DRILL-POWERED CART

DRILL KART ALPHA

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PROBLEM DEFINITION

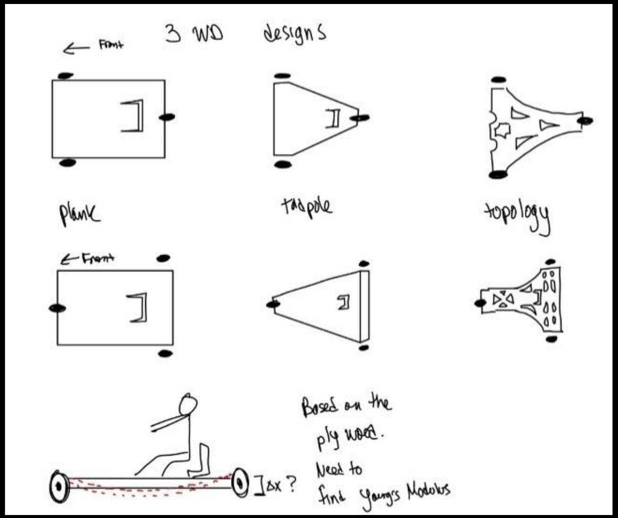
There are negative effects of internal combustion engines (ICEs) in vehicles on the environment and daily lives, specifically in terms of pollution and carbon emission. There is a need for cost and energy efficient transportation alternatives that produce fewer emissions. These carts will be designed to start as an on-campus use, allowing for environmentally friendly forms of transportation for students. In addition, this cart will race against the two other competitors during the design day.

REQUIREMENTS

- The vehicle will be powered by a single electric drill, each team will use the same drill
- The vehicle body will be made from plywood
- The vehicle can be optimized by each individual team
- The vehicle must have a lap style safety belt and horn for the safety purpose
- Pinch points must be guarded and pass inspection by Professor Muir
- Payload will be standardized
- Cart must sustain the weight of the driver
- The vehicle must utilize a non-traditional steering system
- The vehicle must be able to maneuver the course
- Each team will use the same wheels

SPECIFICATIONS

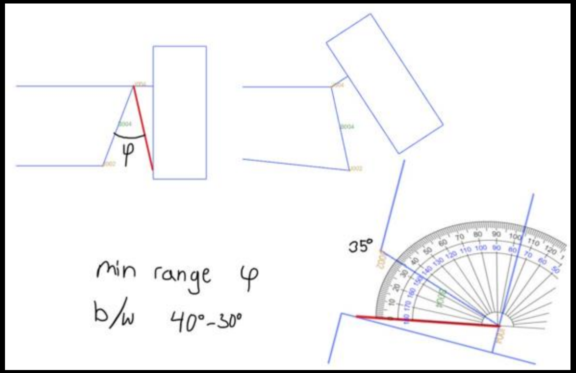
- The vehicle cannot exceed 25 mph
- Payloads must be within 5 lbf of each other
- Maximum brake distance of 15 feet at maximum speed
- The vehicle must have more than or less than 4 wheels
- Turn radius of less than 11 ft.
- Vehicle dimensions 6ft. x 4ft. x 4ft.
- Cart must travel up a slope of 4.3 degrees

