spoke is continuously changing as it rotates. The size of the foot on

each spoke is related to the number of spokes in the system. As the number of spokes increases, the size of the foot decreases. An infinitely small foot (a result of an infinite amount of spokes) would contract the ground only for an instant, thus experiencing no changes in angular velocity while the foot is in contact with the ground. However, too many spokes would result in collisions and interferences within the system as well as increased cost, reduced reliability, and increased lead time for manufacturing.

It was determined that, for a six inch diameter wheel, the maximum feasible number of spokes was seven. In an effort to reduce complexity, cost, and lead time, the team explored the possibility of creating a six spoke system. The team analyzed the kinematics of the system by calculating the velocity and acceleration of each spoke as it rotates around the axle (see Appendix A: Kinematic Analysis of Spokes). The team then extrapolated the velocity and acceleration at the point at which the foot touches the ground (assuming point contact). The seven-spoke design had an overall velocity change of 0.02 feet per second while the foot was in contact with the ground (in a worst case scenario of The Uber Wheel in its maximum ratio), while the six-spoke design had an overall velocity change of 0.03 feet per second. It was noted that as The Uber Wheel shifted towards high gear, gaps began to form between the sections of wheel attached to each spoke (this can be seen in **Error! Reference source not found.**). This ssue was exacerbated by reducing the number of spokes and alleviated by increasing the number of spokes. However, increasing the number of spokes reduced the amount of space available for each spoke. It was apparent that a balance of these two options was required. The team decided that six spokes in a six inch diameter Uber Wheel would provide ample space for each spoke while creating acceptably small gaps when The Uber Wheel was shifted into high gear. A six spoke design would also reduce complexity, cost, lead time, and weight.

Another obstacle that the team faced was that each spoke had to rotate about the same fixed axis but also had to rotate independently from each other spoke. The team briefly considered the idea of making all spokes as one flexible wheel, but this concept was quickly disposed of as it introduced more problems than it solved. Further complicating the issue, the front face of each spoke had to be on the same plane as all other spokes in order to interface with the driver. The solution to these obstacles came in the form of supporting each spoke on two .125” thick tabs, spaced about one inch apart, that rotated about the central axis. The tabs were then staggered such that the six spokes could be packed closely together. This required that each spoke have slightly different dimensions so that all of the fronts could be planar. While making six different spokes for each wheel was not efficient, it provided the most compact design. Illustrations describing this strategy can be seen in Figure 5 and in Figure 6.

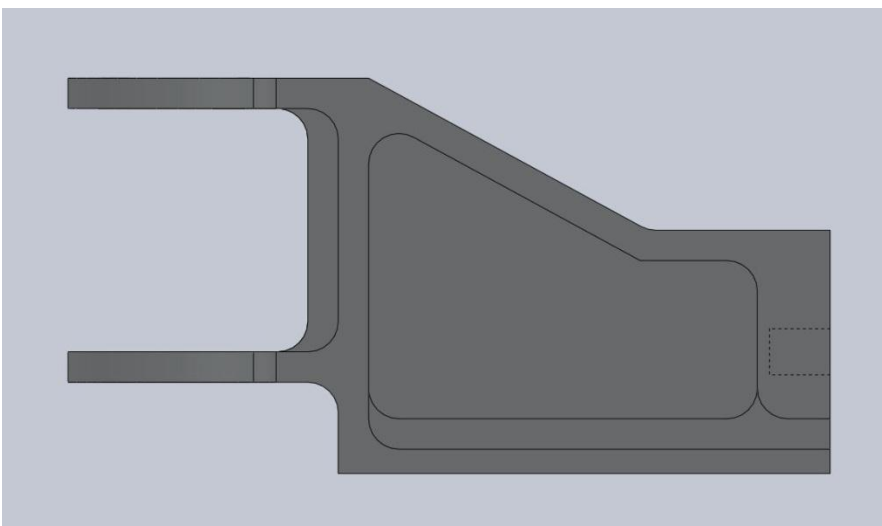

Figure 5: Tabs on the Spokes

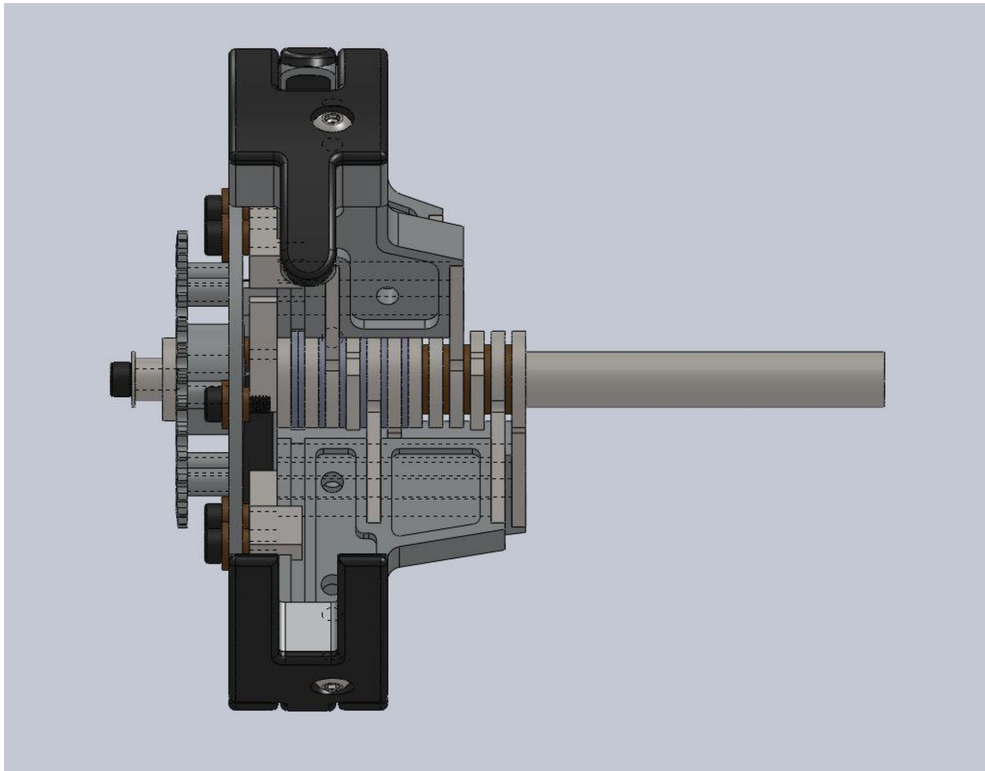

Figure 6: Staggered Spokes

The team initially designed each spoke with a uni-body structure to minimize the number of parts that went into each wheel (Figure 7). However, this severely complicated the machining process of each spoke. In order to reduce the complexity of the machining process for the spokes, the tabs were separated from the spokes and made out of .125” plain carbon steel. This not only simplified the manufacturing process but increased the strength of The Uber Wheel as well. An example of the separate tab design can be seen in Figure 8.

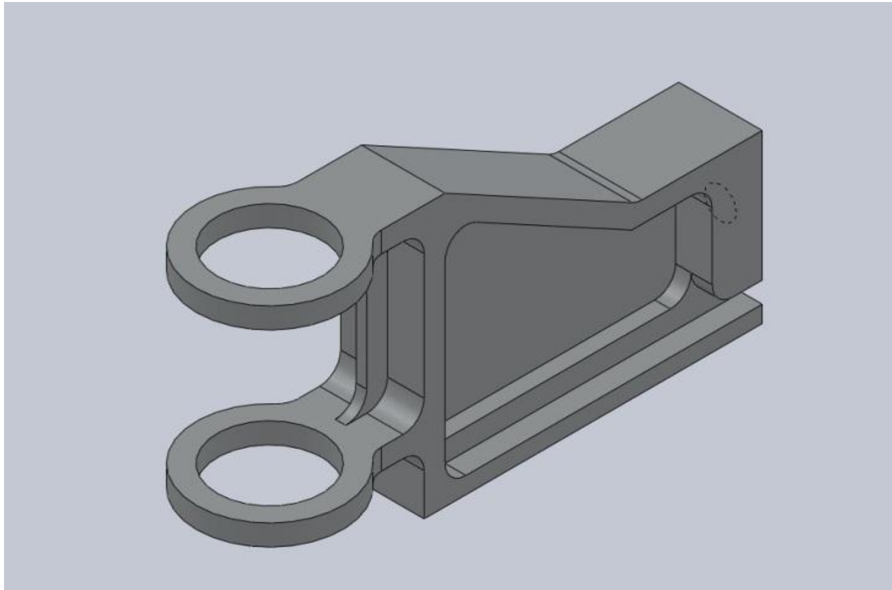

Figure 7: Uni-body spoke design

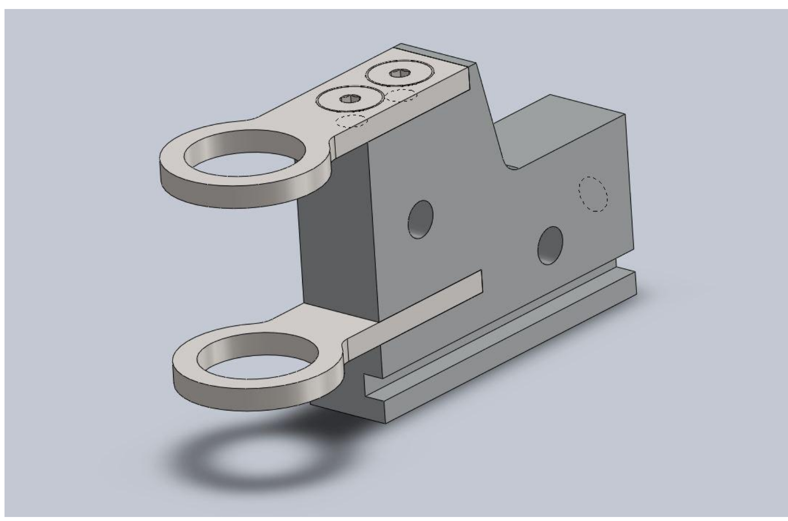

Figure 8: Separate tab design

Driver

The driver's size was constrained by two factors. The driver had to be smaller than the size of the wheel and had to be smaller still in order to be able to move .5" from the center of the wheel in both directions. These size constraints also limited the size of the sprocket attached to the driver. The team selected a 32 tooth sprocket because it fit within the size constraints of the

driver and also, coupled with a 16 tooth sprocket on the output of the primary reduction, allowed for a convenient single stage reduction in the primary reduction to achieve an overall reduction of 10:1. The team originally designed the diver with a uni-body structure (below) but, in an effort to reduce the weight of The Uber Wheel and simplify manufacturing, settled on a simplified design.

Figure 9: Uni-body driver

Primary Reduction

It was decided that a 1:1 robot speed of 10 feet per second would give the system the ability to reach most of the desired range of 6.75 to 15 feet per second while allowing the CIM motor to maintain its desired RPM throughout all but the maximum speeds. In order to propel the robot at 10 feet per second, it was calculated that The Uber Wheel had to rotate at 381.97 RPM. The desired RPM of the CIM motor had been established at 3982.5 RPM requiring a

10.43:1 reduction between the CIM motor and The Uber Wheel. A 2:1 reduction had already been established between the output of the primary reduction and the driver, so a 5:1 reduction in the primary reduction would result in an overall reduction of 10:1. This was the closest ratio the team could achieve without extraneous amounts of gears. In order to achieve this reduction, a 12 tooth pinion gear was attached to the CIM motor and mated with a 60 tooth gear attached to the output shaft of the primary reduction.

Swing Arm

The team came up with several different ideas for the method in which to move the driver up and down. The first concept involved moving the driver up and down using a lead screw. The major flaw of this concept, however, was that the distance between the driver sprocket and the sprocket on the primary reduction would change as the ratio changed. This would change the length of the chain required to connect the two sprockets, leading to undesirable changes in chain tension. Another idea was to place the primary reduction above The Uber Wheel, and to use a four bar linkage to maintain chain tension while the driver was shifted up and down with a lead screw. This concept added an unnecessary amount of complication to The Uber Wheel and was discarded. Finally, the team settled on a swing arm that pivots around the output shaft of the primary reduction. This design allowed for constant chain tension and a lead screw was used to move the swing arm, and attached driver, up and down.

Electrical Design

Controllers

The Arduino Uno was the group's initial choice for a micro-controller. The Uno is an open-source prototyping platform capable of receiving input from a wide range of sensors and controlling many motors at once. Arduino has a large community base with extensive

documentation on how to use their system. The Uno, among all other Arduino products, runs on the Arduino Programming language, a language based off of the open source programming language Wiring. Their language allows for easy control of motors and simple reading and writing to ports.

After testing the Arduino Uno with the CVTV System the group quickly realized that it would not adequately meet the needs of the Victor 884 motor controllers. The Arduino is equipped with a hardware PWM generation capability which allows it to output an 8-bit PWM signal. Unfortunately, the Victor 884 only works with Standard R/C Type PWM, which has a much shorter duty cycle than the Arduino is capable of producing. The only means of fixing this problem involved utilizing the Uno's on-board clock to control the PWM generation, which would have prevented the control algorithm from running correctly.

Another choice for micro-controller came from several WPI alumni. Neuron Robotics, founded in 2008, is a small company whose goal is to create an open source, programmable and cross-platform solution to the lack of unified systems in the robotics community. They offer a module called the DyIO which interfaces with a computer, allowing users to control sensors and motors with ease. Although the DyIO is capable of running the CVTV control algorithm and controlling the PWM output for the motors, it is not currently capable of running independently from a computer which led the group to choose another micro-controller.

The VEX Microcontroller is a system that is very familiar to the WPI robotics community because it has been used in many of the core Robotics Engineering classes. The VEX system is fully capable at handling up to eight PWM signals and processing up to sixteen input/output ports while running separately from a computer. Not only is the system capable of

handling our algorithm and running it independently but WPI's Robotics Resource Center was gracious enough to donate one to the CVTV System as long as it remains with the Center.

Sensors

To control the gear position which the CVTV should be operating the controller must know the exact position of the driver. Using a ten-turn potentiometer, the controller is able to accurately determine the current position of the driver. To control the gear position the controller runs a PID control loop which allows for quick, precise responses to gear changes.

The output velocity of the system (V_O) can be achieved by multiplying the driving sprocket's RPM (D_{RPM}) by the current gear ratio (R_G), see **Eq.1**. The driver's RPM is calculated by taking the output of a quadrature encoder (G_{RPM}), located on the output of the gear box, and multiplying it with the sprocket ratio (R_S), see **Eq.2**. The final result is given by **Eq.3**. The quadrature encoder allows the system to determine not only the RPM of the motor but also the direction which it is spinning. In order to truly determine the current operating conditions of the motor, one must consider the torque output of the motor and the current voltage supply to the motor. However, the process described above produces a fairly accurate representation of the current operating conditions because the load on the system during normal operation can be determined. Because the load on the system during normal operation is known, a relation can be made between the RPM of the motor and its current operating conditions.

$$\boldsymbol{Eq.1}: \quad \boldsymbol{V_O = D_{RPM} * R_G}$$

$$\boldsymbol{Eq.2}: \quad \boldsymbol{D_{RPM} = G_{RPM} * R_S}$$

$$\boldsymbol{Eq.3}: \quad \boldsymbol{V_O = R_G * (G_{RPM} * R_S)}$$

The current RPM of the driver coupled with the user's input allows the controller to determine which gear position to send the gear motor to. If the user demands a speed greater than it is currently running at the system shifts the position of the gear to meet the desired input.

When testing the system it was often desired to control the speed of the driver separately from the gear position without having the control algorithm decided the gear. A ten-turn potentiometer is wired to the VEX controller which allows the user to individually control both speed and position when the system is in *test_mode*.

Control Algorithm*

This section will be documented at a later date.

Final Design Revisions

The design of The Uber Wheel was an iterative process because of its lack of precedent. Without the benefit of CAD software, the team would have had to produce many prototypes of The Uber Wheel, using valuable time. SolidWorks was chosen as the primary design software during the development of The Uber Wheel and it was used to revise the initial design during and after testing in order to improve it. This section describes those changes that were made.

Weight Reduction

Robots entered into the FIRST Robotics Competition must not exceed a defined weight limit of 120 pounds. Mastering the complexities of the games that these robots compete in requires several different systems. Each system has an inherent weight, and all must fit on the robot. So, each system is designed to be as light as possible while still accomplishing the task it was designed for. The Uber Wheel was not initially designed to be as light as possible so, in an effort to reduce the weight as much as possible, material was removed from the primary reduction while maintaining its structural integrity (Figure 10). Excess material was removed from the spokes to further reduce the weight of the system (Figure 11).

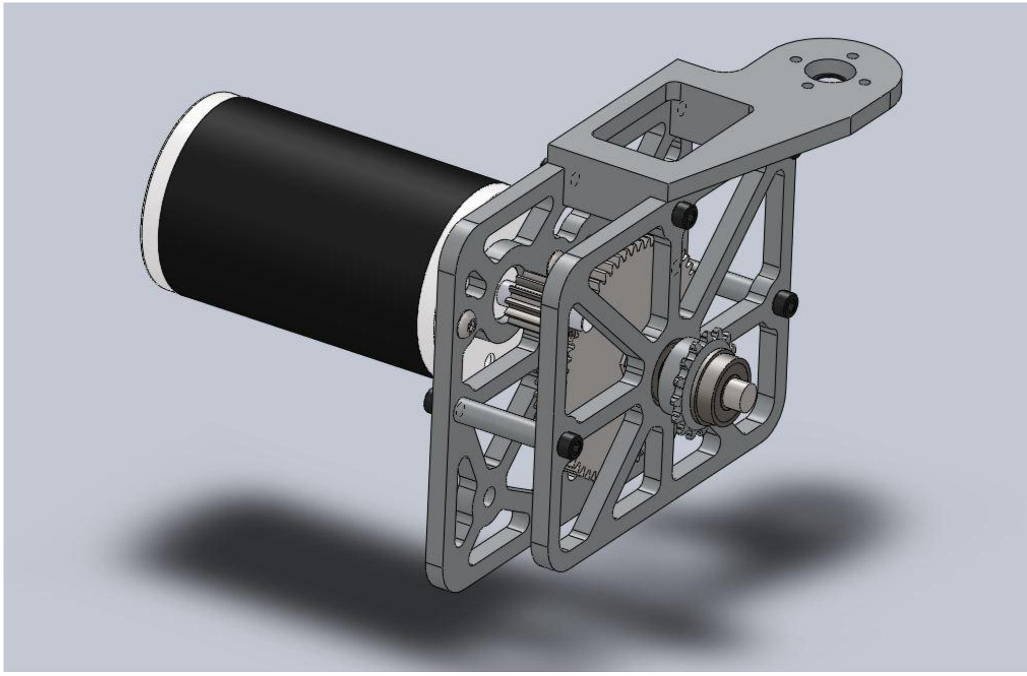

Figure 10: Lightened primary reduction

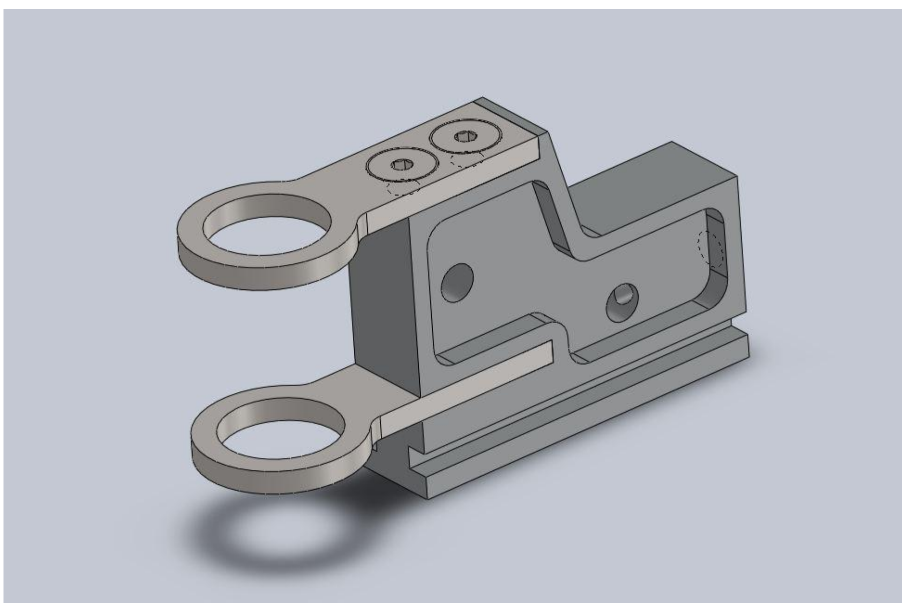

Figure 11: Lightened spoke

Reducing Compliance in the Shifting System

During testing, it was discovered that outside forces could potentially change the height of the driver, undesirably changing the ratio of The Uber Wheel. Investigation showed that this

was due to compliance in the shifting mechanism. The mechanism, which consisted of a swing arm driven by a lead screw, did not hold the driver rigidly enough to prevent outside forces from changing the ratio. The compliance was occurring in two places, the interface between the driver and the sliders and the interface between the lead screw and the swing arm. In order to address this issue, several techniques were used. First, it was noticed that the bushings, and their respective shoulder bolts, that the sliders rotated within were too long. This introduced an extra degree of movement in the sliders because their rear face was not held tightly against the surface of the driver (Figure 12). While this removed some compliance from the shifting system, the majority of the compliance was still present after this fix.

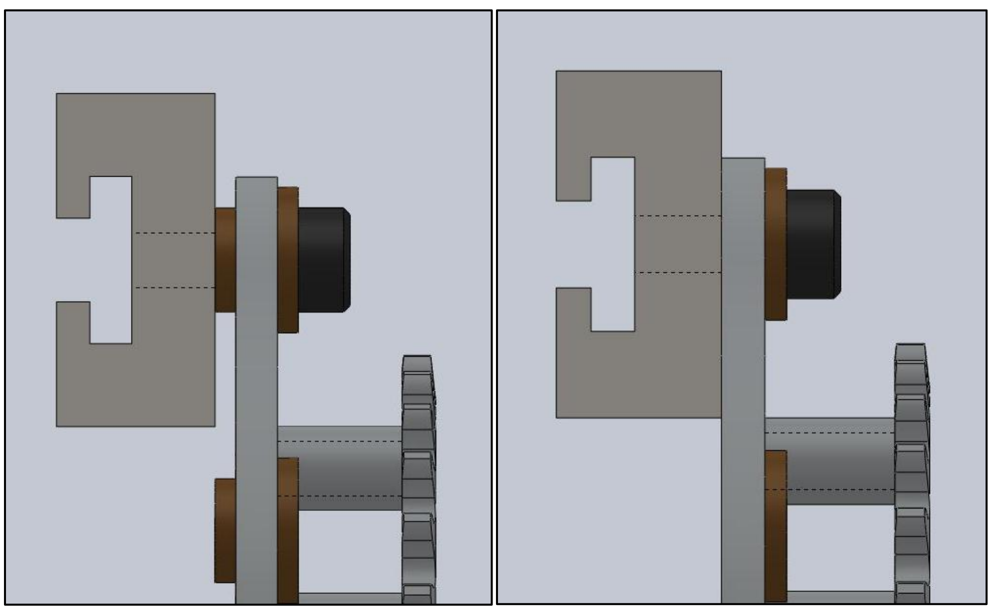

Figure 12: Shortening the bushing on the slider to remove slop from the system.

A similar problem occurred in the interface between the swing arm and the lead screw, called the lead nut assembly. The lead nut assembly consists of an aluminum block with two perpendicular holes drilled in it. The lead screw is threaded into one hole and a shoulder bolt is passed through a slot in the swing arm and threaded into the second hole to transfer movement

from the lead nut assembly to the swing arm. Similar to the sliders in the previous issue, there was a gap between the surface of the swing arm and its mating surface on the lead nut assembly. This allowed the lead nut assembly to pivot within the slot in the swing arm, causing an undesirable amount of compliance. In order to eliminate this gap, the lead nut assembly was elongated to take up the extra distance. This reduced the compliancer in the system, but also sparked another idea.

The distance between the lead screw and the swing arm is spanned by the lead nut assembly. As the lead nut assembly was elongated, it was noticed that the motor powering the lead screw appeared to become less rigidly attached to the primary reduction. However, the increased movement of the lead screw motor was a direct result of the increased forces on the lead screw motor caused by the elongated lead nut assembly. This increased movement was resulting in additional compliance in the system. In order to resolve this, the lead screw was moved closer to the swing arm by changing its mounting bracket (Figure 13), thus shortening the lead nut assembly and decreasing compliance.

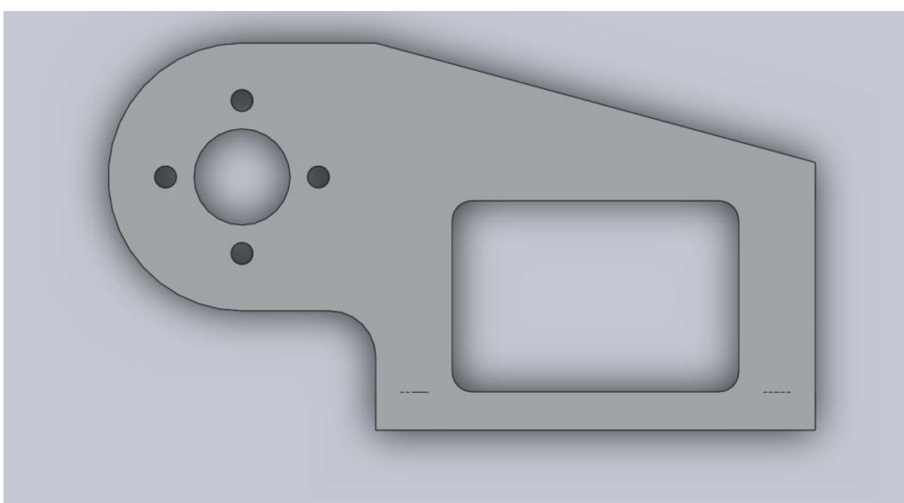

Figure 13: Modified lead screw motor mount

Molded Feet

The feet on the first prototype of The Uber Wheel were originally made of solid aluminum. This made for a very strong foot that was more than capable of handling the forces generated during operation, but did not provide adequate traction on the carpeted surface of a FIRST Robotics Competition field. In order to provide traction on the carpeted surface, the feet had to have a rubberized surface. The team initially tried rubberized truck bed lining, but found that excessive heat generated by spinning wheels on carpet could cause the coating to rub off of the feet. Another concept involved molding each foot entirely from rubber. This would give The Uber Wheel the desired traction, but fears were expressed regarding the structural rigidity of an entirely rubber foot. As a result, a hybrid solution of molding rubber over an aluminum structural frame was decided on (Figure 14). This solution gave the feet the structural rigidity of aluminum while providing adequate traction. Additionally, because a significant amount of each aluminum foot was being replaced with rubber, this method helped to reduce the weight of The Uber Wheel.

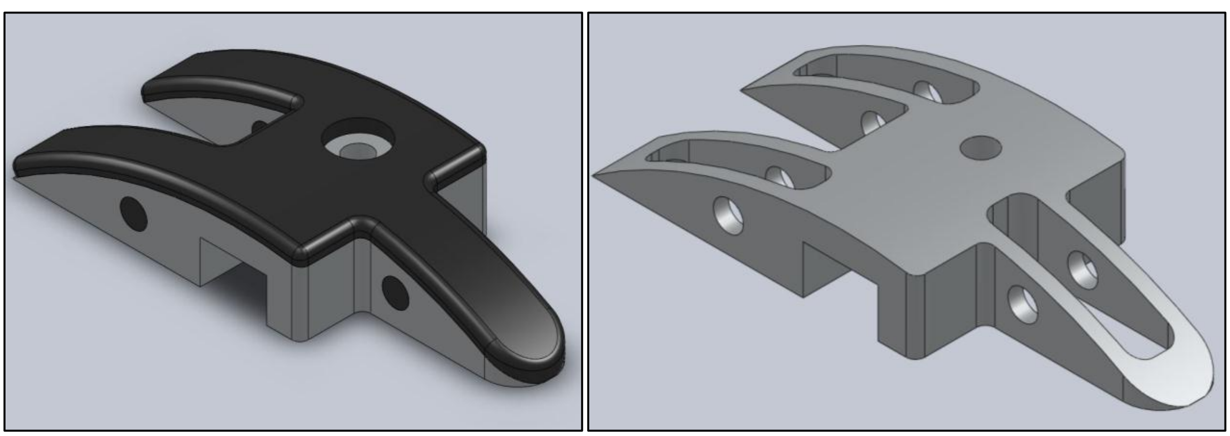

Figure 14: Over molded foot (left) and aluminum structure (right)

Final Design Description

Figure 15 shows the completed model of The Uber Wheel. The system consists of several components: the primary reduction, the driver, the wheel, and the swing arm. The wheel is composed of six individually rotating spokes that pivot around a central free spinning axle. Attached to each spoke is a foot over which is molded a rubberized material to provide traction on a carpeted surface. Each spoke has an engaging feature that allows a slider to travel its length. Each slider engages with a pivot point on the driver, which, when rotated, moves each spoke. The driver is mounted on a swing arm that can move the driver up to 0.5 inches from the center of the wheel on either side, changing the ratio of the system.

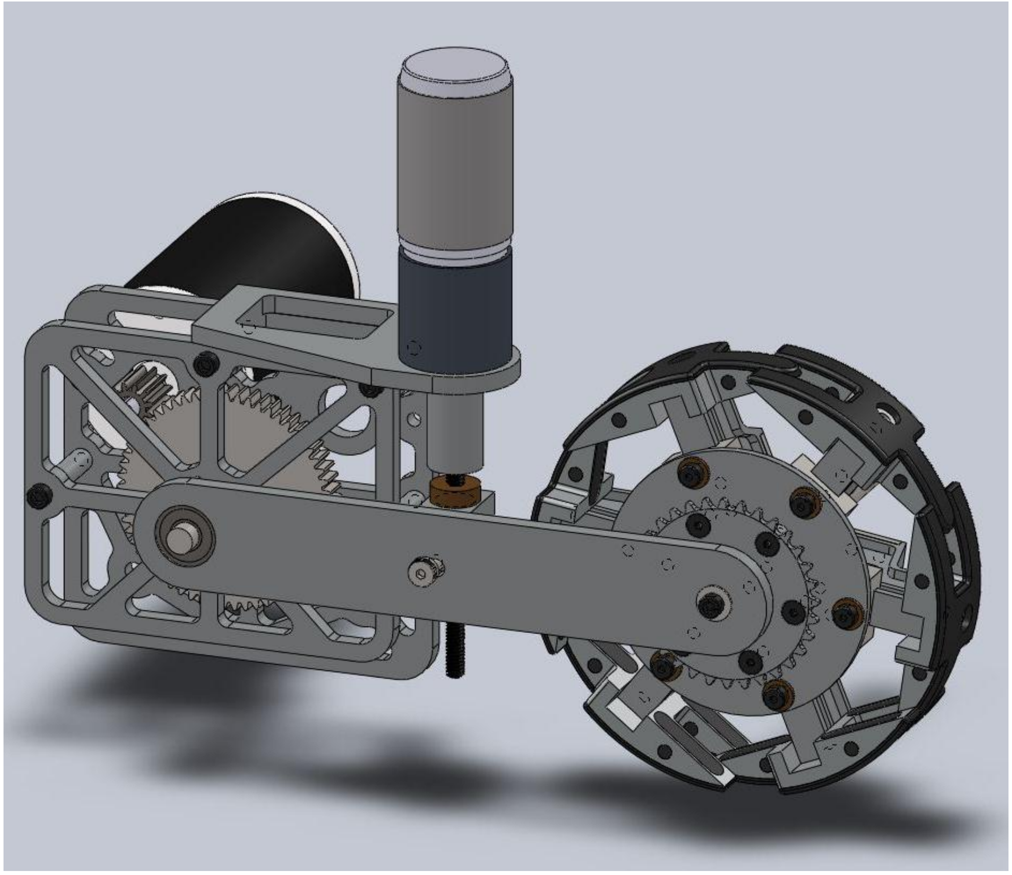

Figure 15: The Uber Wheel

Primary Reduction

A primary reduction was developed to reduce the output speed of the motors so that the speed requirements of the robot could be met. This reduction also increases the torque output of the system. The final design of the primary reduction utilizes a 5:1 reduction via gears and a 2:1 reduction via chain for an overall reduction of 10:1. The output pinions of the DC drive motors have 12 teeth and both mesh with the same 60-tooth gear. The 60-tooth gear is hex-broached and is coupled directly to a 16-tooth sprocket via a steel hex shaft. The 16-tooth sprocket is coupled, via chain, to a 32-tooth sprocket that is directly attached to the driver. The chain used in the primary reduction is ANSI #25 chain. This was chosen because it is the primary chain size used on Team 190 robots. The primary reduction can be seen in Figure 16.

