The S-90 Go-Kart

Optimal Design Report

By

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1. Optimal Design

1.1 Introduction

This project is intended to design and create a go-kart for a child with severe cerebral palsy. The client is a ten year old male who is very smart and enjoys all things related to motor vehicles and driving. His condition makes it nearly impossible for him to operate a typical go-kart, however. The client has no reliable use of his arms or legs at this time. He has been working to develop enough motor control in his arms to allow him to use a power wheelchair with joystick control. The client can use a head switch with great reliability and this is an important factor in the design of this go-kart.

In addition to a lack of reliable motor control the client also needs to be positioned correctly both for comfort, and to optimize the motor control he does possess. He needs to be secured tightly in his seat at the waist. This is to ensure that his waist is constantly at a 90° angle, which helps his movement. The controls must also be setup in such a way that the client’s thumbs are pointing upwards. This is both to help train his muscles to maintain that position and for comfort. The most important part of this go-kart is to maximize the client’s safety and fun while using it.

The go-kart for this project will be built from the ground up to maximize the efficient use of space, and to ensure that the needs of the client are met. The frame will consist of a steel open roll cage design with independent front suspension and semi-independent rear suspension. A 10 horsepower gas motor will provide power for the drive, and also run a 7 amp alternator. A gas motor will be used both to provide adequate power, and for the sounds and attitude it brings to the vehicle. To accommodate the client’s lack of physical ability all of the systems on the go-kart will be actuated using electric motors. The electric motors will interface to the mechanical systems to control them without the operator having to apply force directly. This will allow the client to control the go-kart with minimal physical input.

The power for all of the electrical components essential to the go-kart will come from a deep cycle car battery. This battery will in turn be charged by the alternator to ensure that there is always electrical power being supplied to the system. The battery will supply the electric motors and the electronic control components. These control components are necessary to take small make use of the user’s inputs to the system and translate them into something that can actually drive the go-kart.

Three possible methods of control will be available on a user-selectable basis. The main method of control will be a joystick that controls steering, throttle, and braking using a two axis system. This method is similar to the way the client’s power wheelchair is controlled, and with practice the hope is that the client will be able to learn this system of control. To allow the client to use the go-kart immediately the second control system is based on remote control. A radio controller designed for model aircraft will be controlled by a guardian with similar controls to the joystick. A radio receiver on the go-kart will take the transmitted signal and feed it to the microprocessor. The final method of
control will be a steering wheel and pedals that will allow the vehicle to be operated like a normal car or go-kart. These inputs will be connected to the microprocessor instead of mechanically attached. By running all of the control systems through the same microprocessor system switching between the methods of control is simplified. This method also isolates each system from the motors, ensuring that only one control method can be in use at any given time.

In addition to the custom control methods this go-kart will have a number of other features tailored directly to meet the client’s needs. The seat is the most important of these features. The Tumble Forms 2 Carrie seating system is designed to keep the client bent 90° at the waist at all times. This is essential for allowing the client to maximize his limited movement while driving the go-kart. The Carrie seat is expensive, so a mount will be made to allow the client’s current Carrie seat to easily attached and removed from the go-kart. This will allow the client to have the proper seating arrangements without breaking the budget of the project.

The client’s most reliable form of physical control is his use of a head switch. For safety reasons, a head switch will be used as a kill switch for the go-kart. This safety feature will allow the client to stop the go-kart at any time he feels unsafe or out of control. It is also important for the client’s thumbs to be pointed upwards while he is performing most activities. The meet this specification Velcro on the steering wheel and the joystick will be coupled with special gloves for the client to wear. The Velcro will hold the client’s hands in the correct position regardless of the selected control method.

1.2 Subunits

The complete go-kart described above is made up of a number of smaller systems that come together to make everything work. Each of these subunits has to be carefully designed so that it not only accomplishes its task, but also integrates into the larger system. The following section details the design of each of these subunits, and describes where they fit in the complete design.

**Software Control Architecture**

The go-kart will rely heavily on software control to allow it to function with minimal physical inputs from the operator. Embedded software takes away the need for complex analog circuits that would otherwise make up a control system like this. The software for the go-kart has two main purposes: to provide control over all of the systems necessary to operate the go-kart, and to recognize when the go-kart is not functioning properly and to shut it down safely. To accomplish these two tasks the software will be comprised of two infinite loops. The primary loop will service all of the normal routines that must be controlled, and check to make sure everything is operating properly. The emergency loop will be activated by the primary loop and will function to safely shut down the go-kart.
and keep it shut down. The basics of the overall software design are discussed in this section, each major component is discussed in detail in its corresponding section.

**Microcontroller Hardware**

The hardware that will be responsible for running the software routines is the Microchip PIC16F877. This is a 40-pin version of Microchip’s mid-level 8-bit microcontroller. This microcontroller is ideal because it combines versatility with simplicity. The PIC16F877 has a number of peripherals and modules embedded in its design that can be easily accessed and put to use through relatively simple coding. The PIC includes an on-board analog to digital (A/D) converter, two pulse width modulation modules, and a number of other useful features. The 40 pins combine to have 35 input/output ports, 8 of which can take an analog input and route it through the A/D converter. Due to the constraints of only two PWM modules, however, the go-kart will make use of two PICs running in parallel to one another.

**Programming Language**

The PIC16 series microcontrollers are designed to operate based on a 35 function instruction set. Each instruction corresponds to one or two machine cycles of the microcontroller. Programming language that makes use of only instruction set commands called assembly language. Assembly is efficient to run, but tedious to write. For this application embedded C code will be used for writing microcontroller software. Embedded C essentially takes the C code programming language and converts it into the equivalent assembly instruction set. This set is then loaded onto the chip and run continuously. C code is more intuitive to use than assembly and there are fewer chances of major software errors that could otherwise prove to be dangerous.

**Steering**

**Steering Mechanics**

The steering system of the vehicle is designed to be able to withstand the large forces generated from the steering gearmotor. The gearmotor itself will be mounted to a plate that is attached to the front suspension supports. The gearmotor will have a 2:1 increase in gear ratio so that it will drive the rack and pinion at 180rpm. The gear on the gearmotor output will be a 48tooth spur gear, part number 6325K21 from mcmastercarr.com and the gear on the rack and pinion will be a 24 tooth spur gear, part number 6325K16 from mcmastercarr.com. The assembly will go together as shown in Fig. 1.
The ends of the rack and pinion are equipped with 3/8” tie-rod ends with grease fittings and ball joints. To connect to these, more 3/8” tie rod ends (High-Strength Ball Joint Rod End 3/8”-24 Rh Female Shank, 5100 Pound Load Capacity with part number 4444T211 from mcmastercarr.com will be attached on either end of 10.25” long 3/8” diameter tie rods. The configuration can be seen in Fig. 2.
The tie rod ends will then connect to the front wheel spindles via the extended lever arms with 3/8” holes as shown above.

The steering wheel assembly will be made to be adjustable in terms of height and depth. The depth adjustment will be set by a knob put into a tapped hole in a 7/8” OD, 5/8” ID sheath. A 5/8” rod going through two sets of bearings will be inserted into the sheath on one end and left loose so that the knob pressure can lock it in position while another 5/8” piece of rod that is attached to the steering wheel mount will be inserted into the other end of the sheath. The piece of rod going through the bearings will have its end lathed down to ¼” for a length of about 1.5” so that a timing pulley can be placed on the end of it. Another timing pulley will be fixed to a shaft of a potentiometer and will be mounted to the extended plate that the bearings are mounted to. The area between the bearings will house an assembly consisting of two springs on either side of the steering column, a section of metal cable that has been wrapped around the steering column, and a tack of weld holding the center of the metal cable to the column. The purpose of this apparatus is to center the wheel automatically to give the driver a sense of natural wheel return as well as automatically calibrating the steering wheel to the forward position on startup. The general setup is shown in Fig. 3.