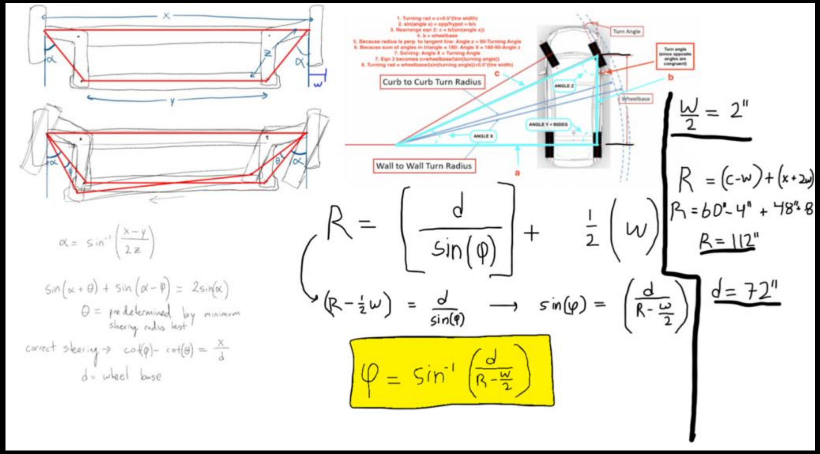


Frame Criterion 2.0	Simple Plank Rectangle (baseline)	Tadpole shape (3WD)	2D topology with plank running along frame (front steer)	Inverted Tadpole shape (3WD)	Inverted 2D topology with plank running along frame
Time (design)	0	-	-	-	-
Weight	0	+	+	+	+
Flexibility	0	-	+	-	+
Manufacturability	0	=	=	=	=
Driver Comfort	0	=	=	=	=
Steering Space	0	+	+	-	-
Drivetrain space	0	-	-	=	=
Seat and brakes space	0	-	=	=	=
Total	0	-2	1	-2	0

CONCEPT/DESIGN DISCUSSION (FRAME)

- Pugh Matrix to organize the concepts for the shape of a frame around a 3 wheeled kart was made to gather a better sense of which concept should be explored further. Four main concepts were considered in the Pugh Matrix.
- The first concept was a simple tadpole shape, usually in recumbent bikes, second concept was the tadpole shape but topologically optimized to further reduce weight in the frame, and the other two concepts being the tadpole shape facing the opposite way, as well as the sheet of plywood being the baseline.

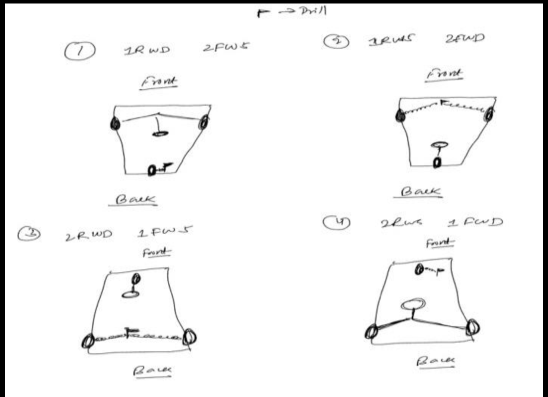


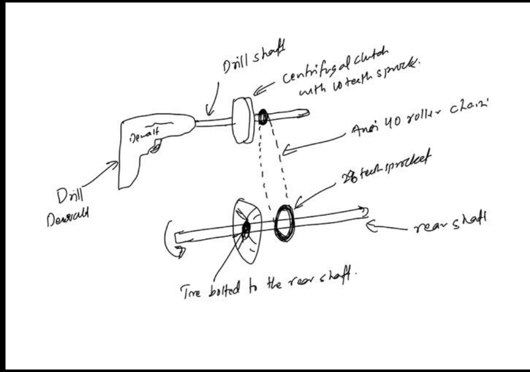


Steering	Baseline (Steering Column)	Joystick	Hand Levers
Manufacturing	0	-	+
Assembly	0	0	0
Handling	0	-	+
Control	0	0	-
Turning Radius	0	0	+
Ergonomics	0	+	-
Total	0	-	+

CONCEPT/DESIGN DISCUSSION (STEERING)

- Without the option to use a steering wheel and central steering column, new ideas for steering were conceived. Two hand levers with an incorporated Ackermann link was decided upon to be the easiest to manufacture and control. Calculations to determine the minimum required steering angle and turn radius were based upon the course.