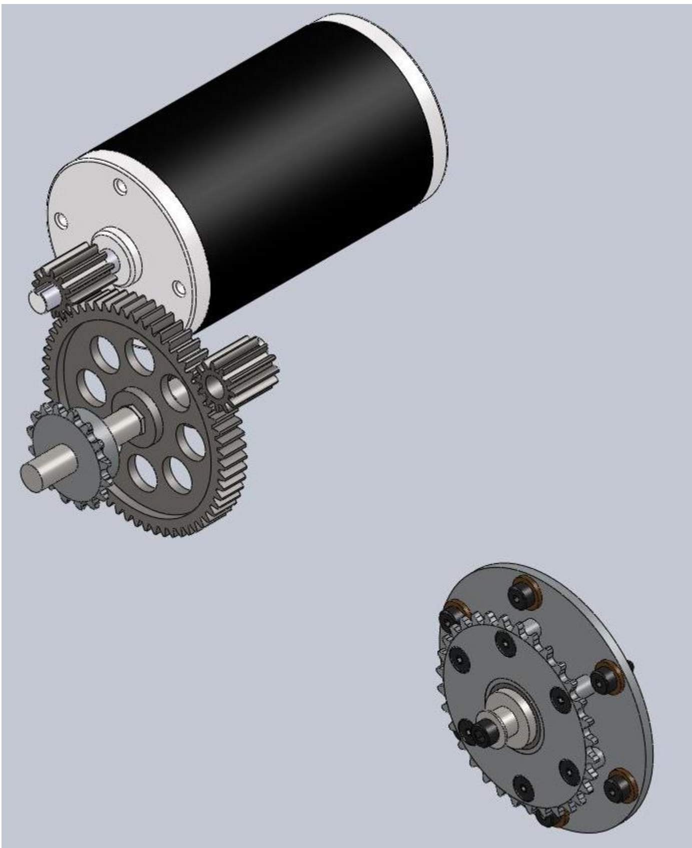

Figure 16: Primary Reduction

Wheel

The wheel was the primary focus during the design and development of The Uber Wheel. It is constructed from three components: the spokes, the main axle, and the feet. The spokes of The Uber Wheel were designed such that they could each rotate independently about the same axle. Ensuring that the front faces of all spokes were in the same plane was also important in order to facilitate interfacing each spoke with the driver. To allow this, each spoke is slightly different as seen in Figure 17.

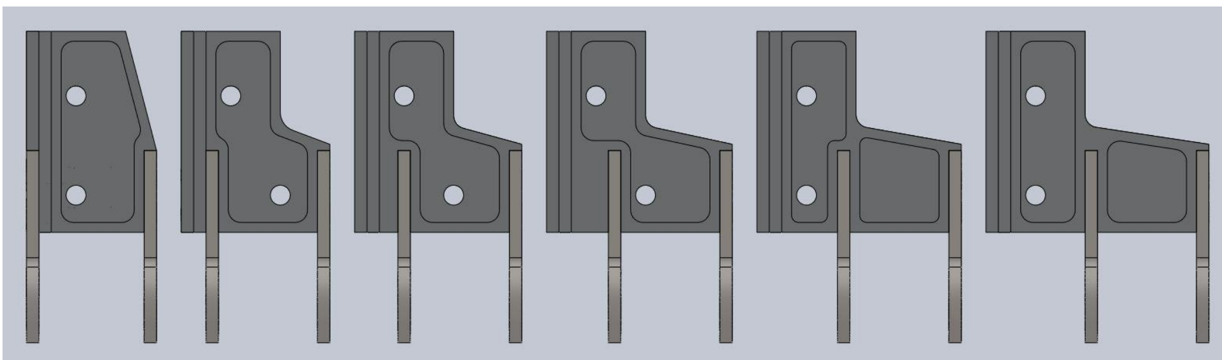

Figure 17: Six different spokes

Two .125" thick carbon steel tabs occupy slots in each spoke and are fixed in place via counter-sunk machine screws. Both tabs are spaced the same distance apart on all spokes except for one where it was necessary to increase the spacing to allow space for the slider. These tabs support the weight of the robot while reducing the amount of space needed for The Uber Wheel. Each tab also has a threaded hole in the its top for attaching a foot as well as strategic pocketing to reduce the weight of each spoke while maintaining structural integrity.

The main axle of The Uber Wheel is a .5" carbon steel, cantilevered, free spinning rod with a bronze bushing pressed onto its end. There are typically two types of axle used in FIRST Robotics competitions. The robot frame rigidly supports one type of axle, called a fixed axle. It

remains stationary while the robot's wheels spin about it. Conversely, a free spinning axle is supported by either bushings or bearings and allowed to spin freely with the wheel rigidly attached to it. Typically, these axles are supported on both ends, but the design of the driver and swing arm prevents this, so the axle is cantilevered.

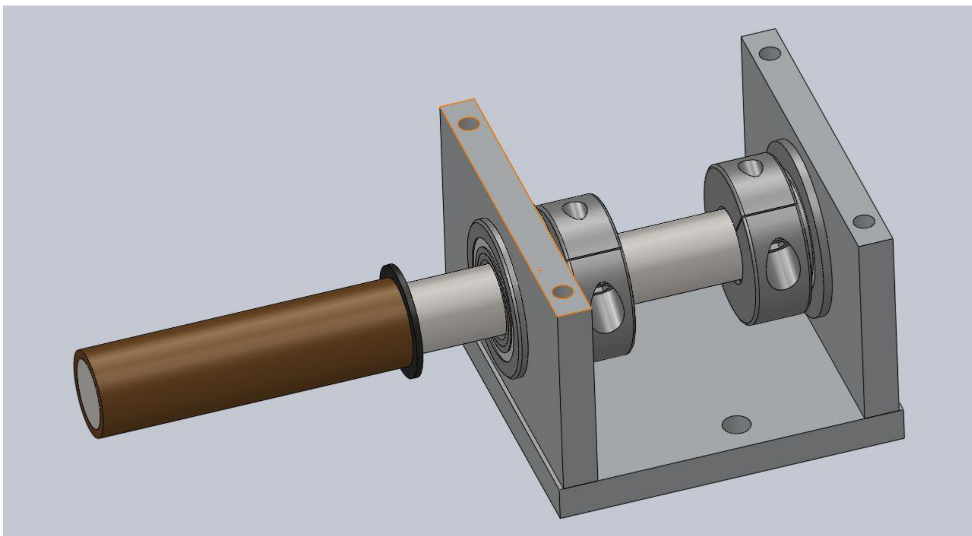

Figure 18: The main axle

The function of The Uber Wheel requires each spoke to be able to rotate independently about the main axle. In order to achieve this, the staggered tab design discussed in Design Process and Initial Designs was developed. Two .125" thick steel tabs support each spoke. These tabs create large concentrations of force on the main axle as the spoke they are attached to supports the robot's weight. In order to reduce the wear on the main axle, a bronze bushing is fitted around the main axle to serve as a bearing surface for the steel tabs. To further reduce wear, the axle was allowed to spin freely in a hybrid form of the two axle types discussed above. This significantly reduced the amount of relative motion between the spokes and the main axle by allowing the tabs supporting the most weight to remain stationary while the others moved around the axle.

The structural frames of the feet are made of 6061-alloy aluminum for strength as well as its relatively low weight. As The Uber Wheel shifts down, the feet get closer together. Because of this, the design of each foot (seen in Figure 19) allows it to interface with the foot in front of it in order to allow the system to reach lower ratios. The bottom of each foot has a relief that interfaces with the spoke to increase rigidity when attached. Original designs planned for a rubber coating to be applied to the feet to increase traction but testing proved this unreliable. As previously described, the final design of the feet allows for a traction material to be molded onto the feet (Figure 19).

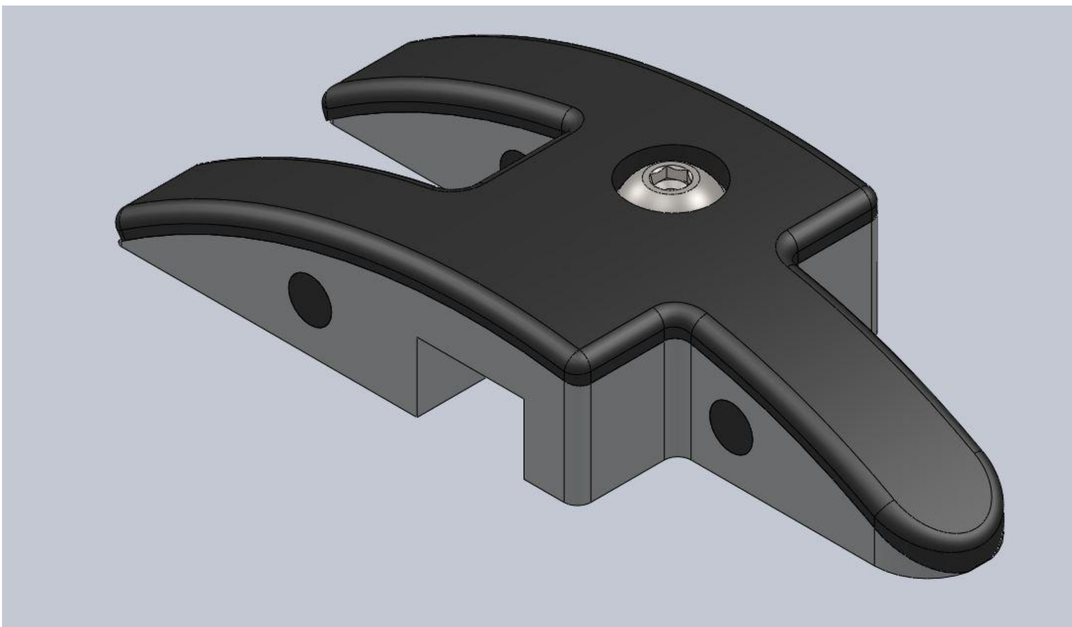

Figure 19: Foot

Driver

The driver consists of a 32-tooth sprocket attached via six standoffs to a .125” aluminum plate. Inserted in the plate are six bronze bushings that allow six shoulder bolts to pivot

smoothly. Each shoulder bolt is threaded into a steel slider with a T-slot cut into it to allow it to interface with the spoke. Original designs did not include the pivoting sliders but instead included pegs rigidly attached to the driver. These pegs were intended to slide within slots that were cut into the spokes but, because they were round, would have caused a concentration of forces due to line contact. The pivoting sliders distribute the load over a larger area, reducing the chances of deformation. Two bearings are pressed into the driver, one into the sprocket and one into the plate, these bearings ride on an aluminum shaft protruding from the swing arm. The driver can be seen in Figure 20.

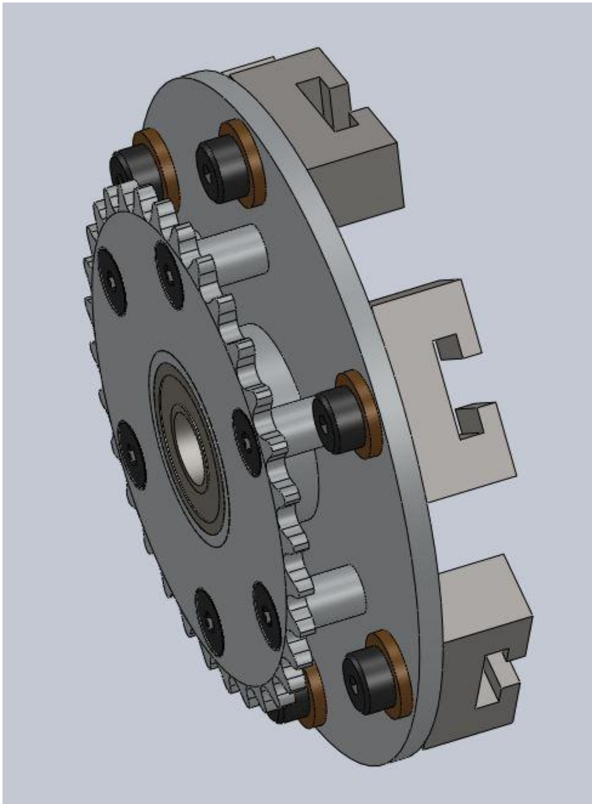

Figure 20: Driver

Swing Arm

The swing arm's primary purpose is to move the driver up and down to change the ratio. Original designs did not include a swing arm, but instead used a lead screw to move the driver. However, moving the driver linearly changed the center-to-center distance between the sprocket on the primary reduction and the sprocket on the driver leading to undesired changes in chain tension. By moving the driver in an arc centered about the output shaft of the primary reduction, the center-to-center distance remained the same and a complicated tensioning system wasn't necessary. The arm is constructed from ¼" thick 6061-alloy aluminum to provide a rigid mount for the driver and to reduce weight. The swing arm pivots around the output shaft of the primary reduction on a bearing pressed into one end. Pressed into the other end is an aluminum shaft used as the driver's axle (Figure 21).

Figure 21: Swing Arm

A lead screw is still used to change the height of the driver, but does so by changing the angle of the swing arm. The motor powering the lead screw is a Globe Motor that was, until recently, popular in FIRST robotics. The motor is coupled to an ACME lead screw, the pitch of which was chosen to reduce shifting time. The lead screw is fixed in place and the lead nut is allowed to travel along its length. The lead nut is threaded into an aluminum block that provides a mounting surface for a shoulder bolt. The shoulder bolt is inserted through a slot in the swing arm that allows it to travel along the swing arm a small amount as the angle of the swing arm changes. A diagram showing why this slot is necessary can be seen in Figure 22. The material for the lead nut assembly was originally designed to be acetal, but the flexibility of this material contributed to the slop in the shifting system discussed in Final Design Revisions.

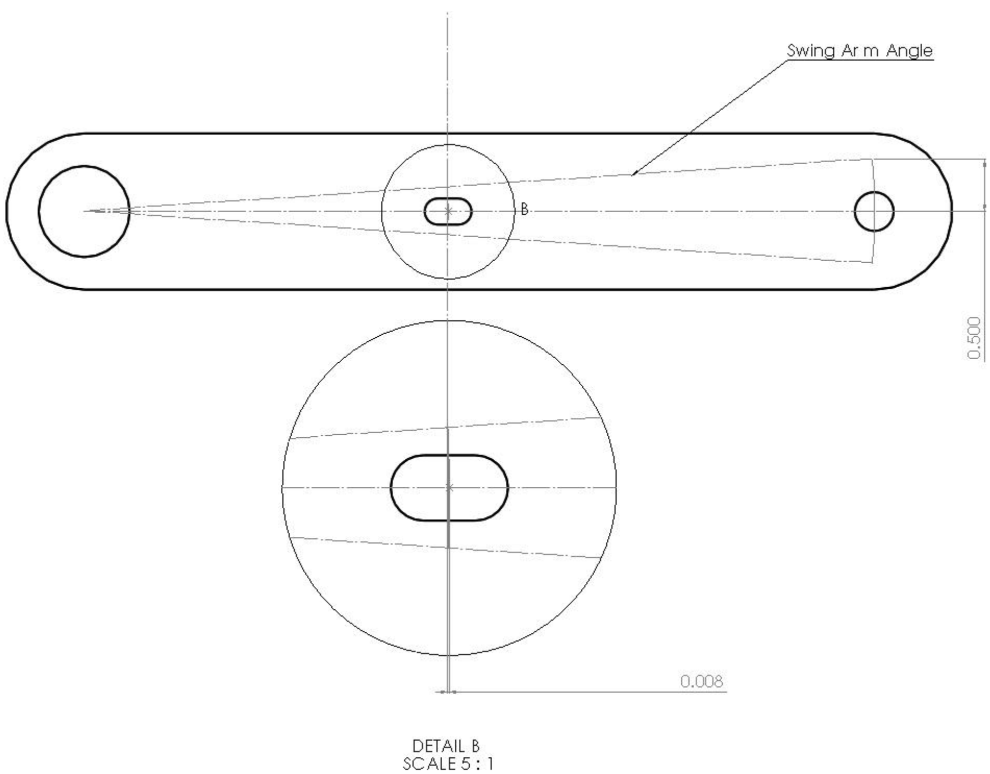

Figure 22: Swing arm geometry

Control Algorithm

The Uber Wheel is able to accurately control the gear position of the system while controlling the output to the CIM motor using a control algorithm. A set point for the output of the system is set with the "Throttle" control potentiometer on the prototype display. The system uses three phases of operation to achieve the desired output from the system. Each phase has a unique way of controlling the gear position and drive motor. Each phase has its own way of dealing with motor control, gear position, and external loads on the system. The phases allow for the robot to correctly react to external forces which are typical in a FIRST competition, giving the Uber Wheel a competitive advantage over other conventional wheels and transmissions.

The first phase of the control is when the user desires to go between 0-6ft/sec or the system is operating within those speeds. During this phase, the motor is directly controlled and operates between 0rpm and the optimal rpm, which can be set by the user in code. During this phase, the gear position of the system is always in LOW gear to get the most torque out of the system, allowing for fast acceleration. Once the optimal rpm has been achieved the system switches into phase two.

The second, and middle, phase is active when the system is operating between 6-12ft/sec. During this phase, the user's demand will be met by holding the rpm at the optimal range and shifting the gear position swing arm to achieve the desired output speed. The system attempts to maintain the optimal motor rpm throughout this phase; if there is an external load on the wheel, the system will compensate by reducing the gear position and maintaining the drive rpm. If the system drops below 6ft/sec in this phase, control will be switched back to phase one.

The third and last phase is active when the system is operating above the optimal rpm and highest gear ratio. Throughout this phase, the gear position is consistently held at the HIGH gear position while the drive motor operates from the optimal range up to the max rpm of the motor. Similar to the second phase, if there is an external load on the system the wheel will react and try to get more torque output. The load will cause the system to maintain the gear position until the drive motor's rpm drops into the optimal speed. Once the system drops back into phase two, the system operates via phase two control.

The control of the Uber wheel makes the system robotic and very dissimilar to any automatic/manual transmission available today. There is no way to have the system function properly without accurate control. Unlike a manual transmission that uses the mechanics of gears to achieve the output power of the system; the Uber Wheel requires intelligent gear position control and sensors to accurately control the output speed of the system. The architecture of the system allows for the easy changing of certain parameters which provide the user with the ability to change the phase speeds and overall performance.

Social Implications

The mission statement of FIRST "is to inspire young people to be science and technology leaders, by engaging them in exciting mentor-based programs that build science, engineering and technology skills, that inspire innovation, and that foster well-rounded life capabilities including self-confidence, communication, and leadership." Because the Uber Wheel was developed to be used in a FIRST competition, its potential future implementation on a FRC robot could help to contribute to the mission of FIRST. Mentors of the implementing robotics team could help the high school students understand the operation and design parameters of the Uber Wheel, furthering the inspiration of science and technology in high school students.

Results and Discussion

The following section will examine the performance and operation of The Uber Wheel. First, the theoretical data that describes the operation and reaction of The Uber Wheel as it changes ratios will be presented. Second, the control of the system and how it reacts to changing loads will be discussed. Third, a finite element analysis of critical elements of The Uber Wheel will be presented.

Kinematics

Microsoft excel was used to calculate the ratios that The Uber Wheel was capable of. The results were compiled into graphs in order to make them easier to understand at a glance. Figure 23 shows the relationship between driver height and system ratio. The minimum ratio occurs when the diver is at its lowest point and the maximum ratio occurs when the driver is at its highest point of one inch. The ratio of The Uber Wheel system varies from .75:1 to 1.5:1. It should be noted that this relationship is not linear and should thus be considered in the design of the algorithm.

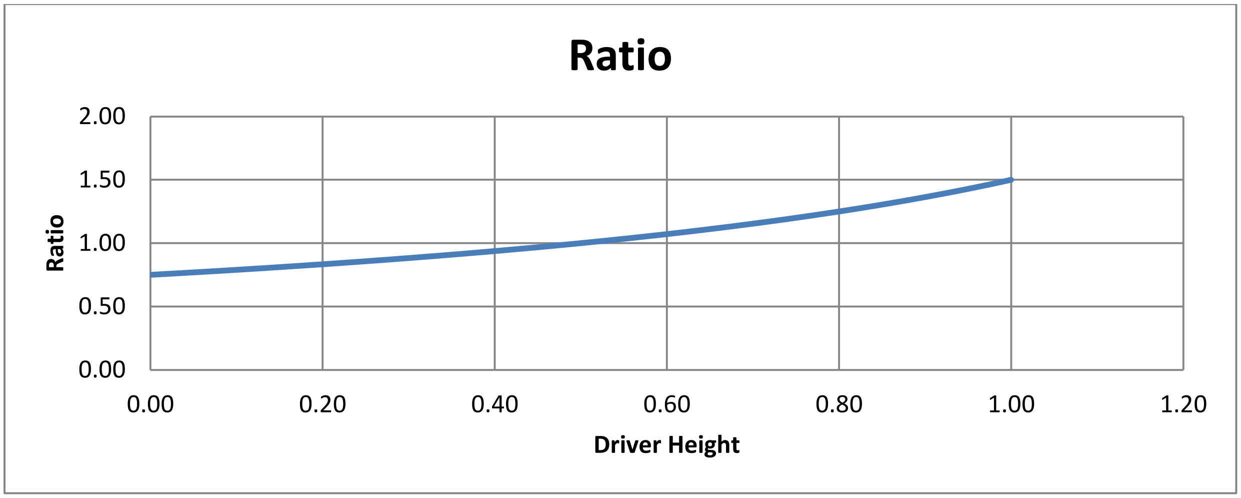

Figure 23: The relationship between driver height and ratio

The Uber Wheel was designed to be implemented on a FIRST robot. The team decided that a speed range of 6.75-12 feet per second while the DC drive motors operated within the desired range would allow the robot to win most pushing matches and most races. Figure 24 shows the section of the theoretical transmission curve of the robot in which The Uber Wheel would be shifting. While maintaining the desired RPM of the DC Drive motor, the Uber Wheel is capable of producing a speed of 6 ft. /s while in low gear, and 12 feet per second while in high gear.

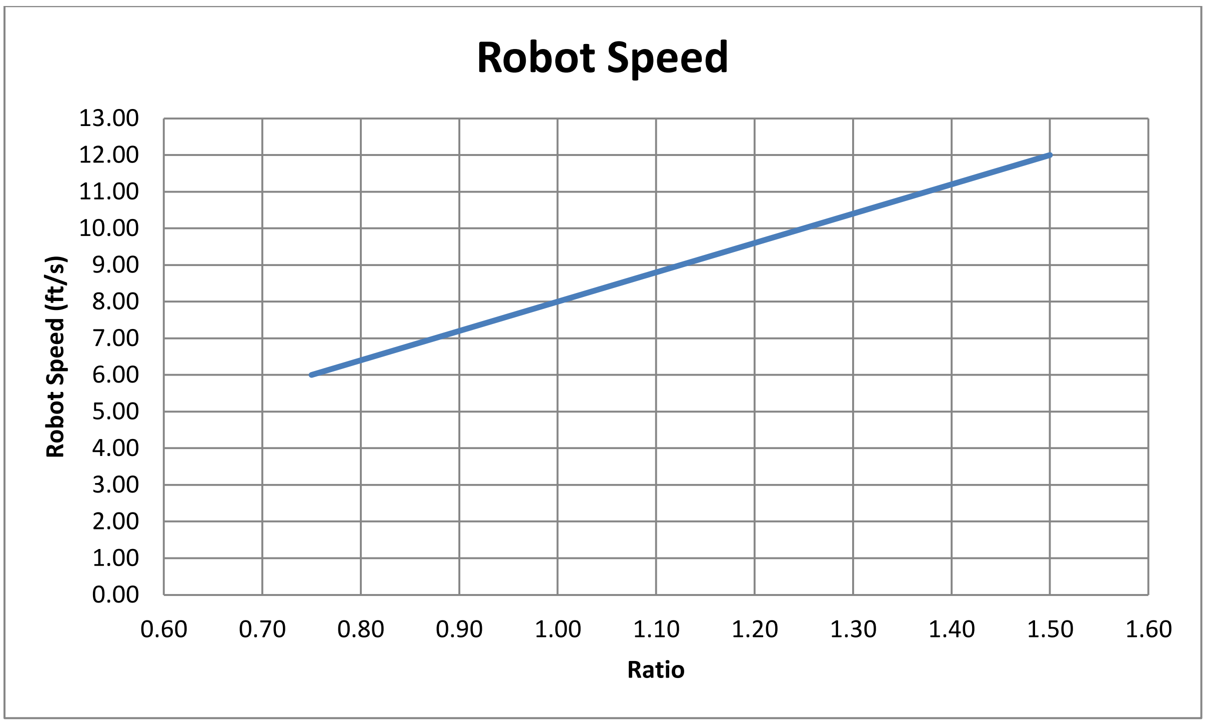

Figure 24: Ideal robot speed with respect to ratio

In the initial stages of design, the relationship shown in Figure 24 was believed to be linear. It was later noticed that the spokes' angular velocities would be constantly changing throughout each rotation, leading to cyclic variations in robot speed while each foot was in contact with the ground. The cyclic variations are greatest when The Uber Wheel was in high gear. The theoretical data representing these variations can be seen in Figure 25. These

variations are quite significant when considered on their own but, when considering the speed at which these variations occur, they would be experienced as vibrations rather than positive and negative accelerations.

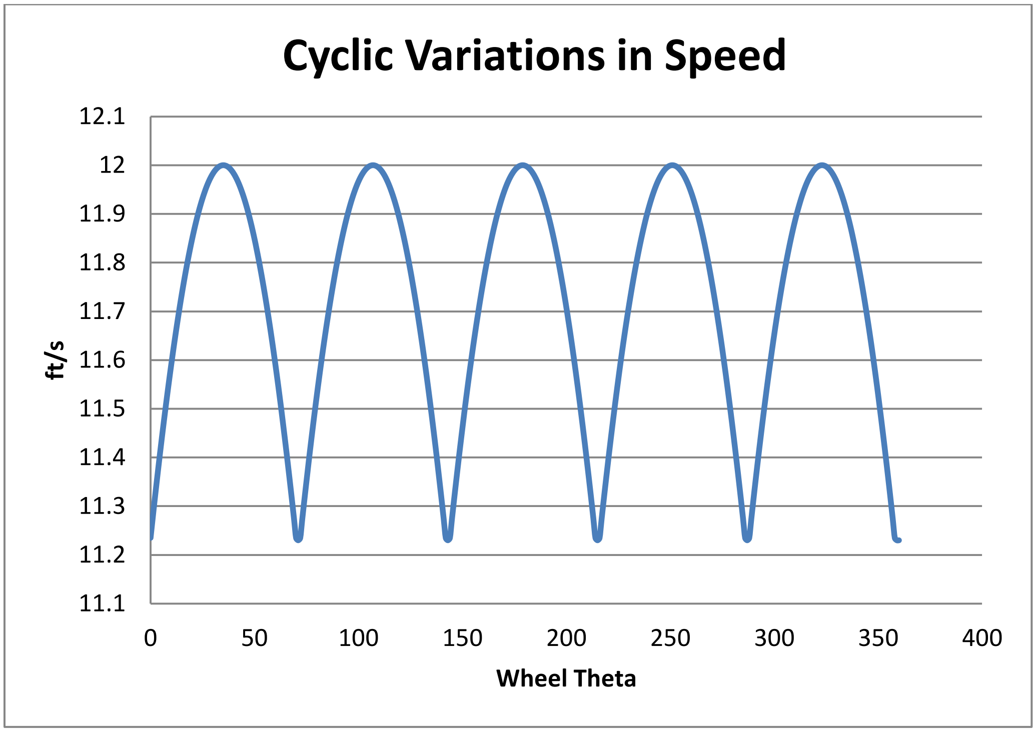

Figure 25: Cyclic Variations in Robot Speed in High Gear

In addition to the ability to change the speed of a drivetrain, transmissions can also change the torque output of a drivetrain. Figure 26 shows how the torque of The Uber Wheel changes as the ratio changes.

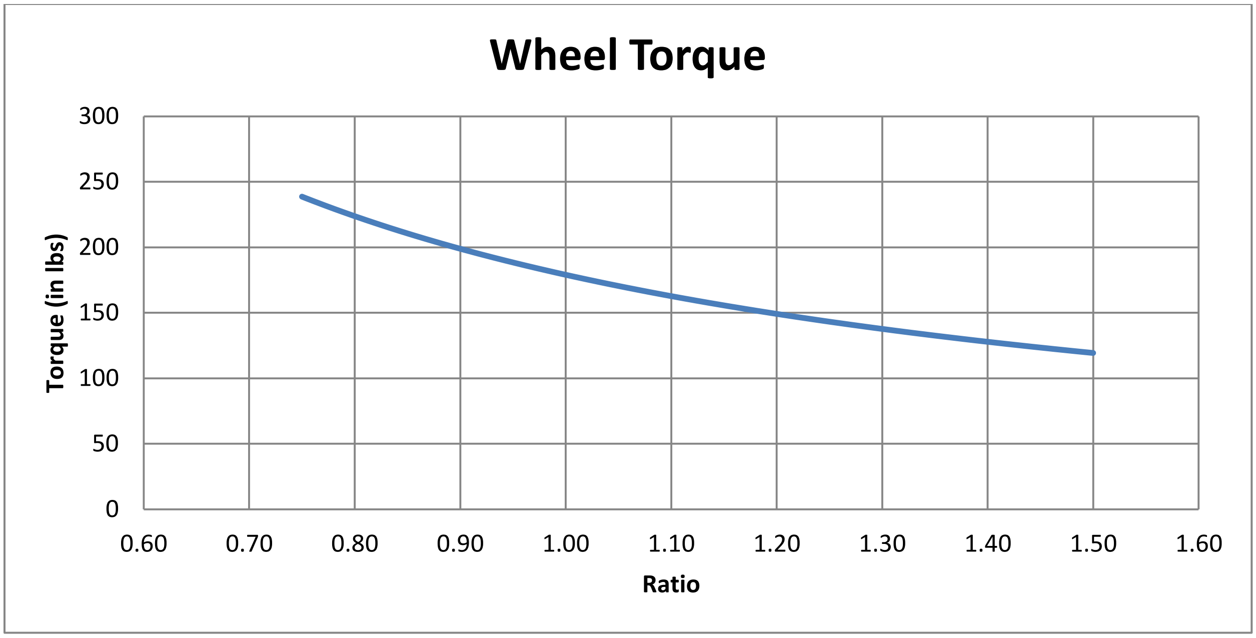

Figure 26: Wheel Torque vs. Ratio

Each spoke on The Uber Wheel rotates at a different speed when The Uber Wheel is at a ratio other than 1:1. In order to analyze what a point on the wheel experiences as it travels through a rotation of The Uber Wheel, a ratio in which the point would experience the most extreme velocities and accelerations was selected. Figure 27 shows the point's velocity as it travels around the wheel and Figure 28 shows the tangential acceleration of the point.

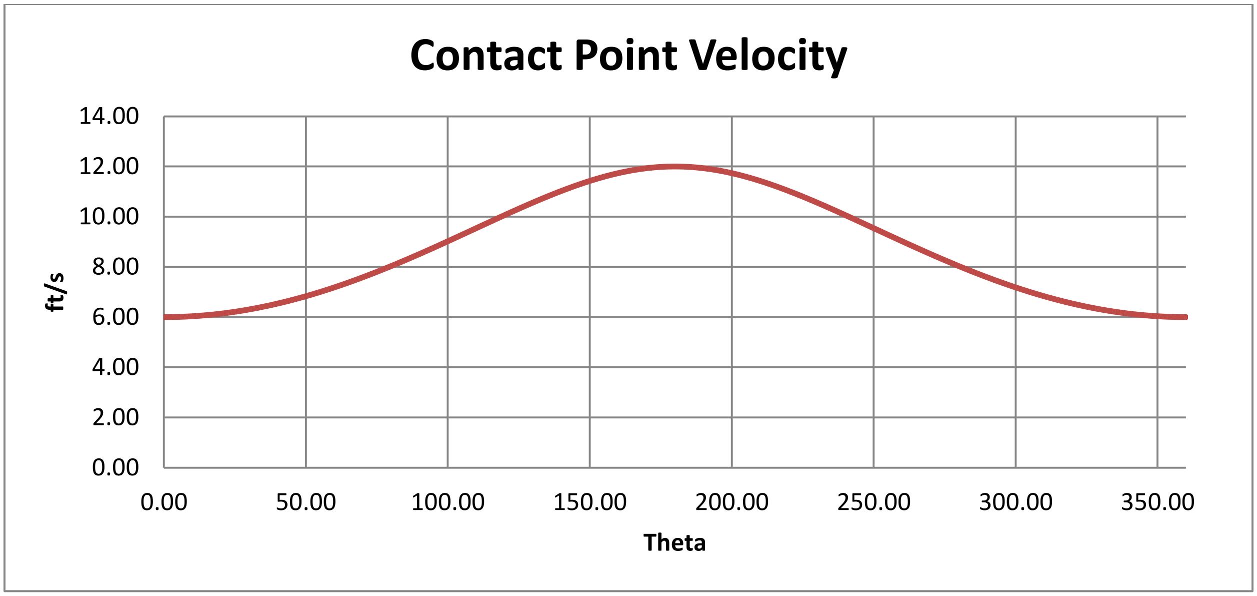

Figure 27: Contact Point Velocity

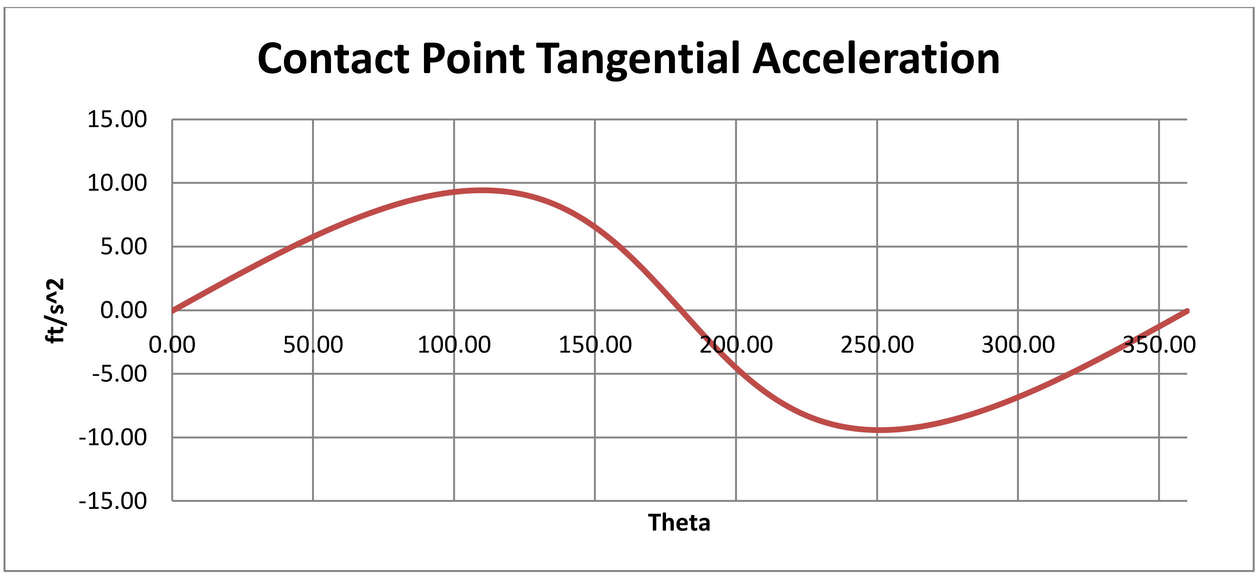

Figure 28: Contact Point Acceleration

Each spoke operates 60 degrees out of phase from the spokes adjacent to it. Taking this into account, the graphs of the velocity and acceleration of the same point on each foot were combined as shown in Figure 29 and Figure 30. Looking closely at Figure 29 shows that, if all values were averaged, the overall contact point velocity of The Uber Wheel would be constant.