The steering assembly will be able to tilt up and down based on the pivot/mounting point at the base of the assembly, and a pin that will slide through the metal tube mounted under the plate shown. The pin will go through two support arms not shown that will be mounted to the front suspension support bar at simple pivot points. The adjustment will be incremental, as there will be set holes drilled in the support arms that the pin can go through to lock the height of the steering assembly.

Figure #3: Steering Wheel Assembly
Steering Control

The steering control is one of the most important subsystems on the entire vehicle, and it is also one of the most novel. In order for the steering on this go-kart to be useful to the client it has to be able to move the wheels in a way comparable to how a fully capable person with a steering wheel can. A number of components go into this system which allows it to accomplish this task. The components of the steering control are: the rack and pinion with linkage, a Dayton 1L469 gearmotor, an LWG position transducer, an IFI Thor 883 speed controller, software controls, and the input control. Each of these components will be described in detail below.

Dayton 1L469 Gearmotor

The Dayton model number 1L469 gear motor will be used as the steering motor in the go-kart. The motor is geared in such a way to produce 50 inch pounds of torque and rotate at 90 RPM. The operating voltage of the motor is 12 volts with a full load current of 9.0amps. The 12 volt input for the motor is ideal for this particular situation as it is the same voltage as the battery. An IFI Thor 883 speed controller will be supplying the gearmotor with the forward and reverse currents allowing the motor to turn clockwise or counterclockwise as needed. The gear motor will only be drawing power when the wheels need to be turned and not when the go-kart is maintaining a particular wheel position, thus the 7 amp alternator will be able to recharge the battery. A gear on the shaft of the motor will interface with the gear on the rack and pinion for the steering of the go-kart. A linear position encoder will give feedback to the logic unit, determining the position of the wheels, and in turn determining whether or not the gearmotor needs to be activated and rotated. Rotating at 90 RPM will move the rack and pinion back and forth from one extreme to the other in a short period of time, allowing for good control over the direction of the go-kart. For the gear ratios selected, it will take one second for the gearmotor to cause the rack and pinion to travel from one extreme to the other. The gear motor will be bolted to a mounting plate which will in turn be welded to the chassis of the go-kart.

Figure #4: Dayton Gearmotor
Position Transducer

The rack and pinion is not mechanically connected to any of the user interfaces for the steering control system. For this reason it is important that there is another way of tracking the position of the rack and pinion, and ultimately the wheels themselves. This is done using a NovoTechnik LWG Series position transducer as shown in Fig. 5. This transducer has potentiometric properties based on the position of the shaft in its sleeve. The theory behind this mode of operation is that as the shaft moves it changes the internal resistance of the device. By applying a reference voltage to the device a voltage divider is created. The output voltage of the device then becomes dependent on the position of the shaft, and the corresponding resistance.

The LWG position transducer will be attached parallel to the rack and pinion. As the gearmotor moves the rack and pinion the linear motion will also be transferred to the position transducer. With this setup the output voltage of the position transducer becomes a measure of absolute position of the rack and pinion and ultimately a measure of exactly which way the wheels are turned. This output voltage is connected directly to one of the input ports of the microcontroller for processing.

Control Methods

The three selectable methods of control are the main user interfaces for the go-kart. Each of them is designed to carry out the same function, but the reason for each method is unique. The joystick is intended to be the primary mode of control for the go-kart. It will likely take a lot of practice for the client to learn how to use, but it provides him with total control of the vehicle for himself. The radio control method is designed to allow the client to use the go-kart right away. His parents will be able to grasp the controls quickly, and this method requires little to no input from the client himself. The steering wheel with pedals method of control is there for two reasons. There is a hope the someday the client will be able to master his condition well enough to drive normally. It is also there to allow other operators a chance to drive the go-kart normally.

Figure #5: NovoTechnik Linear Position Transducer
Joystick

The joystick control is considered the primary control because it is the most direct form. Many of the elements of this control system are used in the other two systems also. The joystick is a P-Q Controls Inc., M215-28, which has two axes of motion and a rocker switch at the top. The rocker switch will not be used on the go-kart. When the rocker switch goes unused the joystick has four useful leads. Two correspond to the positive and negative supply voltages, and the other two correspond to the x and y axes of control. The M215-28 works like two potentiometers. Each axis outputs a voltage based on the position of the joystick handle. These values are taken separately on the two distinct output leads. Full positive deflection causes an output of 80% of the supply voltage and full negative deflection outputs 20% of the supply voltage. When the handle is resting in the middle both outputs present 50% of the supply voltage. These output voltages are connected directly to an input port of the microcontroller for processing.

The M215-28 joystick will be used to control the steering, throttle, and braking when the go-kart is in joystick control mode. The x-axis will control the steering, and the y-axis will control both the throttle and the brakes. The direction of the wheels will follow the position of the joystick on the x-axis, and the entire axis will be used for this mode of control. The y-axis will control throttle and braking by splitting the axis down the middle. As the joystick handle is pushed forward up the y-axis the throttle will be progressively opened. Likewise, as the handle is pulled back down the y-axis the brake will be incrementally engaged. When the handle rests in the middle of the y-axis the engine will idle with the brake disengaged.

Figure #6: M215-28 Joystick
Radio Control

The radio control is the most complex method of control from an electronics standpoint. The radio control will be implemented using a Futaba Skysport 4YF controlled coupled with a Futaba FP-R127DF receiver. This controller-receiver combination is designed for use with model airplanes and offers a 650 foot range. The controller makes use of two twin axis joysticks for control. Each axis on the controller outputs to a different channel on the receiver, giving four possible outputs that can be used for controlling the go-kart.

The signal that is output from the receiver is in the form of pulse width modulation (PWM); because it is designed to directly drive the small servo motors in model airplanes. The pulse width is changed based on the position of the joystick axis on the controller. While PWM is a convenient signal form to drive a servo motor directly, it is difficult to make use of as a microcontroller input. To make use of the signal coming from the receiver the PWM must be converted into an analog voltage before being routed to the microcontroller.

![Figure #7: RC Smoothing Circuit Diagram and Results](image-url)
The easiest way to make this digital to analog conversion is to use a simple RC circuit to smooth the pulses and give an average DC value. The smoothing effect of the capacitor in the RC circuit creates an averaging effect on the pulses, and creates an analog output proportional to the duty cycle of the PWM. As the duty cycle increases the DC voltage increases giving a controllable analog signal that can be taken by the microcontroller. Once the analog signal arrives at the microcontroller it can be processed in the same manner as the joystick voltage signal. Fig. 7 above shows the effectiveness of this method. The circuit in the diagram was run using a 2.5% duty cycle and a 7.5% duty cycle. There is clear change in the output voltage that can be used for A/D conversion.

**Steering Wheel and Pedals**

The steering wheel with pedals is the third mode of control for the go-kart. It works off of nearly identical principles as the joystick. The steering wheel will be mechanically attached to a potentiometer via a belt. The turning of the wheel will subsequently turn the potentiometer and change the output voltage with respect to the supply. This voltage will then be sent directly to the microcontroller. A spring mechanism will center the steering wheel when no force is being applied to it. This is intended to give the operator the feel of a normal vehicle where the wheels work to right themselves automatically.

The pedals will work in the same way as the steering wheel, except they will be directly linked to potentiometers. There will be separate potentiometers to control the throttle and braking, as they will take inputs from two separate pedals. Both signals from the potentiometers will be connected directly to inputs on the microcontroller. Each of the pedals will also be attached to a spring to bring them back to their original position. This is important to ensure that neither pedal remains in the active position when the operator does not intend for them to be there.