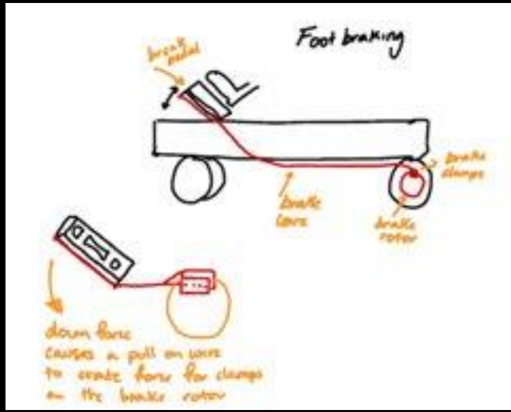


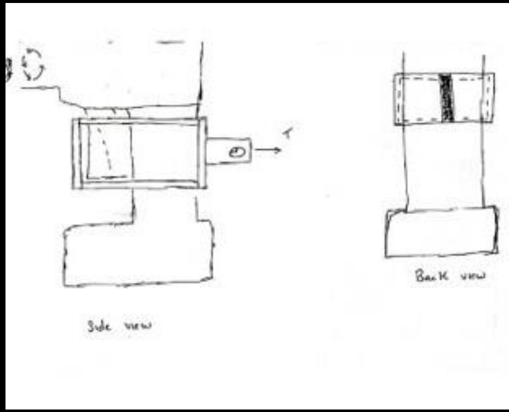


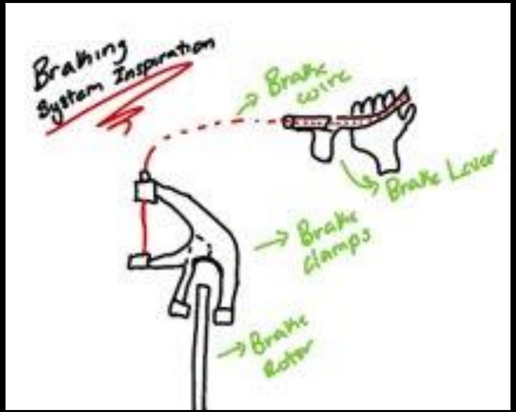
	1) 1 RWD 2 FWS	2) 1 RWS 2 FWD	3) 2 RWD 1 FWS	4) 2 RWS 1 FWD
Complexity	0	-	0	0
Maneuvering	0	-	-	-
Assembly	0	-	0	-
Total	0	-3	-1	-2

CONCEPT/DESIGN DISCUSSION (DRIVETRAIN)

- Pugh selection matrix was used with complexity, maneuvering, and assembly as three criteria to select the drivetrain design from four different choices.
- One rear wheel drive and two front wheel steering cart design was selected based on stability, weight distribution, tighter turns, and greater precision.
- Chain system was used to connect the drill on the drive shaft to the rear shaft supporting rear wheel, and a single gear system was chosen for reduced complexity and increased reliability.







Braking Methods	Disc Brake	Drum Brake	Roller Brake
Complexity	0	-	-
Effectiveness	0	+	-
Assembly Efficiency	0	-	+
Thermal Efficiency	0	-	-
Cost	0	-	0
Total	0	-4	-3

