HPVC at UCI

APRIL 2023

PROBLEM DEFINITION

- Design, manufacture, and test an ergonomic, electric recumbent bike for an endurance race

RACE

- 2.5 hour relay
- 1.5km laps
- Patches of rough pavement
- 5% grade uphill, 7% grade downhill
- Cargo parcel
- Hairpin turns & Slalom sections

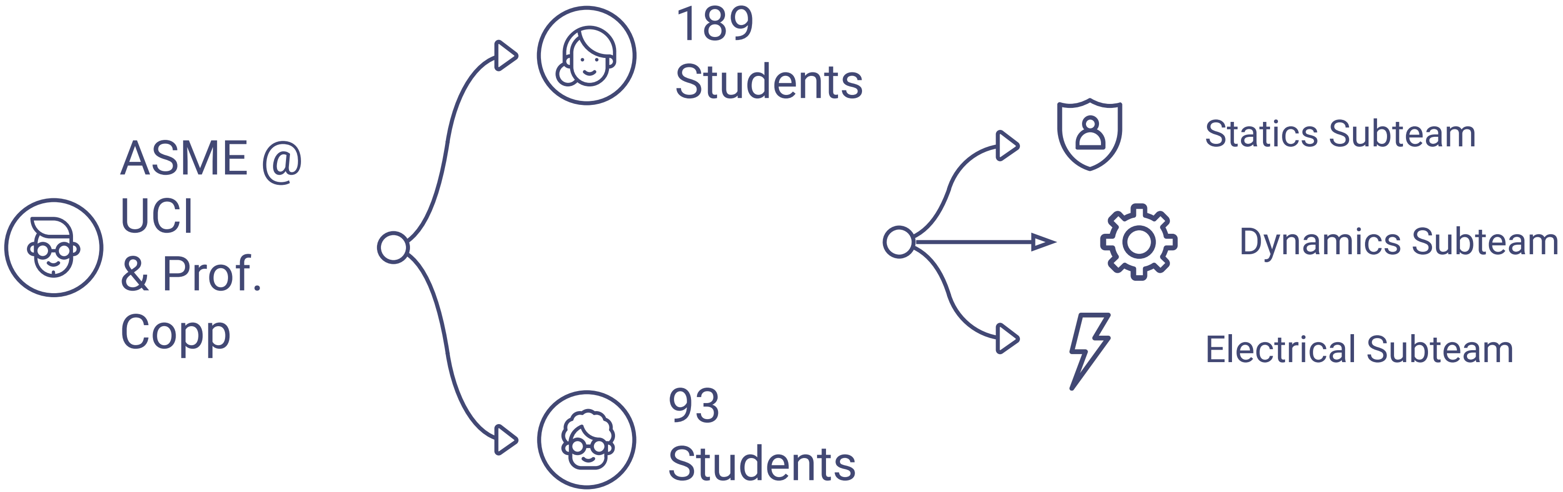
SAFETY

- 25km/hr to 0 within 6m
- 8m turning radius
- Brakes for each front wheel
- Rollover system with 2670N top load, 1330N side load

ELECTRICAL

- One electric motor (500W maximum rating)
- 10 Ah capacity battery
- Battery isolated from driver
- Fireproof