**Steering Software Control**

The software control for steering is responsible for taking information from two main inputs and using the gathered information to update a single output. The inputs for the steering control come from the LGW position transducer and the steering output from the selected control method. Both of these inputs are of the same form when they arrive as signals at the microcontroller. They are both analog DC voltages, and their magnitude is based on the mechanical positions at their respective origins. Each signal must go through an analog to digital conversion (ADC) process in within the microcontroller to be useful for digital analysis. The ADC process is carried out by a routine in the software that utilizes a 10-bit converter that is on board the PIC16F877 microcontroller. The conversion process compares the input voltage level to a known reference voltage level and assigned a number 0-1023 based on the relationship between the two levels. This number is stored to a location on the chip and can be used for comparisons. The ADC routine written in embedded C code is shown below.

```c
void ReadADC(){
    unsigned char wheel1, posit1;
    ADCON1 = 0x49;  //set for left justified
    if(ContMode == 0)
    {
        ADCON0 = 0x09;  // Enable ADC, Fosc/2, for AN1
```
Both input signals undergo ADC and are stored as finite, 10-bit, values. The software takes the 8 most significant bits from these values and stores them as designated variables. One input represents the wheel position and the other represents the desired wheel position. When both inputs are close in value the wheels are essentially in the correct position. If the control value is much different than the wheel values then the software must configure the output so the gearmotor can move the wheels to the correct position.

The code shown below demonstrates this comparison method using embedded C code. The variable “posit” holds the position value of the wheels, and the variable “wheel” holds the position value of the steering input. The variable “toler” is defined at the beginning of the program and is a value that represents the maximum error or tolerance allowed between the two position values before the motor is made to update the position of the wheels. The final value for “toler” will be decided after the performance of the steering is tested. The example code here is configured to update PORTD, a digital output port on the microcontroller. This is to demonstrate the feasibility of the code. When the code is finalized the output will be a PWM signal that is sent to a speed controller connected to the gearmotor.

```c
void SUpdate(unsigned char posit, unsigned char wheel)
{
    if(posit>=wheel-toler && posit<wheel+toler)
    {
        PORTD = 0;  // No change if encoder is within tolerance of input
    }
    else if(posit<wheel+toler)
    {
        PORTD = 0x0F;  // Move to left to compensate
    }
    else
    {
        PORTD = 0xF0;  // Move to right to compensate
    }
    return;
}
```
**Speed Controller**

The gearmotor that powers the steering for the go-kart will be directly regulated by an IFI Thor 883 speed controller. Speed controllers take an input signal and modulate the direction and level of current that a motor receives. This in turn controls the direction and speed of the motor. The Thor 883 takes a PWM signal, which will come from the output of the microcontroller, and uses the encoded information to drive the motor. For the purposes of the go-kart the speed controller will be used only to control the forward and reverse motion of the motor. The 120A continuous current rating for the Thor 883 makes it ideal for the application with the Dayton 1L469 gearmotor, because there is little to no chance of the motor drawing enough current to blow the speed controller.

**Drive Train**

The drive train system of the go-kart is designed to be both robust and adjustable. It consists of an engine mounting plate, a gearbox mounting plate, and the rear axle. The engine mounting plate will be welded to the chassis at a pre-determined position so that the exhaust from the muffler does not expel directly onto any components and so that the engine has enough clearance from the rear suspension. The horizontal positioning of the gearbox mounting plate will be determined by the position of the Comet 500 series torque convertor setup. The end of the gearbox will have an extra support bearing that will be mounted to the rear chassis on a slotted piece of metal. The gearbox mounting plate itself will be adjustable so that the tension in both the torque convertor belt and the drive chain can be adjusted by turning a 5/8” lead screw. This assembly can be seen in Fig. 8 and Fig. 9. The rear area where the engine mounting plate will be welded to is shown in Fig. 10.

![Figure #8: Gearbox Mount Assembly](image)
Figure #9: Gearbox Mount Assembly (Under)

Figure #10: Rear Chassis (Full)
The driven large sprocket on the rear axle has been tested under a high simulated load, as well as the axle itself. The included stress analysis shows that they can withstand the forces generated by the 10HP Tecumseh engine under maximum loading conditions with an 800lb assumed vehicle/passenger weight. Full stress analysis can be found in Appendix A. Both the gearbox and torque convertor are rated to handle up to 16hp 4-stroke engines. The torque convertor clutch is designed to engage at 2100rpm, meaning that the engine should never stall upon engagement due to the fact that at 2100rpm it is high up in its power curve. This will provide good initial acceleration of the vehicle, allowing for a thrilling ride and powerful cornering in off-road conditions.

**Engine**

The engine selected for this vehicle is the Tecumseh Formula Horizontal Engine with Electric Start — 10 HP, 1in. x 2 7/8in. Shaft, Model# HM100-168416T. The reason for this engine’s selection is that it comes with a muffler, a gas tank, a kill switch, a 7 amp alternator, an electric starter and emergency pull-start option, as well as having 10hp and a 1” diameter drive shaft with ¼” keyway which fits the donated torque convertor clutch. This motor is also designed for off-roading, so the oil sensor automatic shutoff is set up so that it won’t automatically shut off the engine if it gets jostled in off-road conditions. The 10hp fits with the hp ranges for the transmissions (8hp-16hp) without being too powerful since the client does not need to go very fast. Also, the price of the motor compared to similar motors with similar features is competitive at $539.99. This motor should allow for an exciting ride with lots of torque to provide good initial acceleration for the client with a max rpm of about 3800.

**Torque Convertor**

The automatic part of the transmission is a Comet 500 series torque convertor with a low range of 3.34:1 and a high range of .81:1. This will ensure that at low engine rpm the transmission will still have enough power to accelerate the go kart by providing a reduction of 3.34 which will be augmented Figure

![Tecumseh Formula Horizontal Engine](image)
to the roughly 6:1 gear ratio provided by the fixed axle and gearbox sprockets. The torque convertor is belt driven and the clutch is centrifugal, so the passenger will be able to easily maneuver the vehicle at low speeds due to a combination of belt slipping and engine loading decreasing the shaft rpm. This dynamic transmission is commonly found in snowmobiles, and allows the engine to reach its full power curve.

**Gearbox**

The gearbox is made by Comet, and is for go-karts, utility vehicles and other applications up to 16 hp. Lightweight, rugged gearbox that allows operator the selection of three positions: forward, neutral and reverse. Forward ratio is 1:1 and the reverse ratio is 2.7:1. This is to be used with other comet torque convertors, like the 500 Series mentioned. The gearbox will have a drive sprocket mounted to its output shaft, which will engage the drive sprocket on the axle. The input shaft will have the driven clutch of the torque convertor as well as an extra support bearing on the end of the input shaft. The gearbox’s mounting plate will be adjustable so that the proper belt and chain tensions can be achieved.

**Throttle**

A servo motor controlled by the microcontroller will operate the rotary valve controlling the throttle on engine. Rotation in one direction gives the engine more gas, and rotation in the opposite
direction limits the gas entering the motor. This throttle motion will be controlled by a closed loop system that will verify the expected position of the servo motor and ensure that the throttle is always in the correct place.

**Input Control**

The input for the throttle control system comes from the selected method of overall control. These methods of control are described above in the Steering Control section of this report. Regardless of the method of control, the signal that ends up as an input to the microcontroller is an analog voltage corresponding to the position of the input controller. This analog signal is converted to digital as it enters the microcontroller and from there the software uses this signal for comparison.

**Feedback Potentiometer**

The shaft of the servo motor that is attached to the throttle control will also be attached directly to a potentiometer. This potentiometer will serve to provide feedback data for the position of the servo motor and ultimately the throttle. As the servo motor turns it will also turn the potentiometer, which will modify the output voltage going to the microcontroller. This step is not necessary for the function of the servo motor, but it is useful to confirm that the servo motor is operating correctly. In an important application like throttle control it is important to be sure that all components are responding properly to the control system. If the signal from the potentiometer does not correctly correspond to the PWM signal being sent to the servo motor the software will automatically send the go-kart into the emergency shutdown routine.