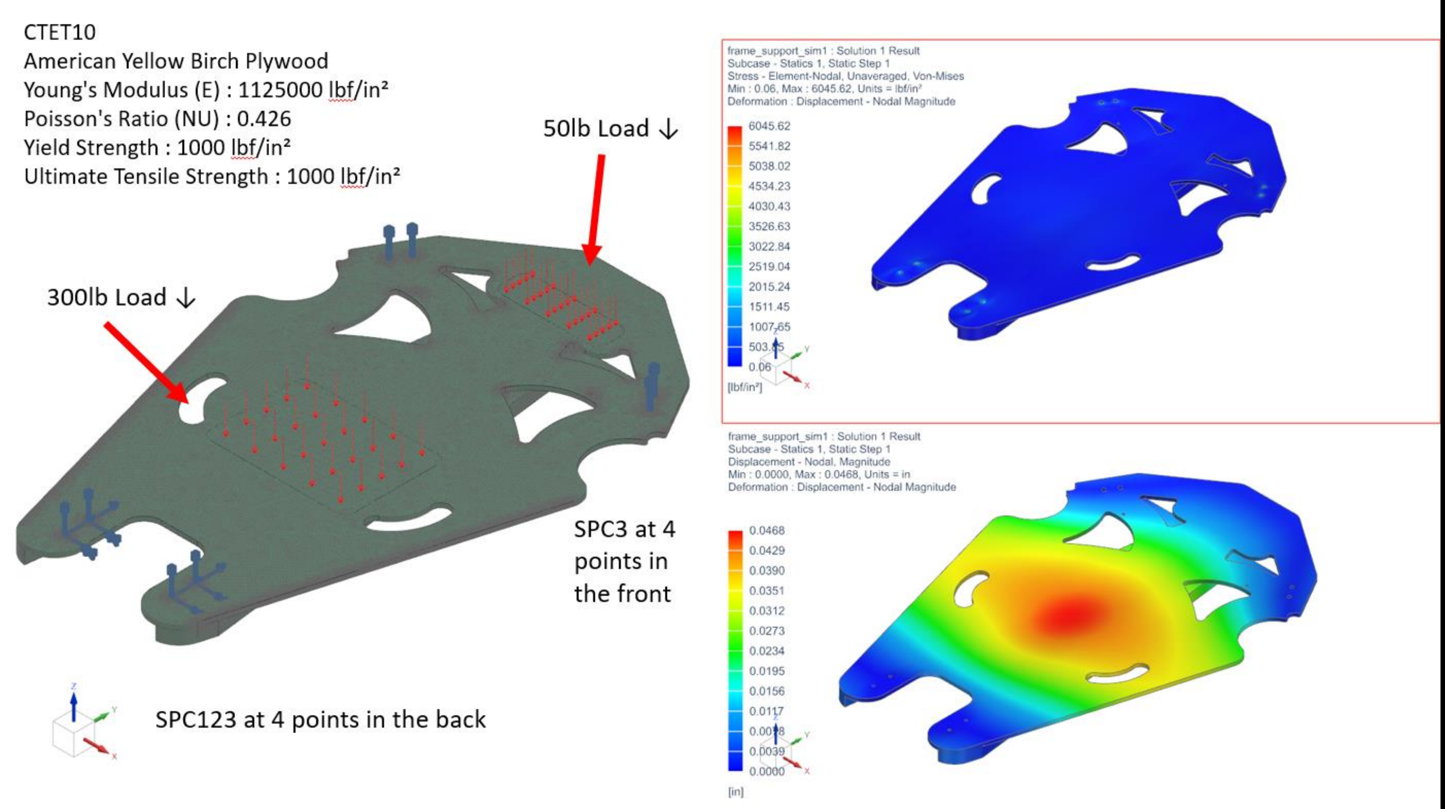
CONCEPT/DESIGN DISCUSSION (USABILITY)

- Pugh selection matrix was used with complexity, effectiveness, and efficiency as the main components in order to decide what braking system to use.
- Final decision being the disc mechanical brake.
- Deciding between hand braking and foot braking, hand braking became the best option for comfort and efficiency on the frame sizing.
- Coming up with a drill engagement system took 4 iterations, finally using a spring mechanism as the final one.