ORGANIZATIONAL CHART



01. STATIC SUBSYSTEM

Keep the rider safe and comfortable

Bike Elements

01. Front

02. Back

Steering
Breaking
Drivetrain

RPB
Rear Wheel
Seat

Stable
Can't tip over

Ergonomic
Riders must be comfortable

Safe
Must keep rider safe

Presentors: Darren

Tubing

	Outer Diameter (in)	Wall Thickness (in)	Cost/in	Rank	Max stress (N/mm^2)	Rank	Max displacement(mm)	Rank	Max strain	Rank	Weight/in	Rank (weight	Mount-ability
	1	0.125	$0.57	1	4.322E+07	17	1.563E-01	17	5.038E-04	17	0.405	1	17
C	1.25	0.125	$1.38	5	2.435E+07	15	8.087E-02	15	3.099E-04	15	0.52	2	16
I	1.5	0.125	$2.20	14	1.674E+07	13	4.913E-02	12	2.064E-04	13	0.635	4	14
R	1.75	0.125	$2.62	16	1.289E+07	10	3.333E-02	7	1.491E-04	10	0.75	6	13
C	2	0.125	$1.57	8	9.258E+06	5	2.435E-02	5	1.124E-04	6	0.866	8	11
U	2.5	0.125	$1.88	11	1.337E+06	2	3.408E-03	2	1.607E-05	2	1.096	10	7
L	3	0.125	$1.47	7	9.650E+05	1	2.422E-03	1	1.152E-05	1	1.33	13	6
A	1.5	0.25	$1.72	9	1.105E+07	7	2.980E-02	6	1.316E-04	8	1.156	12	12
R	1.75	0.25	$1.89	12	8.201E+06	4	1.939E-02	4	8.895E-05	4	1.39	14	10
	2	0.25	$2.70	17	6.035E+06	3	1.373E-02	3	7.209E-05	3	1.617	16	8
S	1	0.125	$0.79	2	3.13E+07	16	9.92E-02	16	3.11E-04	16	0.526	3	15
Q	1.25	0.125	$1.02	3	2.07E+07	14	5.59E-02	13	2.27E-04	14	0.654	5	9
U	1.5	0.125	$1.12	4	1.45E+07	11	3.94E-02	10	1.50E-04	11	0.809	7	5
A	1.75	0.125	$1.76	10	1.13E+07	8	3.41E-02	8	1.35E-04	9	0.956	9	4
R	2	0.125	$1.40	6	1.05E+07	6	3.43E-02	9	1.00E-04	5	1.102	11	3
E	2.5	0.125	$2.03	13	1.20E+07	9	4.64E-02	11	1.24E-04	7	1.426	15	2
	3	0.125	$2.44	15	1.45E+07	12	7.08E-02	14	1.57E-04	12	1.691	17	1

* This is a generalized chart

Main Frame #1 Mountability → Square Tubing

RPB #1 Weight → FEA on Square v. Circular

Rear Forks #1 Affordability → Use rear forks from salvaged bikes

Presentor: Sophia

Tadpole

Courtesy of RAD Innovations

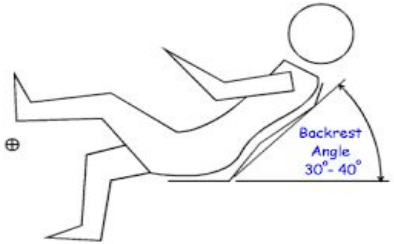
Courtesy of HPVC - UW Madison

- 500m or 60sec penalty if tips over
- Must exit vehicle within 15sec without assistance

Presentor: Darren

Seat

	Cushion	Hardshell
		
Comfortable	●●●	●
Price	●●	●●
Stability	●●	●●●



Courtesy of Jetrike

OUR SEAT: VELODREAMER

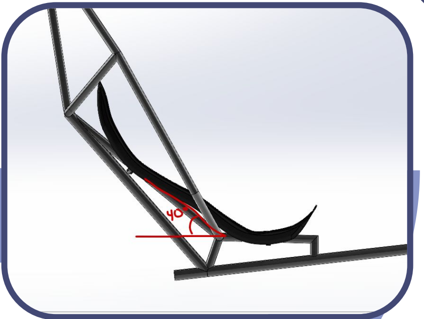
- Cushion
- Freedom to adjust angle
- Under budget ($150)