The velocity of a point on The Uber Wheel is directly related to the spoke's angular velocity. Thus, variations in the tangential velocity of The Uber Wheel were achieved without changing the overall angular velocity.

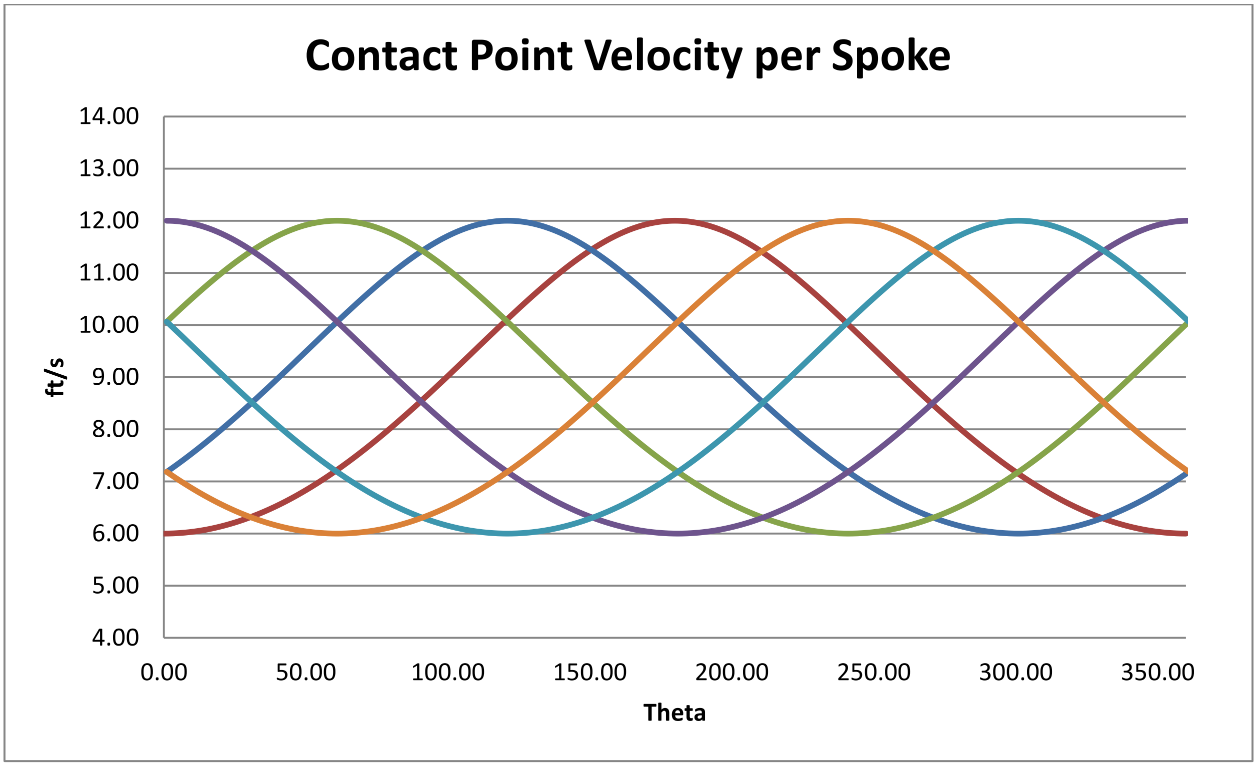

Figure 29: Contact Point Velocity per Spoke

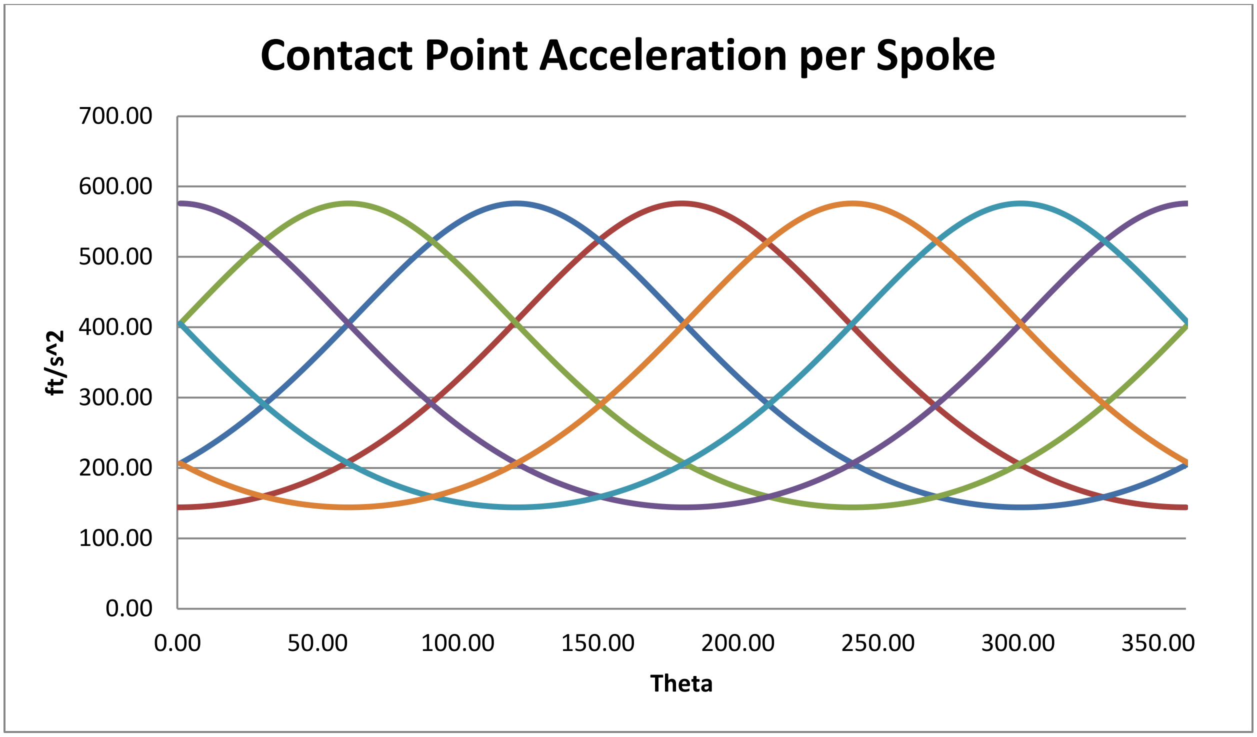

Figure 30: Contact Point Acceleration per Spoke

Control Algorithm*

This section will be documented at a later date.

Finite Element Analysis

In order to ensure that The Uber Wheel could withstand the rigors of a FIRST Robotics Competition match, the team analyzed the potential forces The Uber Wheel could experience during that match. FRC legal robots can weigh up to 150 pounds, so it was important to determine if The Uber Wheel could support the weight of a 150 pound robot. To determine this, a drivetrain that included The Uber Wheel was first chosen. The team chose a 6-wheel tank drive train in which the center two wheels were slightly lowered to improve maneuverability. This drivetrain is very common in FIRST Robotics Competitions, and the team chose it because it was representative of many of the robots in FIRST.

After choosing a potential drivetrain, the team chose a worst-case scenario to analyze. Because the center wheels of the selected drivetrain are lowered, the worst case scenario chosen was a case in which the full weight of the robot was supported by the two center wheels, which were Uber Wheels. This resulted in a 75 pound force on each wheel. The finite element analysis program, ANSYS, was used to analyze the stress propagation in each spoke as a result of the 75 pound force and a factor of safety was determined. Figure 31 shows the distribution of stresses in Spoke 4 of The Uber Wheel under a 75 pound load. It is important to note that the most stress in the model was located in the 8-32 flathead machine screws that were used to hold the tabs in place. This cannot be seen in the figure below.

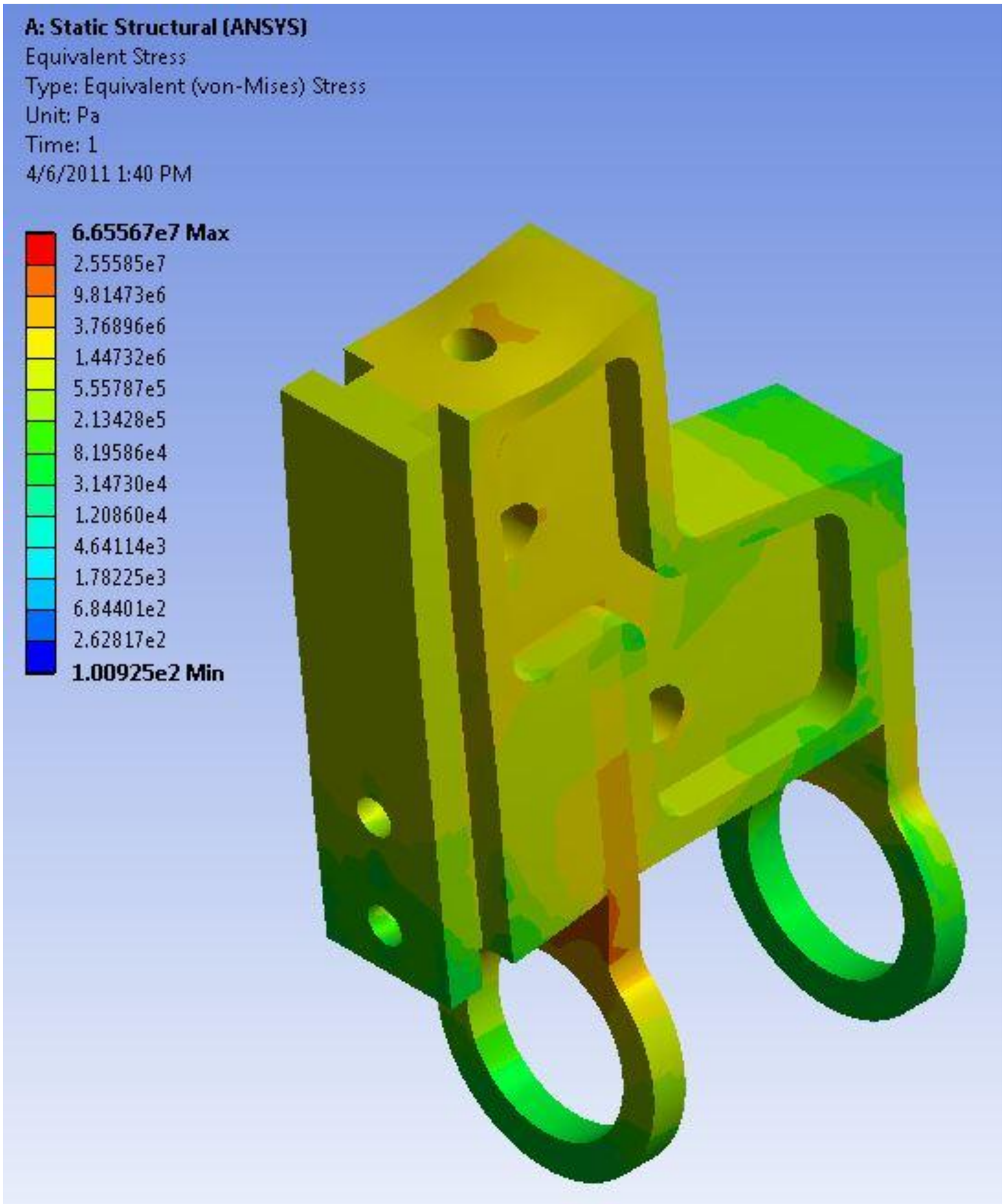

Figure 31: Finite Element Analysis of Spokes (Top Load)

FRC robots also encounter high speed collisions throughout a match. To determine the forces imparted on The Uber Wheel during one of these collisions, a coefficient of friction

between the surface of the playing field and the surface of the wheel was chosen that would present a worst-case scenario. The coefficient of friction chosen was 2, resulting in a maximum force imparted on the wheel during a collision of 150 lbs. ANSYS was again used to analyze the stress propagation within the spoke as result of the imparted force. Again, it is important to note that the highest concentrations of stress occurred in the screws holding the tabs in place.

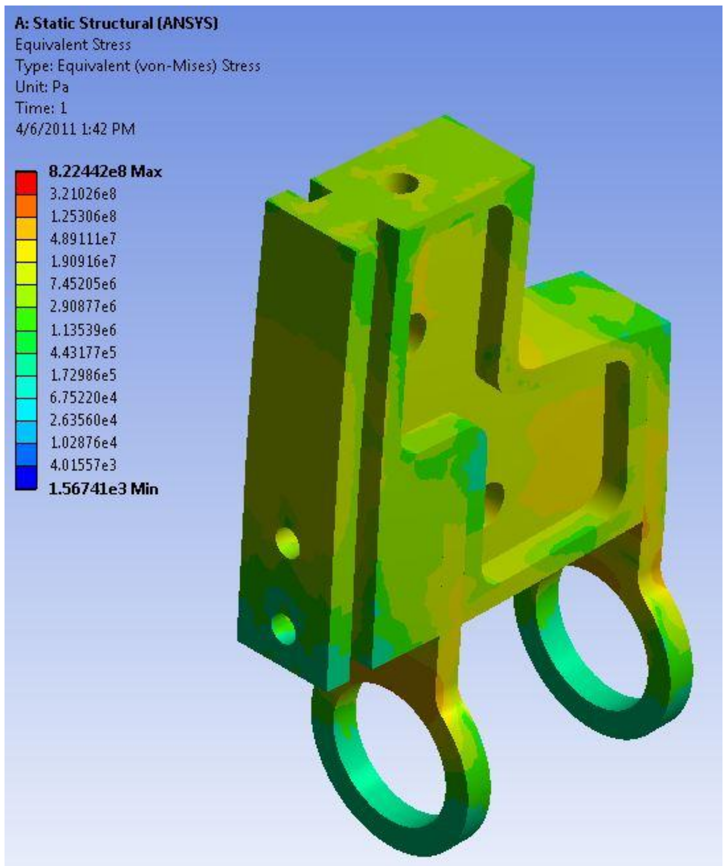

Figure 32: Finite Element Analysis of Spokes (Side Load)

Functional Requirements

In order to determine whether or not The Uber Wheel was a success, a comparison with the team's original functional requirements was conducted. The functional requirements can be seen in Table 1. The desired optimum RPM that the team chose for the motor was 3186 RPM. This speed, reduced 10:1 by the primary reduction allows the Uber Wheel to travel at 8 fps when

in the 1:1 ratio. When the Uber Wheel is in its lowest ratio of .75:1 the optimal motor RPM results in a robot speed of 6 fps. When the Uber Wheel is in its highest ratio of 1.5:1 the optimal motor RPM results in a robot speed of 12 fps. Increasing the RPM of the motor allows the Uber Wheel to achieve a top speed of 18 fps. As seen in Figure 24, the relationship between driver height and ratio is not linear. This means that changes in the height of the driver while the Uber Wheel is in low gear result in a smaller response from the system than changes the height of the driver while the Uber Wheel is in high gear. Throughout the testing of the system, all power to the DC drive motor passed through a 40 Amp breaker. The breaker did not trip during any testing, proving that the motor was running below 40 Amps.

The control algorithm of the Uber Wheel was designed to maintain the desired motor RPM during normal operation. The desired motor RPM was chosen based on the motor curves discussed in the DC Motor Characteristics section. The algorithm watches for a change in the motor's RPM and shifts accordingly if the motor's speed changes. The algorithm allows the motor to run at the desired RPM for longer than a traditional transmission.

The Uber Wheel was designed with the fast pace repairs of a FIRST competition in mind. All hardware can be removed and installed with hex keys and the system was designed to be fairly modular in construction. The wheel is separate from the primary reduction, but is easily connected by installing the drive chain and swing arm with one screw. This design feature allows the Uber Wheel to be repaired without dismantling the entire system. The Uber Wheel is also designed to take up the same envelope of space as a traditional transmission and fits within a 10in x 8in x 8in envelope. It also has a 6 inch diameter wheel, a size common in FIRST robotics. Despite these advantages, complications in the manufacturing process of the Uber Wheel led Team 190 to choose a different drivetrain for their 2011 robot. As a result, it was no

longer necessary to build the Uber Wheel in accordance with FIRST rules. This allowed the team to use a Globe motor as a shifting motor instead of a Keyang motor. This decision was made because the Globe motor was easier to mount and had a smaller form factor than the Keyang motor. The Keyang motor can still be sued to shift the system, but a custom mounting bracket must be developed.

Conclusion and Future Recommendations

The primary objective of this project was to design and produce a continuously variable transmission (CVT) for a mobile robot platform. The innovative approach was to develop a system that could continuously vary the tangential velocity of a wheel without changing its overall angular velocity or diameter. This form of CVT is known as a continuously variable tangential velocity (CVTV) system. A set of functional requirements was developed in order to constrain and guide the design. The functional requirements were developed in conjunction with the WPI / Massachusetts Academy of Math and Science FIRST Team 190 in order to gain a full understanding of FIRST Robotics Competitions.

Kinematic analysis and iterative design using SolidWorks were used to develop a prototype CVTV. Important components of the CVTV that were considered during development were the primary reduction, the wheel, the driver, and the swing arm. The prototype CVTV system, the "Uber Wheel," was produced, but had room for improvement. Some of the improvements that were made to the first prototype of the Uber Wheel include weight reduction, reducing slop in the shifting system, and attaching a traction surface to the feet. An optimized control system to automate ratio changes based on system demand was developed using data from an encoder to calculate motor RPM and a potentiometer to determine system ratio. The prototype Uber Wheel and control system were tested using a custom made dynamometer. Success was based on performance criteria which included dynamic response to varying load and input conditions. The Uber Wheel successfully met all functional requirements.

The first recommendation for future work on the Uber Wheel involves addressing the issue of cyclic variations in robot speed. Each spoke continuously changes velocity as it travels

around the wheel. As a result, the foot in contact with the ground experiences quite large changes in velocity while it is in contact with the ground. Finding a way to reduce the amount of time that each foot is in contact with the ground will reduce the cyclic variations in robot speed. Another recommendation for future work is to use hardened steel pins in the joint between the tabs and the spokes. The current design concentrates too much force on the screws holding the tabs in place. This results in undesirable factors of safety and a potential for failure.

The team did not have enough time to test the system to a point where it was satisfied. Additional testing of the Uber Wheel to determine the speeds and torques of the system would be beneficial. Most continuously variable transmissions contain friction elements that severely reduce the efficiency of the system. The Uber Wheel, however, has no friction elements and is theoretically more efficient than traditional continuously variable transmissions. Further testing into the efficiency of the Uber Wheel could produce some promising results.

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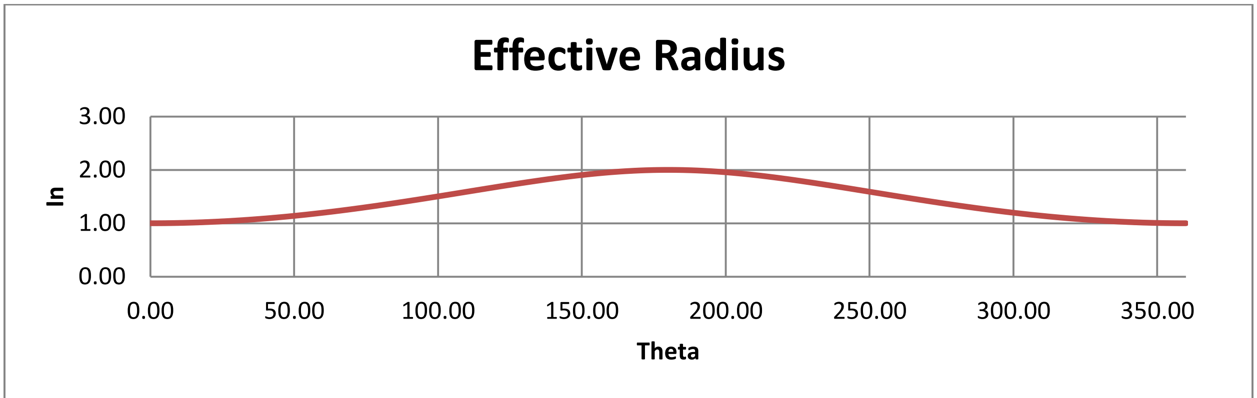
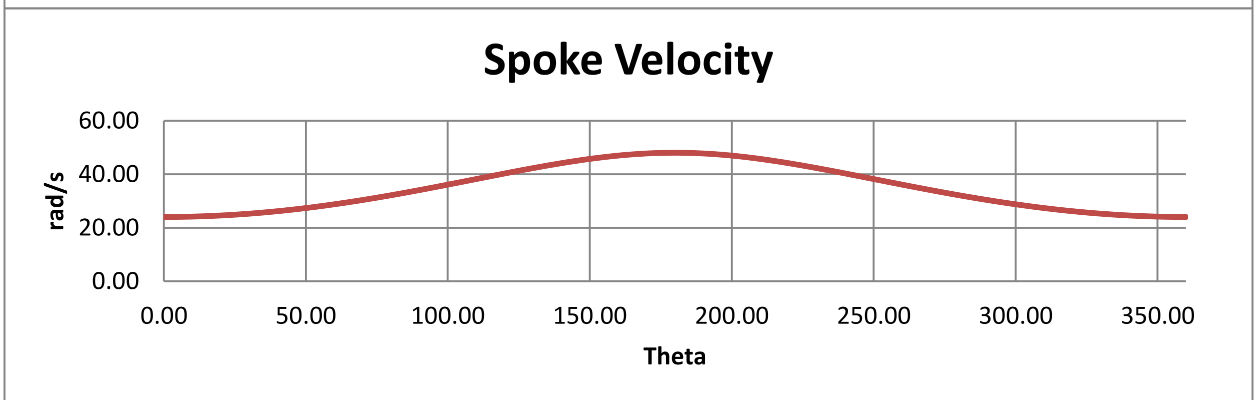
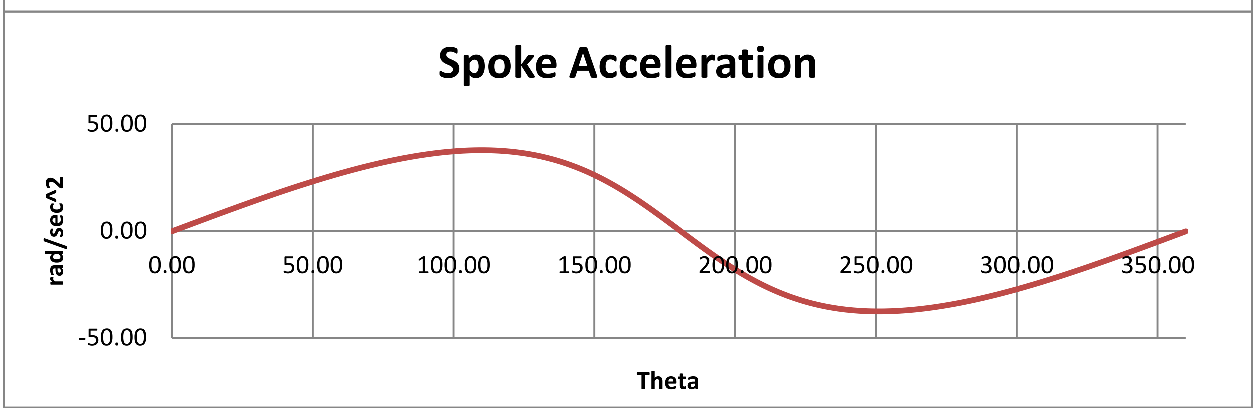
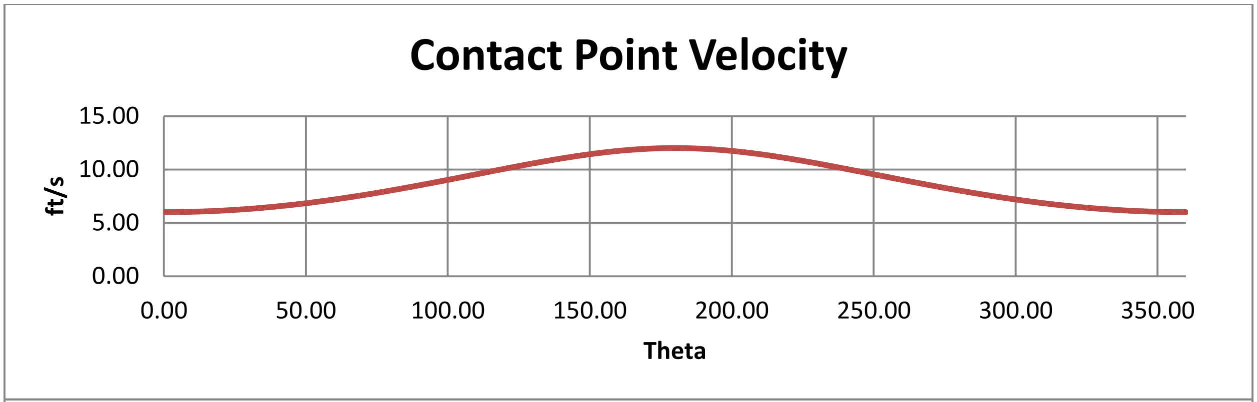
Appendices

Appendix A: Kinematic Analysis of Spokes





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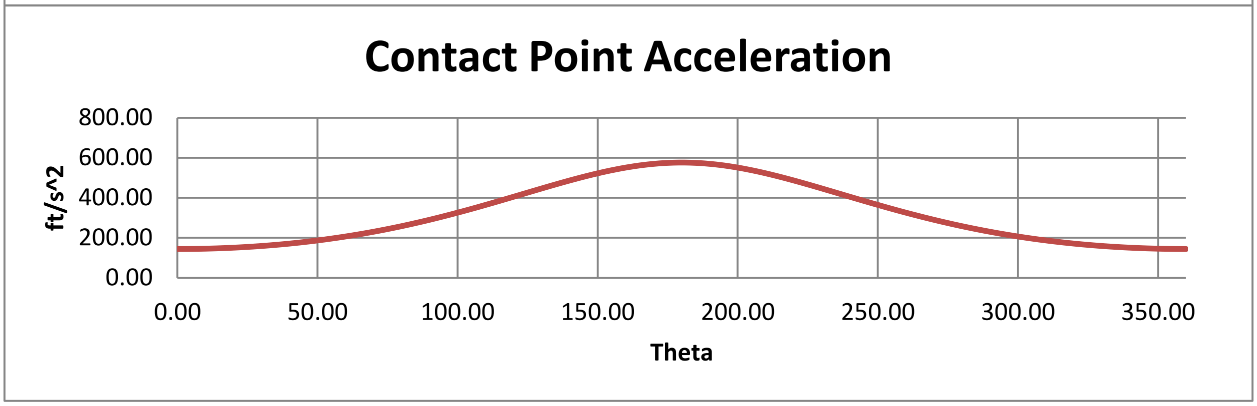
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200.00
250.00
300.00
350.00
Theta

Appendix B: Investigating Different Top Speed and Wheel Sizes

Input
Output

Wheel Diameter (in)	6	7	8	9	10	Desired Speed @ 1:1 (fps)
Driver rpm	229.18	196.44	171.89	152.79	137.51	6
	267.38	229.18	200.54	178.25	160.43	7
	305.58	261.92	229.18	203.72	183.35	8
	343.77	294.66	257.83	229.18	206.26	9
	381.97	327.40	286.48	254.65	229.18	10
	420.17	360.14	315.13	280.11	252.10	11
	458.37	392.89	343.77	305.58	275.02	12
	496.56	425.63	372.42	331.04	297.94	13

Desired Operating Motor Speed (%)	60
Desired Operating Motor Speed (rpm)	3186

Wheel Diameter (in)	6	7	8	9	10	Desired Speed @ 1:1 (fps)
Required Gear Ratio	13.90	16.22	18.54	20.85	23.17	6
	11.92	13.90	15.89	17.87	19.86	7
	10.43	12.16	13.90	15.64	17.38	8
	9.27	10.81	12.36	13.90	15.45	9
	8.34	9.73	11.12	12.51	13.90	10
	7.58	8.85	10.11	11.37	12.64	11
	6.95	8.11	9.27	10.43	11.58	12
	6.42	7.49	8.55	9.62	10.69	13

Output Torque from "Motor Data" (Nm)	0.97

Wheel Diameter (in)	6	7	8	9	10	Desired Speed @ 1:1 (fps)
Torque at Driver (in lbf)	238.70	278.49	318.27	358.05	397.84	6
	204.60	238.70	272.80	306.90	341.00	7
	179.03	208.86	238.70	268.54	298.38	8
	159.14	185.66	212.18	238.70	265.23	9
	143.22	167.09	190.96	214.83	238.70	10
	130.20	151.90	173.60	195.30	217.00	11
	119.35	139.24	159.14	179.03	198.92	12
	110.17	128.53	146.89	165.26	183.62	13

Driver Radius (in)	1.5

Wheel Diameter (in)	6	7	8	9	10	Desired Speed @ 1:1 (fps)
Force at Driver Peg (lb)	159.14	185.66	212.18	238.70	265.23	6
	136.40	159.14	181.87	204.60	227.34	7
	119.35	139.24	159.14	179.03	198.92	8
	106.09	123.77	141.45	159.14	176.82	9
	95.48	111.39	127.31	143.22	159.14	10
	86.80	101.27	115.73	130.20	144.67	11
	79.57	92.83	106.09	119.35	132.61	12
	73.45	85.69	97.93	110.17	122.41	13

Slider Distance from Lowest Point	1
CVTV Ratio	1.5

Wheel Diameter (in)	6	7	8	9	10	Desired Speed @ 1:1 (fps)
Maximum Force at Ground Contact (lb)	53.05	53.05	53.05	53.05	53.05	6
	45.47	45.47	45.47	45.47	45.47	7
	39.78	39.78	39.78	39.78	39.78	8
	35.36	35.36	35.36	35.36	35.36	9
	31.83	31.83	31.83	31.83	31.83	10
	28.93	28.93	28.93	28.93	28.93	11
	26.52	26.52	26.52	26.52	26.52	12
	24.48	24.48	24.48	24.48	24.48	13

Motor Speed (%)	90
Motor Speed (rpm)	4779

Wheel Diameter (in)	6	7	8	9	10	Desired Speed @ 1:1 (fps)
Wheel Speed (rpm)	343.77	294.66	257.83	229.18	206.26	6
	401.07	343.77	300.80	267.38	240.64	7
	458.37	392.89	343.77	305.58	275.02	8
	515.66	442.00	386.75	343.77	309.40	9
	572.96	491.11	429.72	381.97	343.77	10
	630.25	540.22	472.69	420.17	378.15	11
	687.55	589.33	515.66	458.37	412.53	12
	744.85	638.44	558.63	496.56	446.91	13

Wheel Diameter (in)	6	7	8	9	10	Desired Speed @ 1:1 (fps)

Speed of Robot (ft/s)	13.50	13.50	13.50	13.50	13.50	6
	15.75	15.75	15.75	15.75	15.75	7
	18.00	18.00	18.00	18.00	18.00	8
	20.25	20.25	20.25	20.25	20.25	9
	22.50	22.50	22.50	22.50	22.50	10
	24.75	24.75	24.75	24.75	24.75	11
	27.00	27.00	27.00	27.00	27.00	12
	29.25	29.25	29.25	29.25	29.25	13

Appendix C: Relevant FRC Rules

Section 4.3 ROBOT RULES

These rules establish the global ROBOT construction and performance constraints dictated by the characteristics of the provided KOP, along with the size and weight design limits. Compliance with the rules is mandatory, and is the responsibility of every team! Any ROBOT construction not in compliance with the rules (as determined at inspection) must be rectified before a ROBOT will be allowed to compete.

When constructing the ROBOT, the team is allowed to use the items in the 2011 KOP Checklist and additional materials. Many of the rules listed below explicitly address what and how parts and materials may be used. There are many reasons for the structure of the rules, including safety, reliability, parity, creation of a reasonable design challenge, adherence to professional standards, impact on the competition, compatibility with the KOP, etc. When reading these rules, please use technical common sense (engineering thinking) rather than "lawyering" the interpretation and splitting hairs over the precise wording in an attempt to find loopholes. Try to understand the reasoning behind a rule.

