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KSU AUTONOMOUS GO-KART FRAME

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ABSTRACT

An autonomous go-kart frame was required in order to expand the testing capabilities of line detection and line following. The paper below covers the design and construction of this frame. The project life cycle was one semester and the costs could not exceed $650. Every aspect of the design needed to be analyzed on paper or using finite element analysis to ensure the design would effectively meet the design requirements. The autonomous go-kart frame would need to hold a microcontroller, batteries, motor drivers, a camera and sensors to perform its autonomous movement on roads. The two forward wheels would be driven by individual motors, while the rear wheels are on casters. This configuration allowed the vehicle to more and steer along pavement. The final design was successful because it was able to meet both the schedule and the cost requirements.

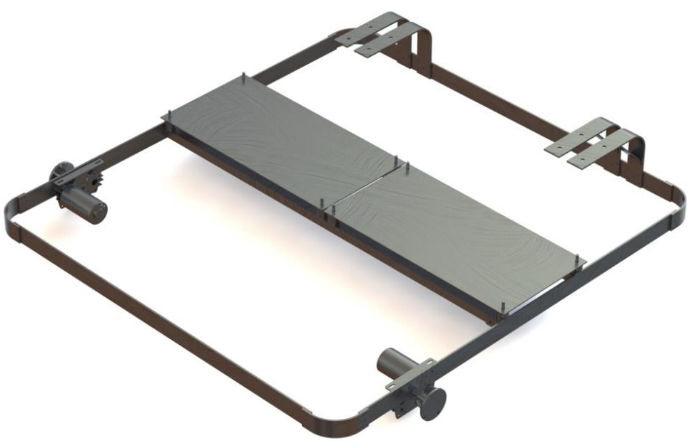

Figure 1: Rendering of the final model assembly.

INTRODUCTION

During the previous semester a peer designed a "Low-cost Platform for Autonomous Ground Vehicle Research" [3]. This design was the initial testing bed for software that would allow the kart to move autonomously through the streets of Kennesaw State University. The project lacked funding for structure, but a new semester leads to new prospects and better funding. This large opportunity for design freedom and educational expansion could not be ignored. A vision of a higher performance, modular and easy to use go-kart frame drove the objectives. The main goals of this project are to improve the functionality of the go-kart in carrying capability, strength, speed, and steering, while keeping cost low.

GATHERING INFORMATION

To begin the design process, a viewing of the formula one team's racecar at KSU was conducted. The race team was nationally recognized and a natural place to start looking when dealing with a moving vehicle. Information obtained about the steering system and wheel base dimension was vital to moving the project forward. After the viewing it became clear that it would be too expensive to build a custom steering system at this time. The race team used professionally manufactured parts and welds their frame together. The professionally cut annuluses are then welded together by the team's most experience welders. After examining the racecar material geometry, a search for material costs was performed. Using simple square models on paper three different quotes were put together. The first quote was an all steel frame with thin walled tubes that would have to be welded together to make a frame. The second quote was simple aluminum bar stock that was bent and riveted and the third was a quote for extruded aluminum 8020. The first round of quotes included CV joint for a shock absorbing system, pivot joints for the steering system, and shocks. All three quotes came in above price point, the cheapest being the aluminum bar stock at $1010. The CV joints were $110 each and the shocks were $15 each. These items along with the pivot joints were cut. After running the quotes again the aluminum bar stock came was only at $481 per appendix, which was back inside the set price limit. The next step was a decision matrix, to ensure the project on schedule.

PROBLEM STATEMENT

Field testing on a previous generation go-kart's wooden frame design revealed the need for a sturdier frame. The previous frame was difficult to drive due to its low torque output and the tended to veer in one direction. The direct drive system did not work when turning and the wooden panel deflects significantly due to the weight of the equipment. Tiny caster wheels in the front of the kart provided little turning ability and would jam often due to deflection. All around the design was effective for the first field test but further progress required a stable rugged platform.

CUSTOMER REQUIREMENTS

The customer required a frame which could mount 100 lbs of equipment and still clear speed bumps at low speed. This would allow the kart to travel along the school road and mount any configuration of equipment required. The new frame needed to be light, have seven sensor mount points, and be able to absorb vibration from the road. The kart would need to be sufficiently light to be carried by two people along with the equipment needed to operate it. The seven sensors consisted of one for the forward camera, an encoder on each of the two drive wheels, and a collision distance sensor on each of the four corners of the kart. The frame needed to be modifiable in case unforeseen challenges arise in the future. Deflection at the caster wheels needed to be less than two degrees to prevent rotational jamming and sticking. The kart also had to be able to turn. Vibration on the equipment needed be kept to a minimum to ensure equipment life.