Presentor: Darren

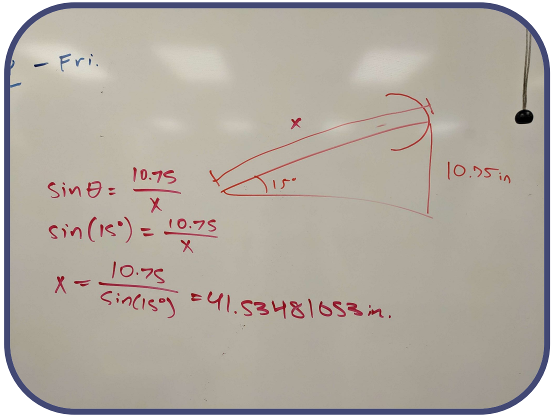
Seat

- CAD model
- 40 degree angle

CAD model of Seat & Frame for visual reference



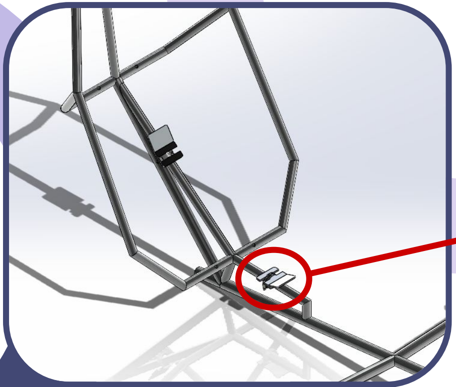
Measuring the angle of the seat

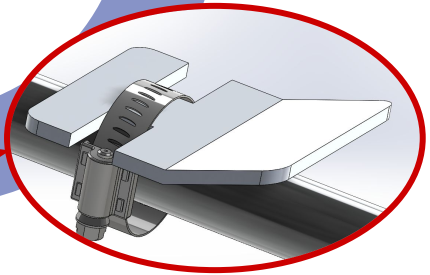


Estimated calculations of crankshaft placement

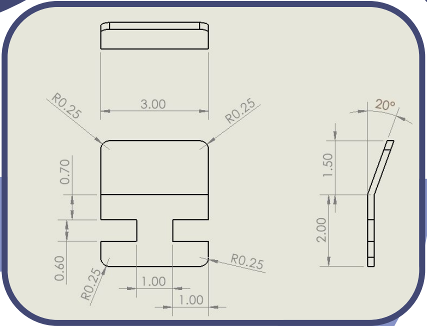
Mounts

- Adjustable
- Forgiving angles
- Easily manufacturable

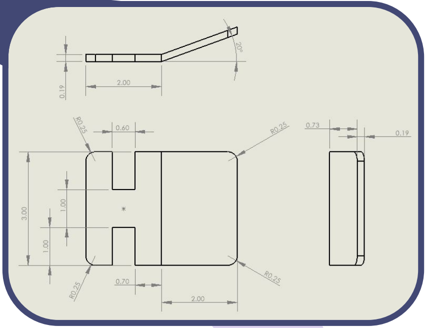




Seat mount on the frame



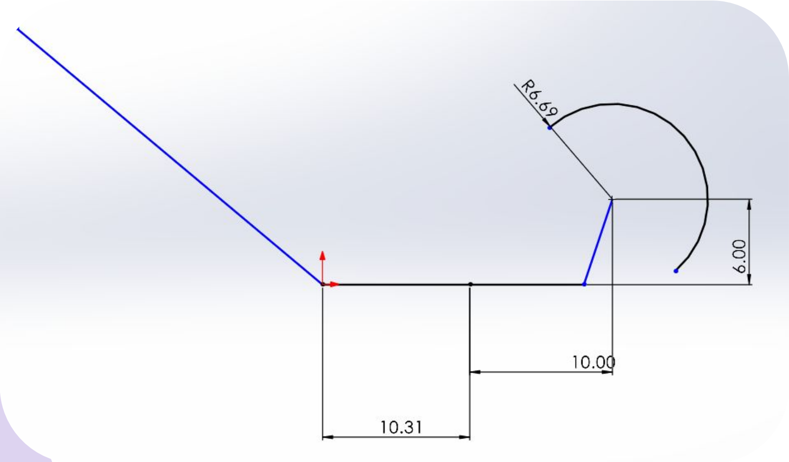
Bottom Seat mount



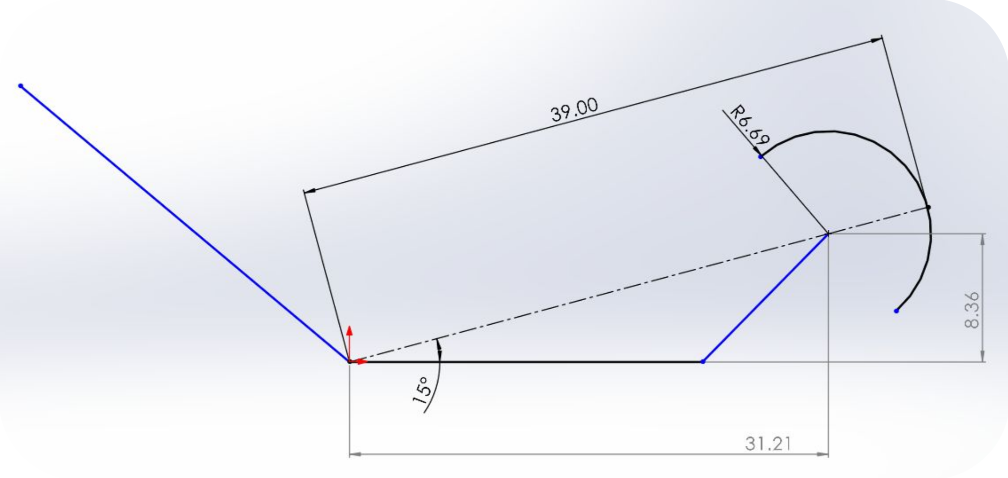
Top Seat mount

Crankshaft Placement

Original: Based off Jetrike Ratios



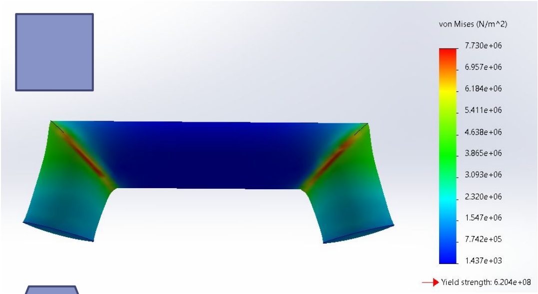
Updated: Based off our rider leg length & Design of Human-Powered Vehicles by March Archibald

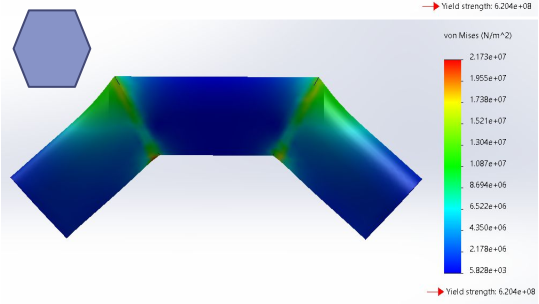


Presentor: Sophia