One of the purposes of the FIRST Robotics Competition is to provide team members with the experience of conceiving, designing, and constructing their solution to the annual competition challenge. We want each student to have the experience of creating a new system each year. As the team considers the creation of their machine, this aspect of the program should be kept in mind. Solutions that merely bolt together a minimum number of externally-designed COTS subsystems may not offer the students the opportunity to understand the "why" or "how" of an item's design. Likewise, solutions that are merely minor modifications of a design utilized for a previous competition does not offer the current students complete insight into the full

design process. Purchasing optimization and design re-use are both important concepts, however teams must be cautious not to over-utilize them to the point that the student's experience is compromised.

This intent is clearly met when a team obtains a MECHANISM or COTS items that was designed for non-FIRST purposes, and then modifies or alters it to provide functionality for the ROBOT. For example, if a team obtains a gearbox from a power drill and modifies it to use on the ROBOT, they gain insight into the design of the original gearbox purpose, learn to characterize the performance of the original design, and implement the engineering design process to create their customized application for the gearbox.

However, COTS items that have been specifically designed as a solution to part of the FRC challenge may or may not fit within the FRC intent, and must be carefully considered. If the item provides general functionality that can be utilized in any of several possible configurations or applications, then it is acceptable (as the teams will still have to design their particular application of the item). However, COTS items that provide a complete solution for a major ROBOT function (e.g. a complete manipulator assembly, pre-built pneumatics circuit, or full mobility system) that require no effort other than just bolting it on to the ROBOT are against the intent of the competition, and will not be permitted.

In addition, another intent of these rules is to have all energy sources and active actuation systems on the ROBOT (e.g. batteries, compressors, motors, servos, cylinders, and their controllers) drawn from a well-defined set of options. This is to ensure that all teams have access to the same actuation resources, and to ensure that the inspectors are able to accurately assess the legality of a given part.

Section 4.3.1 Safety & Damage Prevention

<R01> Energy used by FRC ROBOTS, (i.e., stored at the start of a MATCH), shall come only from the following sources:

A. Electrical energy derived from the onboard 12V battery (see Rule <R34> for specifications and further details).

<R03> Custom circuits and COTS electronics are expressly prohibited if they:

A. Interfere with the operation of other ROBOTS.
B. Directly affect any output devices on the ROBOT. Examples of items that are considered directly affecting the output devices on the ROBOT include those that directly power a motor, supply a PWM signal directly to a speed controller or supply a control signal directly to a relay module (see Rules <R58> and <R59> for the specific exception regarding CAN-bus devices).

<R05> MECHANISMS or COMPONENTS on the ROBOT shall not pose obvious risk of entanglement. If the structure of a COMPONENT permits easy penetration by an object less than 4"2 in cross section, it will invite detailed inspection.

Nets, loose rope or wire, voluminous sheets of fabric, etc. may be carefully inspected for these hazards. A ⅛" x ⅛" tight-mesh net (or very loose mesh fabric, depending on your point of view) may be a reasonable material that would not automatically pose an entanglement hazard. However, any flexible material has the potential to become an entanglement hazard if it is not firmly attached to an appropriate structure or left in a loose, voluminous configuration.

Therefore, you must use your best judgment to determine if your particular use of the material will pose an entanglement hazard.

Actual performance on the playing field will determine if the potential for entanglement is significant or not. Willful entanglement actions are addressed in Rule <G48>.

<R06> ROBOT wheels, tracks, and other parts intended to provide traction on the carpet may be purchased or fabricated ("traction devices" include all parts of the ROBOT that are designed to transmit any propulsive and/or braking forces between the ROBOT and the FIELD). In no case will traction devices that damage the carpet or other playing surfaces be permitted. Traction devices shall not have surface features such as metal, sandpaper, hard plastic studs, cleats, or other attachments.

Section 4.3.8 Power Distribution

<R34> The only legal source of electrical energy for the ROBOT/HOSTBOT during the competition is one MK ES17-12 12VDC non-spillable lead acid battery, OR one EnerSys NP 18-12 battery, as provided in the 2011 KOP. Batteries integral to and part of a COTS computing device are also permitted (i.e. laptop batteries), provided they're only used to power the COTS computing device.

<R37> The 12V battery, the main 120-amp circuit breaker, and the PD Board shall be connected as shown in Figure 3-4. In particular:

A. The battery must be connected to the ROBOT power system through the use of the Anderson Power Products (APP) connector.

B. The APP connector must be attached to the battery with either the copper lugs provided in the KOP or appropriately-rated and -sized lug connectors.

C. The battery terminals and the connecting lugs must be insulated with shrink tubing and/or electrical tape.

D. The main 120-amp circuit breaker must be directly connected to the hot (+) leg of the ROBOT-side APP connector. Only one 120-amp main circuit breaker is allowed. This breaker must not be bypassed.

E. The PD Board must be directly connected to the APP connector and main 120-amp circuit breaker. No other loads may be connected to the main 120-amp circuit breaker. F. Each primary power connection between the battery and PD Board must be made with #6 AWG (4.11mm) red and black wire or larger.

G. The 120-amp circuit breaker must be quickly accessible from the exterior of the ROBOT.

<R38> All electric power utilized by the ROBOT shall be distributed from the load terminals of the PD Board. Circuits may not bypass the PD Board to connect directly to the 120-amp loop.

A. The cRIO-FRC power input must be connected to the 24 Vdc supply terminals on the PD Board. With the exception of one Solenoid Breakout Board, no other electrical load can be connected to these terminals.

B. The radio power feed must be connected via the 5V converter (model # TBJ12DK025Z) to the marked 12 Vdc supply terminals located at the end of the PD Board (i.e. the terminals located between the indicator LEDs, and not the main WAGO connectors along the sides of the PD Board). No other electrical load can be connected to these terminals

(please see the 2011 Robot Power Distribution Diagram posted online at www.usfirst.org/frc/kitofparts for wiring information).

C. All other branch circuits must connect to, and have power sourced solely by, a protected 12 Vdc WAGO connector pair on the PD Board.

D. Only one wire shall be connected to each WAGO connector on the PD Board. If multi-point distribution of circuit power is required (e.g. to provide power to the three KOP breakout boards via one 20-amp circuit), then all incoming wires must be appropriately spliced into the main lead, and only one lead inserted into the WAGO connector to connect the circuit.

Sensors and custom circuits may be connected to the 5 Vdc sources on the Analog Breakout boards or the Digital Sidecars. By being logically downstream from the PD Board, they are protected by the 20-amp breaker at the circuit root.

Servos may be connected to the 6 Vdc sources on the Digital Sidecars (via the designated PWM connections, and with a "6Vdc enable" jumper in place for the corresponding port). By being logically downstream from the PD Board, they are protected by the 20-amp breaker at the circuit root. No other electrical load can be connected to these sources.

<R39> All active PD Board branch circuits shall be protected from overload with an appropriate value auto resetting Snap Action circuit breaker (from the KOP or identical equivalent).

A. Each speed controller branch circuit must be protected by one and only one 20-amp, 30-amp, or 40-amp circuit breaker on the PD Board. No other electrical load can be connected to the breaker supplying this circuit.

E. A single branch supply circuit may be spliced to supply power to one, two or three of the Analog/Solenoid Breakout Boards. This circuit must be protected with one and only one 20-amp circuit breaker on the PD Board. No other electrical load can be connected to the breaker supplying this circuit.

F. Custom circuits and sensors powered via the cRIO-FRC or the Digital Sidecar are protected by the breaker on the circuit(s) supplying those devices. Power feeds to all other custom circuits must be protected with a dedicated 20-amp circuit breaker on the PD Board.

<R42> Each power-regulating device (speed controller or relay module) shall control one and only one electrical load (motor, actuator, light or compressor).

Section 4.3.9 Motors & Actuators

<R45> Motors specifically permitted on 2011 FRC ROBOTS include:

A. all motors, actuators, and servos listed in the 2011 KOP Checklist,

B. an unlimited number of COTS servos with a maximum power rating of 4W,

C. one or two additional 2½" CIM motors (part #FR801-001, M4-R0062-12, AM802-001A, or PMR25R-45F-1003) in addition to those provided in the KOP. This means that up to four, and no more, 2½" CIM motors can be used on the ROBOT,

D. up to four, in any combination, of the BaneBots motors provided in the KOP (acceptable part numbers are M7-RS775-12, M7-RS775-18, M5-RS550-12, M5-RS550-12-B, M5-RS540-12, and M3-RS395-12),

Example combinations include, but are not limited to,

- four RS-775s,

- one of each motor
- two RS-775s and two RS-550s,
- three RS-540s and one RS-395.

E. identical one-to-one SPARE PARTS for motors, actuators, and servos provided in the 2011 KOP that may have failed or become damaged,

F. drive motors or fans that are part of a speed controller or COTS computing device.

<R48> All electrical loads (motors, actuators, compressors) must be supplied by an approved power regulating device (speed controller, relay module, or Digital Sidecar PWM port) that is controlled by the cRIO-FRC on the ROBOT.

A. Each CIM motor and Fisher-Price motor must be connected to one and only one approved speed controller. These motors must not be connected to relay modules.

B. Servos must be directly connected to the PWM ports on the Digital Sidecar. They must not be connected to speed controllers or relay modules.

C. If used, the compressor must be connected to one and only one approved relay module.

D. Each other electrical load (motor or actuator) must be supplied by one and only one approved speed controller, or one and only one relay module.

<R49> ROBOTS must be controlled via the programmable National Instruments cRIO-FRC (National Instruments part number 780406-01)), with image version FRC_2011_v28. Other controllers shall not be used.

<R58> Each Jaguar must be controlled with signal inputs sourced from the cRIO-FRC and passed via either a connected PWM cable or a CAN-bus connection.

A. The Jaguar must receive signals via either a PWM cable -OR- a CAN-bus connection. Both may not be used simultaneously.

B. PWM configuration: If the Jaguar speed controller is controlled via PWM communications, the PWM port on the Jaguar speed controller must be connected directly to a PWM port on the Digital Sidecar with a PWM cable. No other devices may be connected to these PWM ports. No other devices may be connected to any other ports on the Jaguar speed controller with the exception of connection to the coast/brake port.

A full list of the 2011 FRC Game Rules can be found in the 2011 FRC Game Manual or online at <http://www.usfirst.org/roboticsprograms/frc/content.aspx?id=452>

Appendix D: Control Algorithm Code

```
/*
 * algorithm.c
 *
 * Created on: Feb 24, 2011
 * Modified on: Apr 18, 2011
 * Author: Elan Pelletier
 */
#include "BuiltIns.h"
#include "API.h"

//USER DEFINED VARIABLES
//These variables can be changed
#define HIGH_GEAR 500
#define LOW_GEAR 410
#define OPTIMAL_RPM 3168
#define OPTIMAL_RPM_PWM 45
#define MAX_RPM 1062
#define K_P 2


//GLOBAL CONSTANTS
//These varialbes should NEVER be changed
#define CIM 1
#define GLOBE 2
#define ENCODER_A 1
#define ENCODER_B 10
#define GEAR_POT 6
#define USER_INPUT 5
#define ON_SWITCH 15
#define HIGH 1
#define LOW 0
#define PULSES_PER_REV 180

//SYSTEM VARIABLE INITIALIZATIONS
int IO_flag = HIGH;
long rpm;
int enc_count = 0;
signed long PID_error = 0;
long PID_output = 0;
long lastTime = 0;
long currentTime = 0;
long D_Time = 0;
long lastTickCt = 0;
long currentTickCt = 0;
long D_Tick = 0;
int user_demand = 0;
int RpmOffset = 0;
int RpmError = 0;
int lastRpmError = 0;
int desired_gear = 0;
int current_gear = 0;
int val;
int desired_rpm = 0;
int actual_rpm = 0;
```

```
void Initialize(void){
	DefineControllerIO(6, INPUT, INPUT, INPUT, INPUT, INPUT, INPUT, INPUT,
INPUT, INPUT, INPUT, INPUT, INPUT, INPUT, INPUT, INPUT, INPUT);
	StartQuadEncoder(ENCODER_A, ENCODER_B, 0);
	PresetQuadEncoder(ENCODER_A, ENCODER_B, 0);
	StartTimer(1);
	PresetTimer(1,0);
	PrintToScreen("READY");
}


void GetRPM(void)
{
	currentTime = GetTimer(1);
	if(currentTime >= lastTime+250){
		D_Time = currentTime - lastTime;
		currentTickCt = GetQuadEncoder(ENCODER_A,ENCODER_B);
		rpm = ((currentTickCt*333)/D_Time);

		StopQuadEncoder(ENCODER_A,ENCODER_B);
		StartQuadEncoder(ENCODER_A,ENCODER_B,0);
		PresetQuadEncoder(ENCODER_A,ENCODER_B,0);

	lastTime = currentTime;
	}
}


//maps the value x, found in rage (in_min,in_max) to rage (out_min, out_max)
long map(long x, long in_min, long in_max, long out_min, long out_max)
{
	return (x - in_min) * (out_max - out_min) / (in_max - in_min) +
out_min;
}
//Sends the shifter to the desired gear while protecting the system from
crashes
void SetGearPos(unsigned long desired_gear){
	current_gear = GetAnalogInput(GEAR_POT);
	//This if statement ensures that the gear will not be sent to an
invalid position
	if(desired_gear >= HIGH_GEAR){
		desired_gear = HIGH_GEAR;
	}
	else if(desired_gear <=LOW_GEAR) {
		desired_gear = LOW_GEAR;
	}
	PID_error = desired_gear - current_gear;
	PID_output = (K_P * PID_error);
	if((PID_output + 127) >= 255){
		PID_output = 127;
	}
	else if ((PID_output + 127) <= 0){
		PID_output = -126;
```

```
	}
	else if (PID_output <= 10 && PID_output >=-10){
		PID_output = 0;
	}
	SetPWM(GLOBE, (127 + PID_output));
	//PrintToScreen("current gear = %d\n\r", current_gear);

	//PrintToScreen("PID_out = %ld\n\r", PID_output);
}


void main(void){
	int user_demand;
	int gear_position;
	int lastRpmError;
	long calculated_rpm;
	long RpmError;
	long desired_rpm= 0;
	long actual_rpm= 0;
	int x = 0;
	int y = 0;
	int val;

	Initialize();
	while(1){
		IO_flag = GetDigitalInput(ON_SWITCH);
		while(IO_flag == LOW){ //While the system is ON...
			lastRpmError = RpmError;
			GetRPM();
			desired_rpm = map(GetAnalogInput(USER_INPUT), 0, 1024, 0,
150);
			calculated_rpm = (9*desired_rpm) - 36;
			if(calculated_rpm <= 0){
				calculated_rpm = 0;
			} else if(calculated_rpm >= 400){
				calculated_rpm = 400;
			}
			RpmError = calculated_rpm - rpm;
			PrintToScreen("desired / actual  / calculated / error
%ld",desired_rpm);
			PrintToScreen(" / %ld",rpm);
			PrintToScreen(" / %ld",calculated_rpm);
			PrintToScreen(" / %ld\n\r",RpmError);


			if(desired_rpm <= 50){ //phase 1 if the user wants to
travel at speeds below 6ft/s
				PrintToScreen("PHASE 1 ");
				SetGearPos(LOW_GEAR); // set gear position to low
gear
				x = desired_rpm;
				SetPWM(CIM, 127 + x );

			} else if((desired_rpm >= 50) && (desired_rpm <= 100)){
//phase 2 if the user wants to travel 6-12ft/s
				x = map(desired_rpm,50,100,0,(HIGH_GEAR-LOW_GEAR));
```

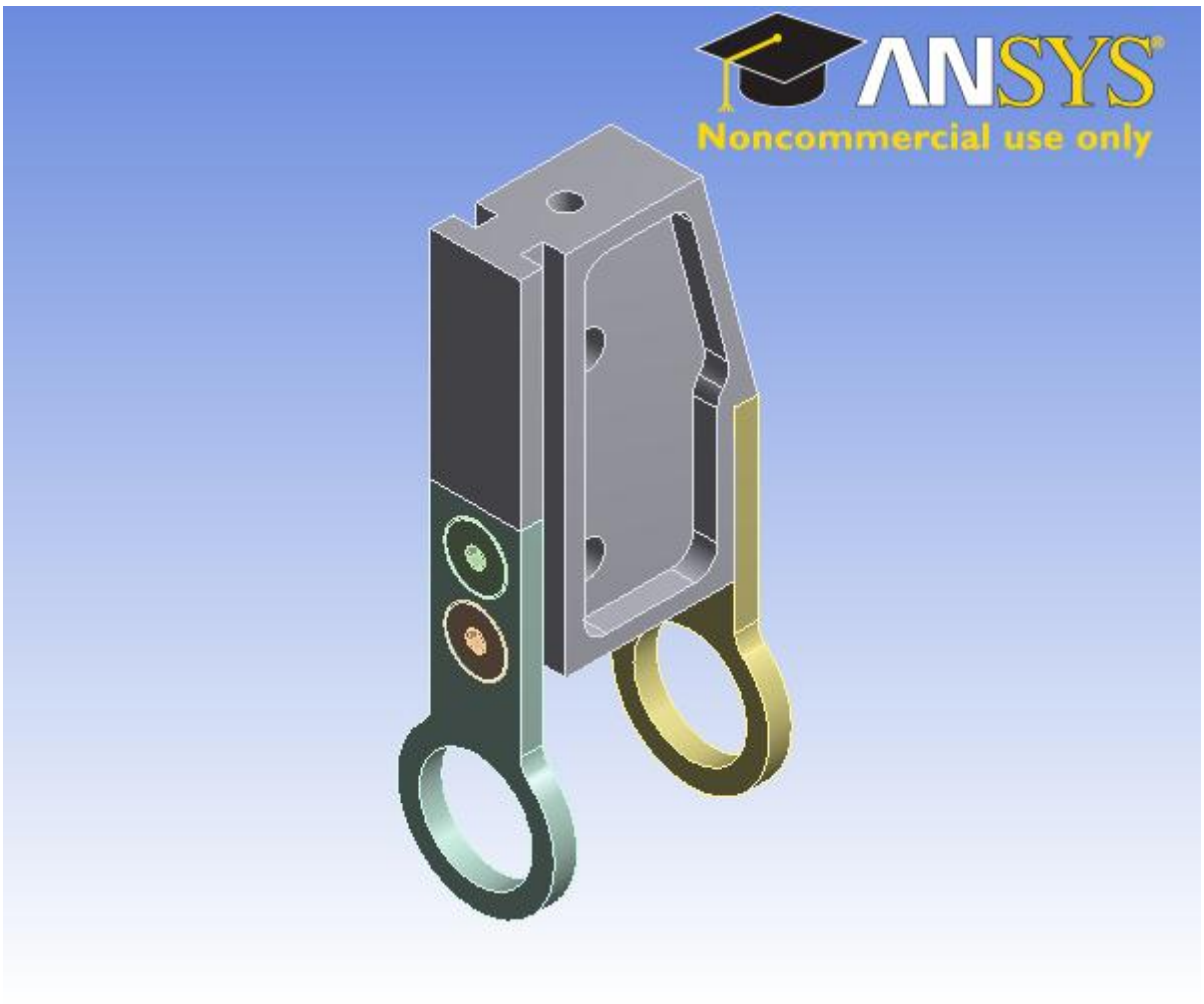
```
                        y = map(RpmError,-75,75,(-1*(HIGH_GEAR-
LOW_GEAR)),(HIGH_GEAR-LOW_GEAR)); // if there is a load on the system, offset
the gear pos by calculated value *system offset
                        val = LOW_GEAR + x - y;
                        SetGearPos(val);
                        SetPWM(CIM, 127 + 50);
                        PrintToScreen("PHASE 2 ");


                  }
                  else if(desired_rpm >> 100){ //phase 3 if the user wants to
travel faster than 12ft/s
                        x = map(desired_rpm, 100, 150, 0, 20);
                        y = map(RpmError,-75,75,-20,20);
                        SetGearPos(HIGH_GEAR-y);
                        SetPWM(CIM, 127 + 50 + x);
                        PrintToScreen("PHASE 3 ");

                        //PrintToScreen("CIM PWM Signal = %d\n\r", val);
                  }
                  IO_flag = GetDigitalInput(ON_SWITCH);
            }

            PrintToScreen("CVTV POWER OFF \n");
            SetPWM(CIM, 127);
            SetPWM(GLOBE, 127);
            while(IO_flag == HIGH){ //While the system is OFF...
                  IO_flag = GetDigitalInput(ON_SWITCH);
            }
      }
}
```

Appendix E: ANSYS Reports

Spoke 1: Side Load

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke1.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	2.2225e-002 m
Length Y	7.9693e-002 m
Length Z	3.3338e-002 m

Properties	
Volume	1.4555e-005 m³
Mass	6.0183e-002 kg
Scale Factor Value	1.
Statistics	
Bodies	7
Active Bodies	7
Nodes	86361
Elements	41014
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No
Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (.5) Flat*	*8-32 (.5) Flat*	*8-32 (.5) Flat*	*8-32 (.5) Flat*	*Tab*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					

Length X	1.1757e-002 m		8.9973e-003 m		2.2225e-002 m
Length Y	1.1757e-002 m		8.9973e-003 m		4.9213e-002 m
Length Z	1.27e-002 m				3.175e-003 m
Properties					
Volume	2.0905e-007 m³				1.5371e-006 m³
Mass	1.641e-003 kg				1.2066e-002 kg
Centroid X	4.3444e-003 m		4.3445e-003 m		
Centroid Y	-1.7526e-002 m	-2.7686e-002 m	-1.7526e-002 m	-2.7686e-002 m	-3.4764e-002 m
Centroid Z	-2.6149e-002 m		-2.25e-003 m		8.3605e-004 m
Moment of Inertia Ip1	2.877e-008 kg·m²				2.3574e-006 kg·m²
Moment of Inertia Ip2	2.8785e-008 kg·m²				3.4332e-007 kg·m²
Moment of Inertia Ip3	7.003e-009 kg·m²				2.6808e-006 kg·m²
Statistics					
Nodes	12776				7950
Elements	6831				1424
Mesh Metric	None				

TABLE 4
Model (A4) > Geometry > Parts

Object Name	*Tab*	*Generic Spoke1*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Material		
Assignment	Structural Steel	Aluminum Alloy
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	2.2225e-002 m	1.27e-002 m
Length Y	4.9213e-002 m	5.1435e-002 m
Length Z	3.175e-003 m	3.3337e-002 m
Properties		
Volume	1.5371e-006 m³	1.0645e-005 m³
Mass	1.2066e-002 kg	2.9487e-002 kg
Centroid X	4.3445e-003 m	4.3444e-003 m
Centroid Y	-3.4764e-002 m	-4.9725e-003 m
Centroid Z	-2.9235e-002 m	-1.2737e-002 m
Moment of Inertia Ip1	2.3574e-006 kg·m²	9.1476e-006 kg·m²
Moment of Inertia Ip2	3.4332e-007 kg·m²	2.7125e-006 kg·m²

Moment of Inertia Ip3	2.6808e-006 kg·m²	6.9591e-006 kg·m²
Statistics		
Nodes	7950	19357
Elements	1424	10842
Mesh Metric	None	

Coordinate Systems

TABLE 5
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 6
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	2.2299e-004 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region 2*	*Contact Region 3*	*Contact Region 4*	*Contact Region 5*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	2 Faces	14 Faces	2 Faces	14 Faces	2 Faces
Target	1 Face				
Contact Bodies	8-32 (.5) Flat				
Target Bodies	Tab	Generic Spoke1	Tab	Generic Spoke1	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 8
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*	*Contact Region 9*	*Contact Region 10*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	14 Faces	2 Faces	14 Faces	2 Faces	
Target	1 Face			2 Faces	
Contact Bodies	8-32 (.5) Flat			Tab	
Target Bodies	Generic Spoke1	Tab	Generic Spoke1		
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

Mesh

TABLE 9
Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.8741e-004 m
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	86361
Elements	41014
Mesh Metric	None

Static Structural (A5)

TABLE 10
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural

Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C
Generate Input Only	No

TABLE 11
Model (A4) > Static Structural (A5) > Analysis Settings

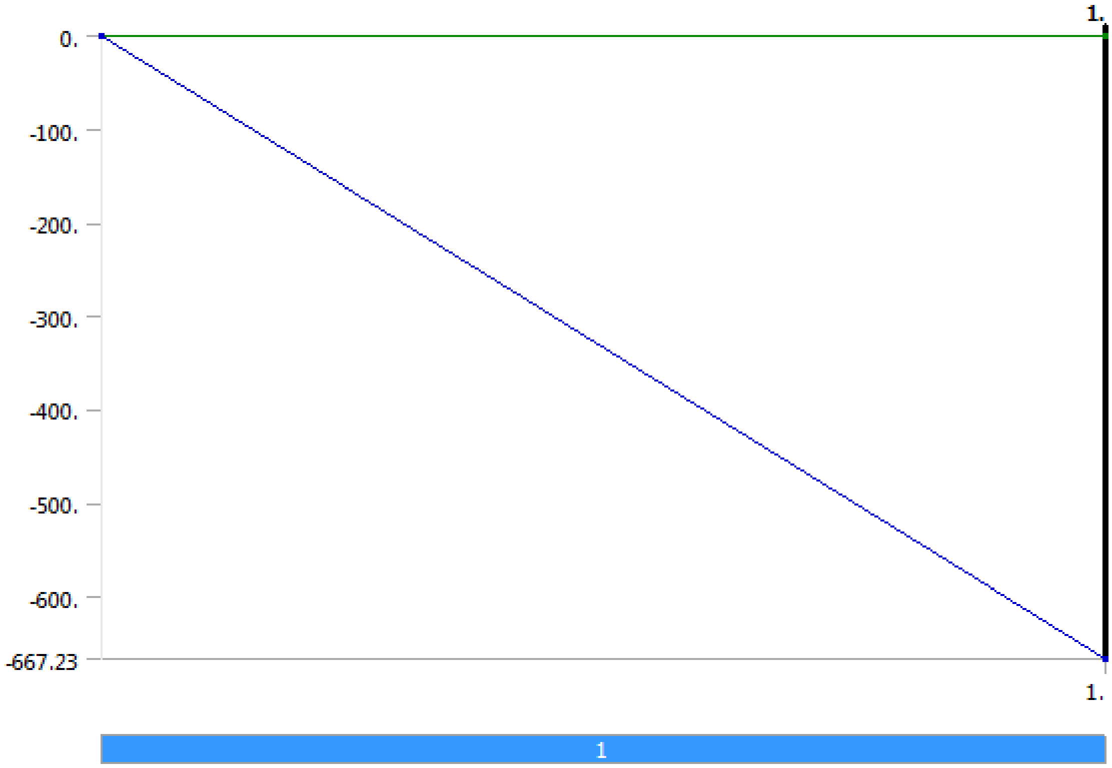
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\jmarrion\Downloads\Ansys\Spoke 1_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 12
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force

Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System
X Component		0. N (ramped)
Y Component		0. N (ramped)
Z Component		-667.23 N (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 13
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output

Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Equivalent Stress*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Total Deformation	Equivalent (von-Mises) Stress
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Results		
Minimum	0. m	7100.9 Pa
Maximum	3.5598e-005 m	4.5322e+008 Pa
Minimum Occurs On	Tab	
Maximum Occurs On	Generic Spoke1	8-32 (.5) Flat
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	
Integration Point Results		
Display Option		Averaged

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 17
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last

Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged
Results	
Minimum	0.55161
Minimum Occurs On	8-32 (.5) Flat
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

Chart

TABLE 18
Model (A4) > Chart

Steps	End Time [s]
1	1.

Material Data

Structural Steel

TABLE 19
Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

TABLE 20
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 21
Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

TABLE 22
Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

TABLE 23
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
4.6e+008

TABLE 24
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 25
Structural Steel > Alternating Stress Mean Stress

Alternating Stress Pa	Cycles	Mean Stress Pa
3.999e+009	10	0
2.827e+009	20	0
1.896e+009	50	0
1.413e+009	100	0
1.069e+009	200	0
4.41e+008	2000	0
2.62e+008	10000	0
2.14e+008	20000	0
1.38e+008	1.e+005	0
1.14e+008	2.e+005	0
8.62e+007	1.e+006	0

TABLE 26
Structural Steel > Strain-Life Parameters

Strength Coefficient Pa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient Pa	Cyclic Strain Hardening Exponent
9.2e+008	-0.106	0.213	-0.47	1.e+009	0.2

TABLE 27
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.e+011	0.3	1.6667e+011	7.6923e+010

TABLE 28
Structural Steel > Isotropic Relative Permeability

Relative Permeability
10000

Aluminum Alloy

TABLE 29
Aluminum Alloy > Constants

Density	2770 kg m^-3
Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat	875 J kg^-1 C^-1

TABLE 30
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 31
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength Pa
2.8e+008

TABLE 32
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength Pa
2.8e+008

TABLE 33
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
3.1e+008

TABLE 34
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 35
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity W m^-1 C^-1	Temperature C
114	-100
144	0
165	100
175	200

TABLE 36
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress Pa	Cycles	R-Ratio
2.758e+008	1700	-1
2.413e+008	5000	-1
2.068e+008	34000	-1
1.724e+008	1.4e+005	-1
1.379e+008	8.e+005	-1
1.172e+008	2.4e+006	-1
8.963e+007	5.5e+007	-1
8.274e+007	1.e+008	-1
1.706e+008	50000	-0.5
1.396e+008	3.5e+005	-0.5
1.086e+008	3.7e+006	-0.5
8.791e+007	1.4e+007	-0.5
7.757e+007	5.e+007	-0.5
7.239e+007	1.e+008	-0.5

1.448e+008	50000	0
1.207e+008	1.9e+005	0
1.034e+008	1.3e+006	0
9.308e+007	4.4e+006	0
8.618e+007	1.2e+007	0
7.239e+007	1.e+008	0
7.412e+007	3.e+005	0.5
7.067e+007	1.5e+006	0.5
6.636e+007	1.2e+007	0.5
6.205e+007	1.e+008	0.5

TABLE 37
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm m	Temperature C
2.43e-008	0
2.67e-008	20
3.63e-008	100

TABLE 38
Aluminum Alloy > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	7.1e+010	0.33	6.9608e+010	2.6692e+010

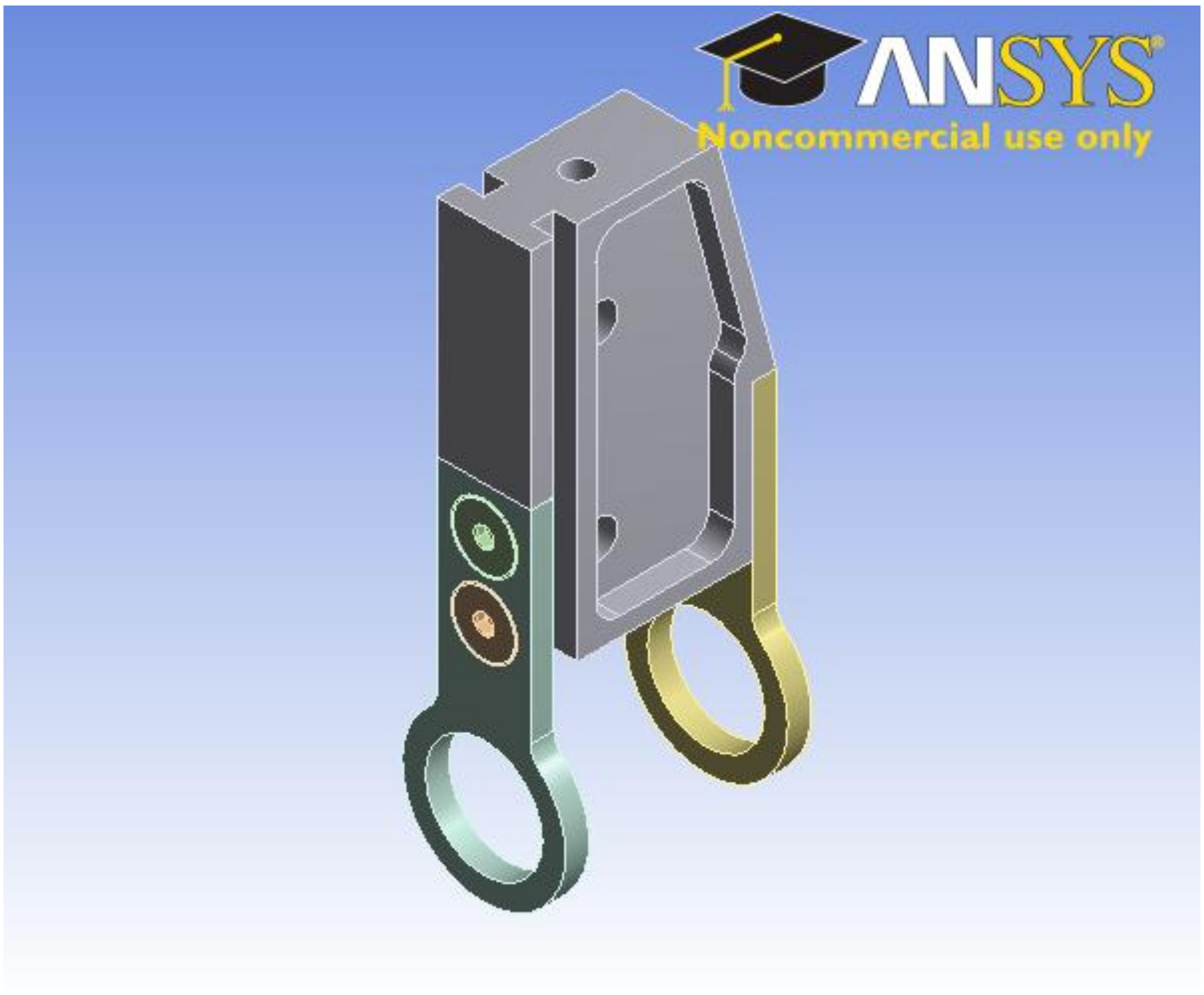
TABLE 39
Aluminum Alloy > Isotropic Relative Permeability