DESIGN SPECIFICATIONS

The kart would be about four feet by four feet to match the size of a small car and allow for parking simulations. To accommodate a lightweight design requirement the frame needed to weigh less than fifty pounds. The frame also needed be able to navigate speed bumps; the average speed bump is five inches high and eighteen inches deep. To reduce deflection, in the equipment mounting surface and the entire kart to less than an eighth of an inch, rigid beams with supports were used. Materials needed to be strong, lightweight with good fatigue life and corrosion resistance. Many of these choices came down to three main factors; how affordable is it, can it be manufactured and will it satisfy the customer's requirements?

DESIGN MATRIX

The design matrix using score multipliers was used to calculate the best design. The multipliers are based on how important that parameter is to the project. Then a datum concept is picked at random and all other concepts are compared to it. Once a winner is found the datum is switched to the winner and the matrix is run again. After two matrixes the Riveted Bar frame concept was chosen.

Table 1: Design Matrix

	Cost (Low)	Manufacturability (High)	Weight (Low)	Payload (High)	Total	
Multiplier	0.9	1	0.8	0.7		
Aluminum 8020	5	5	5	5	17	Datum
Welded Annuluses	3.5	3	10	9	20.45	
Riveted Bar	8	4	8	8	23.2	
	Cost (Low)	Manufacturability (High)	Weight (Low)	Payload (High)	Total	
Multiplier	0.9	1	0.8	0.7		
Aluminum 8020	3.5	7	2	7	16.65	
Welded Annuluses	3	2.5	7	7	15.7	
Riveted Bar	5	5	5	5	17	Datum

FRONT WHEELS

A minimum of a 10" diameter wheel was required to traverse speed bumps without the frame bottoming out. If a ten inch affordable wheel could be found then it would satisfy this object's selection. Many race car /go-kart manufacturers sell wheels in sets of four and at very high prices. However, the kart requires two different types of wheels since there is no steering system. Harbor freight sells affordable wheels which allows for low cost replacement. Since it is a brick and mortar store, replacement of these parts could be purchased same day if a problem were to arise.

REAR WHEELS

Large ten inch caster wheels are needed for this area of the kart. The rear wheel assembly can take a maximum load of three hundred pounds, which far exceed the working load of the kart. Like the previous parts there needed to be cheap easy replacement with a high safety factor. Rubber tires are prone to wearing out and would be a hassle replacing them. With a vendor already chosen for the front wheels it is simple to search. Harbor freight also offers a ten inch caster system for only $15 each with the top mounted double bearing assembly will allow for easy rotation. Making the choice to purchase Harbor Freight wheels saved a minimum of $50.

DRIVETRAIN

The heritage motors are two 2.5 cm electric motors from the AndyMark Inc. The 12 volt DC motors can run at 5,310 RPM unloaded. They are low torque high RPM motors. Since the motors could not turn the kart individually the prototype required two drivetrains for maneuvering. The data from the prototype made it clear that a drivetrain was needed. This combined with the steering system quotes lead to the decision for two drive train systems. Purchasing the CIMple boxes raised the overall cost by $100, but still saved money compared to $350 required for steering equipment. The Andy mark CIMple box was an obvious choice, it was built for the current motors, the gear ratio is 16:46, and at $50 apiece they are affordable. Adding to their allure was the fact that two of the motors used can be mounted to it giving the kart the ability to double its power in the future. There were also sensor mount points drilled out to record the rpm of the wheels, which satisfied a customer requirement. The drivetrain came with a precision machined shaft with a keyway already cut out allowing for a keyed coupling to be used. The mounting plate had holes drilled ready to mount on purchase to make assembly even easier. Since the CIMple box provided a solution for all of the customer requirements two were purchased to be added to the go-kart.

VIBRATION ABSORBERS COUPLINGS

There are many types and styles of shock absorber available but many of them are expensive and do not allow easy installation. The chosen design needs to be simple, easy to use, cheap and effective. These criteria lead to a simple rubber cylinder with threaded bolts attached to each end for mounting. The size and effectiveness of the absorber was unknown during procurement, this lead to two types being purchased, one eight millimeter large set and one six millimeter small set. The two sizes would go through two field tests to see if they are sufficient for use.

MOUNTING PLATFORMS

The platform must hold a minimum 100 pounds of equipment; this includes multiple batteries, motor drives, and a CPU. The preferred way to get a cheap, light weight, strong and durable platform was to get eighth inch aluminum plate and mount the vibration absorber to it. Composites were considered next but the price increases when a large surface area and thickness are required. Carbon fiber plate and G10 composites were two of the best composites available. However carbon fiber was problematic to work with and G10 prices climb quickly when a four foot by one foot sheet was needed. There was also a concern that the stress concentrations in the mounting holes could crack the brittle composites due to the vibration.