RPS FRAME SHAPE

Rating: 1-4 (worst to best)





equal: height, length, applied load(2670N), cross-sectional area

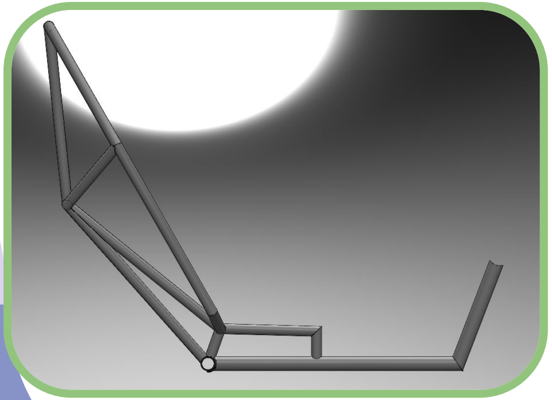
		Concepts							
		Triangular		Circular		Square		Hexagonal	
Selection Criteria	Weight (%)	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Weld-able & Prototype-able	50%	1	50	2	100	4	200	4	200
Rollover (minimal points of stress)	25%	1	25	4	100	2	50	3	75
Support top load (2670N)	25%	4	100	1	25	2	50	3	75
Total	100%	6	175	7	225	8	300	10	350
Continue?		No		No		No		Proceed	

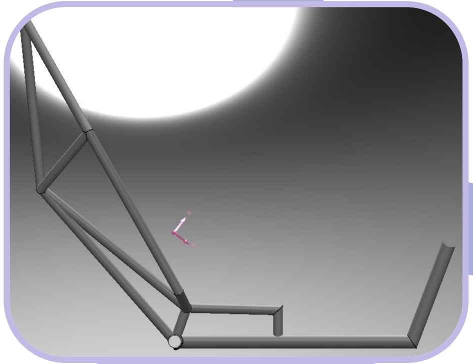
Presentor: Sophia

Final Frame

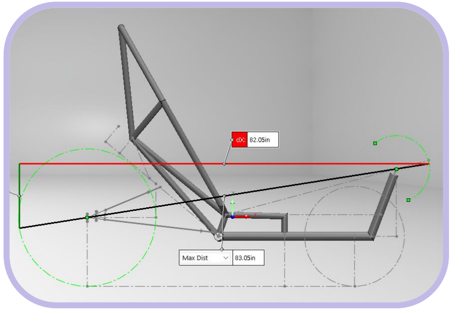
Weight: ~20lbs:
Height: 52.3”
Length: 82.05”
Width: 26”
- comfortable room for shoulders

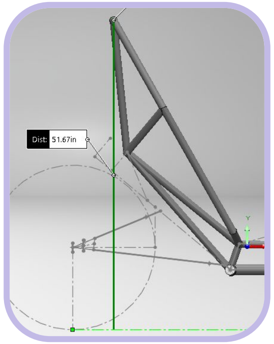
Height from back of seat: ~18”
- comfortable room for head, helmet & anatomical proportions