IMPORTANT ANALYSIS/SIMULATION

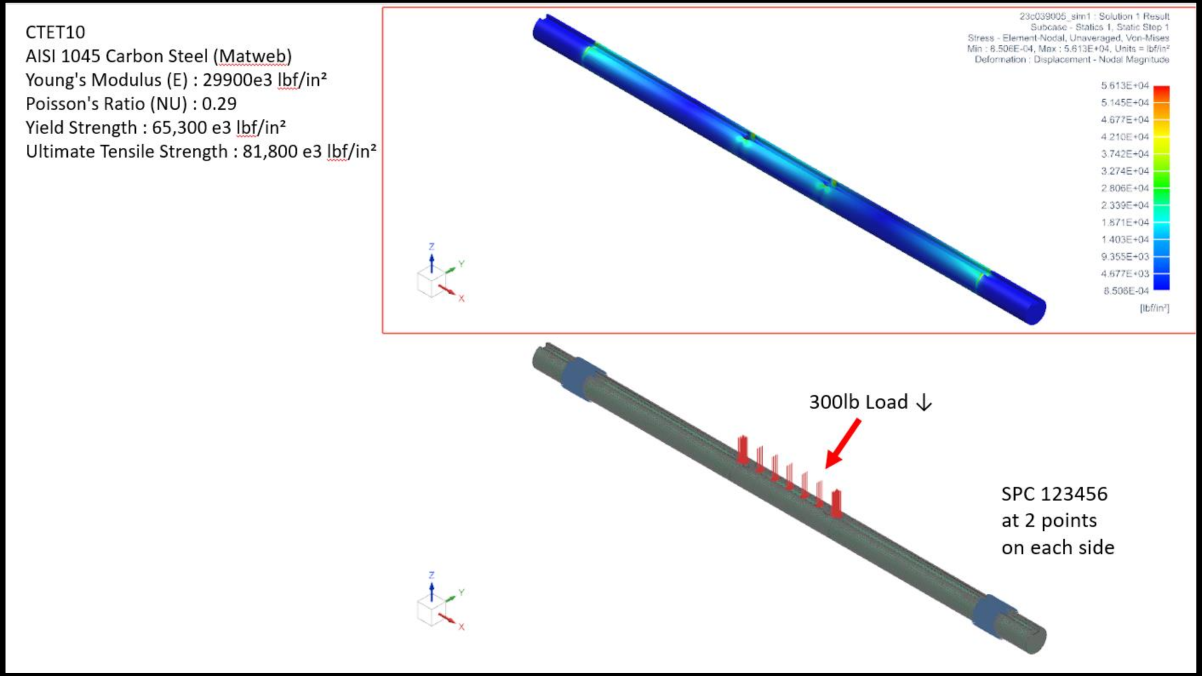
MECHANICAL ANALYSIS

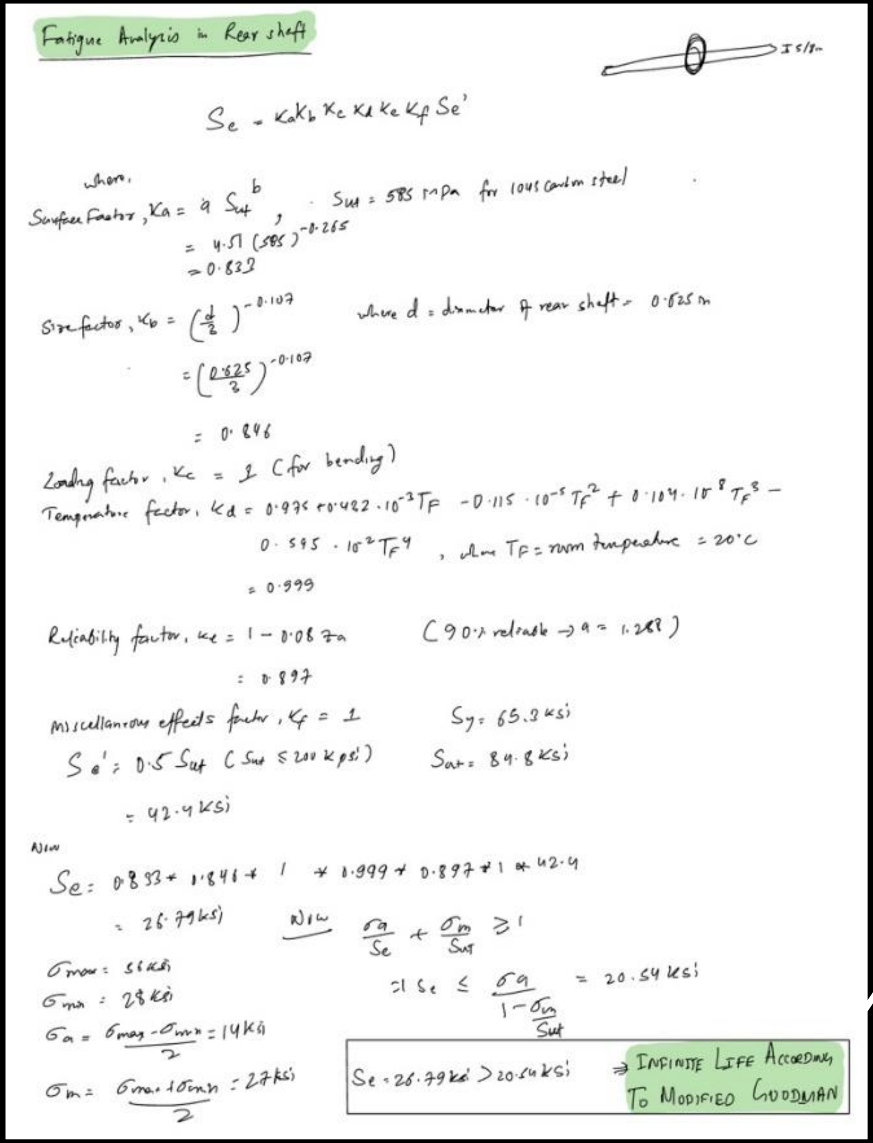
- The mechanical properties of the plywood were crucial in modeling the computer simulation and design of the frame, and a flexure test was conducted to determine the Young's Modulus of the American Yellow Birch plywood used.
- The frame was modeled using Finite Element Analysis (FEA) under a simple supported statics load case, with constraints and RBE2s used to simulate the wheels and suspension connection points. Supports were placed underneath the frame to stiffen it and reduce flexure based on the fundamental analysis and primary design.