SENSOR MOUNTS

The material selected to hold the 4 sensors mounted on the corner of the vehicle was Aluminum 6061-t6. It matched many of the other components and provided a very strong and versatile structure. The mount was a simple square tube that is three feet long and half an inch wide, the walls are eighth inch thick. Since the weight of the sensor and beam weight was less than half a pound combined, the main driving factor for this component was the deflection due to acceleration and deceleration. Five pounds of force were chosen to size the width and wall thickness, this was derived from the mass of the bar and the sensor assembly mass at a conservative acceleration of 7.5 feet per second squared. This was assuming the cart could reach 15 feet per second in 2 seconds. The component becomes a simple beam and the max deflection is 5.96E-5 inches. This does not account for manufacturing tolerances but under its own forces the beam was very stable.

WHEEL ROTATION SENSOR

The sensors to monitor the wheel velocity were chosen from AndyMark website. They mate up to the drivetrain easily and required no tooling holes or modifications. The optical encoder simply mounted directly on to the drive shaft, where the drive train housing had pre drilled holes.

MODELING

To begin the process of modeling, the purchased pieces were drawn in their simplest forms possible, how they shipped. This meant the manufacturing issues were brought to the forefront while still in the design phase and many of the issues could be solved early. This proved to be an advantage and made manufacturing the parts very stream line later on. An example of this is the main beam which holds the drive train in place. If the part needed a mounting hole, one was added in using Hole Wizard and a drill size was recorded. This insured that all pieces could be made with little use of heavy machinery. The most complicated parts to model where the couplings and the rear wheel bracings. The couplings were hard due to the level of precision required and the rear wheel bracing was hard due to the bend required.

COUPLINGS

With the precision ground shaft to work with a coupling system needed to be manufactured to connect the wheels and drivetrain. This involved designing, analyzing and manufacturing them in house to save cost. Raw material would then need to be chosen and purchased ahead of time so these could be used on the prototype. The first phase was sizing the coupling dimension, things such as thickness, height, diameter and features (figure 2). The wheel bolt pattern was found using caliper and the shaft size and tolerance was given in the drivetrain specification. A key slot was also needed and this was a manufacturing issue at first. Later after talking to a few machinists it was discovered that a post machining process was necessary.

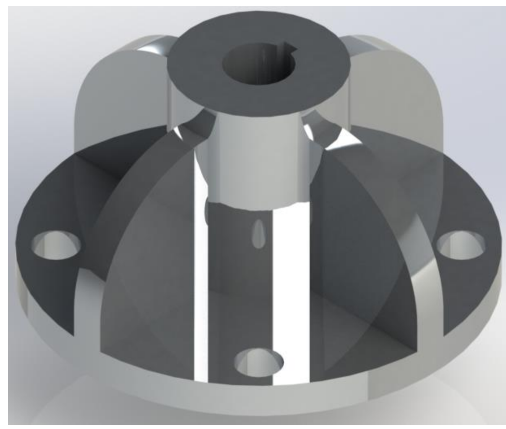

Figure 2: Rendering of coupling 1.0.

After the keyway was performed the coupling needed to be analyzed to ensure that it was in the ballpark on thicknesses. The bolt preload needed to be considered as well and sizing the new bolts that would hold the wheel and coupling together need to be found too. After running a shear stress calculation on the included bolts, it was discovered they had a factor of safety was in the teens. Next the moment and preload tension were calculated along with the combined load of all three. The FEA to support the hand calculations is below in Figures 3 and 4.

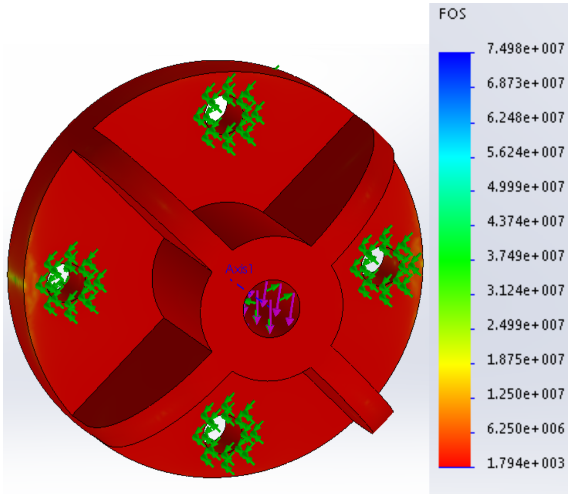

Figure 3: Factor of Safety fringe plot of Coupling 1.0.