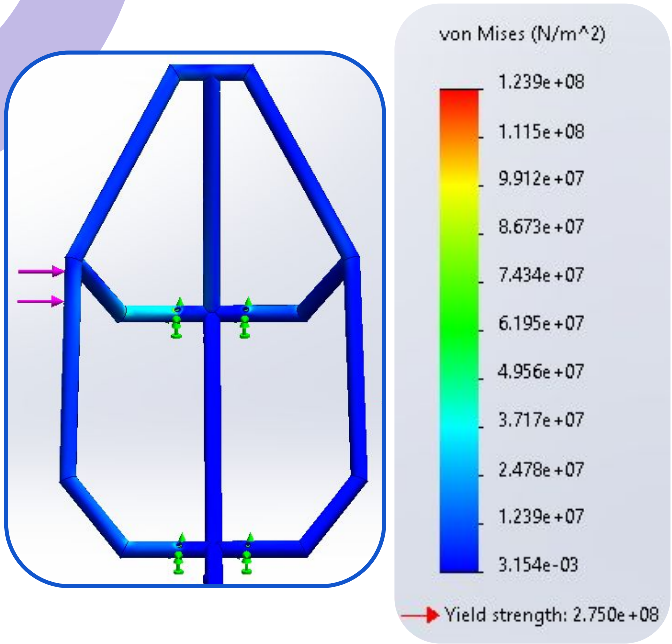
Center of mass: (inches)
X = -3.02
Y = 10.03
Z = -13.00

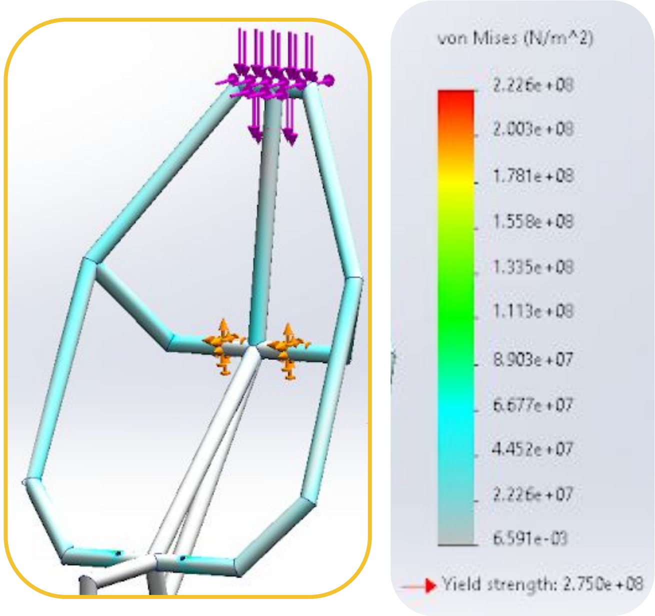




Seat mount raised above the Center Frame so no interference with Drive train or E-Box.

Frame + RPS FEA





Side Load: 1350N PASS ✔
Top Load: 2670N 15° to RPB PASS ✔ Factor of Safety ~ 2.1
Industrial Metal Supply CO., Irvine 1.25”-0.25” & 1.75” 6061 Aluminum

02. DYNAMIC SUBSYSTEM

Control and drive the bike efficiently

MAJOR COMPONENTS

Drivetrain System

Design an efficient drivetrain that can adjust gearing for uphill/downhill riding and reach 30 mph

Braking System

Create a braking system that can go from 25 km/hr to 0 km/hr within 6 m.

Steering System

Construct steering system with maximum turning radius within 8 m and drive straight for 30m at speeds of 5~8 km/hr