Relative Permeability
1

Spoke 1: Top Load

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke1.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	2.2225e-002 m
Length Y	7.9693e-002 m
Length Z	3.3338e-002 m
Properties	
Volume	1.4555e-005 m^3

Mass	6.0183e-002 kg
Scale Factor Value	1.
Statistics	
Bodies	7
Active Bodies	7
Nodes	86361
Elements	41014
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No
Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (.5) Flat*	*8-32 (.5) Flat*	*8-32 (.5) Flat*	*8-32 (.5) Flat*	*Tab*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					
Length X	1.1757e-002 m		8.9973e-003 m		2.2225e-002 m
Length Y	1.1757e-002 m		8.9973e-003 m		4.9213e-002 m

Length Z	1.27e-002 m				3.175e-003 m
Properties					
Volume	2.0905e-007 m³				1.5371e-006 m³
Mass	1.641e-003 kg				1.2066e-002 kg
Centroid X	4.3444e-003 m		4.3445e-003 m		
Centroid Y	-1.7526e-002 m	-2.7686e-002 m	-1.7526e-002 m	-2.7686e-002 m	-3.4764e-002 m
Centroid Z	-2.6149e-002 m		-2.25e-003 m		8.3605e-004 m
Moment of Inertia Ip1	2.877e-008 kg·m²				2.3574e-006 kg·m²
Moment of Inertia Ip2	2.8785e-008 kg·m²				3.4332e-007 kg·m²
Moment of Inertia Ip3	7.003e-009 kg·m²				2.6808e-006 kg·m²
Statistics					
Nodes	12776				7950
Elements	6831				1424
Mesh Metric	None				

TABLE 4
Model (A4) > Geometry > Parts

Object Name	*Tab*	*Generic Spoke1*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Material		
Assignment	Structural Steel	Aluminum Alloy
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	2.2225e-002 m	1.27e-002 m
Length Y	4.9213e-002 m	5.1435e-002 m
Length Z	3.175e-003 m	3.3337e-002 m
Properties		
Volume	1.5371e-006 m³	1.0645e-005 m³
Mass	1.2066e-002 kg	2.9487e-002 kg
Centroid X	4.3445e-003 m	4.3444e-003 m
Centroid Y	-3.4764e-002 m	-4.9725e-003 m
Centroid Z	-2.9235e-002 m	-1.2737e-002 m
Moment of Inertia Ip1	2.3574e-006 kg·m²	9.1476e-006 kg·m²
Moment of Inertia Ip2	3.4332e-007 kg·m²	2.7125e-006 kg·m²
Moment of Inertia Ip3	2.6808e-006 kg·m²	6.9591e-006 kg·m²
Statistics		

Nodes	7950	19357
Elements	1424	10842
Mesh Metric	None	

Coordinate Systems

TABLE 5
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 6
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	2.2299e-004 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region 2*	*Contact Region 3*	*Contact Region 4*	*Contact Region 5*

State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	2 Faces	14 Faces	2 Faces	14 Faces	2 Faces
Target	1 Face				
Contact Bodies	8-32 (.5) Flat				
Target Bodies	Tab	Generic Spoke1	Tab	Generic Spoke1	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 8
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*	*Contact Region 9*	*Contact Region 10*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	14 Faces	2 Faces	14 Faces	2 Faces	
Target	1 Face			2 Faces	
Contact Bodies	8-32 (.5) Flat			Tab	
Target Bodies	Generic Spoke1	Tab	Generic Spoke1		
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

Mesh

TABLE 9
Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.8741e-004 m
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	86361
Elements	41014
Mesh Metric	None

Static Structural (A5)

TABLE 10
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	

Environment Temperature	22. °C
Generate Input Only	No

TABLE 11
Model (A4) > Static Structural (A5) > Analysis Settings

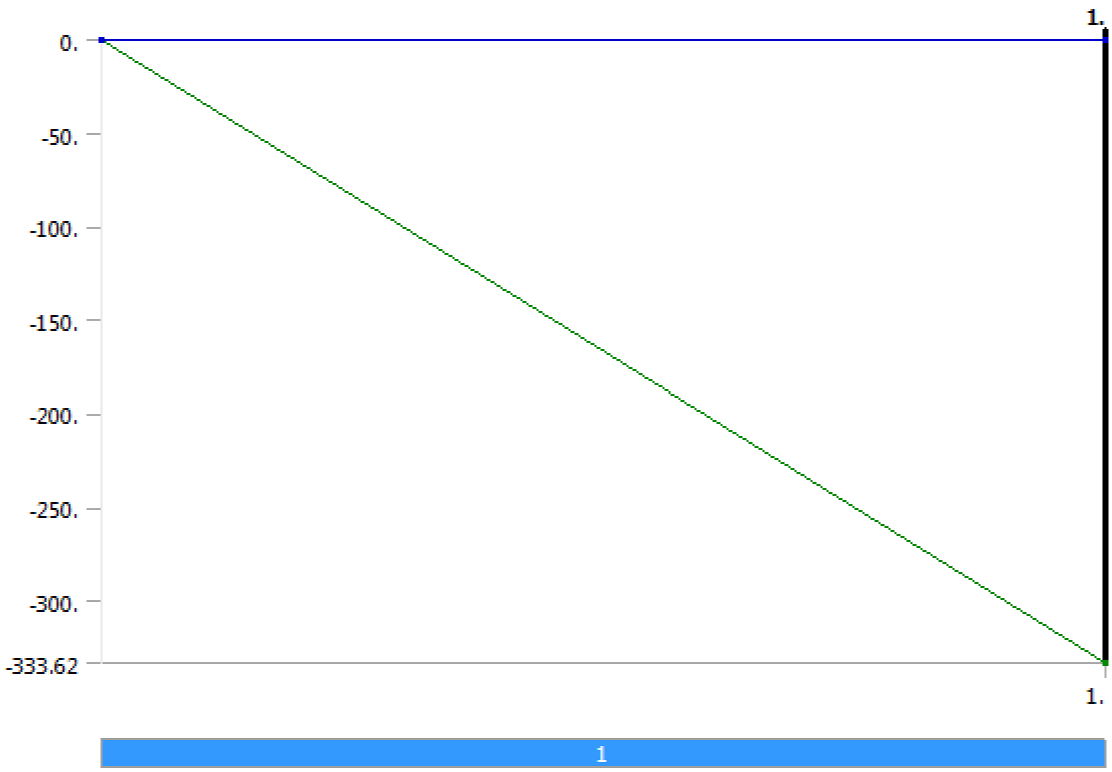
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\jmarrion\Downloads\Ansys\Spoke 1_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 12
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components

Coordinate System		Global Coordinate System
X Component		0. N (ramped)
Y Component		-333.62 N (ramped)
Z Component		0. N (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 13
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s

Display Points	All

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Equivalent Stress*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Total Deformation	Equivalent (von-Mises) Stress
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Results		
Minimum	0. m	748.16 Pa
Maximum	2.1881e-006 m	7.0453e+007 Pa
Minimum Occurs On	Tab	
Maximum Occurs On	Generic Spoke1	8-32 (.5) Flat
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	
Integration Point Results		
Display Option		Averaged

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 17
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	

Integration Point Results	
Display Option	Averaged
Results	
Minimum	3.5485
Minimum Occurs On	8-32 (.5) Flat
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

Chart

TABLE 18
Model (A4) > Chart

Steps	End Time [s]
1	1.

Material Data

Structural Steel

TABLE 19
Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

TABLE 20
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 21
Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

TABLE 22
Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

TABLE 23
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa

4.6e+008

TABLE 24
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 25
Structural Steel > Alternating Stress Mean Stress

Alternating Stress Pa	Cycles	Mean Stress Pa
3.999e+009	10	0
2.827e+009	20	0
1.896e+009	50	0
1.413e+009	100	0
1.069e+009	200	0
4.41e+008	2000	0
2.62e+008	10000	0
2.14e+008	20000	0
1.38e+008	1.e+005	0
1.14e+008	2.e+005	0
8.62e+007	1.e+006	0

TABLE 26
Structural Steel > Strain-Life Parameters

Strength Coefficient Pa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient Pa	Cyclic Strain Hardening Exponent
9.2e+008	-0.106	0.213	-0.47	1.e+009	0.2

TABLE 27
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.e+011	0.3	1.6667e+011	7.6923e+010

TABLE 28
Structural Steel > Isotropic Relative Permeability

Relative Permeability
10000

Aluminum Alloy

TABLE 29
Aluminum Alloy > Constants

Density	2770 kg m^-3
Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat	875 J kg^-1 C^-1

TABLE 30
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength Pa

0

TABLE 31
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength Pa
2.8e+008

TABLE 32
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength Pa
2.8e+008

TABLE 33
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
3.1e+008

TABLE 34
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 35
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity W m^-1 C^-1	Temperature C
114	-100
144	0
165	100
175	200

TABLE 36
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress Pa	Cycles	R-Ratio
2.758e+008	1700	-1
2.413e+008	5000	-1
2.068e+008	34000	-1
1.724e+008	1.4e+005	-1
1.379e+008	8.e+005	-1
1.172e+008	2.4e+006	-1
8.963e+007	5.5e+007	-1
8.274e+007	1.e+008	-1
1.706e+008	50000	-0.5
1.396e+008	3.5e+005	-0.5
1.086e+008	3.7e+006	-0.5
8.791e+007	1.4e+007	-0.5
7.757e+007	5.e+007	-0.5
7.239e+007	1.e+008	-0.5
1.448e+008	50000	0
1.207e+008	1.9e+005	0

1.034e+008	1.3e+006	0
9.308e+007	4.4e+006	0
8.618e+007	1.2e+007	0
7.239e+007	1.e+008	0
7.412e+007	3.e+005	0.5
7.067e+007	1.5e+006	0.5
6.636e+007	1.2e+007	0.5
6.205e+007	1.e+008	0.5

TABLE 37
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm m	Temperature C
2.43e-008	0
2.67e-008	20
3.63e-008	100

TABLE 38
Aluminum Alloy > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	7.1e+010	0.33	6.9608e+010	2.6692e+010

TABLE 39
Aluminum Alloy > Isotropic Relative Permeability

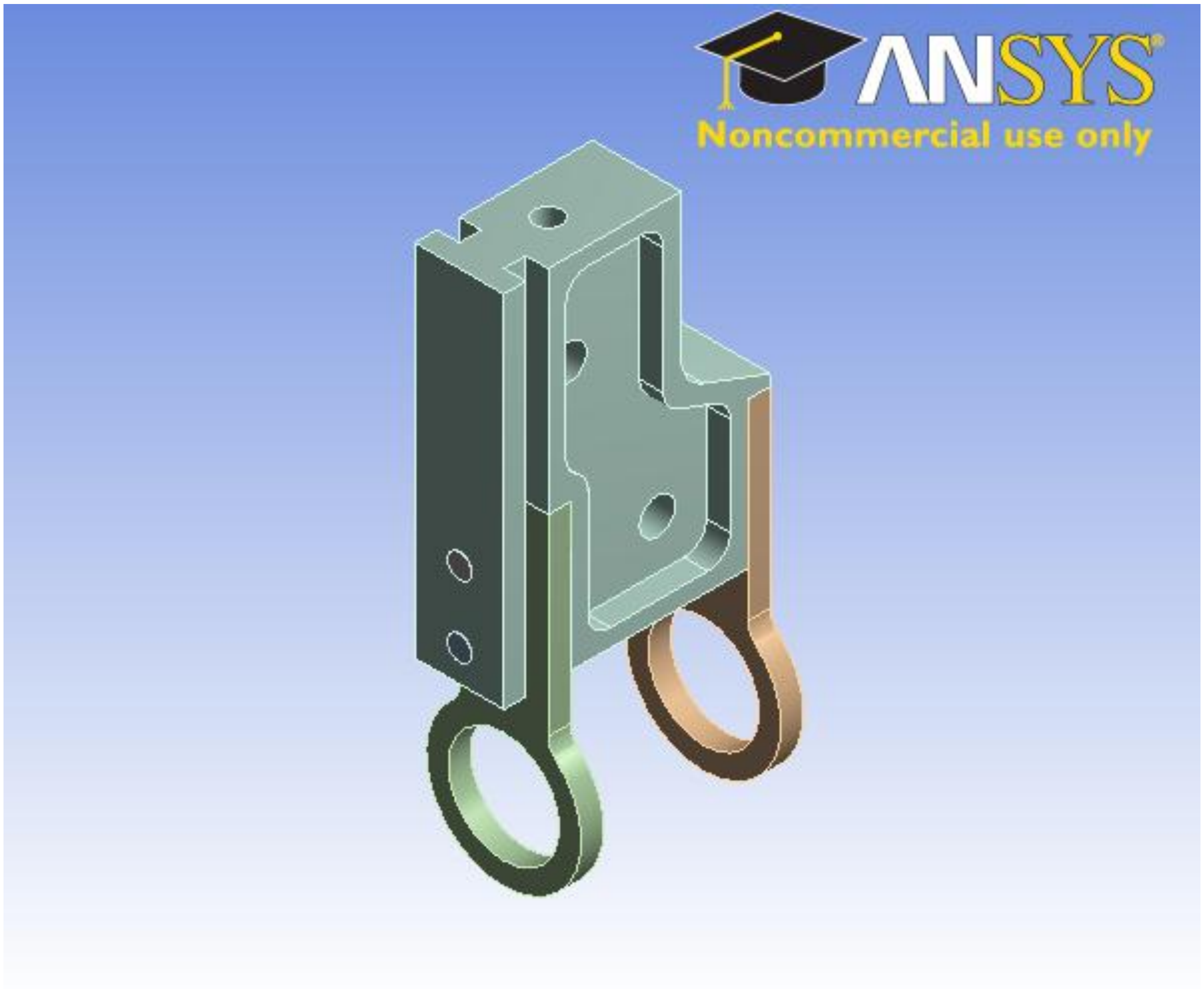
Relative Permeability
1

Spoke 2: Side Load

ANSYS®

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

- **Material Data**
    - Structural Steel
    - Aluminum Alloy

Units

TABLE 1

Unit System	U.S. Customary (in, lbm, lbf, s, V, A) Degrees rad/s Fahrenheit
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Fahrenheit

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke2.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	0.875 in
Length Y	3.1375 in
Length Z	1.5 in
Properties	
Volume	0.95013 in^3
Mass	0.14233 lbm
Scale Factor Value	1.
Statistics	
Bodies	5
Active Bodies	5
Nodes	88840
Elements	43910
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No

Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (1.5) Flat*	*8-32 (1.5) Flat*	*Tab no Countersink*	*Tab*	*Generic Spoke2*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				Aluminum Alloy
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					
Length X	0.49811 in		0.875 in		0.5 in
Length Y	0.49811 in		1.9375 in		2.025 in
Length Z	1.5 in		0.125 in		1.5 in
Properties					
Volume	3.2437e-002 in³		9.8761e-002 in³	9.3798e-002 in³	0.69269 in³
Mass	9.1992e-003 lbm		2.8009e-002 lbm	2.6601e-002 lbm	6.9319e-002 lbm
Centroid X	-1.0412 in				
Centroid Y	-0.27957 in	-0.67957 in	-0.93437 in	-0.95818 in	0.14359 in
Centroid Z	0.6833 in		1.2233 in	0.10014 in	0.94673 in
Moment of Inertia Ip1	1.9571e-003 lbm·in²		8.4264e-003 lbm·in²	8.0557e-003 lbm·in²	3.5953e-002 lbm·in²
Moment of Inertia Ip2	1.9573e-003 lbm·in²		1.1853e-003 lbm·in²	1.1732e-003 lbm·in²	1.1521e-002 lbm·in²
Moment of Inertia Ip3	4.1191e-005 lbm·in²		9.5388e-003 lbm·in²	9.1608e-003 lbm·in²	2.6504e-002 lbm·in²

Statistics				
Nodes	27953	5565	7542	19827
Elements	15335	942	1344	10954
Mesh Metric	None			

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. in
Origin Y	0. in
Origin Z	0. in
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	8.965e-003 in
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region*	*Contact Region*	*Contact Region 4*	*Contact Region*

		2	3		5
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	6 Faces	1 Face	27 Faces	6 Faces	1 Face
Target	1 Face		2 Faces	1 Face	
Contact Bodies	8-32 (1.5) Flat				
Target Bodies	Tab no Countersink	Tab	Generic Spoke2	Tab no Countersink	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Contact	27 Faces	3 Faces	2 Faces
Target	2 Faces	3 Faces	2 Faces
Contact Bodies	8-32 (1.5) Flat	Tab no Countersink	Tab
Target Bodies	Generic Spoke2		
Definition			
Type	Bonded		
Scope Mode	Automatic		
Behavior	Symmetric		
Suppressed	No		
Advanced			
Formulation	Pure Penalty		
Normal Stiffness	Program Controlled		
Update Stiffness	Never		
Pinball Region	Program Controlled		

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*

State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	2.7063e-002 in
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	88840
Elements	43910
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	71.6 °F

Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

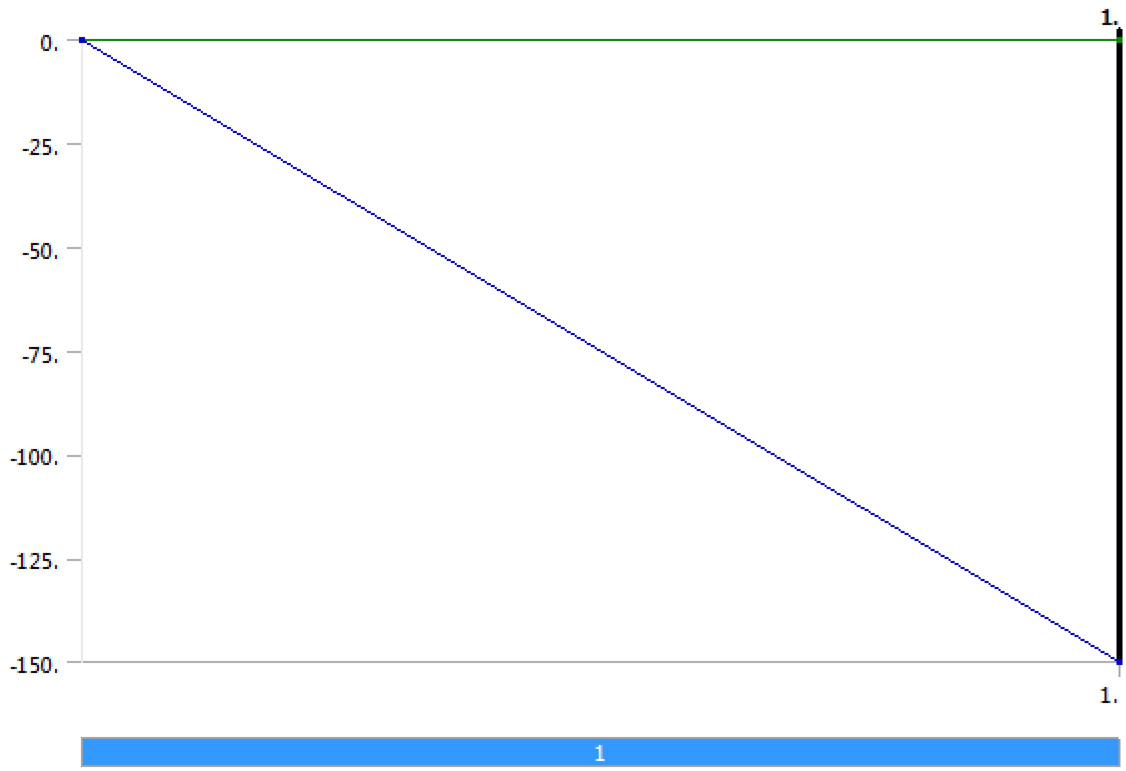
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	

Solver Files Directory	C:\Users\jmarrion\AppData\Local\Temp\WB_HARPOON_4976_4\unsaved_project_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	Bin

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System
X Component		0. lbf (ramped)
Y Component		0. lbf (ramped)
Z Component		-150. lbf (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Equivalent Stress*	*Total Deformation*
State	Solved	
Scope		

Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent (von-Mises) Stress	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Integration Point Results		
Display Option	Averaged	
Results		
Minimum	0.29897 psi	0. in
Maximum	44190 psi	1.693e-003 in
Minimum Occurs On	Tab	Tab no Countersink
Maximum Occurs On	8-32 (1.5) Flat	Generic Spoke2
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged
Results	
Minimum	0.82053
Minimum Occurs On	8-32 (1.5) Flat
Information	
Time	1. s

Load Step	1
Substep	1
Iteration Number	1

Material Data

Structural Steel

TABLE 17
Structural Steel > Constants

Density	0.2836 lbm in^-3
Coefficient of Thermal Expansion	6.6667e-006 F^-1
Specific Heat	0.10366 BTU lbm^-1 F^-1
Thermal Conductivity	8.0917e-004 BTU s^-1 in^-1 F^-1
Resistivity	8.5235 ohm cmil in^-1

TABLE 18
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength psi
0

TABLE 19
Structural Steel > Compressive Yield Strength

Compressive Yield Strength psi
36259

TABLE 20
Structural Steel > Tensile Yield Strength

Tensile Yield Strength psi
36259

TABLE 21
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength psi
66717

TABLE 22
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature F
71.6

TABLE 23
Structural Steel > Alternating Stress Mean Stress

Alternating Stress psi	Cycles	Mean Stress psi
5.8001e+005	10	0
4.1002e+005	20	0
2.7499e+005	50	0
2.0494e+005	100	0
1.5505e+005	200	0

63962	2000	0
38000	10000	0
31038	20000	0
20015	1.e+005	0
16534	2.e+005	0
12502	1.e+006	0

TABLE 24
Structural Steel > Strain-Life Parameters

Strength Coefficient psi	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient psi	Cyclic Strain Hardening Exponent
1.3343e+005	-0.106	0.213	-0.47	1.4504e+005	0.2

TABLE 25
Structural Steel > Isotropic Elasticity

Temperature F	Young's Modulus psi	Poisson's Ratio	Bulk Modulus psi	Shear Modulus psi
	2.9008e+007	0.3	2.4173e+007	1.1157e+007

TABLE 26
Structural Steel > Isotropic Relative Permeability

Relative Permeability
10000

Aluminum Alloy

TABLE 27
Aluminum Alloy > Constants

Density	0.10007 lbm in^-3
Coefficient of Thermal Expansion	1.2778e-005 F^-1
Specific Heat	0.20899 BTU lbm^-1 F^-1

TABLE 28
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength psi
0

TABLE 29
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength psi
40611

TABLE 30
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength psi
40611

TABLE 31
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength psi

44962

TABLE 32
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature F
71.6

TABLE 33
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity BTU s^-1 in^-1 F^-1	Temperature F
1.5247e-003	-148
1.926e-003	32
2.2068e-003	212
2.3406e-003	392

TABLE 34
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress psi	Cycles	R-Ratio
40001	1700	-1
34998	5000	-1
29994	34000	-1
25004	1.4e+005	-1
20001	8.e+005	-1
16998	2.4e+006	-1
13000	5.5e+007	-1
12000	1.e+008	-1
24743	50000	-0.5
20247	3.5e+005	-0.5
15751	3.7e+006	-0.5
12750	1.4e+007	-0.5
11251	5.e+007	-0.5
10499	1.e+008	-0.5
21001	50000	0
17506	1.9e+005	0
14997	1.3e+006	0
13500	4.4e+006	0
12499	1.2e+007	0
10499	1.e+008	0
10750	3.e+005	0.5
10250	1.5e+006	0.5
9624.7	1.2e+007	0.5
8999.6	1.e+008	0.5

TABLE 35
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm cmil in^-1	Temperature F
1.2184	32
1.3387	68
1.82	212

TABLE 36
Aluminum Alloy > Isotropic Elasticity

Temperature F	Young's Modulus psi	Poisson's Ratio	Bulk Modulus psi	Shear Modulus psi
	1.0298e+007	0.33	1.0096e+007	3.8713e+006

TABLE 37
Aluminum Alloy > Isotropic Relative Permeability

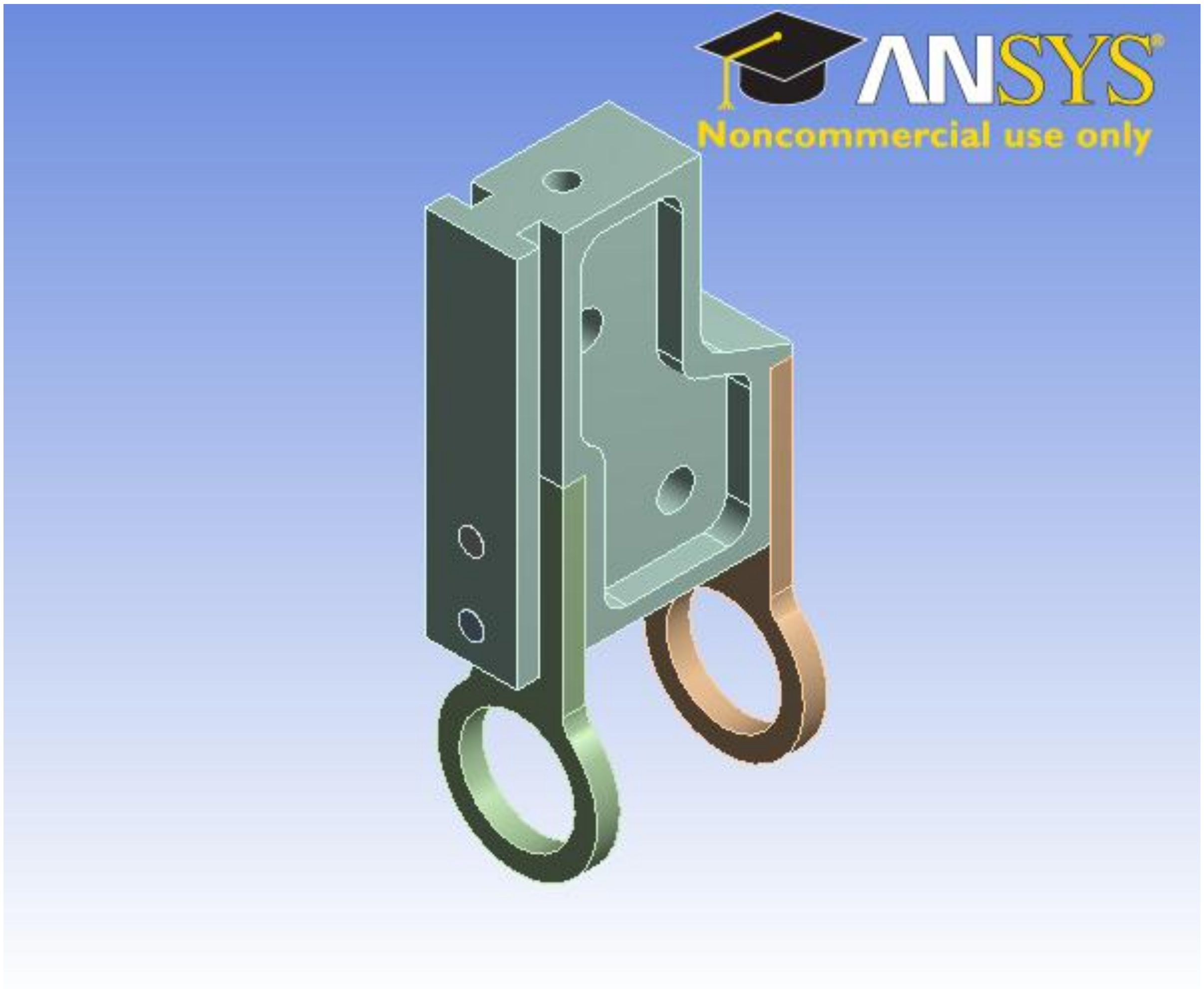
Relative Permeability
1

Spoke 2: Top Load

ANSYS®

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

- **Material Data**
  - Structural Steel
  - Aluminum Alloy

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke2.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	2.2225e-002 m
Length Y	7.9693e-002 m
Length Z	3.81e-002 m
Properties	
Volume	1.557e-005 m³
Mass	6.4559e-002 kg
Scale Factor Value	1.
Statistics	
Bodies	5
Active Bodies	5
Nodes	88840
Elements	43910
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No

Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (1.5) Flat*	*8-32 (1.5) Flat*	*Tab no Countersink*	*Tab*	*Generic Spoke2*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				Aluminum Alloy
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					
Length X	1.2652e-002 m		2.2225e-002 m		1.27e-002 m
Length Y	1.2652e-002 m		4.9213e-002 m		5.1435e-002 m
Length Z	3.81e-002 m		3.175e-003 m		3.81e-002 m
Properties					
Volume	5.3155e-007 m³		1.6184e-006 m³	1.5371e-006 m³	1.1351e-005 m³
Mass	4.1727e-003 kg		1.2704e-002 kg	1.2066e-002 kg	3.1443e-002 kg
Centroid X	-2.6447e-002 m		-2.6446e-002 m		
Centroid Y	-7.1012e-003 m	-1.7261e-002 m	-2.3733e-002 m	-2.4338e-002 m	3.6472e-003 m
Centroid Z	1.7356e-002 m		3.1073e-002 m	2.5436e-003 m	2.4047e-002 m
Moment of Inertia Ip1	5.7273e-007 kg·m²		2.4659e-006 kg·m²	2.3574e-006 kg·m²	1.0521e-005 kg·m²
Moment of Inertia Ip2	5.7277e-007 kg·m²		3.4685e-007 kg·m²	3.4332e-007 kg·m²	3.3716e-006 kg·m²
Moment of Inertia Ip3	1.2054e-008 kg·m²		2.7914e-006 kg·m²	2.6808e-006 kg·m²	7.7563e-006 kg·m²

Statistics				
Nodes	27953	5565	7542	19827
Elements	15335	942	1344	10954
Mesh Metric	None			

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	2.2771e-004 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region*	*Contact Region*	*Contact Region 4*	*Contact Region*

		2	3		5
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	6 Faces	1 Face	27 Faces	6 Faces	1 Face
Target	1 Face		2 Faces	1 Face	
Contact Bodies	8-32 (1.5) Flat				
Target Bodies	Tab no Countersink	Tab	Generic Spoke2	Tab no Countersink	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Contact	27 Faces	3 Faces	2 Faces
Target	2 Faces	3 Faces	2 Faces
Contact Bodies	8-32 (1.5) Flat	Tab no Countersink	Tab
Target Bodies	Generic Spoke2		
Definition			
Type	Bonded		
Scope Mode	Automatic		
Behavior	Symmetric		
Suppressed	No		
Advanced			
Formulation	Pure Penalty		
Normal Stiffness	Program Controlled		
Update Stiffness	Never		
Pinball Region	Program Controlled		

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*

State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.8741e-004 m
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	88840
Elements	43910
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C

Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

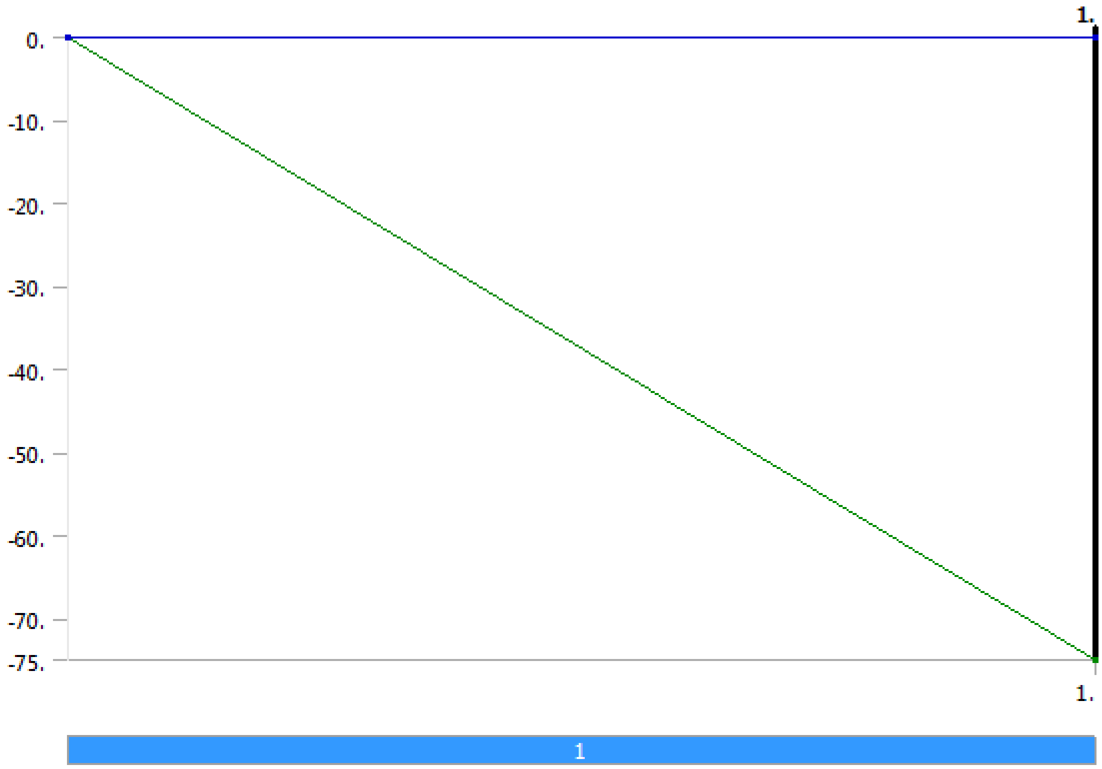
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\jmarrion\Downloads\Ansys\Spoke 2_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System