**Throttle Servo Motor PWM**

The servo motor on the throttle takes a pulse width modulation signal to determine the position in its rotation that it should jump to. The various positions of the throttle control valve will correspond to different points in the servo rotation, and the PWM signals corresponding to those points. The software will take the digitally converted signal from the selected control method and compare the desired position of the throttle to the actual position of the throttle servo. If the two positions do not match within a relative tolerance the software will modify the output port to the PWM signal corresponding to the desired position.

**Braking System**

The system for braking control is very similar to the system for steering control. It uses a smaller gearmotor to move the lever to open and close the caliper. The action of the gearmotor is controlled using a microcontroller and a commercial H-bridge.

**Mechanical Braking System**

The brake system has been over-built as a safety concern. The 10" disk brake is much larger than a typical 6" disk brake used on most go-karts. This combined with a high end twist-type caliper system
allows for tremendous forces to be generated on the brake with moderate forces applied to the caliper lever arm. The lever arm will be actuated by using a high-torque gearmotor that will have a further improved mechanical advantage before being linked to the caliper lever arm. The increase in mechanical advantage is possible due to the fact that the brake caliper lever only needs to move ½” for a fully open to fully closed position, so the gearmotor being used can convert all of its speed in its rotating parts to a very high pulling force. The general position of the brake and the general location of where the caliper will be located can be seen in Fig. 13.

**AME 218-series gearmotor**

The AME 218-series gearmotor will be used to apply a force to the braking mechanism. This gear motor operates at 12 volts, the same voltage supplied by the battery, rotating at 116 RPM when no load is applied. With no load on the gearmotor 1.4 amps are drawn and at stall the gearmotor draws 21.3 amps. This gearmotor is able to supply 98 inch pounds of torque. The Simple-H H-bridge will be supplying the power to this gear motor in the forward and reverse directions. When current is flowing in the forward direction, this gearmotor will rotate applying a force to the brake lever on the disc brake assembly. The lever will then in turn press the ceramic pads against the disc brake, slowing the go-kart. A linear position encoder will be used to determine the position of the brake lever, and in turn will determine whether or not the gearmotor needs to be turned on and the position of the lever adjusted. This feedback will keep the motor from applying excessive force to the braking assembly and will keep the motor from burning out due to extended periods of activation. Sending current through the gearmotor in the reverse direction will release the brake. The position of the gearmotor will be constantly monitored whether it is applying a force to the braking mechanism or released.

![Figure #13: Rear Base Composite Assembly](image-url)
Braking Control System

Braking H-Bridge
The commercial H-bridge that will be used to drive the braking gearmotor is the SyRen Regenerative Motor Driver. This driver takes a PWM signal from the microcontroller and uses it to switch the direction of the current flowing into the gearmotor. The SyRen is rated for use with 25A continuous current and can handle current spikes up to 45A. This is much more current than the braking gearmotor would ever actually draw, which means that the chances of this component failing are small. The SyRen will control switching between full forward, full reverse and idle. This will correspond to the opening and closing of the brake calipers, as well as allowing them to hold position.

Braking Position Transducer
The braking motor has no way of tracking its own position, so position will be measured using a NovoTechnik LWG Linear Position Transducer. The equipment and method for control using this position transducer is nearly identical to the method used for tracking the steering position. It is important to have data about the position of the brake calipers to allow for smooth braking. If the braking were to be done using only limit switches the only braking options would be full brakes or no brakes. The position transducer allows enough feedback from the brake mechanism to the microcontroller to incrementally increase braking power using the software.

Braking Control Software
The software controlling the braking system takes two inputs and compares them to modify a single PWM output. The two inputs are the signal from the selected control method, and the signal from the linear position transducer attached to the braking gearmotor. The input from the user controls will only utilize the bottom half of the y-axis (except for the pedal control method) and the software will default to no brakes when the go-kart is accelerating. The braking will be setup to run to a specified number of positions based on the intensity of the stopping needed. Each position of the brake will be a case and have constraints. If the position transducer is not in the correct position based on the current selected case the software will send the appropriate PWM to the H-bridge to correct the position of the brakes.

Gearbox Control
The go-kart will have a transmission that can switch the drive from the engine between forward and reverse. This will be accomplished by attaching a linear actuator to the selector arm of the transmission. The linear actuator will be controlled by the software and a custom designed H-bridge.

Gearbox H-Bridge
The transmission H-bridge will be designed using a very simple h-bridge concept. It uses two mechanical relays and two limit switches to route current between the two poles of the linear actuator.
The diagram below shows the design of the h-bridge. When the first relay is activated by a signal from the microcontroller it opens and allows current to flow into the positive terminal from the high side of the bridge. When the linear actuator reaches the limit switch it cuts off the current flow from the negative terminal of the actuator. The linear actuator will stay in place until the microcontroller activates the other relay at which point the actuator will move off of the first limit switch and move until it hits the other limit switch.

Gearbox Control

The software control for the transmission will be a very simple design. A switch on the side of the go-kart will be able to be set for either forward or reverse. This switch will send a digital signal to the correct input pin on the microcontroller. The software will compare the digital signal to the last one it received and if they are different it will activate the output to switch which relay is active at that point. This method is a simple, yet effective way to switch gears without heeding to physically move the handle.

Motion System 9234c120 linear actuator

The Motion System Corp model 9234C120-R10 linear actuator will be used to move the gear lever on the gearbox of the go-kart. This actuator is able to provide enough force and has a long enough stroke to push the gear lever from the forward to reverse positions. This actuator operates at 12 volts, consequently the same voltage as the battery for the go-kart. The speed at which the actuator moves is suitable for the task of changing gears in the gearbox. External limit switches will be placed such that the current flowing to the actuator will be halted once the gear lever is in its proper position. This will...
keep the actuator from exerting unnecessary forces on the gear lever and will also protect the actuator from becoming burnt out due to it perpetually being on. A bolt through the ball joint on the actuator will connect to the gear lever and the actuator will be mounted to the chassis of the go-kart.

Other Mechanical Systems

Roll Cage System

The roll cage system is an extremely robust, over-engineered design that will keep the passenger safe in the case of a rollover at speed (approx 30mph). The roll cage will be made of a single piece of bent 1.5” OD ¼” wall thickness pipe that is reinforced by two extra pieces of pipe as shown in Fig. 15.

There will be extra pieces mounted to the chassis that support these side bars. The roll bar needs to be able to withstand significant lateral forces, and a stress simulation has been included to prove that the design is more than strong enough. Full stress analysis can be found in Appendix B. Also the roll cage will feature a dual role: both a safety role and a suspension role. The rear suspension will mount to a crossmember on the roll cage. The forces generated by the rear suspension will be mostly absorbed by the two side supports that are angled forward. The remaining forward forces will be taken
up by the gussets welded to the bottom of the main roll bar and the side assemblies that are welded to the chassis to support the side support tubes. The roll cage system will also include a rigid steel pipe welded to the main roll bar that the joystick can mount to. In the same way that the steering wheel depth is adjustable, the joystick will have a knob that can be tightened built into it that can fix it in position at any depth along the steel pipe.
Seat System

The seat system is designed to be adjustable and strong. The seat mounting plate has to be strong enough to control the passenger’s inertia, as it is the only real structural interface between the passenger and the vehicle. In order to accomplish both strength and adjustability, a heavy duty linear actuator has been chosen to move the seat mounting plate forward and backward on two strong, reinforced steel rails. The seat mounting plate is fixed laterally by the geometry of the rails and the up/down movement is restricted by tabs and angle iron welded to the seat mounting plate. The linear actuator is rated for 750lbs, which is more than any passenger that can fit in the vehicle can possibly weigh. The linear actuator setup can be seen in Fig. 16.