Drivetrain Review

Rear

8-Speed Flywheel Cassette
11-32T

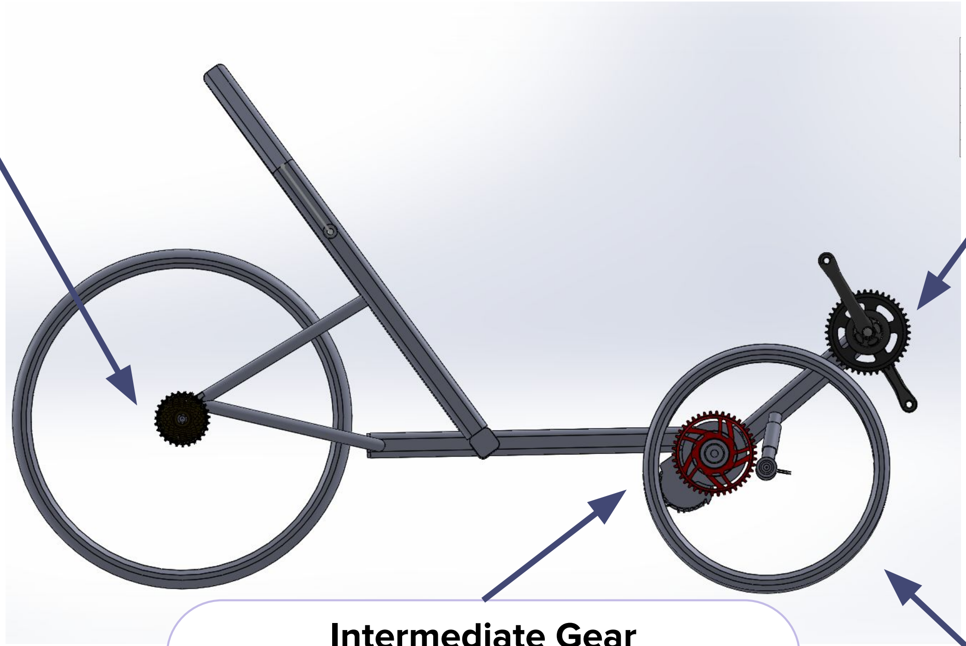
700C Wheel

Hardware

Chain Drive

Motor and crankset on 68mm bottom brackets and shells

Derailleurs on crankset and cassette



Crank

3-Speed Crankset
42-34-24T

170mm Crank Arm

Intermediate Gear

Bafang BBS02 500W Mid-Drive Electric Motor w/ two Chainrings

30T input/38T output
Gear Ratio = 1.2667

Front Wheels

20” Wheels with Disc Brake Mounts

Presentor(s): David Lozano

FINAL Drivetrain Overview

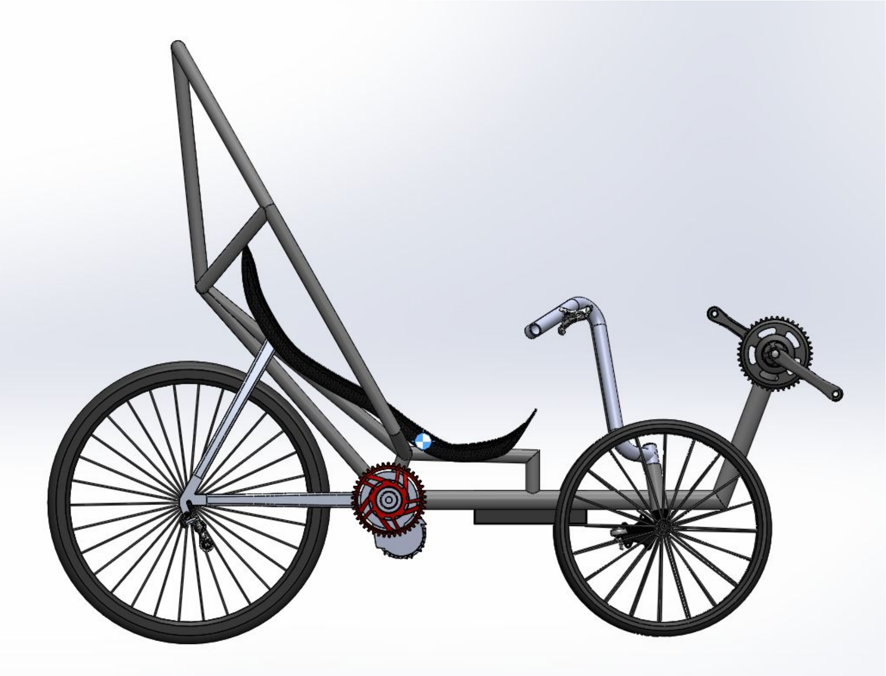
Configuration

3-Speed Crankset on front

Intermediate gears attached to electric motor

8-Speed Cassette on rear

700C wheel on rear, 20” wheels on front



Speed @ max development and 100 RPM = *38.9 mph*

Drivetrain Verification

Using Chosen Components

$$G_D = \frac{N_{chainring}}{N_{freewheel}} * \frac{N_{mid-output}}{N_{mid-input}} * D_{drive\ wheel} * \pi$$

- 2.0-2.5m development for 5% uphill grades
- 8m> development for speed and 7% downhill grades