X Component		0. N (ramped)
Y Component		-75. N (ramped)
Z Component		0. N (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Equivalent Stress*	*Total Deformation*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent (von-Mises) Stress	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Integration Point Results		
Display Option	Averaged	
Results		
Minimum	21.732 Pa	0. m
Maximum	1.1684e+007 Pa	5.0159e-007 m
Minimum Occurs On	Tab	Tab no Countersink
Maximum Occurs On	8-32 (1.5) Flat	Generic Spoke2
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged

Results	
Minimum	> 10
Minimum Occurs On	8-32 (1.5) Flat
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

Material Data

Structural Steel

TABLE 17
Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

TABLE 18
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 19
Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

TABLE 20
Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

TABLE 21
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
4.6e+008

TABLE 22
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 23
Structural Steel > Alternating Stress Mean Stress

Alternating Stress Pa	Cycles	Mean Stress Pa

3.999e+009	10	0
2.827e+009	20	0
1.896e+009	50	0
1.413e+009	100	0
1.069e+009	200	0
4.41e+008	2000	0
2.62e+008	10000	0
2.14e+008	20000	0
1.38e+008	1.e+005	0
1.14e+008	2.e+005	0
8.62e+007	1.e+006	0

TABLE 24
Structural Steel > Strain-Life Parameters

Strength Coefficient Pa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient Pa	Cyclic Strain Hardening Exponent
9.2e+008	-0.106	0.213	-0.47	1.e+009	0.2

TABLE 25
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.e+011	0.3	1.6667e+011	7.6923e+010

TABLE 26
Structural Steel > Isotropic Relative Permeability

Relative Permeability
10000

Aluminum Alloy

TABLE 27
Aluminum Alloy > Constants

Density	2770 kg m^-3
Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat	875 J kg^-1 C^-1

TABLE 28
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 29
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength Pa
2.8e+008

TABLE 30
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength Pa

2.8e+008

TABLE 31
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
3.1e+008

TABLE 32
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 33
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity W m^-1 C^-1	Temperature C
114	-100
144	0
165	100
175	200

TABLE 34
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress Pa	Cycles	R-Ratio
2.758e+008	1700	-1
2.413e+008	5000	-1
2.068e+008	34000	-1
1.724e+008	1.4e+005	-1
1.379e+008	8.e+005	-1
1.172e+008	2.4e+006	-1
8.963e+007	5.5e+007	-1
8.274e+007	1.e+008	-1
1.706e+008	50000	-0.5
1.396e+008	3.5e+005	-0.5
1.086e+008	3.7e+006	-0.5
8.791e+007	1.4e+007	-0.5
7.757e+007	5.e+007	-0.5
7.239e+007	1.e+008	-0.5
1.448e+008	50000	0
1.207e+008	1.9e+005	0
1.034e+008	1.3e+006	0
9.308e+007	4.4e+006	0
8.618e+007	1.2e+007	0
7.239e+007	1.e+008	0
7.412e+007	3.e+005	0.5
7.067e+007	1.5e+006	0.5
6.636e+007	1.2e+007	0.5
6.205e+007	1.e+008	0.5

TABLE 35
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm m	Temperature C
2.43e-008	0
2.67e-008	20
3.63e-008	100

TABLE 36
Aluminum Alloy > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	7.1e+010	0.33	6.9608e+010	2.6692e+010

TABLE 37
Aluminum Alloy > Isotropic Relative Permeability

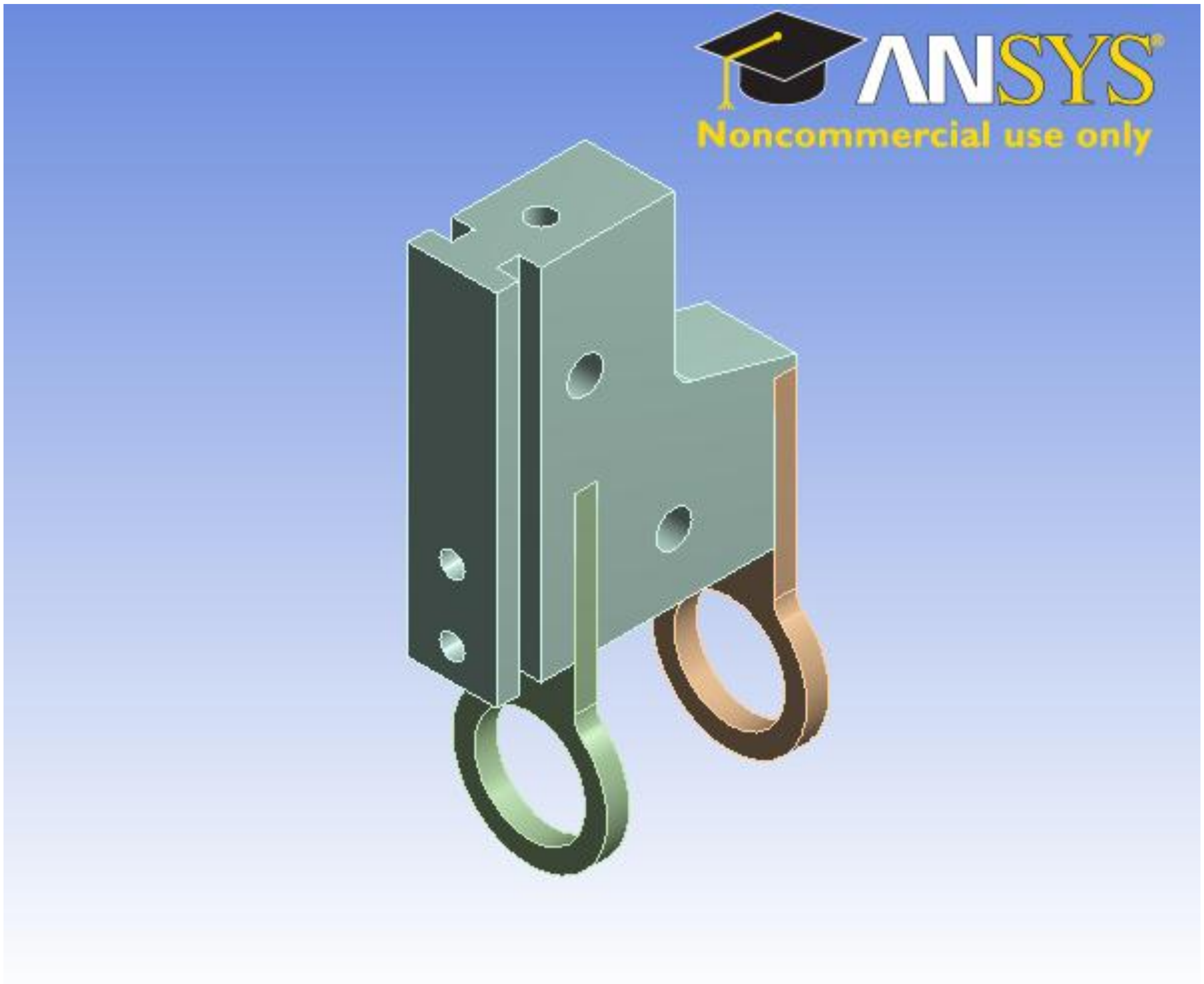
Relative Permeability
1

Spoke 3: Side Load

ANSYS®

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

- Material Data
  - Structural Steel
  - Aluminum Alloy

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke3.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	2.2225e-002 m
Length Y	7.9693e-002 m
Length Z	4.2863e-002 m
Properties	
Volume	2.2262e-005 m³
Mass	8.3096e-002 kg
Scale Factor Value	1.
Statistics	
Bodies	5
Active Bodies	5
Nodes	88618
Elements	44643
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No

Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (1.5) Flat*	*8-32 (1.5) Flat*	*Tab no Countersink*	*Tab*	*Generic Spoke3*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				Aluminum Alloy
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					
Length X	1.1757e-002 m		2.2225e-002 m		1.27e-002 m
Length Y	1.1757e-002 m		4.9213e-002 m		5.1435e-002 m
Length Z	3.81e-002 m		3.175e-003 m		4.2863e-002 m
Properties					
Volume	5.3155e-007 m³		1.6184e-006 m³	1.5371e-006 m³	1.8043e-005 m³
Mass	4.1727e-003 kg		1.2704e-002 kg	1.2066e-002 kg	4.998e-002 kg
Centroid X	-3.3898e-002 m				
Centroid Y	2.3077e-003 m	-7.8523e-003 m	-1.4324e-002 m	-1.4929e-002 m	1.1346e-002 m
Centroid Z	2.5137e-003 m		1.6231e-002 m	-1.2299e-002 m	1.1097e-002 m
Moment of Inertia Ip1	5.7273e-007 kg·m²		2.4659e-006 kg·m²	2.3574e-006 kg·m²	1.6369e-005 kg·m²
Moment of Inertia Ip2	5.7277e-007 kg·m²		3.4685e-007 kg·m²	3.4332e-007 kg·m²	5.484e-006 kg·m²
Moment of Inertia Ip3	1.2054e-008 kg·m²		2.7914e-006 kg·m²	2.6808e-006 kg·m²	1.2231e-005 kg·m²

Statistics				
Nodes	28797	5172	6963	18889
Elements	15898	870	1228	10749
Mesh Metric	None			

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	2.3294e-004 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region*	*Contact Region*	*Contact Region 4*	*Contact Region*

		2	*3*		*5*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	6 Faces	1 Face	26 Faces	6 Faces	1 Face
Target	1 Face		2 Faces	1 Face	
Contact Bodies	8-32 (1.5) Flat				
Target Bodies	Tab no Countersink	Tab	Generic Spoke3	Tab no Countersink	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Contact	26 Faces	3 Faces	2 Faces
Target	2 Faces	3 Faces	2 Faces
Contact Bodies	8-32 (1.5) Flat	Tab no Countersink	Tab
Target Bodies	Generic Spoke3		
Definition			
Type	Bonded		
Scope Mode	Automatic		
Behavior	Symmetric		
Suppressed	No		
Advanced			
Formulation	Pure Penalty		
Normal Stiffness	Program Controlled		
Update Stiffness	Never		
Pinball Region	Program Controlled		

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*

State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.8741e-004 m
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	88618
Elements	44643
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C

Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

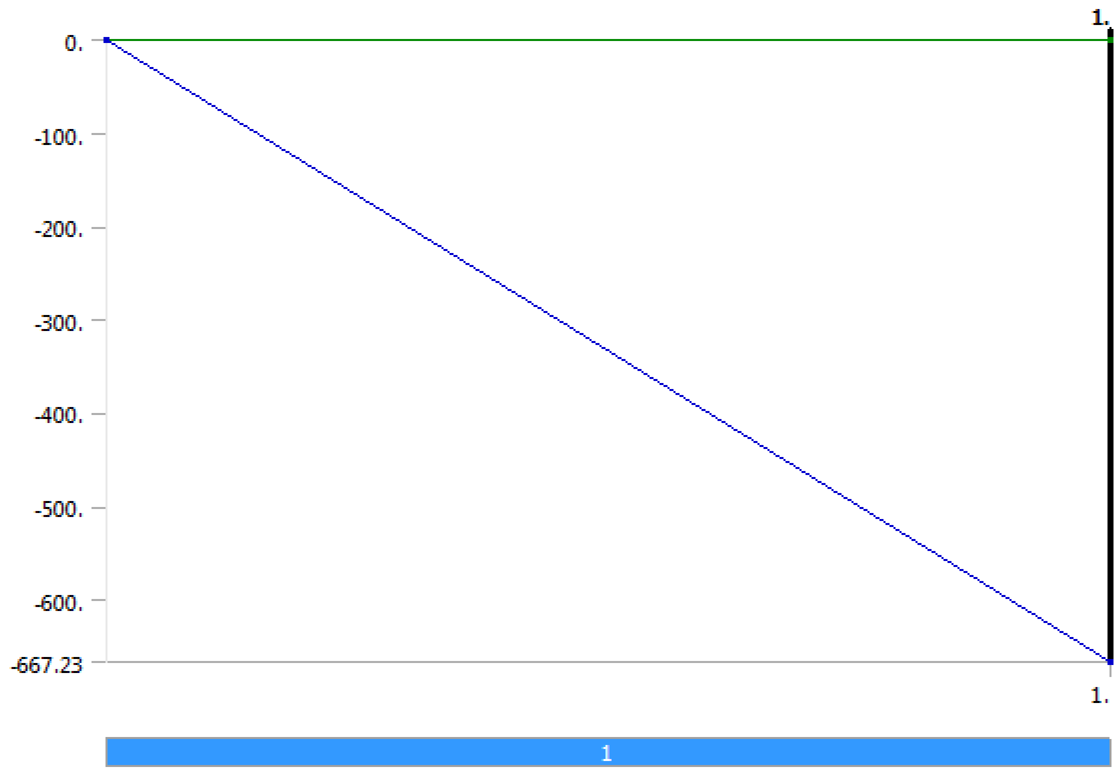
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	

Solver Files Directory	C:\Users\jmarrion\AppData\Local\Temp\WB_HARPOON_4976_6\unsaved_project_files\dp0 \SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System
X Component		0. N (ramped)
Y Component		0. N (ramped)
Z Component		-667.23 N (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Equivalent Stress*	*Total Deformation*
State	Solved	
Scope		

Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent (von-Mises) Stress	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Integration Point Results		
Display Option	Averaged	
Results		
Minimum	7355.4 Pa	0. m
Maximum	4.8148e+008 Pa	3.8189e-005 m
Minimum Occurs On	Tab no Countersink	
Maximum Occurs On	8-32 (1.5) Flat	Generic Spoke3
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged
Results	
Minimum	0.51924
Minimum Occurs On	8-32 (1.5) Flat
Information	
Time	1. s

Load Step	1
Substep	1
Iteration Number	1

Material Data

Structural Steel

TABLE 17
Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

TABLE 18
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 19
Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

TABLE 20
Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

TABLE 21
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
4.6e+008

TABLE 22
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 23
Structural Steel > Alternating Stress Mean Stress

Alternating Stress Pa	Cycles	Mean Stress Pa
3.999e+009	10	0
2.827e+009	20	0
1.896e+009	50	0
1.413e+009	100	0
1.069e+009	200	0

4.41e+008	2000	0
2.62e+008	10000	0
2.14e+008	20000	0
1.38e+008	1.e+005	0
1.14e+008	2.e+005	0
8.62e+007	1.e+006	0

TABLE 24
Structural Steel > Strain-Life Parameters

Strength Coefficient Pa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient Pa	Cyclic Strain Hardening Exponent
9.2e+008	-0.106	0.213	-0.47	1.e+009	0.2

TABLE 25
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.e+011	0.3	1.6667e+011	7.6923e+010

TABLE 26
Structural Steel > Isotropic Relative Permeability

Relative Permeability
10000

Aluminum Alloy

TABLE 27
Aluminum Alloy > Constants

Density	2770 kg m^-3
Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat	875 J kg^-1 C^-1

TABLE 28
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 29
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength Pa
2.8e+008

TABLE 30
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength Pa
2.8e+008

TABLE 31
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength Pa

3.1e+008

TABLE 32
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 33
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity W m^-1 C^-1	Temperature C
114	-100
144	0
165	100
175	200

TABLE 34
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress Pa	Cycles	R-Ratio
2.758e+008	1700	-1
2.413e+008	5000	-1
2.068e+008	34000	-1
1.724e+008	1.4e+005	-1
1.379e+008	8.e+005	-1
1.172e+008	2.4e+006	-1
8.963e+007	5.5e+007	-1
8.274e+007	1.e+008	-1
1.706e+008	50000	-0.5
1.396e+008	3.5e+005	-0.5
1.086e+008	3.7e+006	-0.5
8.791e+007	1.4e+007	-0.5
7.757e+007	5.e+007	-0.5
7.239e+007	1.e+008	-0.5
1.448e+008	50000	0
1.207e+008	1.9e+005	0
1.034e+008	1.3e+006	0
9.308e+007	4.4e+006	0
8.618e+007	1.2e+007	0
7.239e+007	1.e+008	0
7.412e+007	3.e+005	0.5
7.067e+007	1.5e+006	0.5
6.636e+007	1.2e+007	0.5
6.205e+007	1.e+008	0.5

TABLE 35
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm m	Temperature C
2.43e-008	0
2.67e-008	20
3.63e-008	100

TABLE 36
Aluminum Alloy > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	7.1e+010	0.33	6.9608e+010	2.6692e+010

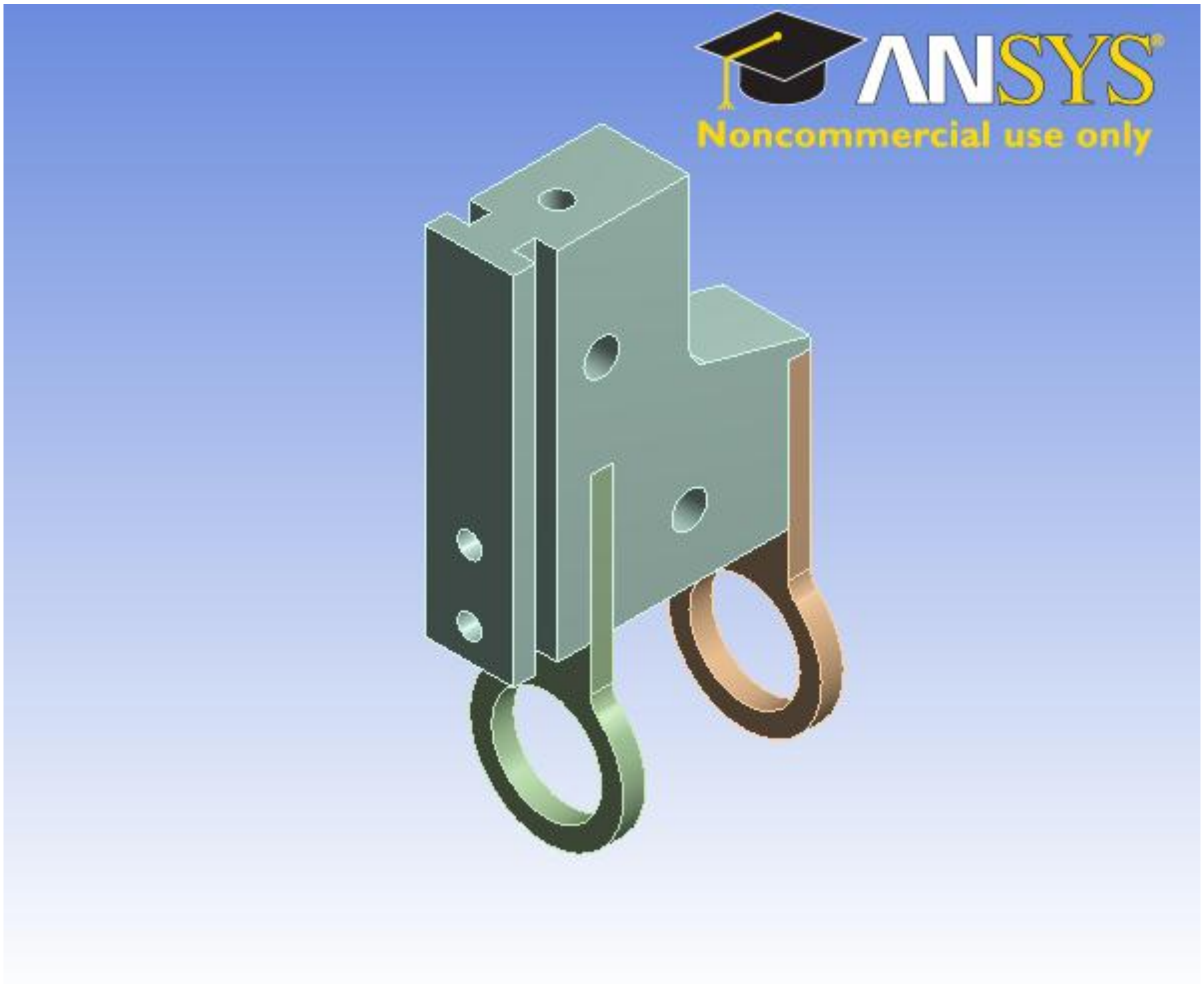
TABLE 37
Aluminum Alloy > Isotropic Relative Permeability

Relative Permeability
1

Spoke 3: Top Load

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke3.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	2.2225e-002 m
Length Y	7.9693e-002 m
Length Z	4.2863e-002 m
Properties	
Volume	2.2262e-005 m³
Mass	8.3096e-002 kg
Scale Factor Value	1.
Statistics	
Bodies	5
Active Bodies	5
Nodes	88618
Elements	44643
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No

Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (1.5) Flat*	*8-32 (1.5) Flat*	*Tab no Countersink*	*Tab*	*Generic Spoke3*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				Aluminum Alloy
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					
Length X	1.1757e-002 m		2.2225e-002 m		1.27e-002 m
Length Y	1.1757e-002 m		4.9213e-002 m		5.1435e-002 m
Length Z	3.81e-002 m		3.175e-003 m		4.2863e-002 m
Properties					
Volume	5.3155e-007 m³		1.6184e-006 m³	1.5371e-006 m³	1.8043e-005 m³
Mass	4.1727e-003 kg		1.2704e-002 kg	1.2066e-002 kg	4.998e-002 kg
Centroid X	-3.3898e-002 m				
Centroid Y	2.3077e-003 m	-7.8523e-003 m	-1.4324e-002 m	-1.4929e-002 m	1.1346e-002 m
Centroid Z	2.5137e-003 m		1.6231e-002 m	-1.2299e-002 m	1.1097e-002 m
Moment of Inertia Ip1	5.7273e-007 kg·m²		2.4659e-006 kg·m²	2.3574e-006 kg·m²	1.6369e-005 kg·m²
Moment of Inertia Ip2	5.7277e-007 kg·m²		3.4685e-007 kg·m²	3.4332e-007 kg·m²	5.484e-006 kg·m²
Moment of Inertia Ip3	1.2054e-008 kg·m²		2.7914e-006 kg·m²	2.6808e-006 kg·m²	1.2231e-005 kg·m²

Statistics				
Nodes	28797	5172	6963	18889
Elements	15898	870	1228	10749
Mesh Metric	None			

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	2.3294e-004 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region*	*Contact Region*	*Contact Region 4*	*Contact Region*

		2	*3*		*5*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	6 Faces	1 Face	26 Faces	6 Faces	1 Face
Target	1 Face		2 Faces	1 Face	
Contact Bodies	8-32 (1.5) Flat				
Target Bodies	Tab no Countersink	Tab	Generic Spoke3	Tab no Countersink	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Contact	26 Faces	3 Faces	2 Faces
Target	2 Faces	3 Faces	2 Faces
Contact Bodies	8-32 (1.5) Flat	Tab no Countersink	Tab
Target Bodies	Generic Spoke3		
Definition			
Type	Bonded		
Scope Mode	Automatic		
Behavior	Symmetric		
Suppressed	No		
Advanced			
Formulation	Pure Penalty		
Normal Stiffness	Program Controlled		
Update Stiffness	Never		
Pinball Region	Program Controlled		

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*

State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.8741e-004 m
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	88618
Elements	44643
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C

Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

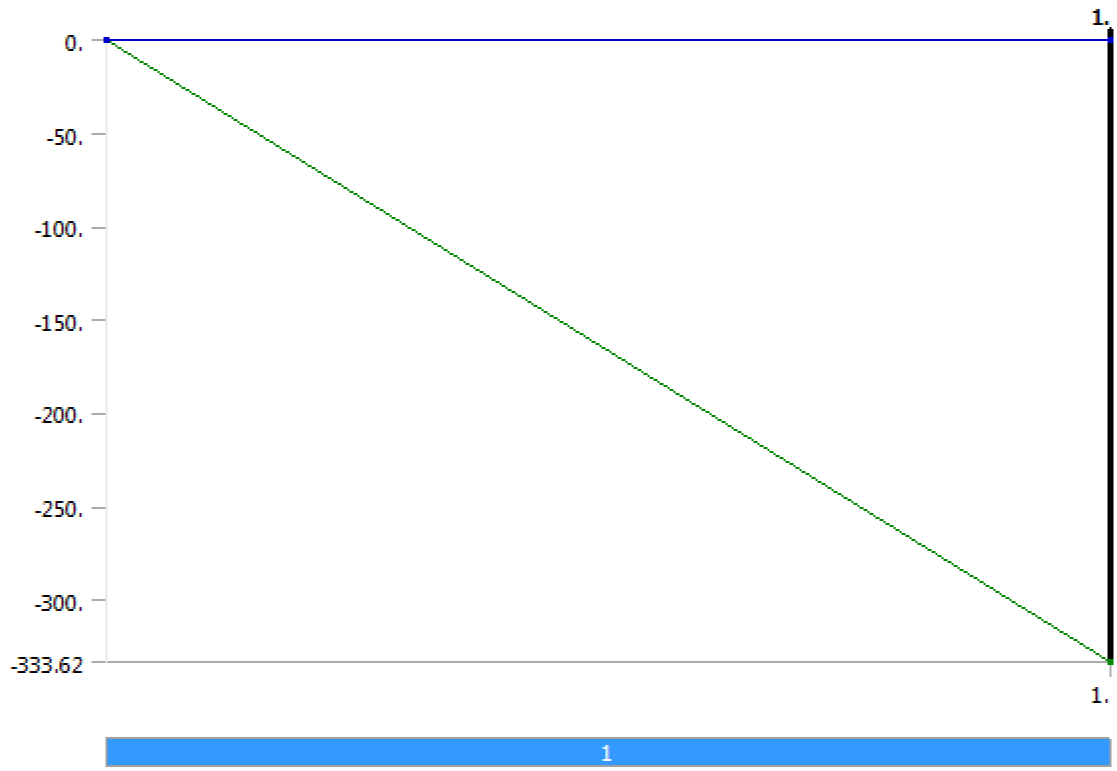
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	

Solver Files Directory	C:\Users\jmarrion\AppData\Local\Temp\WB_HARPOON_4976_6\unsaved_project_files\dp0 \SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System
X Component		0. N (ramped)
Y Component		-333.62 N (ramped)
Z Component		0. N (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Equivalent Stress*	*Total Deformation*
State	Solved	
Scope		

Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent (von-Mises) Stress	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Integration Point Results		
Display Option	Averaged	
Results		
Minimum	8.7573 Pa	0. m
Maximum	5.5548e+007 Pa	2.5108e-006 m
Minimum Occurs On	8-32 (1.5) Flat	Tab no Countersink
Maximum Occurs On	8-32 (1.5) Flat	Generic Spoke3
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged
Results	
Minimum	4.5006
Minimum Occurs On	8-32 (1.5) Flat
Information	
Time	1. s

Load Step	1
Substep	1
Iteration Number	1

Material Data

Structural Steel

TABLE 17
Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

TABLE 18
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 19
Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

TABLE 20
Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

TABLE 21
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
4.6e+008

TABLE 22
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 23
Structural Steel > Alternating Stress Mean Stress

Alternating Stress Pa	Cycles	Mean Stress Pa
3.999e+009	10	0
2.827e+009	20	0
1.896e+009	50	0
1.413e+009	100	0
1.069e+009	200	0

4.41e+008	2000	0
2.62e+008	10000	0
2.14e+008	20000	0
1.38e+008	1.e+005	0
1.14e+008	2.e+005	0
8.62e+007	1.e+006	0

TABLE 24
Structural Steel > Strain-Life Parameters

Strength Coefficient Pa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient Pa	Cyclic Strain Hardening Exponent
9.2e+008	-0.106	0.213	-0.47	1.e+009	0.2

TABLE 25
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.e+011	0.3	1.6667e+011	7.6923e+010

TABLE 26
Structural Steel > Isotropic Relative Permeability

Relative Permeability
10000

Aluminum Alloy

TABLE 27
Aluminum Alloy > Constants

Density	2770 kg m^-3
Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat	875 J kg^-1 C^-1

TABLE 28
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 29
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength Pa
2.8e+008

TABLE 30
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength Pa
2.8e+008

TABLE 31
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength Pa

3.1e+008

TABLE 32
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 33
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity W m^-1 C^-1	Temperature C
114	-100
144	0
165	100
175	200

TABLE 34
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress Pa	Cycles	R-Ratio
2.758e+008	1700	-1
2.413e+008	5000	-1
2.068e+008	34000	-1
1.724e+008	1.4e+005	-1
1.379e+008	8.e+005	-1
1.172e+008	2.4e+006	-1
8.963e+007	5.5e+007	-1
8.274e+007	1.e+008	-1
1.706e+008	50000	-0.5
1.396e+008	3.5e+005	-0.5
1.086e+008	3.7e+006	-0.5
8.791e+007	1.4e+007	-0.5
7.757e+007	5.e+007	-0.5
7.239e+007	1.e+008	-0.5
1.448e+008	50000	0
1.207e+008	1.9e+005	0
1.034e+008	1.3e+006	0
9.308e+007	4.4e+006	0
8.618e+007	1.2e+007	0
7.239e+007	1.e+008	0
7.412e+007	3.e+005	0.5
7.067e+007	1.5e+006	0.5
6.636e+007	1.2e+007	0.5
6.205e+007	1.e+008	0.5

TABLE 35
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm m	Temperature C
2.43e-008	0
2.67e-008	20
3.63e-008	100

TABLE 36
Aluminum Alloy > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	7.1e+010	0.33	6.9608e+010	2.6692e+010

TABLE 37
Aluminum Alloy > Isotropic Relative Permeability

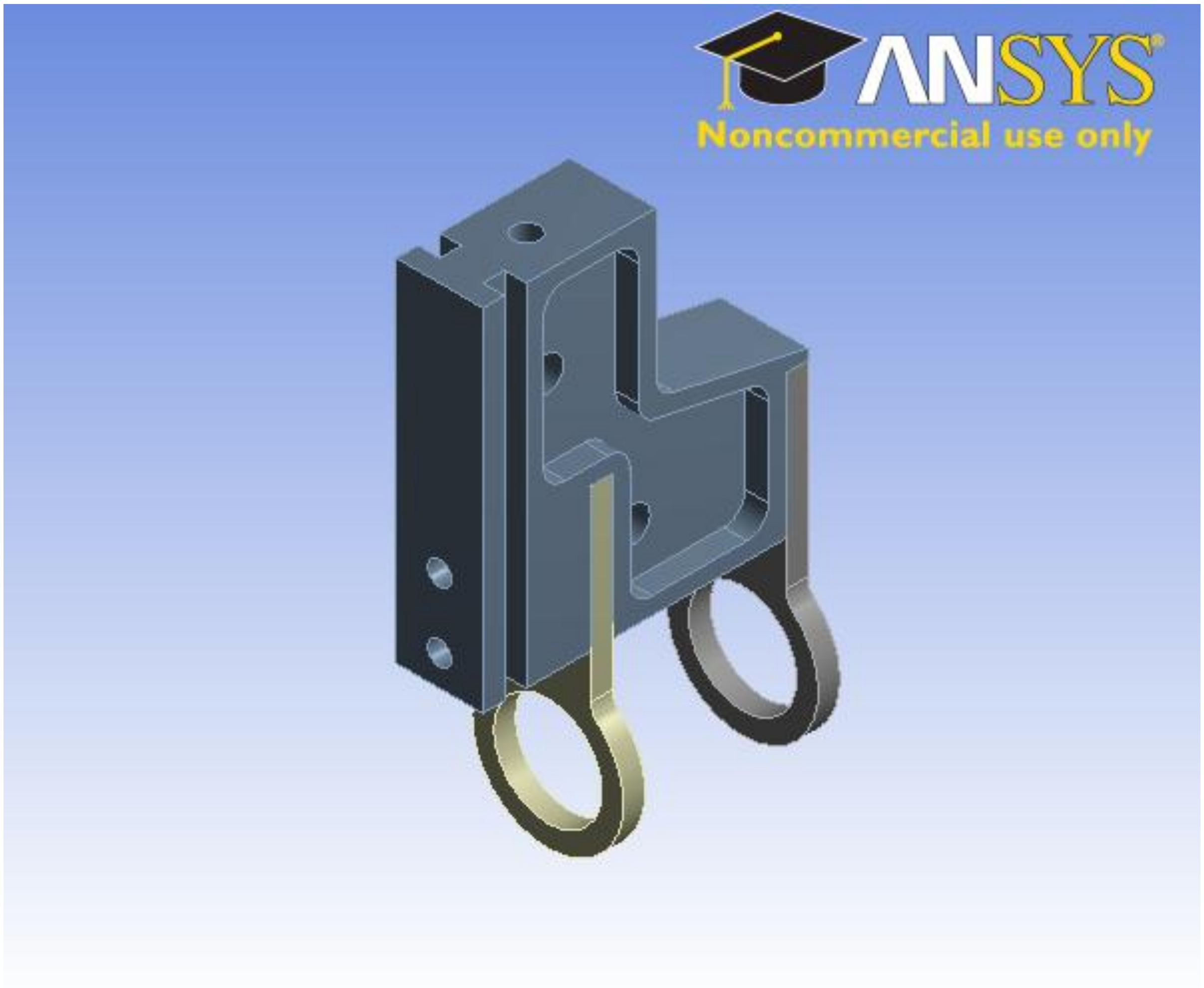
Relative Permeability
1

Spoke 4: Side Load

ANSYS®

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

- **Material Data**
  - Structural Steel
  - Aluminum Alloy

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke4.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	2.2225e-002 m
Length Y	7.9693e-002 m
Length Z	4.7625e-002 m
Properties	
Volume	1.8706e-005 m³
Mass	7.3246e-002 kg
Scale Factor Value	1.
Statistics	
Bodies	5
Active Bodies	5
Nodes	90374
Elements	45792
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No

Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (1.5) Flat*	*8-32 (1.5) Flat*	*Tab no Countersink*	*Tab*	*Generic Spoke4*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				Aluminum Alloy
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					
Length X	1.1757e-002 m		2.2225e-002 m		1.27e-002 m
Length Y	1.1757e-002 m		4.9213e-002 m		5.1435e-002 m
Length Z	3.81e-002 m		3.175e-003 m		4.7625e-002 m
Properties					
Volume	5.3155e-007 m³		1.6184e-006 m³	1.5371e-006 m³	1.4487e-005 m³
Mass	4.1727e-003 kg		1.2704e-002 kg	1.2066e-002 kg	4.013e-002 kg
Centroid X	-1.5774e-003 m		-1.5781e-003 m		
Centroid Y	-2.7239e-003 m	-1.2884e-002 m	-1.9356e-002 m	-1.996e-002 m	5.249e-003 m
Centroid Z	-1.3822e-002 m		-1.0468e-004 m	-2.8634e-002 m	-2.4783e-004 m
Moment of Inertia Ip1	5.7273e-007 kg·m²		2.4659e-006 kg·m²	2.3574e-006 kg·m²	1.514e-005 kg·m²
Moment of Inertia Ip2	5.7277e-007 kg·m²		3.4685e-007 kg·m²	3.4332e-007 kg·m²	5.6041e-006 kg·m²
Moment of Inertia Ip3	1.2054e-008 kg·m²		2.7914e-006 kg·m²	2.6808e-006 kg·m²	1.0374e-005 kg·m²

Statistics				
Nodes	28802	4756	6422	21592
Elements	15896	789	1120	12091
Mesh Metric	None			

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	2.3865e-004 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region*	*Contact Region*	*Contact Region 4*	*Contact Region*

		2	*3*		*5*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	6 Faces	1 Face	26 Faces	6 Faces	1 Face
Target	1 Face		2 Faces	1 Face	
Contact Bodies	8-32 (1.5) Flat				
Target Bodies	Tab no Countersink	Tab	Generic Spoke4	Tab no Countersink	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Contact	26 Faces	3 Faces	2 Faces
Target	2 Faces	3 Faces	2 Faces
Contact Bodies	8-32 (1.5) Flat	Tab no Countersink	Tab
Target Bodies	Generic Spoke4		
Definition			
Type	Bonded		
Scope Mode	Automatic		
Behavior	Symmetric		
Suppressed	No		
Advanced			
Formulation	Pure Penalty		
Normal Stiffness	Program Controlled		
Update Stiffness	Never		
Pinball Region	Program Controlled		

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*

State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.8741e-004 m
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	90374
Elements	45792
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C

Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

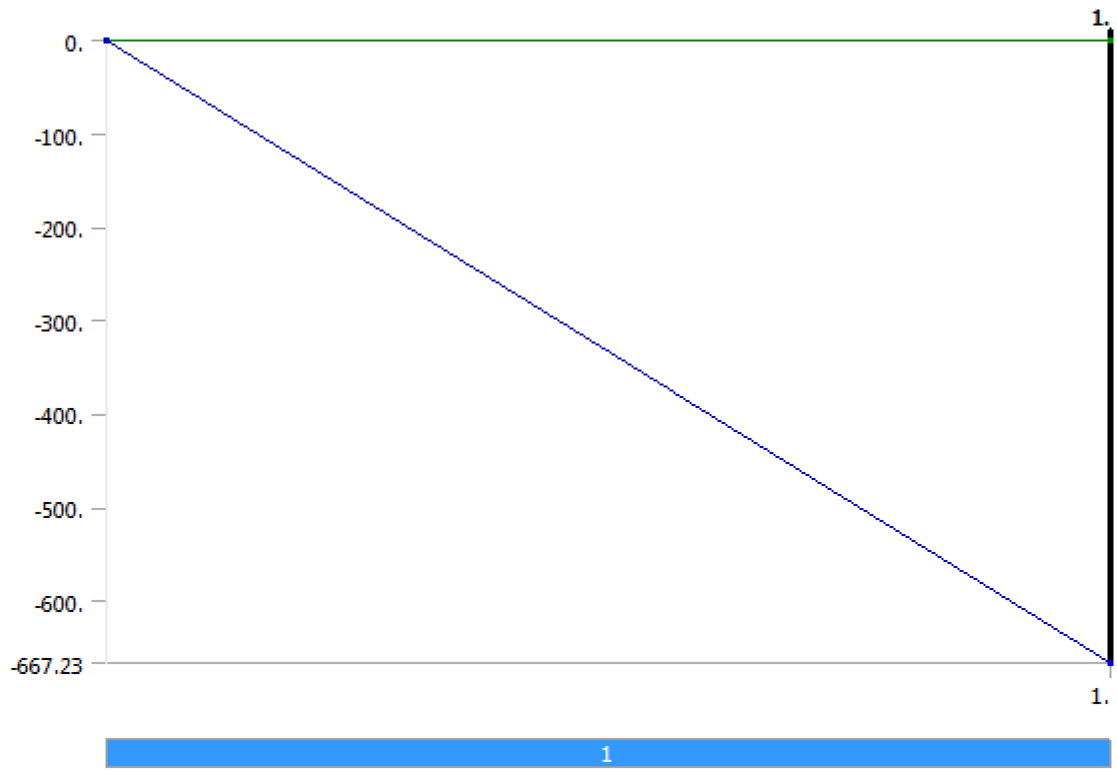
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\jmarrion\Downloads\Ansys\Spoke 4_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System

X Component		0. N (ramped)
Y Component		0. N (ramped)
Z Component		-667.23 N (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Equivalent Stress*	*Total Deformation*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent (von-Mises) Stress	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Integration Point Results		
Display Option	Averaged	
Results		
Minimum	1567.4 Pa	0. m
Maximum	8.2244e+008 Pa	5.8158e-005 m
Minimum Occurs On	8-32 (1.5) Flat	Tab no Countersink
Maximum Occurs On	8-32 (1.5) Flat	Generic Spoke4
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged

Results	
Minimum	0.30397
Minimum Occurs On	8-32 (1.5) Flat
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

Material Data

Structural Steel

TABLE 17
Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

TABLE 18
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 19
Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

TABLE 20
Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

TABLE 21
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
4.6e+008

TABLE 22
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 23
Structural Steel > Alternating Stress Mean Stress

Alternating Stress Pa	Cycles	Mean Stress Pa

3.999e+009	10	0
2.827e+009	20	0
1.896e+009	50	0
1.413e+009	100	0
1.069e+009	200	0
4.41e+008	2000	0
2.62e+008	10000	0
2.14e+008	20000	0
1.38e+008	1.e+005	0
1.14e+008	2.e+005	0
8.62e+007	1.e+006	0

TABLE 24
Structural Steel > Strain-Life Parameters

Strength Coefficient Pa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient Pa	Cyclic Strain Hardening Exponent
9.2e+008	-0.106	0.213	-0.47	1.e+009	0.2

TABLE 25
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.e+011	0.3	1.6667e+011	7.6923e+010

TABLE 26
Structural Steel > Isotropic Relative Permeability

Relative Permeability
10000

Aluminum Alloy

TABLE 27
Aluminum Alloy > Constants

Density	2770 kg m^-3
Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat	875 J kg^-1 C^-1

TABLE 28
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 29
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength Pa
2.8e+008

TABLE 30
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength Pa

2.8e+008

TABLE 31
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
3.1e+008

TABLE 32
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 33
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity W m^-1 C^-1	Temperature C
114	-100
144	0
165	100
175	200

TABLE 34
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress Pa	Cycles	R-Ratio
2.758e+008	1700	-1
2.413e+008	5000	-1
2.068e+008	34000	-1
1.724e+008	1.4e+005	-1
1.379e+008	8.e+005	-1
1.172e+008	2.4e+006	-1
8.963e+007	5.5e+007	-1
8.274e+007	1.e+008	-1
1.706e+008	50000	-0.5
1.396e+008	3.5e+005	-0.5
1.086e+008	3.7e+006	-0.5
8.791e+007	1.4e+007	-0.5
7.757e+007	5.e+007	-0.5
7.239e+007	1.e+008	-0.5
1.448e+008	50000	0
1.207e+008	1.9e+005	0
1.034e+008	1.3e+006	0
9.308e+007	4.4e+006	0
8.618e+007	1.2e+007	0
7.239e+007	1.e+008	0
7.412e+007	3.e+005	0.5
7.067e+007	1.5e+006	0.5
6.636e+007	1.2e+007	0.5
6.205e+007	1.e+008	0.5

TABLE 35
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm m	Temperature C
2.43e-008	0
2.67e-008	20
3.63e-008	100

TABLE 36
Aluminum Alloy > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	7.1e+010	0.33	6.9608e+010	2.6692e+010

TABLE 37
Aluminum Alloy > Isotropic Relative Permeability

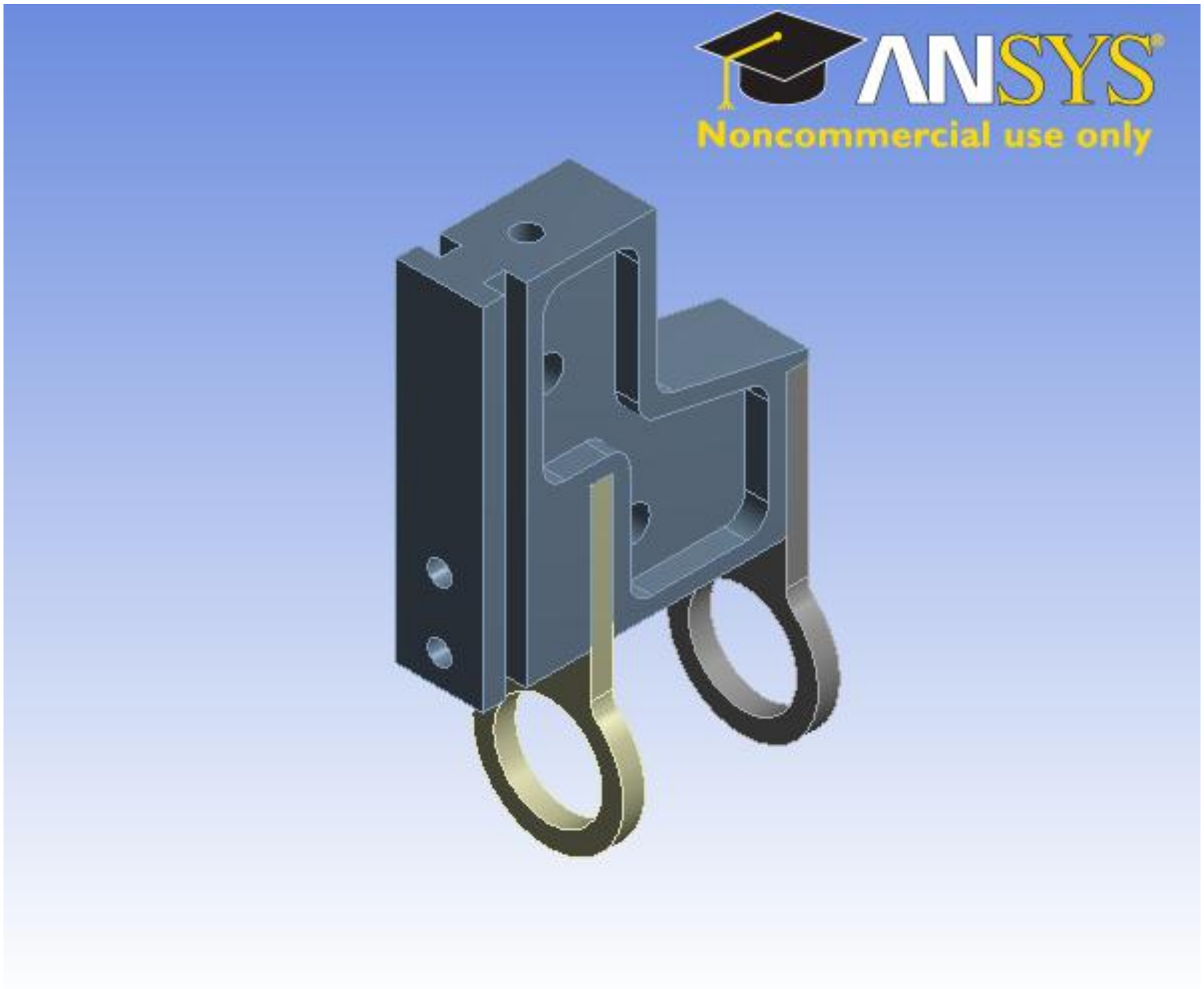
Relative Permeability
1

Spoke 4: Top Load

ANSYS®

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke4.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	2.2225e-002 m
Length Y	7.9693e-002 m
Length Z	4.7625e-002 m
Properties	
Volume	1.8706e-005 m^3
Mass	7.3246e-002 kg
Scale Factor Value	1.
Statistics	
Bodies	5
Active Bodies	5
Nodes	90374
Elements	45792
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No

Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (1.5) Flat*	*8-32 (1.5) Flat*	*Tab no Countersink*	*Tab*	*Generic Spoke4*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				Aluminum Alloy
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					
Length X	1.1757e-002 m		2.2225e-002 m		1.27e-002 m
Length Y	1.1757e-002 m		4.9213e-002 m		5.1435e-002 m
Length Z	3.81e-002 m		3.175e-003 m		4.7625e-002 m
Properties					
Volume	5.3155e-007 m^3		1.6184e-006 m^3	1.5371e-006 m^3	1.4487e-005 m^3
Mass	4.1727e-003 kg		1.2704e-002 kg	1.2066e-002 kg	4.013e-002 kg
Centroid X	-1.5774e-003 m		-1.5781e-003 m		
Centroid Y	-2.7239e-003 m	-1.2884e-002 m	-1.9356e-002 m	-1.996e-002 m	5.249e-003 m
Centroid Z	-1.3822e-002 m		-1.0468e-004 m	-2.8634e-002 m	-2.4783e-004 m
Moment of Inertia Ip1	5.7273e-007 kg·m^2		2.4659e-006 kg·m^2	2.3574e-006 kg·m^2	1.514e-005 kg·m^2
Moment of Inertia Ip2	5.7277e-007 kg·m^2		3.4685e-007 kg·m^2	3.4332e-007 kg·m^2	5.6041e-006 kg·m^2
Moment of Inertia Ip3	1.2054e-008 kg·m^2		2.7914e-006 kg·m^2	2.6808e-006 kg·m^2	1.0374e-005 kg·m^2

Statistics				
Nodes	28802	4756	6422	21592
Elements	15896	789	1120	12091
Mesh Metric	None			

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	2.3865e-004 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region*	*Contact Region*	*Contact Region 4*	*Contact Region*

		2	*3*		*5*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	6 Faces	1 Face	26 Faces	6 Faces	1 Face
Target	1 Face		2 Faces	1 Face	
Contact Bodies	8-32 (1.5) Flat				
Target Bodies	Tab no Countersink	Tab	Generic Spoke4	Tab no Countersink	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Contact	26 Faces	3 Faces	2 Faces
Target	2 Faces	3 Faces	2 Faces
Contact Bodies	8-32 (1.5) Flat	Tab no Countersink	Tab
Target Bodies	Generic Spoke4		
Definition			
Type	Bonded		
Scope Mode	Automatic		
Behavior	Symmetric		
Suppressed	No		
Advanced			
Formulation	Pure Penalty		
Normal Stiffness	Program Controlled		
Update Stiffness	Never		
Pinball Region	Program Controlled		

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*

State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.8741e-004 m
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	90374
Elements	45792
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C

Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

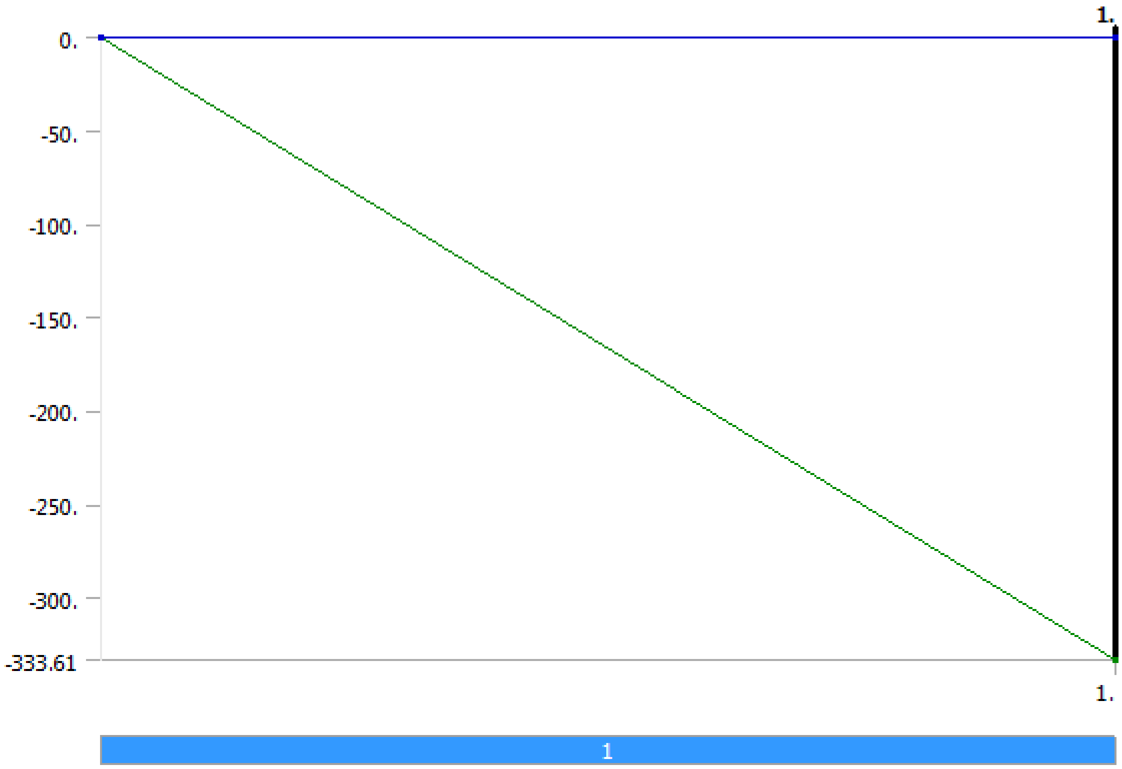
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\jmarrion\Downloads\Ansys\Spoke 4_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System

X Component		0. N (ramped)
Y Component		-333.61 N (ramped)
Z Component		0. N (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Equivalent Stress*	*Total Deformation*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent (von-Mises) Stress	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Integration Point Results		
Display Option	Averaged	
Results		
Minimum	100.92 Pa	0. m
Maximum	6.6557e+007 Pa	4.2392e-006 m
Minimum Occurs On	Tab	Tab no Countersink
Maximum Occurs On	8-32 (1.5) Flat	Generic Spoke4
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged

Results	
Minimum	3.7562
Minimum Occurs On	8-32 (1.5) Flat
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

Material Data

Structural Steel

TABLE 17
Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

TABLE 18
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 19
Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

TABLE 20
Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

TABLE 21
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
4.6e+008

TABLE 22
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 23
Structural Steel > Alternating Stress Mean Stress

Alternating Stress Pa	Cycles	Mean Stress Pa

3.999e+009	10	0
2.827e+009	20	0
1.896e+009	50	0
1.413e+009	100	0
1.069e+009	200	0
4.41e+008	2000	0
2.62e+008	10000	0
2.14e+008	20000	0
1.38e+008	1.e+005	0
1.14e+008	2.e+005	0
8.62e+007	1.e+006	0

TABLE 24
Structural Steel > Strain-Life Parameters

Strength Coefficient Pa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient Pa	Cyclic Strain Hardening Exponent
9.2e+008	-0.106	0.213	-0.47	1.e+009	0.2

TABLE 25
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.e+011	0.3	1.6667e+011	7.6923e+010

TABLE 26
Structural Steel > Isotropic Relative Permeability

Relative Permeability
10000

Aluminum Alloy

TABLE 27
Aluminum Alloy > Constants

Density	2770 kg m^-3
Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat	875 J kg^-1 C^-1

TABLE 28
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 29
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength Pa
2.8e+008

TABLE 30
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength Pa

2.8e+008

TABLE 31
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
3.1e+008

TABLE 32
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 33
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity W m^-1 C^-1	Temperature C
114	-100
144	0
165	100
175	200

TABLE 34
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress Pa	Cycles	R-Ratio
2.758e+008	1700	-1
2.413e+008	5000	-1
2.068e+008	34000	-1
1.724e+008	1.4e+005	-1
1.379e+008	8.e+005	-1
1.172e+008	2.4e+006	-1
8.963e+007	5.5e+007	-1
8.274e+007	1.e+008	-1
1.706e+008	50000	-0.5
1.396e+008	3.5e+005	-0.5
1.086e+008	3.7e+006	-0.5
8.791e+007	1.4e+007	-0.5
7.757e+007	5.e+007	-0.5
7.239e+007	1.e+008	-0.5
1.448e+008	50000	0
1.207e+008	1.9e+005	0
1.034e+008	1.3e+006	0
9.308e+007	4.4e+006	0
8.618e+007	1.2e+007	0
7.239e+007	1.e+008	0
7.412e+007	3.e+005	0.5
7.067e+007	1.5e+006	0.5
6.636e+007	1.2e+007	0.5
6.205e+007	1.e+008	0.5

TABLE 35
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm m	Temperature C
2.43e-008	0
2.67e-008	20
3.63e-008	100

TABLE 36
Aluminum Alloy > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	7.1e+010	0.33	6.9608e+010	2.6692e+010

TABLE 37
Aluminum Alloy > Isotropic Relative Permeability

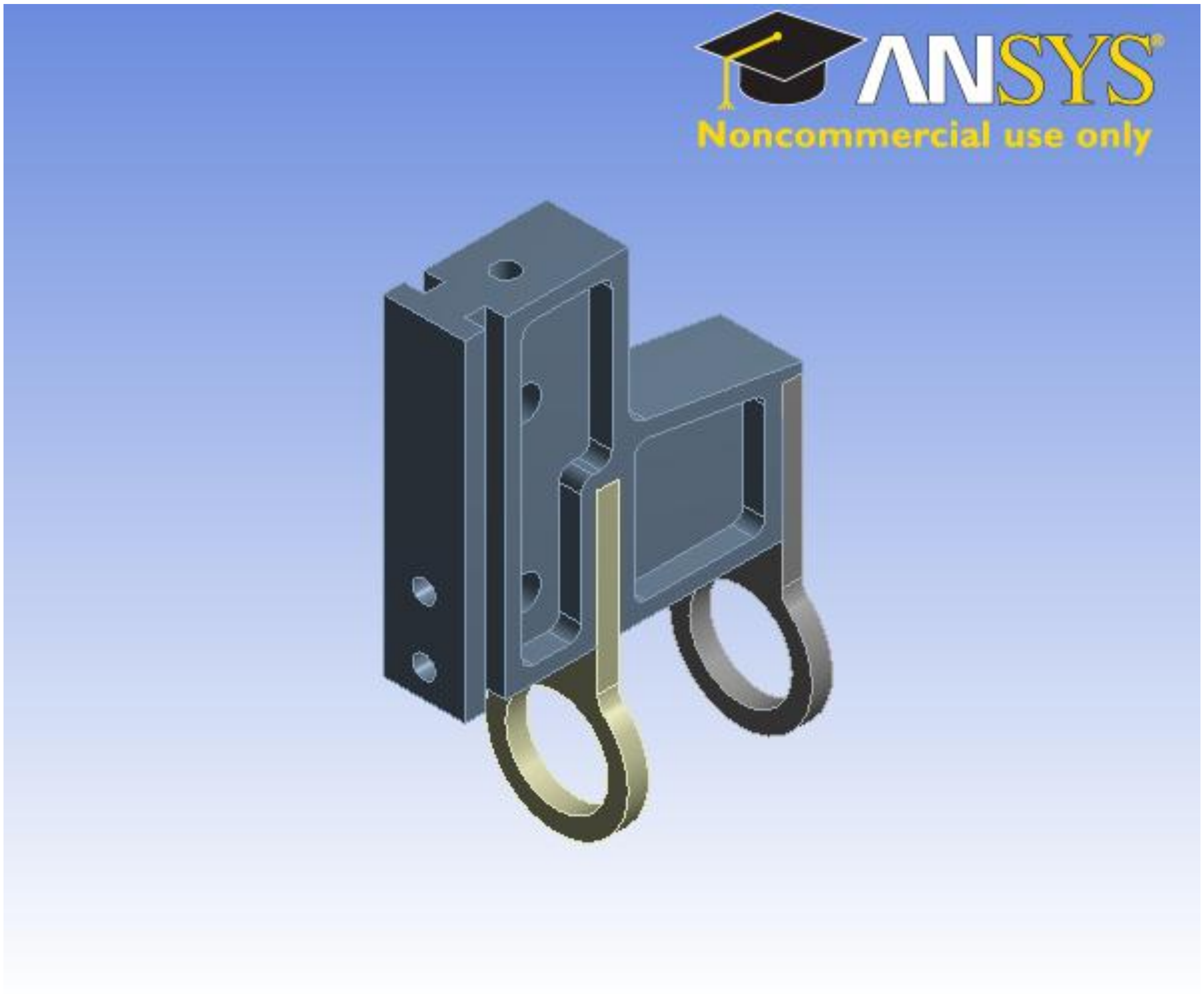
Relative Permeability
1

Spoke 5: Side Load

ANSYS®

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke5.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	2.2225e-002 m
Length Y	7.9693e-002 m
Length Z	5.2388e-002 m
Properties	
Volume	1.8846e-005 m^3
Mass	0.14794 kg
Scale Factor Value	1.
Statistics	
Bodies	5
Active Bodies	5
Nodes	86826
Elements	43744
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No

Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (1.5) Flat*	*8-32 (1.5) Flat*	*Tab no Countersink*	*Tab*	*Generic Spoke5*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					
Length X	1.1757e-002 m		2.2225e-002 m		1.27e-002 m
Length Y	1.1757e-002 m		4.9213e-002 m		5.1435e-002 m
Length Z	3.81e-002 m		3.175e-003 m		5.2387e-002 m
Properties					
Volume	5.3155e-007 m³		1.6184e-006 m³	1.5371e-006 m³	1.4627e-005 m³
Mass	4.1727e-003 kg		1.2704e-002 kg	1.2066e-002 kg	0.11482 kg
Centroid X	1.809e-002 m		1.8089e-002 m		
Centroid Y	-2.0963e-002 m	-3.1123e-002 m	-3.7594e-002 m	-3.8199e-002 m	-1.3101e-002 m
Centroid Z	-1.4507e-002 m		-7.9059e-004 m	-2.932e-002 m	1.6663e-003 m
Moment of Inertia Ip1	5.7273e-007 kg·m²		2.4659e-006 kg·m²	2.3574e-006 kg·m²	4.8288e-005 kg·m²
Moment of Inertia Ip2	5.7277e-007 kg·m²		3.4685e-007 kg·m²	3.4332e-007 kg·m²	1.7062e-005 kg·m²
Moment of Inertia Ip3	1.2054e-008 kg·m²		2.7914e-006 kg·m²	2.6808e-006 kg·m²	3.3467e-005 kg·m²

Statistics				
Nodes	27620	4434	6323	20829
Elements	15152	729	1108	11603
Mesh Metric	None			

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	2.4481e-004 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region*	*Contact Region*	*Contact Region 4*	*Contact Region*

		2	*3*		*5*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	6 Faces	1 Face	26 Faces	6 Faces	1 Face
Target	1 Face		2 Faces	1 Face	
Contact Bodies	8-32 (1.5) Flat				
Target Bodies	Tab no Countersink	Tab	Generic Spoke5	Tab no Countersink	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Contact	26 Faces	3 Faces	2 Faces
Target	2 Faces	3 Faces	2 Faces
Contact Bodies	8-32 (1.5) Flat	Tab no Countersink	Tab
Target Bodies	Generic Spoke5		
Definition			
Type	Bonded		
Scope Mode	Automatic		
Behavior	Symmetric		
Suppressed	No		
Advanced			
Formulation	Pure Penalty		
Normal Stiffness	Program Controlled		
Update Stiffness	Never		
Pinball Region	Program Controlled		

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*

State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.8741e-004 m
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	86826
Elements	43744
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C

Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

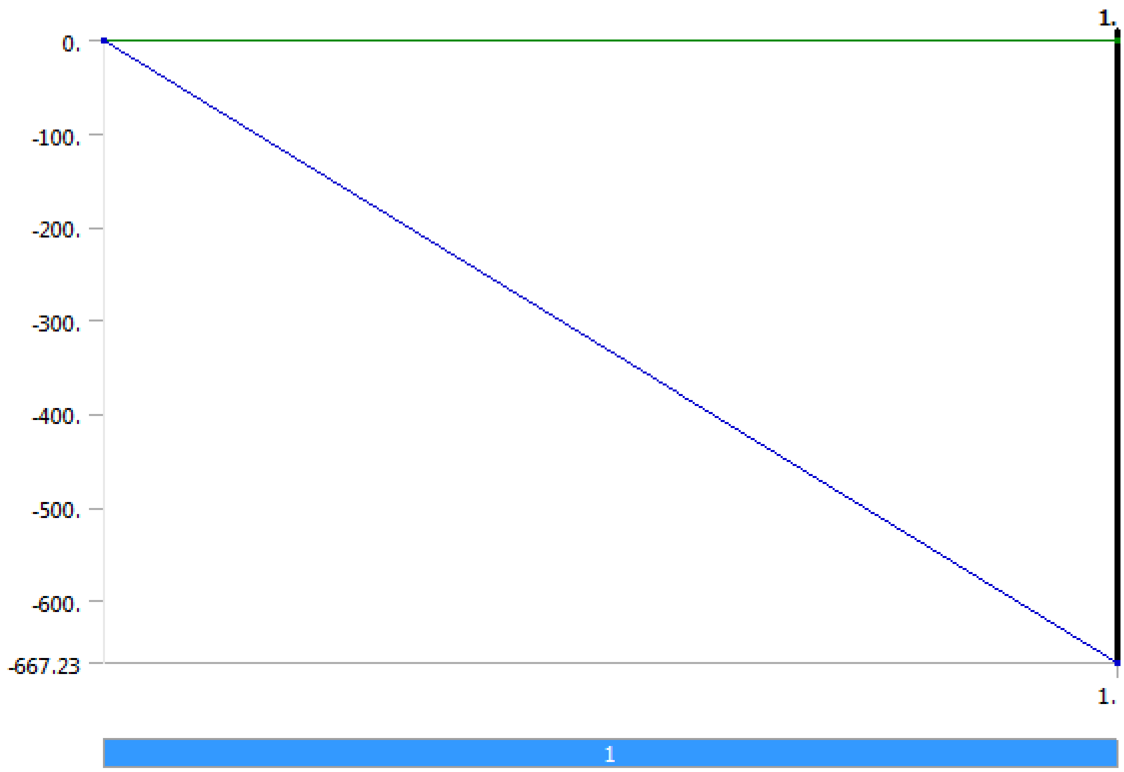
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\jmarrion\Downloads\Ansys\Spoke 5_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System

X Component		0. N (ramped)
Y Component		0. N (ramped)
Z Component		-667.23 N (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Equivalent Stress*	*Total Deformation*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent (von-Mises) Stress	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Integration Point Results		
Display Option	Averaged	
Results		
Minimum	5130.5 Pa	0. m
Maximum	3.4821e+008 Pa	3.5077e-005 m
Minimum Occurs On	8-32 (1.5) Flat	Tab no Countersink
Maximum Occurs On	8-32 (1.5) Flat	Generic Spoke5
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged

Results	
Minimum	0.71795
Minimum Occurs On	8-32 (1.5) Flat
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

Material Data

Structural Steel

TABLE 17
Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

TABLE 18
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 19
Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

TABLE 20
Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

TABLE 21
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
4.6e+008

TABLE 22
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 23
Structural Steel > Alternating Stress Mean Stress

Alternating Stress Pa	Cycles	Mean Stress Pa

3.999e+009	10	0
2.827e+009	20	0
1.896e+009	50	0
1.413e+009	100	0
1.069e+009	200	0
4.41e+008	2000	0
2.62e+008	10000	0
2.14e+008	20000	0
1.38e+008	1.e+005	0
1.14e+008	2.e+005	0
8.62e+007	1.e+006	0

TABLE 24
Structural Steel > Strain-Life Parameters

Strength Coefficient Pa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient Pa	Cyclic Strain Hardening Exponent
9.2e+008	-0.106	0.213	-0.47	1.e+009	0.2

TABLE 25
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.e+011	0.3	1.6667e+011	7.6923e+010