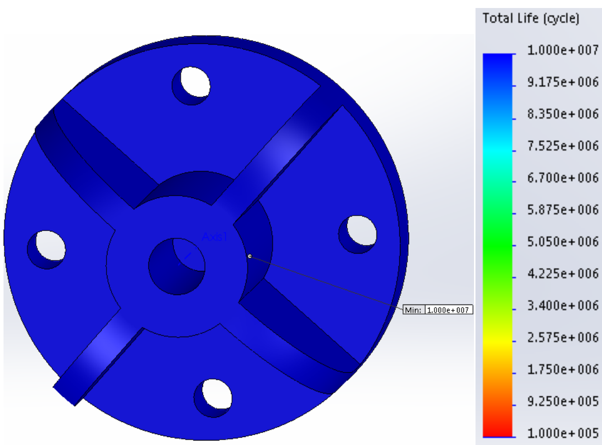

Figure 4: Fatigue Life fringe plot of Coupling 1.0.

The next phase was optimizing the design, finalizing a material and tolerancing the hole for the drive shaft for a loose press fit. For material aluminum 6061-T6 was used for its great properties, the diameter and height of the part was chosen and the raw material was purchased. Coupling 2.0 (Figure 5) came out of the optimization lighter and more efficient.

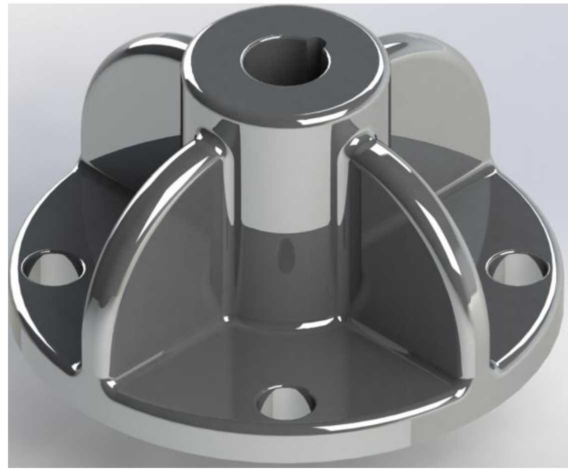

Figure 5: Rendering of coupling 2.0.

FEA

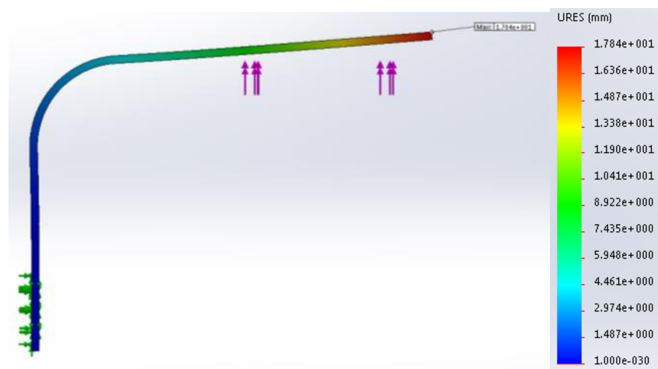

Figure 6: Displacement fridge plot of Rear Wheel Bracket 1.0.

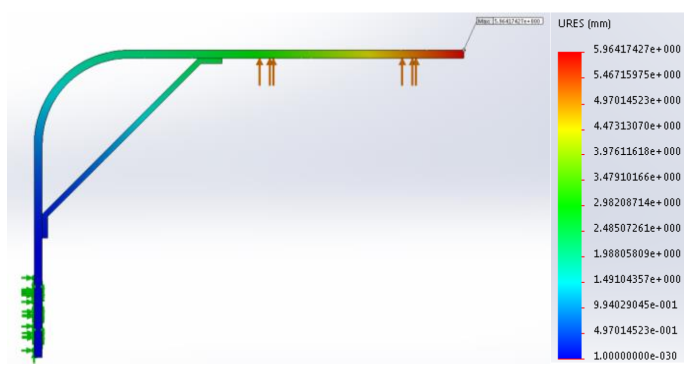

Figure 7: Displacement fridge plot of Rear Wheel Bracket 2.0.

In Figures 6 and 7 a clear difference can be seen in the displacement of the Rear Wheel bracket designs. For this part the driving analysis factor was the displacement of the end, because if the angle becomes too steep the caster wheels will bind. This was clearly demonstrated again in Figures 10 and 11, where the factor of safety never drops below five.

All components were analyzed using a combination of finite element analysis and hand calculations. The entire frame assembly underwent many simulations to determine if the system would work. (Figures 12, 13, and 14) Ensuring the system will not fracture when loaded to the specified weight. The results of the coupling FEA can be seen in Figures 8 and 9. The coupling is constrained at the bolt holes with a force and torque applied to the center drive shaft holes.