GEAR DEVELOPMENT TABLE

# of cassette teeth

	32	28	24	21	18	15	13	11
# of crank teeth				***Development in meters***				
24	2.0	2.3	2.8	3.2	3.7	4.3	5.1	6.0
34	2.9	3.3	3.9	4.4	5.2	6.2	7.1	8.5
42	3.5	4.1	4.8	5.4	6.3	7.6	8.9	10.4

Speed @ max development and 100 RPM = *38.9 mph*

Presentor(s): David Lozano

FINAL Drivetrain Verification

Jig to verify drivetrain mechanism and geometry

26 inch freewheel secured on mount

Motor and crankset on flat surface

Current Results

More spacing needed between intermediate

gears

Solution

Add 2mm spacers between chainrings until

interference is gone

BRAKING SYSTEM: MECHANICAL DISC BRAKES

	Power Rating	Durability	Brake Calipers	Disc Brake Rotor	Total Price (minus rotors)
B-type (Wide, Resin): **B03S** ($16)	4/5	5/5	BR-M375 ($25.98)	180 mm (M) 160 mm (S)	**$41.98**
			BR-TX805 ($18.99)	180 mm (M) 160 mm (S)	**$34.99**
G-type (Narrow, Resin): **G03S** ($18.99)	4/5	5/5	BR-TX805 ($66)	160 mm (S) 140 mm (SS)	**$84.99**
K-type (Narrow, Resin): **K03S** ($12)	4/5	5/5	BR-RS305 ($65)	160 mm (S) 140 mm (SS)	**$77**

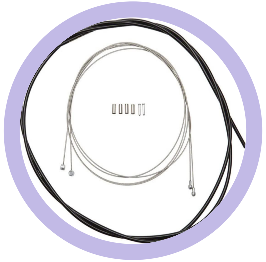
Presentor(s): Anisha Jayasekara

FINAL BRAKING SYSTEM: MECHANICAL DISC

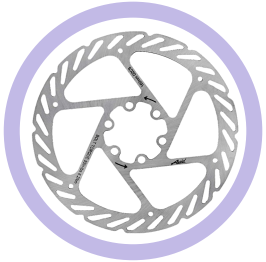
Shimano BR-M375

Disc Brake Adapter

Terra Trike Dual Brake Lever



Shimano Brake Cable Set



160 mm Brake Rotors

Braking Force: 588.6 N
Braking Force Applied: 185.4 N
Braking Distance: 4.9 m

STEERING MECHANISM SELECTION

Track Rod Steering

- Less variables to control
- Cost-effective
- Stable, but potential avenues of bump steer

Six-bar Steering Mechanism

- Five variables to control
- Potential budget sink
- Greater stability and range of motion

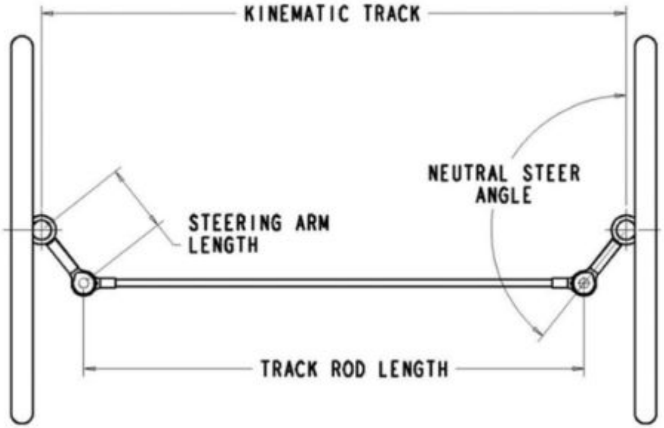


Figure 11-5 Track rod steering parameters

Courtesy of Mark Archibald. *Design of Human Powered Vehicles*

Presentor(s): Daniel Jang

DIRECT VS. INDIRECT STEERING

Direct Steering

Indirect Steering

Direct	Indirect
“Grounded”	“Weightless”
Similar effort as bike steering	Noticeably less effort to steer
Handlebars attached to wheels	Tie rods attached to wheels
Horizontal or vertical handlebars	Vertical handlebars