TABLE 26
Structural Steel > Isotropic Relative Permeability

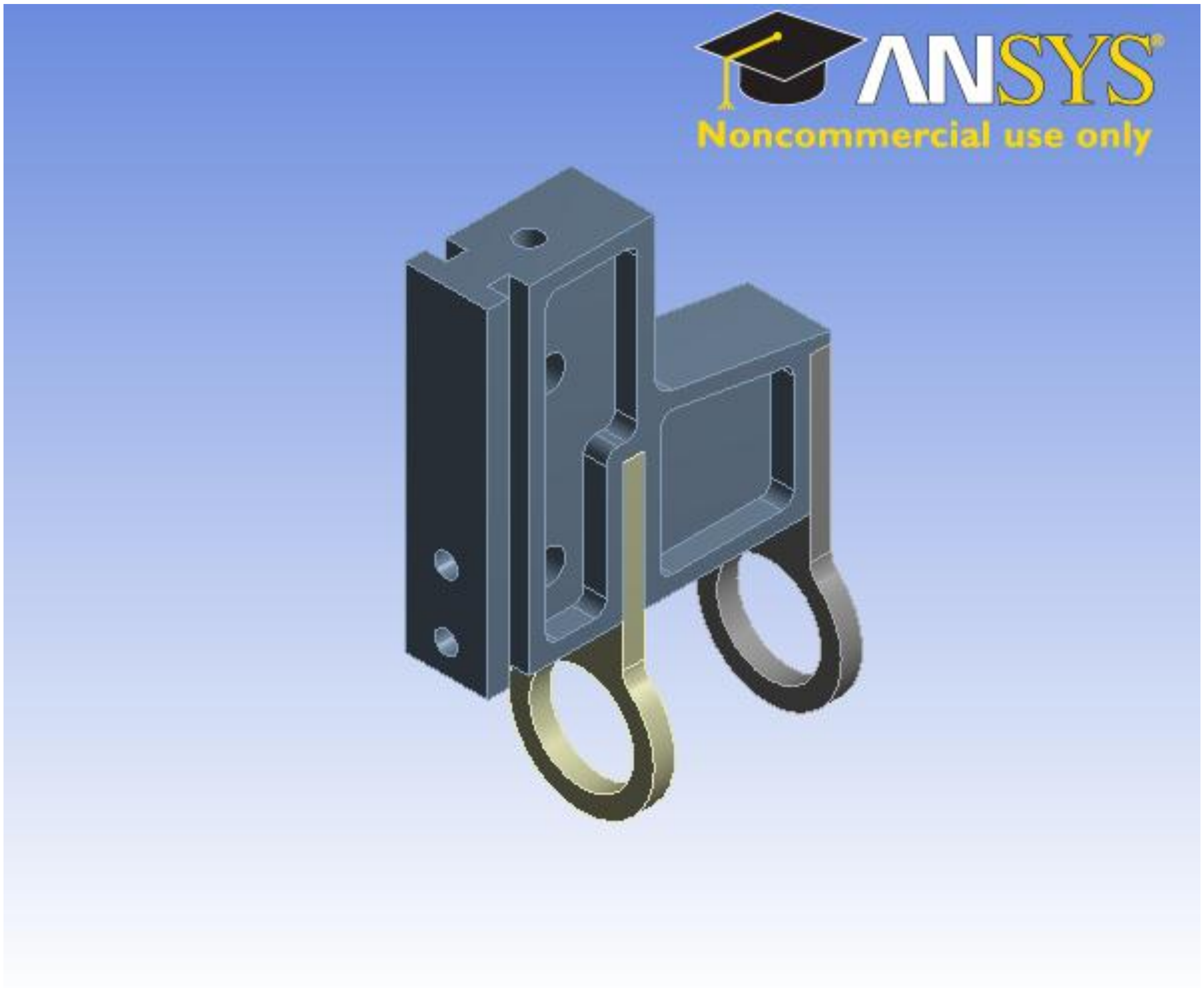
Relative Permeability
10000

Spoke 5: Top Load

ANSYS®

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

- **Material Data**
    - Structural Steel

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke5.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	2.2225e-002 m
Length Y	7.9693e-002 m
Length Z	5.2388e-002 m
Properties	
Volume	1.8846e-005 m³
Mass	0.14794 kg
Scale Factor Value	1.
Statistics	
Bodies	5
Active Bodies	5
Nodes	86826
Elements	43744
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No

Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (1.5) Flat*	*8-32 (1.5) Flat*	*Tab no Countersink*	*Tab*	*Generic Spoke5*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					
Length X	1.1757e-002 m		2.2225e-002 m		1.27e-002 m
Length Y	1.1757e-002 m		4.9213e-002 m		5.1435e-002 m
Length Z	3.81e-002 m		3.175e-003 m		5.2387e-002 m
Properties					
Volume	5.3155e-007 m³		1.6184e-006 m³	1.5371e-006 m³	1.4627e-005 m³
Mass	4.1727e-003 kg		1.2704e-002 kg	1.2066e-002 kg	0.11482 kg
Centroid X	1.809e-002 m		1.8089e-002 m		
Centroid Y	-2.0963e-002 m	-3.1123e-002 m	-3.7594e-002 m	-3.8199e-002 m	-1.3101e-002 m
Centroid Z	-1.4507e-002 m		-7.9059e-004 m	-2.932e-002 m	1.6663e-003 m
Moment of Inertia Ip1	5.7273e-007 kg·m²		2.4659e-006 kg·m²	2.3574e-006 kg·m²	4.8288e-005 kg·m²
Moment of Inertia Ip2	5.7277e-007 kg·m²		3.4685e-007 kg·m²	3.4332e-007 kg·m²	1.7062e-005 kg·m²
Moment of Inertia Ip3	1.2054e-008 kg·m²		2.7914e-006 kg·m²	2.6808e-006 kg·m²	3.3467e-005 kg·m²

Statistics				
Nodes	27620	4434	6323	20829
Elements	15152	729	1108	11603
Mesh Metric	None			

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	2.4481e-004 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region*	*Contact Region*	*Contact Region 4*	*Contact Region*

		2	3		5
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	6 Faces	1 Face	26 Faces	6 Faces	1 Face
Target	1 Face		2 Faces	1 Face	
Contact Bodies	8-32 (1.5) Flat				
Target Bodies	Tab no Countersink	Tab	Generic Spoke5	Tab no Countersink	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Contact	26 Faces	3 Faces	2 Faces
Target	2 Faces	3 Faces	2 Faces
Contact Bodies	8-32 (1.5) Flat	Tab no Countersink	Tab
Target Bodies	Generic Spoke5		
Definition			
Type	Bonded		
Scope Mode	Automatic		
Behavior	Symmetric		
Suppressed	No		
Advanced			
Formulation	Pure Penalty		
Normal Stiffness	Program Controlled		
Update Stiffness	Never		
Pinball Region	Program Controlled		

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*

State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.8741e-004 m
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	86826
Elements	43744
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C

Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

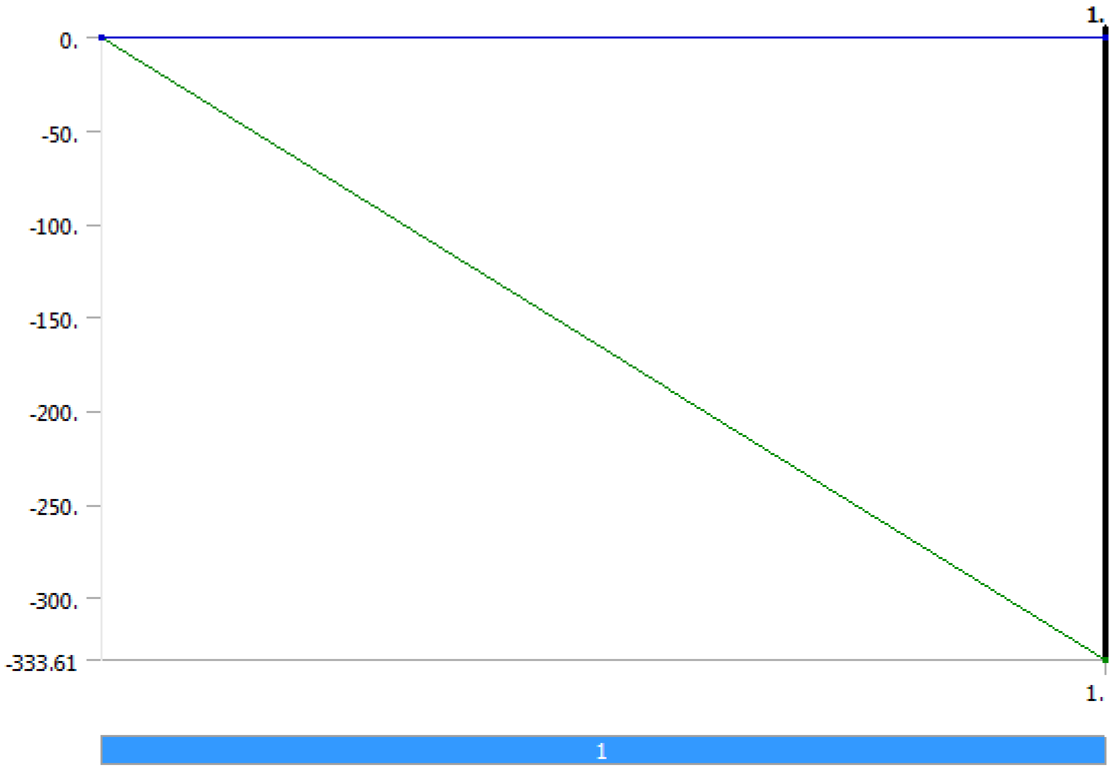
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\jmarrion\Downloads\Ansys\Spoke 5_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System

X Component		0. N (ramped)
Y Component		-333.61 N (ramped)
Z Component		0. N (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Equivalent Stress*	*Total Deformation*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent (von-Mises) Stress	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Integration Point Results		
Display Option	Averaged	
Results		
Minimum	693.75 Pa	0. m
Maximum	6.1889e+007 Pa	4.2427e-006 m
Minimum Occurs On	Tab	Tab no Countersink
Maximum Occurs On	8-32 (1.5) Flat	Generic Spoke5
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged

Results	
Minimum	4.0395
Minimum Occurs On	8-32 (1.5) Flat
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

Material Data

Structural Steel

TABLE 17
Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

TABLE 18
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 19
Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

TABLE 20
Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

TABLE 21
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
4.6e+008

TABLE 22
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 23
Structural Steel > Alternating Stress Mean Stress

Alternating Stress Pa	Cycles	Mean Stress Pa

3.999e+009	10	0
2.827e+009	20	0
1.896e+009	50	0
1.413e+009	100	0
1.069e+009	200	0
4.41e+008	2000	0
2.62e+008	10000	0
2.14e+008	20000	0
1.38e+008	1.e+005	0
1.14e+008	2.e+005	0
8.62e+007	1.e+006	0

TABLE 24
Structural Steel > Strain-Life Parameters

Strength Coefficient Pa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient Pa	Cyclic Strain Hardening Exponent
9.2e+008	-0.106	0.213	-0.47	1.e+009	0.2

TABLE 25
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.e+011	0.3	1.6667e+011	7.6923e+010

TABLE 26
Structural Steel > Isotropic Relative Permeability

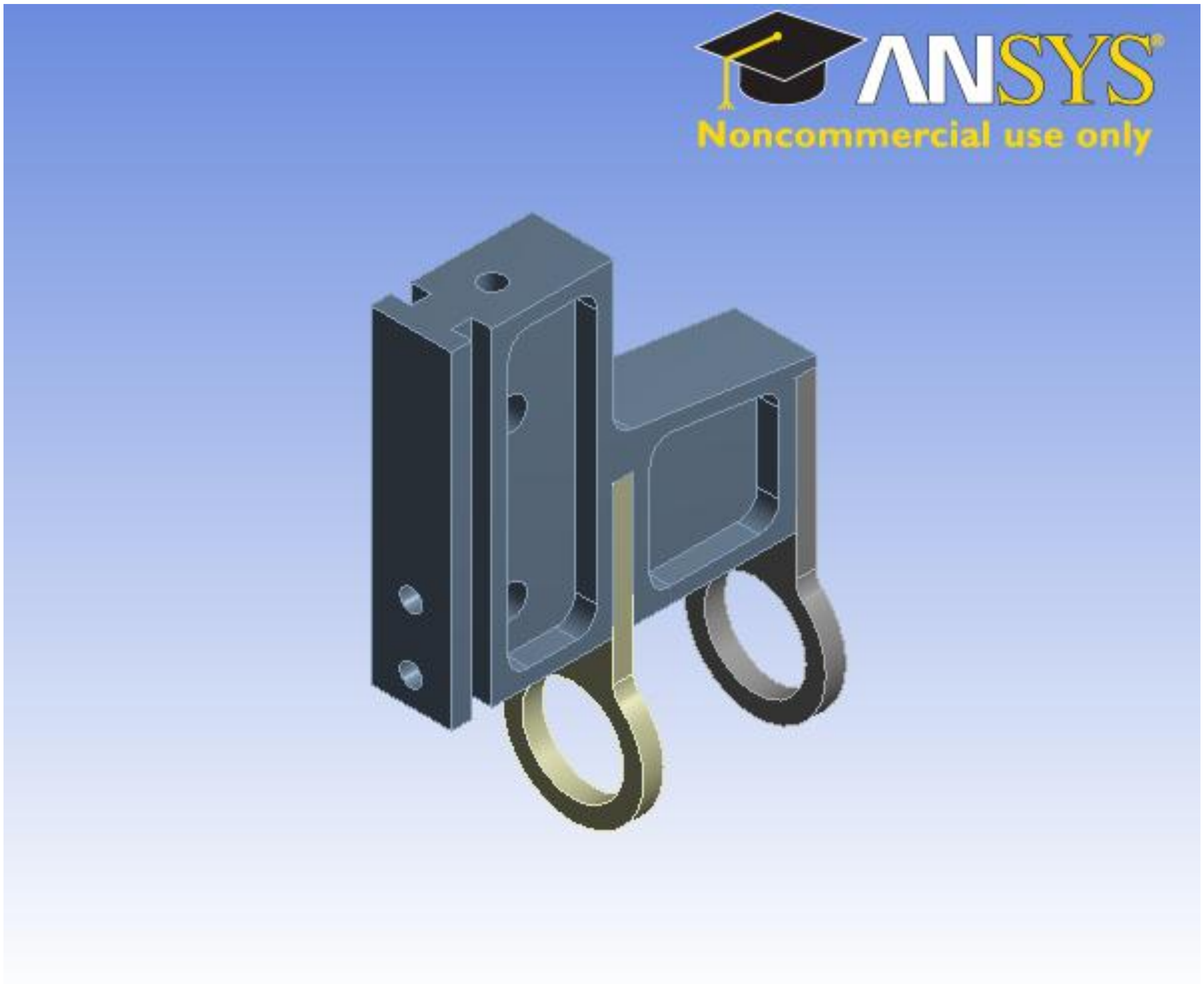
Relative Permeability
10000

Spoke 6: Side Load

ANSYS®

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

- **Material Data**
  - Structural Steel

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke6.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	2.2225e-002 m
Length Y	7.9693e-002 m
Length Z	5.715e-002 m
Properties	
Volume	1.972e-005 m³
Mass	0.1548 kg
Scale Factor Value	1.
Statistics	
Bodies	5
Active Bodies	5
Nodes	82052
Elements	40861
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No

Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (1.5) Flat*	*8-32 (1.5) Flat*	*Tab no Countersink*	*Tab*	*Generic Spoke6*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					
Length X	1.1757e-002 m		2.2225e-002 m		1.27e-002 m
Length Y	1.1757e-002 m		4.9213e-002 m		5.1435e-002 m
Length Z	3.81e-002 m		3.175e-003 m		5.715e-002 m
Properties					
Volume	5.3155e-007 m³		1.6184e-006 m³	1.5371e-006 m³	1.5502e-005 m³
Mass	4.1727e-003 kg		1.2704e-002 kg	1.2066e-002 kg	0.12169 kg
Centroid X	5.8215e-002 m		5.8214e-002 m		
Centroid Y	-1.999e-002 m	-3.015e-002 m	-3.6622e-002 m	-3.7226e-002 m	-1.2622e-002 m
Centroid Z	-3.904e-002 m		-2.5323e-002 m	-5.3853e-002 m	-1.9958e-002 m
Moment of Inertia Ip1	5.7273e-007 kg·m²		2.4659e-006 kg·m²	2.3574e-006 kg·m²	5.6276e-005 kg·m²
Moment of Inertia Ip2	5.7277e-007 kg·m²		3.4685e-007 kg·m²	3.4332e-007 kg·m²	3.9685e-005 kg·m²
Moment of Inertia Ip3	1.2054e-008 kg·m²		2.7914e-006 kg·m²	2.6808e-006 kg·m²	1.8958e-005 kg·m²

Statistics				
Nodes	25516	4277	5901	20842
Elements	13786	702	1028	11559
Mesh Metric	None			

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	2.5138e-004 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region*	*Contact Region*	*Contact Region 4*	*Contact Region*

		2	*3*		*5*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	6 Faces	1 Face	26 Faces	6 Faces	1 Face
Target	1 Face		2 Faces	1 Face	
Contact Bodies	8-32 (1.5) Flat				
Target Bodies	Tab no Countersink	Tab	Generic Spoke6	Tab no Countersink	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Contact	26 Faces	3 Faces	2 Faces
Target	2 Faces	3 Faces	2 Faces
Contact Bodies	8-32 (1.5) Flat	Tab no Countersink	Tab
Target Bodies	Generic Spoke6		
Definition			
Type	Bonded		
Scope Mode	Automatic		
Behavior	Symmetric		
Suppressed	No		
Advanced			
Formulation	Pure Penalty		
Normal Stiffness	Program Controlled		
Update Stiffness	Never		
Pinball Region	Program Controlled		

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*

State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.8741e-004 m
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	82052
Elements	40861
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C

Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

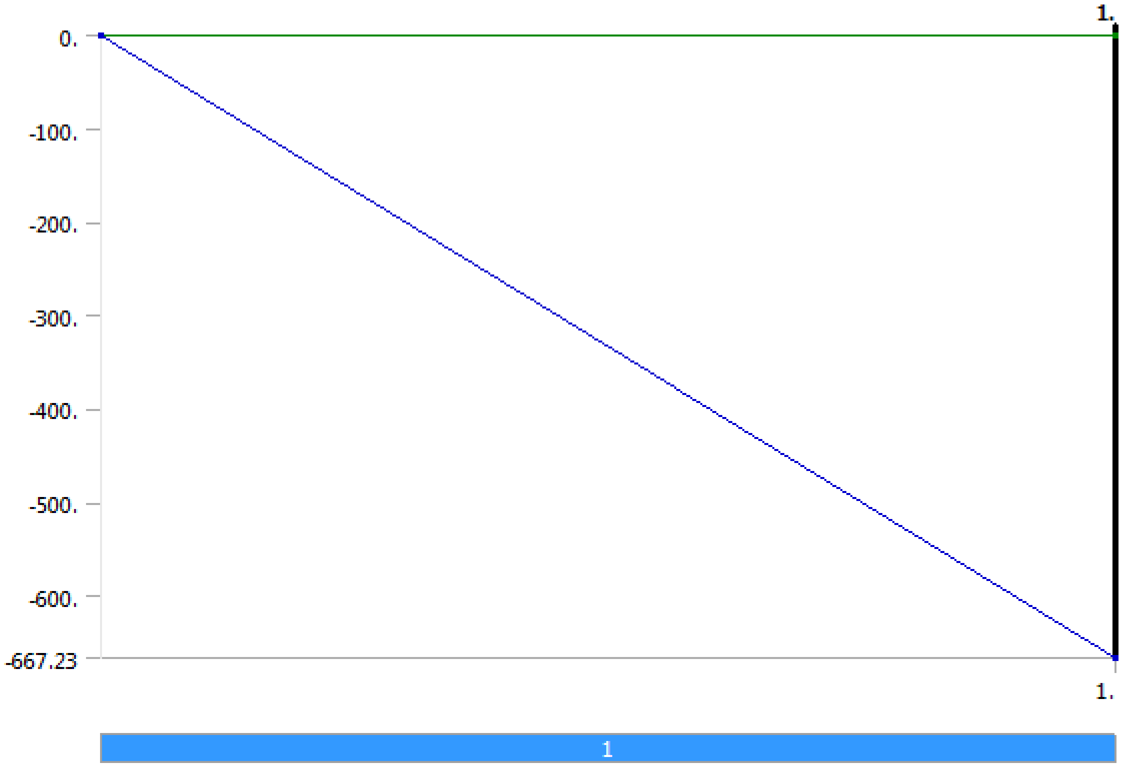
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\jmarrion\Downloads\Ansys\Spoke 6_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System

X Component		0. N (ramped)
Y Component		0. N (ramped)
Z Component		-667.23 N (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Equivalent Stress*	*Total Deformation*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent (von-Mises) Stress	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Integration Point Results		
Display Option	Averaged	
Results		
Minimum	1849.4 Pa	0. m
Maximum	2.2658e+008 Pa	3.8737e-005 m
Minimum Occurs On	Tab	Tab no Countersink
Maximum Occurs On	8-32 (1.5) Flat	Generic Spoke6
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged

Results	
Minimum	1.1034
Minimum Occurs On	8-32 (1.5) Flat
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

Material Data

Structural Steel

TABLE 17
Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

TABLE 18
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 19
Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

TABLE 20
Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

TABLE 21
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
4.6e+008

TABLE 22
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 23
Structural Steel > Alternating Stress Mean Stress

Alternating Stress Pa	Cycles	Mean Stress Pa

3.999e+009	10	0
2.827e+009	20	0
1.896e+009	50	0
1.413e+009	100	0
1.069e+009	200	0
4.41e+008	2000	0
2.62e+008	10000	0
2.14e+008	20000	0
1.38e+008	1.e+005	0
1.14e+008	2.e+005	0
8.62e+007	1.e+006	0

TABLE 24
Structural Steel > Strain-Life Parameters

Strength Coefficient Pa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient Pa	Cyclic Strain Hardening Exponent
9.2e+008	-0.106	0.213	-0.47	1.e+009	0.2

TABLE 25
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.e+011	0.3	1.6667e+011	7.6923e+010

TABLE 26
Structural Steel > Isotropic Relative Permeability

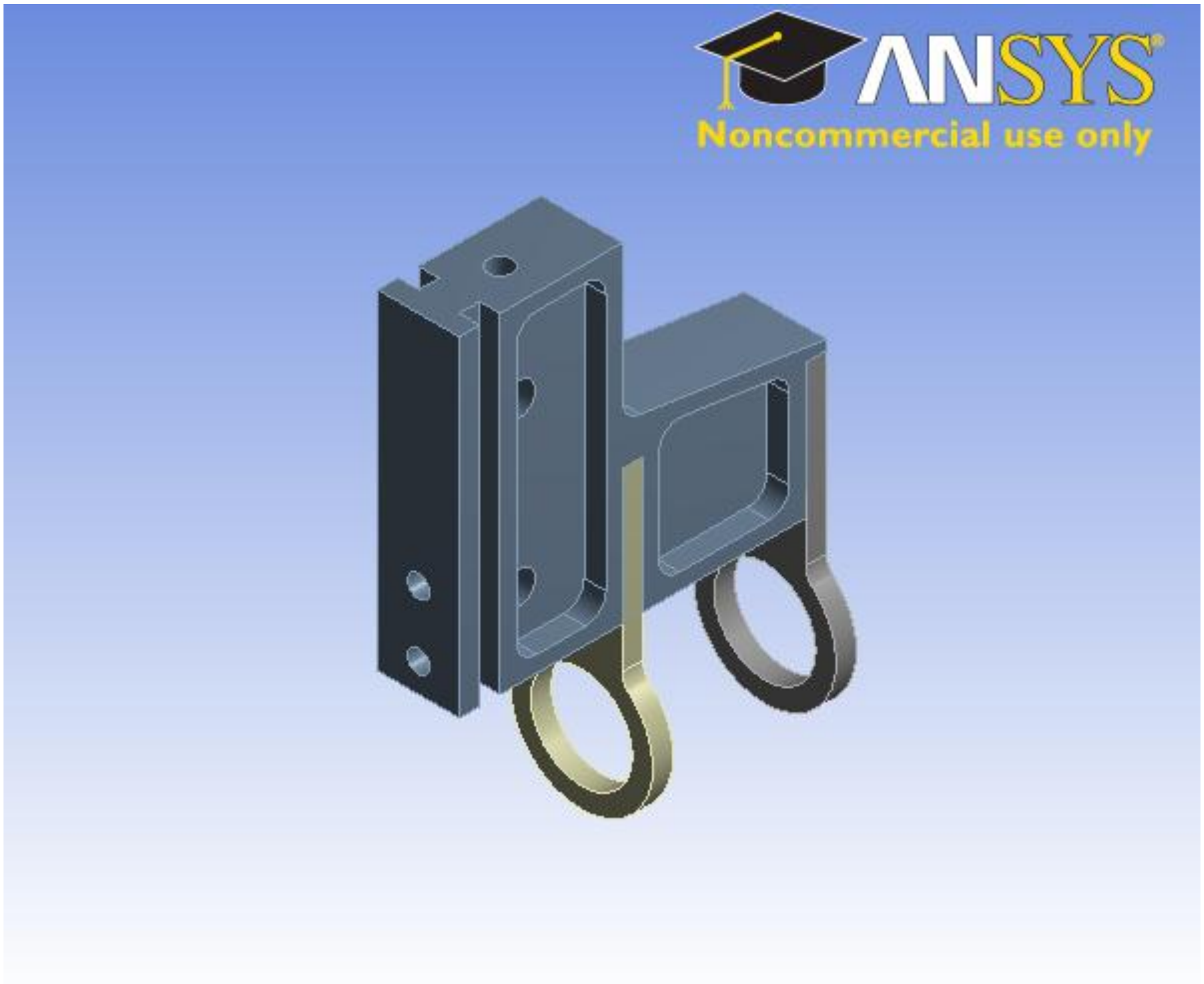
Relative Permeability
10000

Spoke 6: Top Load

ANSYS®

Project

First Saved	Wednesday, April 06, 2011
Last Saved	Wednesday, April 06, 2011
Product Version	12.1 Release



Contents

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\jmarrion\Downloads\CAD_Models\CAD Models\Parasolids\Generic Spoke6.x_t
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	2.2225e-002 m
Length Y	7.9693e-002 m
Length Z	5.715e-002 m
Properties	
Volume	1.972e-005 m^3
Mass	0.1548 kg
Scale Factor Value	1.
Statistics	
Bodies	5
Active Bodies	5
Nodes	82052
Elements	40861
Mesh Metric	None
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No

Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\jmarrion\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*8-32 (1.5) Flat*	*8-32 (1.5) Flat*	*Tab no Countersink*	*Tab*	*Generic Spoke6*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Stiffness Behavior	Flexible				
Coordinate System	Default Coordinate System				
Reference Temperature	By Environment				
Material					
Assignment	Structural Steel				
Nonlinear Effects	Yes				
Thermal Strain Effects	Yes				
Bounding Box					
Length X	1.1757e-002 m		2.2225e-002 m		1.27e-002 m
Length Y	1.1757e-002 m		4.9213e-002 m		5.1435e-002 m
Length Z	3.81e-002 m		3.175e-003 m		5.715e-002 m
Properties					
Volume	5.3155e-007 m³		1.6184e-006 m³	1.5371e-006 m³	1.5502e-005 m³
Mass	4.1727e-003 kg		1.2704e-002 kg	1.2066e-002 kg	0.12169 kg
Centroid X	5.8215e-002 m		5.8214e-002 m		
Centroid Y	-1.999e-002 m	-3.015e-002 m	-3.6622e-002 m	-3.7226e-002 m	-1.2622e-002 m
Centroid Z	-3.904e-002 m		-2.5323e-002 m	-5.3853e-002 m	-1.9958e-002 m
Moment of Inertia Ip1	5.7273e-007 kg·m²		2.4659e-006 kg·m²	2.3574e-006 kg·m²	5.6276e-005 kg·m²
Moment of Inertia Ip2	5.7277e-007 kg·m²		3.4685e-007 kg·m²	3.4332e-007 kg·m²	3.9685e-005 kg·m²
Moment of Inertia Ip3	1.2054e-008 kg·m²		2.7914e-006 kg·m²	2.6808e-006 kg·m²	1.8958e-005 kg·m²

Statistics				
Nodes	25516	4277	5901	20842
Elements	13786	702	1028	11559
Mesh Metric	None			

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Ansys System Number	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	2.5138e-004 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Revolute Joints	Yes
Fixed Joints	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region*	*Contact Region*	*Contact Region*	*Contact Region 4*	*Contact Region*

		2	*3*		*5*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	6 Faces	1 Face	26 Faces	6 Faces	1 Face
Target	1 Face		2 Faces	1 Face	
Contact Bodies	8-32 (1.5) Flat				
Target Bodies	Tab no Countersink	Tab	Generic Spoke6	Tab no Countersink	Tab
Definition					
Type	Bonded				
Scope Mode	Automatic				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Pinball Region	Program Controlled				

TABLE 7
Model (A4) > Connections > Contact Regions

Object Name	*Contact Region 6*	*Contact Region 7*	*Contact Region 8*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Contact	26 Faces	3 Faces	2 Faces
Target	2 Faces	3 Faces	2 Faces
Contact Bodies	8-32 (1.5) Flat	Tab no Countersink	Tab
Target Bodies	Generic Spoke6		
Definition			
Type	Bonded		
Scope Mode	Automatic		
Behavior	Symmetric		
Suppressed	No		
Advanced			
Formulation	Pure Penalty		
Normal Stiffness	Program Controlled		
Update Stiffness	Never		
Pinball Region	Program Controlled		

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*

State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.8741e-004 m
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	82052
Elements	40861
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C

Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

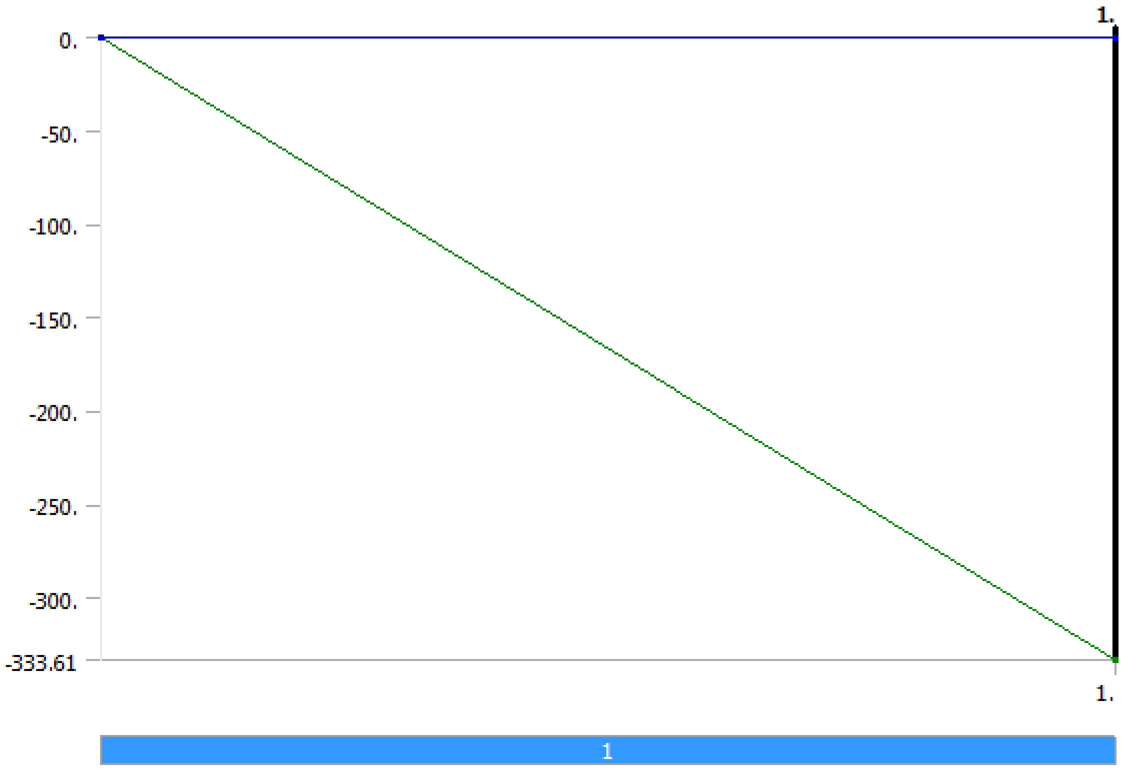
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Contact	No
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\jmarrion\Downloads\Ansys\Spoke 6_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System

X Component		0. N (ramped)
Y Component		-333.61 N (ramped)
Z Component		0. N (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Equivalent Stress*	*Total Deformation*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent (von-Mises) Stress	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Integration Point Results		
Display Option	Averaged	
Results		
Minimum	214.6 Pa	0. m
Maximum	6.8832e+007 Pa	5.9139e-006 m
Minimum Occurs On	Tab	Tab no Countersink
Maximum Occurs On	8-32 (1.5) Flat	Generic Spoke6
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged

Results	
Minimum	3.632
Minimum Occurs On	8-32 (1.5) Flat
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

Material Data

Structural Steel

TABLE 17
Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

TABLE 18
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 19
Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

TABLE 20
Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

TABLE 21
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
4.6e+008

TABLE 22
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 23
Structural Steel > Alternating Stress Mean Stress

Alternating Stress Pa	Cycles	Mean Stress Pa

3.999e+009	10	0
2.827e+009	20	0
1.896e+009	50	0
1.413e+009	100	0
1.069e+009	200	0
4.41e+008	2000	0
2.62e+008	10000	0
2.14e+008	20000	0
1.38e+008	1.e+005	0
1.14e+008	2.e+005	0
8.62e+007	1.e+006	0

TABLE 24
Structural Steel > Strain-Life Parameters

Strength Coefficient Pa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient Pa	Cyclic Strain Hardening Exponent
9.2e+008	-0.106	0.213	-0.47	1.e+009	0.2

TABLE 25
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.e+011	0.3	1.6667e+011	7.6923e+010

TABLE 26
Structural Steel > Isotropic Relative Permeability

Relative Permeability
10000