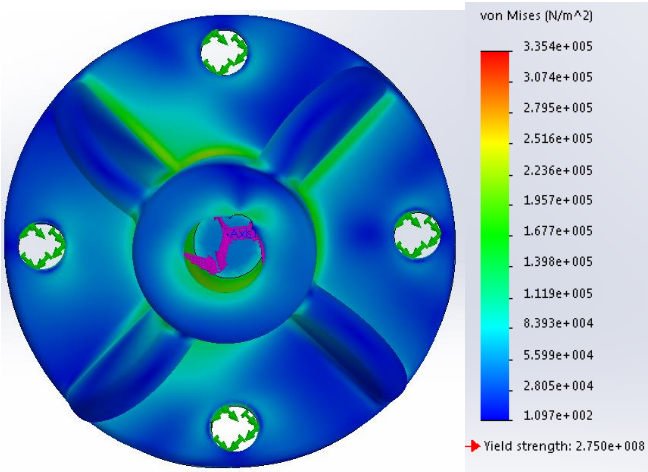

Figure 8: Stress fridge plot of Coupling 2.0.

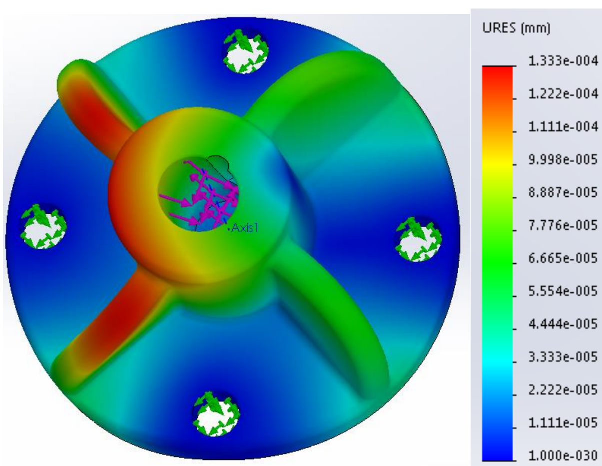

Figure 9: Displacement fridge plot of Coupling 2.0.

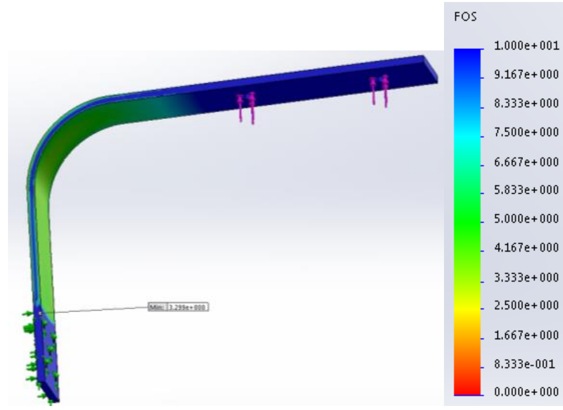

Figure 10: Factor of Safety fridge plot of Rear Wheel Bracket 1.0.

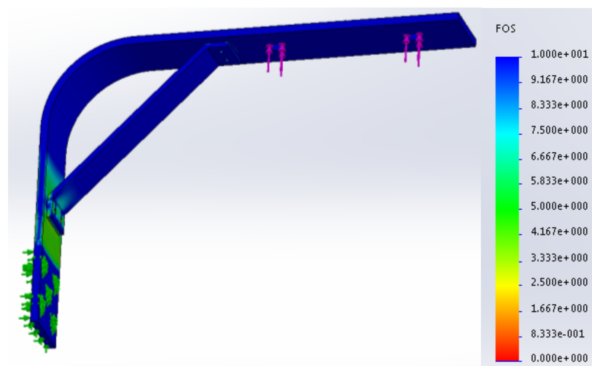

Figure 11: Factor of Safety fridge plot of the Rear Wheel Bracket 2.0.

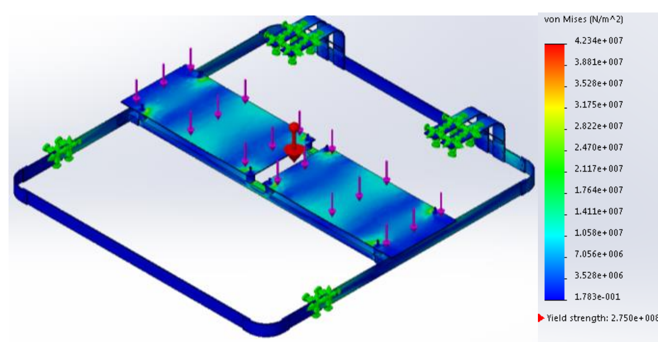

Figure 12: Von Mises Stress fridge plot of the Final Assembly.