The seat coupler for the seat mounting plate will be made out of steel, and there will be two separate couplers, one for the normal seat for test driving, and one for the special seat for the client. The bracket for the normal seat has been designed and looks Fig. 17. The seat coupler for the client’s special car seat will be the reciprocating piece to the bracket currently mounted to the bottom of their seat, which looks like Fig. 18. The seat area will be protected from tree-branches, and other off-road debris by side panels made out of fiberglass. Also, the seat area will have the roll bar support arms running along the edges, which will completely encase the passenger with structural supports in the case of a rollover, making them much safer.

Figure #18: Seat Bracket
**Duff-Norton LSPD 2775-12**

The Duff-Norton LSPD 2775-12 linear actuator will be used to adjust the seat position on the go-kart. This motor has a 750 pound capacity and a 12 inch stroke arm. The operating voltage of this particular actuator is 12 volts, corresponding to the voltage of the battery used in this project. The maximum current draw for this actuator is about 14 amps when the actuator is applying 750 pounds of force. Current will only be drawn when the seat is being adjusted so the 14 amp draw is acceptable even through the alternator is only supplying 7 amps of current to the battery. The speed at which the seat will be adjusted will be comparable to that of adjusting a standard electric car seat. The actuator will extend or contract based upon the direction of current flow through the actuator. Two internal limit switches which will stop current from flowing when the actuator has reached the extremes of its stroke. These limit switches will help to keep the actuator from being damage during usage. One side of the actuator will be bolted to the seat mounting bracket, pushing it along rails which the mounting bracket rests on. The other side of the actuator will be attached to the frame of the go-kart.

![Figure #19: Front Suspension Arm Assembly](image-url)
Front Suspension System

The front suspension system is designed to allow for independent front wheel suspension while impacting the steering system minimally. The front suspension will use Adjustable Shock Absorbers from northerntool.com that have 520lb load rating and 2” of max compression. The shocks will be mounted in parallelogram suspension arm assemblies at the bottom and in the front suspension support bar that runs along the front of the chassis. The parallelogram suspension arms ensure that the front wheels are always vertical with respect to the ground, and causes less of a “toe in” effect on the front wheels when the suspension is compressed. The suspension arms can be seen in Fig. 19.

The design of the suspension arm allows for the front wheel spindles to have maximum turning radius based on the rack and pinion’s maximum stroke length. Also, the suspension arms are extremely rugged, so that if for some reason the front bumper does not hit an obstruction that is too low to the ground, the suspension arms should not bend or break upon normal impacts at reasonable speeds (<20mph). The front suspension assembly can be seen in Fig. 20. This shows the numerous reinforcements to the front area where the suspension arms connect to the front chassis. It also shows the relative positioning of the front bumper to the suspension arms, showing that most objects that would endanger the suspension arms would be blocked by the bumper, except for low-lying obstacles.

Rear Suspension System

The rear suspension system is a three pivot point system that uses heavy duty pins to hold the front and rear chassis together. The upper portion of the rear suspension coincides with the roll cage, as mentioned above. The rear bar of the rear suspension has been tested under simulated loads, and as the weakest of the three pivot points, still shows that it can withstand more than the expected loads. Full stress analysis can be found in Appendix C. The main components to the rear suspension are the upper segment with parallel steel sheaths, the lower segment with parallel solid steel rods, and the two
14” coil-over off road springs that interface the upper and lower segments. The idea is that the springs will provide much of the support for the rear suspension, but the space between the steel sheath and solid steel rod will be greased, trapping air in the hollow segment above the solid steel rods. This air will act as a further dampener for the suspension when experiencing jarring impacts, and will improve the quality of the rear suspension by increasing the force required to bottom out the suspension. This suspension assembly can be seen in Fig. 21.
The actual mounting points for the rear suspension assembly can be seen in the following image showing an isometric wire frame view of the vehicle in Fig. 22.

Chassis (Front and Rear)

The chassis for the vehicle is broken up into two subunits: the front chassis and the rear chassis. These two units are joined by a solid ¾” steel rod at a pivot point used by the rear suspension. The front chassis can be seen in Fig. 24.
These chassis are made to be extremely rigid and strong. They are reinforced with 2” side length right, isosceles triangle gussets at every corner to increase their rigidity. They are however designed to have a moderate amount of flex in the case of twisting. This is to accommodate the numerous high energy impacts that the vehicle will probably encounter while driving off road. The risk of making the chassis resistant to twist is that it could cause a weld joint to snap, since the forces from random off-road impacts can be very large. By keeping the chassis rigid in the x-y plane by flexible in the x-z plane, the front and rear chassis are more suitable to handle the rigors of off roading without sustaining any structural damage, no matter how rough the terrain.

**Front Bumper**

The front bumper will be made out of a single solid piece of 1”x1” steel. This should be able to withstand any impact and transfer the impact to the reinforced front section of the front chassis. The front bumper can be seen in Fig. 30. Since the front piece will be solid steel, the forces that will hit the bumper will travel through that piece and into the 4 front bumper support bars. To test if these bars were up to a severe impact, a stress analysis has been performed on them. Full stress analysis can be found in Appendix D. The front bumper should be strong enough to withstand any impact from the vehicle at speeds under 10mph without any significant deformation, and at speeds above 30mph the front bumper will crumple appropriately, absorbing the energy of the impact like the nose cone of a race car, making the collision more plastic, and therefore helping to protect the passenger from excessive g forces.

2. **Realistic Constraints**

**Economic**

This engineering project, as with all other design projects, has a set budget which cannot be adjusted. A larger budget would allow for the purchasing of better components and result in a better final product. The projected cost of all parts for this go-kart far exceeds the budgetary constraints given, but will ultimately result in a better design. Luckily, donated and salvaged parts required for this go-kart are available for free, allowing for the design of better go-kart, while staying under the allocated funding. It is important to note that if this go-kart were to be manufactured, the free parts would no longer be available and the cost of the go-kart would increase from $2300 for a prototype to $7000 for a production model.
Environmental

The 10 HP engine for this go-kart will be gas powered and operation of the go-kart will result in the release of carbon dioxide and other emissions from the combustion engine. Other components of the go-kart are also known to be potential hazards to the environment. The Die Hard battery used to supply power to the electrical components of the go-kart contains materials that are corrosive and dangerous. Electronic components can also be hazardous to the environment and in the event of a malfunction, the proper disposal of any circuit boards is required. Since this go-kart is going to be operated in the outdoors, it must be driven carefully so the terrain is not excessively damaged.

Outdoor operation also requires that the go-kart be built in such a way so that environmental factors do not hinder its operation. Water can cause electrical components to short, so all electrical components must be protected from any type of moisture. This includes waterproofing the circuit board with the logic units, speed controller, and h-bridge. Mechanical components must be protected from dirt, dust, water, or any other environmental factors which could hinder their operation. Gearmotors, linear actuators, and servos need to be encased in a way such that the environment does not limit the function of the component. The gas engine for this project was chosen because it was specifically made to endure off road and outdoor conditions. Some of the components of this go-kart are rated for certain temperature ranges and parts that are suitable for outdoor temperatures must be found to ensure proper operation. All components must be shock resistant and able to absorb impacts if necessary.