IMPORTANT ANALYSIS/SIMULATION

The fatigue analysis was performed on the rear shaft made from 1045 Carbon Steel which had a diameter of 5/8 inch. The other analysis done were Fundamental/Dynamic analysis on gear ratio, tolerance analysis on steering connection with frame, material selection, fastener torque analysis, bearing analysis and spring analysis





Fatigue Analysis in Rear shaft

$S_e = K_a K_b K_c K_d K_e K_f S_e'$

where,

Surface Factor, $K_a = a\,S_{ut}^{\,b}$, $S_{ut} = 585$ MPa for 1045 carbon steel

$= 4.51\,(585)^{-0.265}$

$= 0.833$

Size factor, $K_b = \left(\frac{d}{3}\right)^{-0.107}$ where d = diameter of rear shaft = 0.625 in

$= \left(\frac{0.625}{3}\right)^{-0.107}$

$= 0.846$

Loading factor, $K_c = 1$ (for bending)

Temperature factor, $K_d = 0.975 + 0.432 \cdot 10^{-3} T_F - 0.115 \cdot 10^{-5} T_F^2 + 0.104 \cdot 10^{-8} T_F^3 - 0.595 \cdot 10^{-12} T_F^4$, where T_F = room temperature = 20°C

$= 0.999$

Reliability factor, $K_e = 1 - 0.08\,z_a$ (90% reliable → a = 1.288)

$= 0.897$

Miscellaneous effects factor, $K_f = 1$

$S_y = 65.3$ ksi

$S_e' = 0.5\,S_{ut}$ ($S_{ut} \le 200$ kpsi)