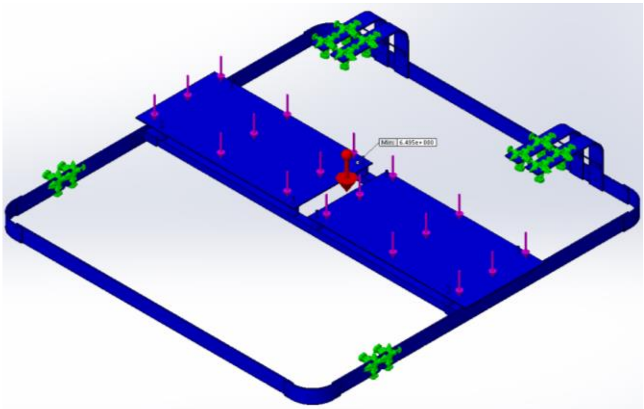

Figure 13: Factor of Safety fridge plot of the Final Assembly, with the lowest FOS being 6.495 around the platform holes.

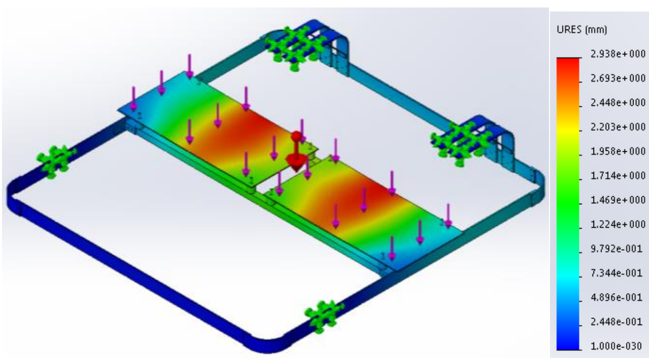

Figure 14: Displacement fridge plot of the Final Assembly.

FATUIGE

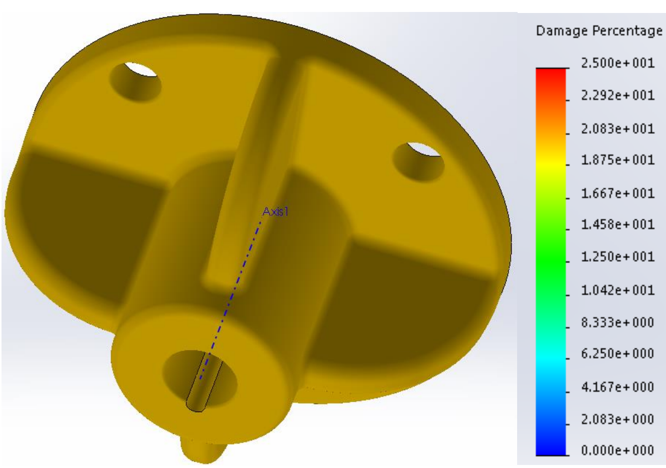

Figure 15: Damage Percent after a million cycle's fridge plot of Coupling 2.0.

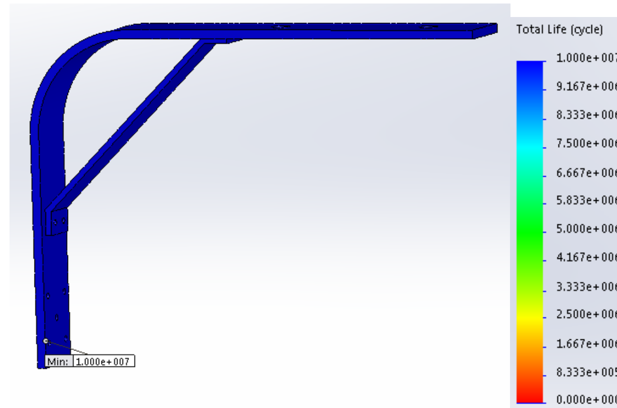

Figure 16: Life Cycles fridge plot of Rear Wheel Bracket 2.0

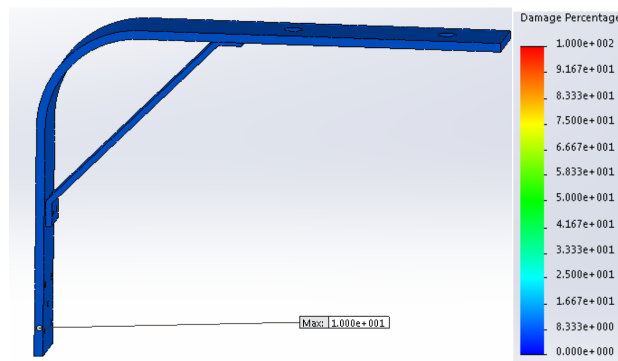

Figure 17: Damage Percent fridge plot of Rear Wheel Bracket 2.0.