Sustainability

As mentioned before, the go-kart will be gas powered and therefore it should be refueled before operation to obtain the maximum driving time. Depending on the speed at which the go-kart is operated the operation time will vary greatly. The go-kart will run much longer at a slow to moderate operating speed as opposed to operating the go-kart at intense speeds. Running the engine not only propels the go-kart but it also will generate current via the alternator. This will recharge the battery and provide power for all of the electrical components. Minor maintenance such as changing the oil and cleaning the go-kart occasionally will extend the lifetime of the vehicle. This go-kart has been designed to withstand collisions and operate in harsh environments. Under typical driving conditions the go-kart should operate without fail for a long time with the proper maintenance and care.

Manufacturability

Obtaining the majority of the parts for this go-kart would pose little challenge if it were to be manufactured on a large scale. If a particular part such as the Motion System linear actuator was not
longer manufactured or could no longer be found, a suitable replacement would be easy to find. With a parts list, the proper mechanical and wiring diagrams, and the code needed to program the microprocessors, the majority of the go-kart ready to go. However, the chassis for this go-kart is custom made and would have to be fabricated in order to make a new go-kart. With the CAD files for the go cart the materials to make the frame it would be possible to manufacture the frame and install all of the components on the frame with little challenge.

Health and Safety

The primary concern of this project and most other engineering projects are safety. The intended operator of this go-kart is a child with Cerebral Palsy. Having any child operate a go-kart or other motorized vehicle has the potential to be dangerous, compounded with the fact that this child has under developed motor skills means that this go-kart has to be designed with the highest safety standards in mind. This go-kart is designed with multiple control methods. The onboard controls can be overridden at any time by a remote operator in the event that the driver is in danger, i.e., about to crash or roll the vehicle. The wheel base of the go-kart is wide and weight is distributed as low as possible to ensure that the go-kart cannot roller over. In the unlikely event that the go-kart does roll over, a roll bar able to withstand thousands of pounds of force will protect the driver. The chassis of the go-kart has been designed to withstand impacts without deforming or breaking. A multi-point harness will secure the driver safely in the seat and keep them from being ejected from the vehicle. A two kill switches have been included in the design, one remote and one onboard, which will stop the gas engine and apply the brake in the event of an emergency. A speed governor has been implemented into the system which will limit the maximum speed of the go-kart. The operator will be able to select between a low, medium, or high speed. A logic unit with multiple processing units has been designed in a way that if one component were to fail, the system would shut down safely. The go-kart has been designed to operate under a variety of environmental conditions so malfunction due to water, dirt, or temperature is unlikely.

Social

One of the main goals of this project is to allow a disabled child to provide a release from the daily hardships of life and to give them a way to interact with the surrounding world. Building this go-kart allows them to live life as a normal child would and show that there really are not many differences between an average child and a child that suffers from a disability. This go-kart is build in such a way that it could be operated by anyone, disabled or not, and when looking at the design it would not look any different than a normal go-kart that could be purchased.
Safety Issues

Safety, as mentioned earlier, is the primary concern of this project. This requires that the operator be safe at all times whether they be sitting in the vehicle or anywhere nears the go-kart. Starting with the electrical systems, all wires carrying a current will be routed through conduits to protect the wires from environmental hazards, but also protect the operator from any currents the wires may be carrying. The conduit will be secured to the chassis so the operator will not become hung up in it when operating the vehicle, or trip over it when entering or exiting the vehicle. There will be no bare wires anywhere in the go-kart. This will prevent any arcing that could potentially start a fire. All electrical equipment used in the go-kart is rated for currents that are higher than what will be experience during the operation of the go-kart. This will keep components from overheating and catching fire. For the mechanical components of the go-kart, all moving parts will be situated in a way that it would be impossible for the operator to become caught in them. A chain guard will protect the chain from being dislocated as well as protecting the operator from accidently becoming caught in the chain. The steel chassis will protect both the components of the go-kart as well as the operator of the go-kart in the event of a collision. The roll bar provides protection in the case of a roll over. All part on the go-kart will be secured to the chassis and there will be no parts that could become dislodged and come off during operation. The engine, gearbox, and torque converter have been located in a position that is inaccessible to the operator during operation of the vehicle. It will not be possible for the operator to become caught in the belt of the torque converter based on its location and where the driver will be positioned when operating the go-kart. The chemical hazards of this project include corrosive materials leaking from the battery, gasoline in the engine, and oil also for the engine. It is unlikely that the sealed battery will leak any chemicals even in the event of a collision of roll over. The same is true for the gasoline and oil which should remain inside of the engine or in the gas tank in the event of an accident. It should be noted that gasoline and oil can be dangerous is swallowed or come in contact with cuts, and also pose a fire hazard if there is a fire nearby when refueling the vehicle or adding engine oil. Other chemical hazards are from the emissions of the vehicle. The go-kart should not be operated inside, especially if there is not adequate ventilation, as this poses a major health risk. Thermal hazards include warm electronic components and a hot engine exhaust. To keep electrical components as cool as possible, active cooling will be employed on the speed controller and h-bridge. Both of these components are rated to operate under currents well above the conditions present in the go-kart. This will also keep the components from overheating. These components will be encased in ventilated boxes to keep the operator from accessing them when they could potentially be hot. The engine exhaust will be situated in a way that the operator will not be able touch it when operating the vehicle. It is also well known that the exhaust on a vehicle is hot to the touch and should not be touched during operation or after operation until it has had time to cool down.
4. Impact of Engineering Solutions

There should be little to no impact based upon the engineering solutions present in this design. This go-kart is intended to be operated by a single client and was designed specifically based on the needs of the client. However, in the event that this go-kart becomes mass produced there could be some considerable effects on economics, society, the environment, and even far reaching global effects. This go-kart could potentially provide a release for any physically handicapped person and it was designed to cost less than other go-karts that have electronic controls. The market for this product is large and there currently are no suitable designs that can provide the same function as this go-kart. By creating a new product for a market that has no other products like it, this go-kart has the potential to make a lot of money for the manufacturer.

If this product were to be purchased by a multitude of people, then society would begin to see disabled people in a new way. They would be seen out riding in go-karts, enjoying activities that which are normally reserved for non-disabled people. Handicapped people would be seen as not being all that different and the differences between people would become less apparent. On the whole society could become more understanding, more accepting, and less judgmental.

The environmental impact is not favorable however. These go-karts are gas powered and release carbon dioxide and other emissions into the atmosphere. Whether or not these emissions lead to global warming has yet to be adequately determined, however it is known that these emissions can lead to acid rain, smog, and unhealthy air to breath. Disposing of a go-kart with these electrical components would be cause trouble as well. Just as a laptop computer should not be disposed of in the garbage, these electrical components should not be just thrown out if the circuits were to malfunction or the go-kart was to be disposed of. The battery would also need to be disposed of properly as it contains corrosive materials that cannot just be thrown away. The same goes for the engine oil when it needs to be changed. Disposing of these materials properly is much better than throwing them out in the garbage, but even when disposed of properly, some materials cannot be recycled and ultimately must be thrown out.

This go-kart could potentially have a global impact. The awareness for disabilities on the global level could rise, resulting in more funding going to research for curing ailments such as Cerebral Palsy. The acceptance of disabled people on the global level would increase as well. If the go-kart became popular in other countries that would result in an increase in the products that the United States exports and bring in more foreign money thereby lowering the trade deficit. The United States would be seen in a friendlier manner globally. If this go-kart were to become popular in a global setting then it would lead to improvements and innovations of the go-kart that could be applied to other engineering specialties.
5. **Lifelong Learning**

In the course of designing this go-kart many new skills have been developed. Designing the chassis for the go-kart required a 3D CAD program. The CAD program that was learned was Solidworks 2007 to create parts and put them together. A method for mechanical stress testing of the components had to be discovered and luckily Solidworks was able to perform this task as well. The system for steering the go-kart involved the most learning. Three systems of controlling the go-kart had to be developed that would not interfere with one another. This required acquiring some programming knowledge in embedded C and how to upload the programs to the processors. In order to be able to have the gearmotors working in both the forward and reverse directions h-bridges had to be made and tested to prove that it would be an acceptable method for quickly changing the direction of the gearmotors. Other options had to be researched as well for this task and the principles behind relays and how to incorporate relays into circuit had to be looked into. The both the speed controller for steering the go-kart and the h-bridge for the braking system take PWM signals as their inputs. Understanding the basic concept of the PWM signal and how to apply it to a particular situation had to be discovered. After understanding how a PWM signal works a method for getting the processors to output such signals had to be determined and programming such a method also had to be done. To generate a smooth ride for the go-kart different types of suspensions had to be investigated. An independent front suspension and a semi-independent rear suspension was determined to be the best overall suspension for the purposes of this go-kart. Different engines had to be researched when choosing the best possible engine for the go-kart. An electrical engine would be the most environmentally friendly engine, but a gas powered engine like the one chosen for this design is able to keep the electronics operational without relying on an array of batteries and refueling a gas engine is much faster than recharging batteries for an electric motor.