$S_{ut} = 84.8$ ksi

$= 42.4$ ksi

Now

$S_e = 0.833 * 1.846 * 1 * 0.999 * 0.897 * 1 * 42.4$

$= 26.79$ ksi

Now $\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}} \geq 1$

$\Rightarrow S_e \leq \frac{\sigma_a}{1 - \frac{\sigma_m}{S_{ut}}} = 20.54$ ksi

$\sigma_{max} = 56$ ksi

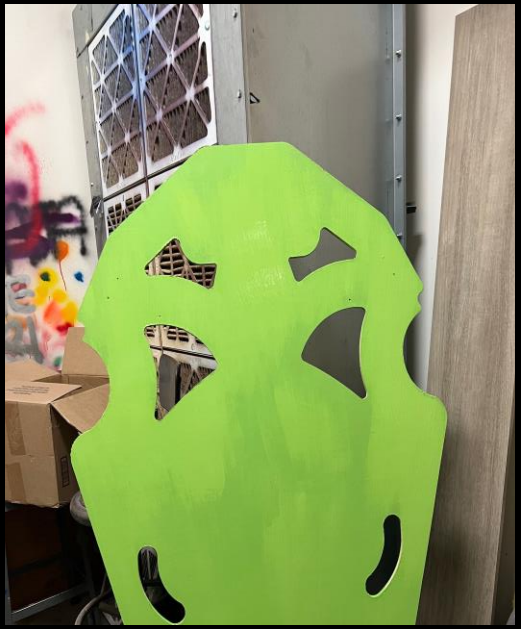
$\sigma_{min} = 28$ ksi

$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} = 14$ ksi

$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} = 27$ ksi

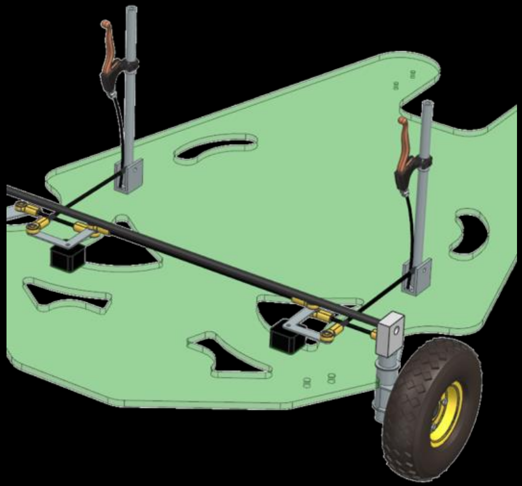
$S_e = 26.79$ ksi > 20.54 ksi ⇒ INFINITE LIFE ACCORDING TO MODIFIED GOODMAN

MANUFACTURING (FRAME)



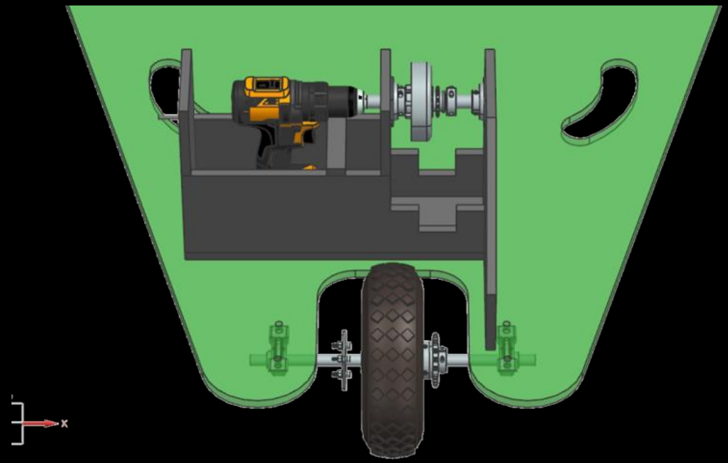
- Once the final design was decided, the frame needed to be cut. For this, the CAD model was programmed on NX Manufacturing to prepare the Shop Bot CNC Router.
- When the cart was being assembled, the team quickly realized that the frame would not be able to support the wheels and a driver, so, a plan to reinforce the frame from underneath was devised.
- The first iteration was running aluminum U-brackets underneath the frame with a bolted connection. Unfortunately, that did not provide enough stiffness and support. So, it was decided to remove the U-brackets and implement the second iteration.
- Using a system of 2x4 wood planks running horizontally and vertically underneath the entirety of the car, we provided support and stability to the cart.

MANUFACTURING (STEERING)



- Steel was used to build the steering knuckle due to the weight distribution and moment considerations. The components were cut using plasma cutting and horizontal band saw and were TIG welded together.
- Preload bar supports were cut from steel rod on the mill due to its ease of manufacturing and low stresses in the block to support the camber of the front wheels.

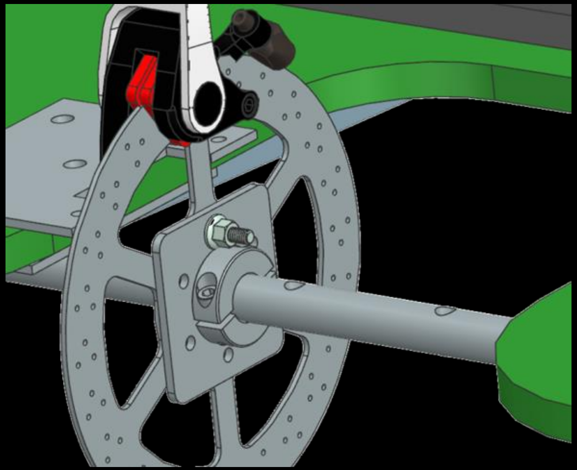
MANUFACTURING (DRIVETRAIN)