Critical components were analyzed using a fatigue simulation package (Figures 15-17). This ensured that key components under cyclical loading would not wear out of become damaged during the life of the vehicle.

BUCKLING ANALYSIS

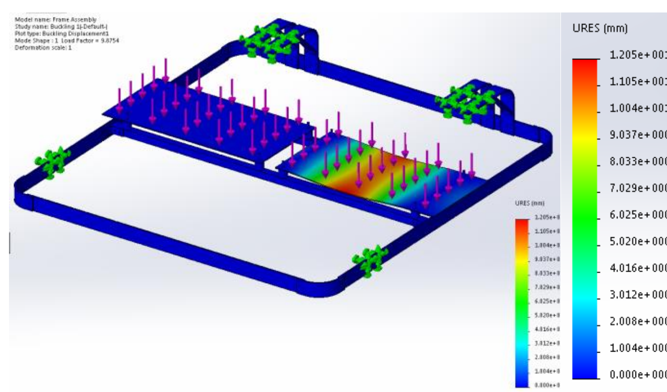

Figure 18: Buckling Analysis of the Entire Vehicle

The entire structure was tested using a buckling analysis package, with data loaded directly from the stress FEA. Isolated buckling was a large concern when considering the usability of the kart. Figure 18 does show areas which could suffer isolated buckling; the right hand platform deflects twelve millimeters. This was further analyzed using hand calculations which yielded very low displacement values. It can also be seen that the left hand platform in Figure 18 does not deflect more than one or two millimeters. This was further cause for concern and was a critical factor in deciding whether to analysis the platform further.

PRE-ASSEMBLY

The only components that needed pre assembly were the motor, drivetrain, and wheel assembly. This was done ahead of schedule to allow for use on the temporary cart. The drive train was assembled using the AndyMark Inc. published video.

MANUFACTURING

The first pieces to be manufactured were the two couplings; this was a request by the customer. Once the material, tooling and FEA were in and completed manufacturing could begin. The tolerances and dimensions were double checked per machining good practices. The CNC machine schedule was developed before this project but is was modified to ensure minimal tool damage. However two end mill bits were broken on the first coupling, the first broke due to a feed speed error. The aluminum became hot and gummy due to the temperature, and then bonded to the carbide steel end mill bit. The second bit was smashed by the machine due to operator error. After the first bit broke the machine was started half way through the milling cycle, this was a huge mistake! The end mill bit was driven deep into the material at the jogging velocity and the bit was shattered. After these two mistakes were corrected the milling process went smoothly. With the coupling done, the tolerances and drive train assembly were tested before the delivery deadline. The next pieces to be manufactured were the main 90 degree corner pieces which allowed for the cart to begin taking shape. The bends were made on a Chinese pipe bender and then holes were drilled in the desired pattern with a #30 drill bit. Match holes were then drilled in the main beams to ensure a clean fitting joint. Once the pattern was copied and the mating joints were numbered, Clecos were installed. These are temporary mechanical rivets, and allow for the joint to be assembled and disassembled with no damage to the material. The Clecos allowed for a rigid layout to be done and a few mistakes were found and then eliminated. Cut lengths were checked and then the two middle support structures with L-brackets were added to the frame. The forward camera plate was riveted into place along with the camera post bracket, followed by the mounting holes for the drive train. The drive train was not attached yet to allow for easy maneuvering of the assembly. The rear wheel mounting brackets were cut and bent followed by the bracings. These were then mounted to the frame using match holes and then riveted into place. It was important to allow for all of the manufacturing imperfection and again, match holes were used to ensure the rear wheels could be mounted properly. The wheels and drive train were added next to form an almost complete cart. The main mounting plates were added using match and tapped holes, then sensor beam and finally the camera post was put into place.

PERFORMANCE VALIDATION

Three tests were performed on the frame before it was delivered. The first test was done by analyzing the frame for excessive deflection when loaded with hand pressure. As rudimentary as it sounds this was a vital step in checking the handmade kart. The criteria for passing the test were no visual damage or errors in the construction. When this test was passed the kart was loaded to 70% the max recommended load and pushed at speed. This checked the operations of the vehicle under load without damaging it in case of issues. The criteria to pass this test were no excessive or unpredicted displacement and smooth operation of the vehicle. The third and final test was to load the vehicle to 140% of the recommended load. The vehicle was not operated under these conditions but inspected for any mechanical failures. The FEA analysis showed that this load would not damage the kart and performing the test ensures the quality of the manufacturing. The criterion for success was no failure and no audible straining.