Aside from technical aspects that were learned when designing this go-kart, much research about Cerebral Palsy had to be done, including how it affects a person both physically and mentally. Understanding how our client was affected helped to determine how the go-kart needed to be designed in terms of control methods and how his body would be positioned. A body position with the thighs and chest at a 90 degree angle was discovered to be the optimal body position and the client’s arms needed to be as close to their body as possible. Maintaining this position allows the client to have the best control over their arms and legs.
6. References


Appendix A: Gear Stress Analysis

Author: James Paolino

Company: UConn

Date: 10/21/08

1. File Information
2. Materials
3. Load & Restraint Information
4. Study Property
5. Results
   a. Stress
   b. Displacement
   c. Deformation
   d. Design Check
6. Appendix

1. File Information

Model name: drive Gear

Model location: C:\Documents and Settings\JFP\My Documents\Solidworks\Senior\Design\drive Gear.SLDPRT

Results: C:\Documents and Settings\JFP\My Documents\Solidworks\Senior
location: Design\Analysis

Study name: COSMOSXpressStudy (-Default-)

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3. Load & Restraint Information

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4. Study Property

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### 5. Results

#### 5a. Stress

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 drive Gear-COSMOSXpressStudy-Stress-Plot1

 JPEG
5b. Displacement

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5c. Deformation
5d. Design Check
6. Appendix
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Description:

Material Source: Used SolidWorks material

Material Library Name:

Material Model Type: Linear Elastic Isotropic

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<td>Yield strength</td>
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Appendix B: Roll Bar Stress Analysis

Author: James Paolino

Company: UConn

Date: 10/22/08

1. File Information
2. Materials
3. Load & Restraint Information
4. Study Property
5. Results
   a. Stress
   b. Displacement
   c. Deformation
   d. Design Check
6. Conclusion
7. Appendix

1. File Information

Model name: Roll Bar

Model location: C:\Documents and Settings\JFP\My Documents\Solidworks\Senior Design\Roll Bar.SLDPR

Results location: C:\Documents and Settings\JFP\My Documents\Solidworks\Senior Design\Analysis

Study name: COSMOSXpressStudy (-Default-)
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4. Study Property

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5. Results

5a. Stress

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Min</th>
<th>Location</th>
<th>Max</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot1</td>
<td>VON: von Mises stress</td>
<td>128355 N/m^2</td>
<td>21.125 in,</td>
<td>1.87348e+008 N/m^2</td>
<td>21.25 in,</td>
</tr>
</tbody>
</table>
Roll Bar-COSMOSXpressStudy-Stress-Plot1

JPEG
### 5b. Displacement

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Min</th>
<th>Location</th>
<th>Max</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot2</td>
<td>URES: Resultant displacement</td>
<td>0 mm</td>
<td>(-0.433013 in, 0 in, 0.25 in)</td>
<td>4.54771 mm</td>
<td>(9.35526 in, 39.2614 in, -0.130236 in)</td>
</tr>
</tbody>
</table>

*Roll Bar-COSMOSXpressStudy-Displacement-Plot2*

*JPEG*
5c. Deformation

Roll Bar-COSMOSXpressStudy-Deformation-Plot3

JPEG
5d. Design Check

Roll Bar-COSMOSXpressStudy-Design Check-Plot4

JPEG
6. Conclusion

This analysis shows that the roll bar can easily withstand a direct side impact force of 1000lbs without any extra supports, and since there will be extra supports and the vehicle with a 200lb passenger is estimated to weigh 750lbs, this means that the roll bar is more than strong enough to withstand a vehicle rollover with minimal strain effects.

7. Appendix
Material name: [SW]Plain Carbon Steel

Description:

Material Source: Used SolidWorks material

Material Library Name:

Material Model Type: Linear Elastic Isotropic

<table>
<thead>
<tr>
<th>Property Name</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic modulus</td>
<td>3.0463e+007</td>
<td>psi</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>0.28</td>
<td>NA</td>
</tr>
<tr>
<td>Mass density</td>
<td>0.28179</td>
<td>lb/in^3</td>
</tr>
<tr>
<td>Yield strength</td>
<td>32000</td>
<td>psi</td>
</tr>
</tbody>
</table>
Appendix C: Rear Suspension Bar Stress Analysis

Author: James Paolino

Company: UConn

Date: 10/22/08

1. File Information
2. Materials
3. Load & Restraint Information
4. Study Property
5. Results
   a. Stress
   b. Displacement
   c. Deformation
   d. Design Check
6. Conclusion
7. Appendix

1. File Information

Model name: Rear Chassis

Model location: C:\Documents and Settings\JFP\My Documents\Solidworks\Senior Design\Rear Chassis.SLDPR

Results location: C:\Documents and Settings\JFP\My Documents\Solidworks\Senior Design\Analysis
2. Materials

<table>
<thead>
<tr>
<th>No.</th>
<th>Part Name</th>
<th>Material</th>
<th>Mass</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rear Chassis</td>
<td>[SW] Plain Carbon Steel</td>
<td>53.5551 lb</td>
<td>190.051 in^3</td>
</tr>
<tr>
<td>2</td>
<td>Rear Chassis</td>
<td>[SW] Plain Carbon Steel</td>
<td>53.5551 lb</td>
<td>190.051 in^3</td>
</tr>
<tr>
<td>3</td>
<td>Rear Chassis</td>
<td>[SW] Plain Carbon Steel</td>
<td>53.5551 lb</td>
<td>190.051 in^3</td>
</tr>
<tr>
<td>4</td>
<td>Rear Chassis</td>
<td>[SW] Plain Carbon Steel</td>
<td>53.5551 lb</td>
<td>190.051 in^3</td>
</tr>
<tr>
<td>5</td>
<td>Rear Chassis</td>
<td>[SW] Plain Carbon Steel</td>
<td>53.5551 lb</td>
<td>190.051 in^3</td>
</tr>
<tr>
<td>6</td>
<td>Rear Chassis</td>
<td>[SW] Plain Carbon Steel</td>
<td>53.5551 lb</td>
<td>190.051 in^3</td>
</tr>
<tr>
<td>7</td>
<td>Rear Chassis</td>
<td>[SW] Plain Carbon Steel</td>
<td>53.5551 lb</td>
<td>190.051 in^3</td>
</tr>
<tr>
<td>8</td>
<td>Rear Chassis</td>
<td>[SW] Plain Carbon Steel</td>
<td>53.5551 lb</td>
<td>190.051 in^3</td>
</tr>
<tr>
<td>9</td>
<td>Rear Chassis</td>
<td>[SW] Plain Carbon Steel</td>
<td>53.5551 lb</td>
<td>190.051 in^3</td>
</tr>
<tr>
<td>10</td>
<td>Rear Chassis</td>
<td>[SW] Plain Carbon Steel</td>
<td>53.5551 lb</td>
<td>190.051 in^3</td>
</tr>
<tr>
<td>11</td>
<td>Rear Chassis</td>
<td>[SW] Plain Carbon Steel</td>
<td>53.5551 lb</td>
<td>190.051 in^3</td>
</tr>
</tbody>
</table>