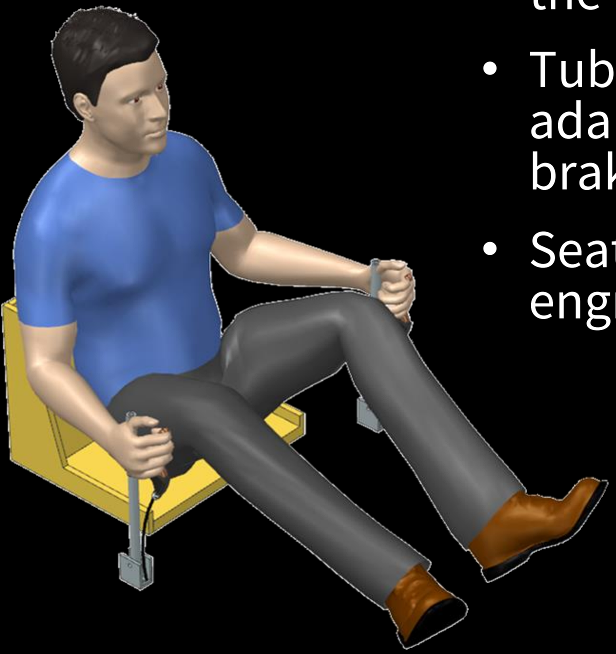


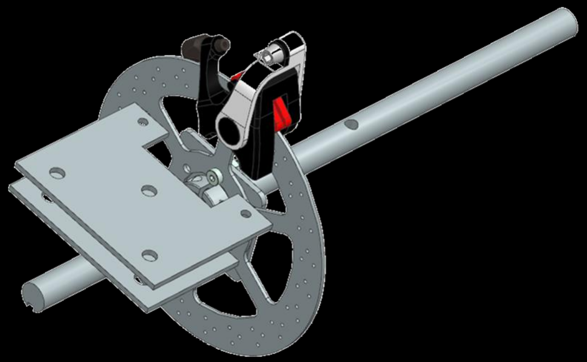
- Aluminum 6061 used for drill shaft and 1045 Carbon Steel used for rear shaft due to their strength and stiffness.
- Diameter of drill shaft was reduced, and a triangle was added to the front for proper drill grip using lathe machine
- Holes were made together in the milling machine through the two rear shafts and the tire support for tight fit tolerance.
- The sprockets were chosen properly to transmit torque as well as allow the required speed and keyed into the shafts.
- Centrifugal clutch was used in the drive shaft to prevent from stalling and allow free-wheel

MANUFACTURING (USABILITY)

- Aluminum 6061 is the main component for the braking system.
- Created a rotor adapter that would connect the braking rotor to the rear shaft.
- Calipers for the braking rotor were mounted using an aluminum sheet that was angled on a piece of wood connecting to the frame. Supports were added to both the bottom and top of the frame.
- Tubes were cut to size and a 3D printed adapter piece was mounted to mount the braking/accelerating handles.
- Seat manufactured from wood and laser engraved for aesthetics.







TESTING AND EVALUATION

The specifications and requirements were tested upon the completion of the cart manufacture and assembly.

- The theoretical maximum speed allowed by the gear ratio is 14 mph, which falls within the speed requirement of 25 mph, and the actual average speed was tested to be 10.07 mph.
- The cart passed payload tests up to 230 lbf and was inspected for the specified number of wheels.
- The cart was able to make a turn of radius 6 ft. which was tested on the track, around the George Eastman statue.
- Its dimensions were measured and were within 6ft X 4ft X 4ft volume space.
- The vehicle also comfortably went up the ramp of 4.3 degrees.
- The braking distance was measured to be 14 ft. which was within 15 ft. specified distance.

FUTURE WORK

- To improve the design, further analysis and testing of subsystems such as drivetrain, frame, usability and steering should be conducted.
- Multiple gear systems in the drivetrain can provide necessary torque adjustments.
- A better alternative to 2x4 lumber should be explored to support the plywood without compromising clearance height.
- Hydraulic brakes could improve braking distance, though they may be costly.
- The steering mechanism should be reinforced to prevent frame flexing and wheel misalignment.

CONCLUSION

We would like to acknowledge the project manager Christopher Muir for this opportunity. We would also like to acknowledge Chris Pratt, Mike Pomerantz, Jim Alkins, Peter Miklavčič, Bill Mildenberger, Conor McCole and our TA, Seungju Yeo for their assistance in the shop and their support answering questions. They were all a huge help in guiding us throughout our development and manufacturing process.