FUTURE RECOMMENDATIONS

Many future recommendations are to improve the karts performance life and increase its weight capacity. The top recommendation is to add a support beam from the forward middle rail to the forward beam that has the camera mounted to it. This would help eliminate vibration in the camera post and provide a clearer picture. Adding two more motors to the frame would allow for faster operating speed and more realistic testing of the visual code. The final recommendation for the vehicle is to add support material to both rear and front wheel supports. These four areas were under the most stress. Adding a welded backbone to all four of the rear brackets would allow for a 40% increase in operation load. Also adding a bottom mounting plate supported on both side to the forward motor mount would allow for the same load increase.

CONCLUSION

The fabrication of the frame took over forty man hours, with another forty-eight hours of CNC time. The frame includes wheels, tire, motors, structure, drive train and sensors mount points. The combined weight of these items was less than fifty pounds allowing for a two man team to easily carry an unloaded structure. Final costs of the project totaled $612, which was $130 more than the original estimate but still less than the price limit. This was a 21% error in estimated cost but, there was a surplus of material when the project ended. All of this time and money gave way to a go-kart frame that is light weight, durable, modular, and stable. The kart can hold one-hundred pounds of equipment that allows for autonomous driving testing. It makes it cheaper and easier to test the next wave of technology that will make the world a safer place.

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[5] "www.AndyMark.com," AndyMark Robot Parts Kits Mecanum Omni Wheels.

APPENDIX A

Category	Description	Price	Quantity
Front Wheels	Angled Caster Wheels	$14.99	2
Rear wheels	Medium width, good price	$7.99	2
Drive Train	CIMple Box, single stage gear	$50.00	2
Vibration absorption	Rubber pads M8	$12.80	1
	Rubber pads M6	$6.00	1
Frame	3/16 X 2 6061 Aluminum Flat 4' long	$11.88	5
	1 x 1 x 1/8 wall 6063 Aluminum Square Tube 4' long	$14.04	2
	2 X 2 X 3/16 Aluminum Angle 6061-T6 Aluminum Structural Angle 2' long	$12.24	1
	.125 (1/8) thick 3003 Aluminum Sheet 1x2'	$22.44	1
	1/8 X 1-1/2 6061 Aluminum Flat 4' long	$4.52	2
End Mill Bit	Carbide End Mill, 1/8In, 4FL	20.41	1
Rivets	Rivet, Brazier, 1/8 Dia, 1/4 L, PK 250	9.27	1
Raw Material	Multipurpose 6061 Aluminum 4" Diameter, 3" tall	23.87	2
Lock washers	3/8" Screw Size, 0.385" ID, 0.680" OD	4.42	1
	1/4" Screw Size, 0.260" ID, 0.487" OD	1.72	1
Washers	Type 18-8 Stainless Steel SAE Flat Washer 3/8" Screw Size, 0.406" ID, 0.812" OD	7	1
	Type 316 Stainless Steel SAE Flat Washer 1/4" Screw Size, 0.281" ID, 0.625" OD	7.55	1
Nuts	Zinc Yellow-Chromate Plated Steel Hex Nut Grade 8, 3/8"-16 Thread Size, 9/16" Wide, 21/64" High	7.65	1
	Zinc Yellow-Chromate Plated Steel Hex Nut Grade 8, 1/4"-20 Thread Size, 7/16" Wide, 7/32" High	3.31	1
Bolts	Coated High-Strength Grade 8 Steel Cap Screw Corrosion-Resistant, 1/4"-20 Thread, 2" Long	7.31	1
	Grade 8 Steel Serrated Flange Head Cap Screw 3/8"-16 Thread, 1" Long, Fully Threaded	4.89	2
	Kart Sub-Total	$481.45	
Rivets	Rivet, Round, 1/4 Dia, 1 1/2 L, PK 50	20.07	1
Rivets	Rivet, Round, 1/8 Dia, 1 In L, PK 250	19.13	1
Vibration absorption	Rubber pads M8	$12.80	1
Frame	.125 (1/8) thick 3003 Aluminum Sheet 1x2'	$22.44	1
for the rear wheel frame	3/16 X 2 6061 Aluminum Flat 6' long	$10.02	1
	2 x 1 x 1/8 wall 6063 Aluminum Rectangle Tube	$11.66	1
Canera post	3/4 SCH 40 (1.05 OD X .113W) 6061-T6 Aluminum Structural Pipe	$11.24	1
	1/2 x 1/2 x 1/16 wall 6063 Aluminum Square	$10.56	1
Camera Post	#47 Rectangular base flandge		1
	Kart Total	$612.44	

APPENDIX B