3. Load & Restraint Information

| Restraint          | Restraint1 <Rear Chassis> | on 2 Face(s) immovable (no translation). |
Load

**Load1 <Rear Chassis>** on 1 Face(s) apply force **200 lb** normal to reference plane with respect to selected reference **Front Plane** using uniform distribution

<table>
<thead>
<tr>
<th>Description:</th>
</tr>
</thead>
</table>

4. **Study Property**

<table>
<thead>
<tr>
<th><strong>Mesh Information</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mesh Type:</strong></td>
</tr>
<tr>
<td><strong>Mesher Used:</strong></td>
</tr>
<tr>
<td><strong>Automatic Transition:</strong></td>
</tr>
<tr>
<td><strong>Smooth Surface:</strong></td>
</tr>
<tr>
<td><strong>Jacobian Check:</strong></td>
</tr>
<tr>
<td><strong>Element Size:</strong></td>
</tr>
<tr>
<td><strong>Tolerance:</strong></td>
</tr>
<tr>
<td><strong>Quality:</strong></td>
</tr>
<tr>
<td><strong>Number of elements:</strong></td>
</tr>
<tr>
<td><strong>Number of nodes:</strong></td>
</tr>
<tr>
<td><strong>Time to complete mesh(hh:mm:ss):</strong></td>
</tr>
<tr>
<td><strong>Computer name:</strong></td>
</tr>
</tbody>
</table>
5. Results

5a. Stress

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Min</th>
<th>Location</th>
<th>Max</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot1</td>
<td>VON: von Mises stress</td>
<td>132946 N/m^2</td>
<td>(-7.50862 in, 9.71524 in, 28.625 in)</td>
<td>6.90272e+007 N/m^2</td>
<td>(-12.7759 in, 9.71524 in, 28.625 in)</td>
</tr>
</tbody>
</table>

Rear Chassis-COSMOSXpressStudy-Stress-Plot1

JPEG
### 5b. Displacement

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Min</th>
<th>Location</th>
<th>Max</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot2</td>
<td>URES: Resultant displacement</td>
<td>0 mm</td>
<td>(13 in, 10.04 in, 28.0625 mm)</td>
<td>0.492878 mm</td>
<td>(5.2377e-007 in, 9.34594 in, 28.0625 mm)</td>
</tr>
</tbody>
</table>
5c. Deformation

Rear Chassis-COSMOSXpressStudy-Deformation-Plot3

JPEG
5d. Design Check

Rear Chassis-COSMOSXpressStudy-Design Check-Plot4

JPEG
6. Conclusion

This Analysis shows that the rear suspension bar can withstand a force of 200lbs with a safety factor of 3.2. This is important because the estimated weight of the vehicle is about 750lbs with a 200lb rider, and the force that the rear suspension bar will see will be about 1/12th of that due to the mechanical design of where the suspension pins are located and the weight distribution of the vehicle. Using a 200lb force simulates more than the bar will probably ever see, and the high safety factor of 3.2 proves that it will be stable.

7. Appendix

Material name: [SW]Plain Carbon Steel

Description:

Material Source: Used SolidWorks material

Material Library Name:

Material Model Type: Linear Elastic Isotropic

<table>
<thead>
<tr>
<th>Property Name</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic modulus</td>
<td>3.0463e+007</td>
<td>psi</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>0.28</td>
<td>NA</td>
</tr>
<tr>
<td>Mass density</td>
<td>0.28179</td>
<td>lb/in^3</td>
</tr>
<tr>
<td>Yield strength</td>
<td>32000</td>
<td>psi</td>
</tr>
</tbody>
</table>
Appendix D: Front Bumper Analysis

Author: James Paolino

Company: UConn

Date: 10/18/08

1. File Information
2. Materials
3. Load & Restraint Information
4. Study Property
5. Results
   a. Stress
   b. Displacement
   c. Deformation
   d. Design Check
6. Appendix

1. File Information

Model name: Front Bumper

Model location: C:\Documents and Settings\JFP\My Documents\Solidworks\Senior Design\Front Bumper.SLDPRT

Results location: C:\Documents and Settings\JFP\My Documents\Solidworks\Senior Design\Analysis

Study name: COSMOSXpressStudy (-Default-)
2. Materials

<table>
<thead>
<tr>
<th>No.</th>
<th>Part Name</th>
<th>Material</th>
<th>Mass</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front Bumper</td>
<td>[SW]Plain Carbon Steel</td>
<td>11.2814 lb</td>
<td>40.0343 in^3</td>
</tr>
<tr>
<td>2</td>
<td>Front Bumper</td>
<td>[SW]Plain Carbon Steel</td>
<td>11.2814 lb</td>
<td>40.0343 in^3</td>
</tr>
<tr>
<td>3</td>
<td>Front Bumper</td>
<td>[SW]Plain Carbon Steel</td>
<td>11.2814 lb</td>
<td>40.0343 in^3</td>
</tr>
<tr>
<td>4</td>
<td>Front Bumper</td>
<td>[SW]Plain Carbon Steel</td>
<td>11.2814 lb</td>
<td>40.0343 in^3</td>
</tr>
</tbody>
</table>

3. Load & Restraint Information

<table>
<thead>
<tr>
<th>Restraint</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restraint1</td>
<td>on 1 Face(s) immovable (no translation).</td>
</tr>
</tbody>
</table>

4. Study Property

<table>
<thead>
<tr>
<th>Load</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load1</td>
<td>on 1 Face(s) apply normal force 1000 lb using uniform distribution</td>
</tr>
</tbody>
</table>

Mesh Information
Mesh Type: Solid mesh

Mesher Used: Standard

Automatic Transition: Off

Smooth Surface: On

Jacobian Check: 4 Points

Element Size: 0.15443 in

Tolerance: 0.0077217 in

Quality: High

Number of elements: 7503

Number of nodes: 15128

Time to complete mesh(hh:mm:ss): 00:00:03

Computer name: JAMES

### Solver Information

<table>
<thead>
<tr>
<th>Quality</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solver Type</td>
<td>Automatic</td>
</tr>
</tbody>
</table>

## 5. Results

### 5a. Stress

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Min</th>
<th>Location</th>
<th>Max</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot1</td>
<td>VON: von Mises stress</td>
<td>1.30864e+007 N/m²</td>
<td>(18.5 in, 0.12 in, 0.069282 in)</td>
<td>2.01538e+007 N/m²</td>
<td>(19 in, 1 in, 0.57735 in)</td>
</tr>
</tbody>
</table>
5b. Displacement

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Min</th>
<th>Location</th>
<th>Max</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot2</td>
<td>URES: Resultant displacement</td>
<td>0 mm</td>
<td>(18 in, 1 in, 0.57735 in)</td>
<td>0.0203959 mm</td>
<td>(19 in, 0 in, 9 in)</td>
</tr>
</tbody>
</table>
5c. Deformation
5d. Design Check
6. Appendix
**Material name:** [SW]Plain Carbon Steel

**Description:**

**Material Source:** Used SolidWorks material

**Material Library Name:**

**Material Model Type:** Linear Elastic Isotropic

<table>
<thead>
<tr>
<th>Property Name</th>
<th>Value</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>Elastic modulus</td>
<td>3.0463e+007</td>
<td>psi</td>
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<tr>
<td>Poisson's ratio</td>
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<td>Yield strength</td>
<td>32000</td>
<td>psi</td>
</tr>
</tbody>
</table>