Presentor(s): Daniel Jang

Courtesy of Laid Back Cycles

WHEEL ANGLES

	Cost	Stability
(-) Camber		
(+) Castor		
Kingpin	Necessary	Necessary

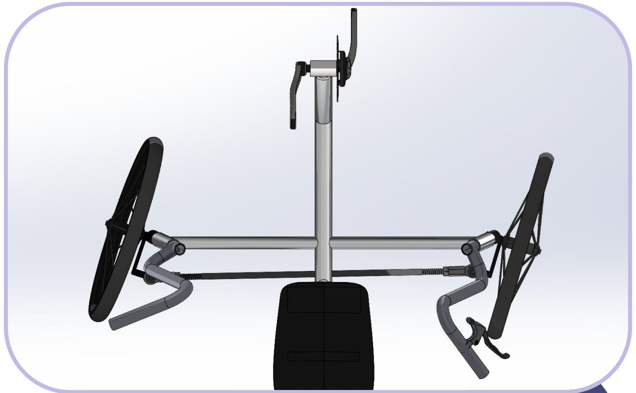
Presentor(s): Daniel Jang

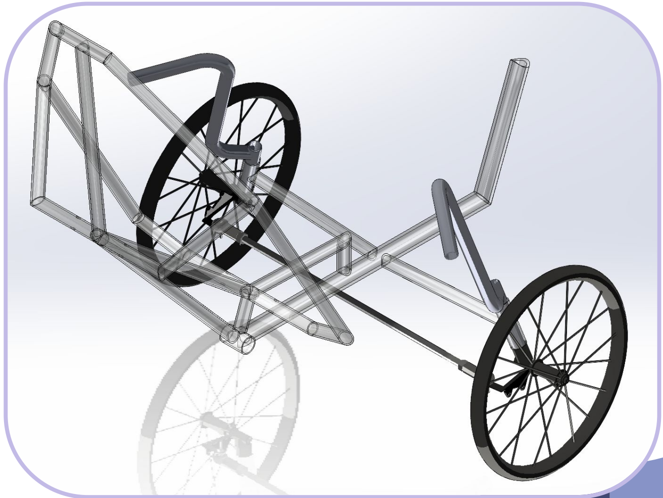
FINAL STEERING MECHANISM

Track Rod Steering

- Ackermann steering
- Three-linkage system connecting two front tires
- Separated handlebars for control of each tire
- Able to turn 8m without significant turning force

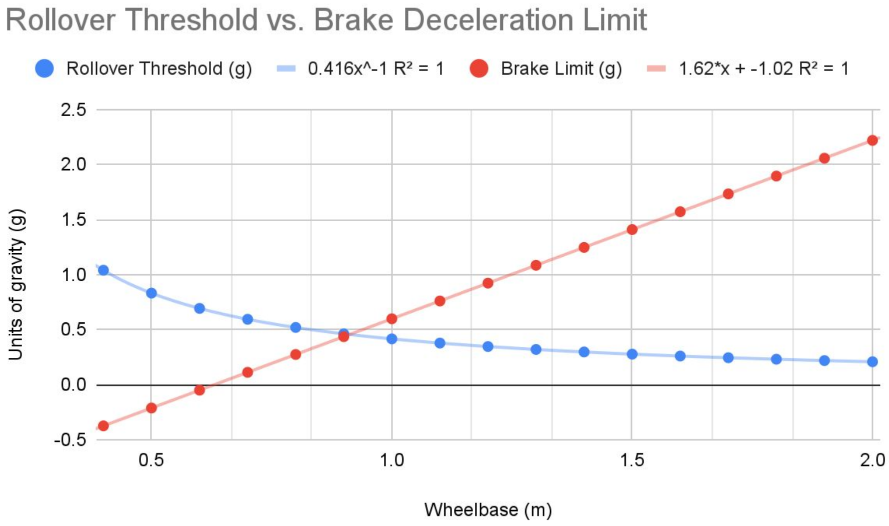
Turning Radius (m)	Inside Wheel Angle (degrees)	Outside Wheel Angle (degrees)
3	27.65373425	21.74977077
4	20.71522981	17.14054905
5	16.48066143	14.11003001
6	13.6557804	11.97670301
7	11.64608878	10.3975395
8	10.14660647	9.183131741





Wheelbase and Track Length

- Wheel Track: **28 inches**
  - Stable when moving straight
  - Linkage connections
- Wheelbase: **39 inches**
  - Optimized for rollover threshold vs. brake limit
  - For safety, prioritize brake limit



03. ELECTRIC SUBSYSTEM

Safely power and control the bike

Electric Box

Material: ABS

3D print @ UCI, maybe

Fireproof blanket encasing (rulebook)

Weight: ~12 lbs (including battery)

Dimensions (LxWxH): ~12” by 8” by 5”

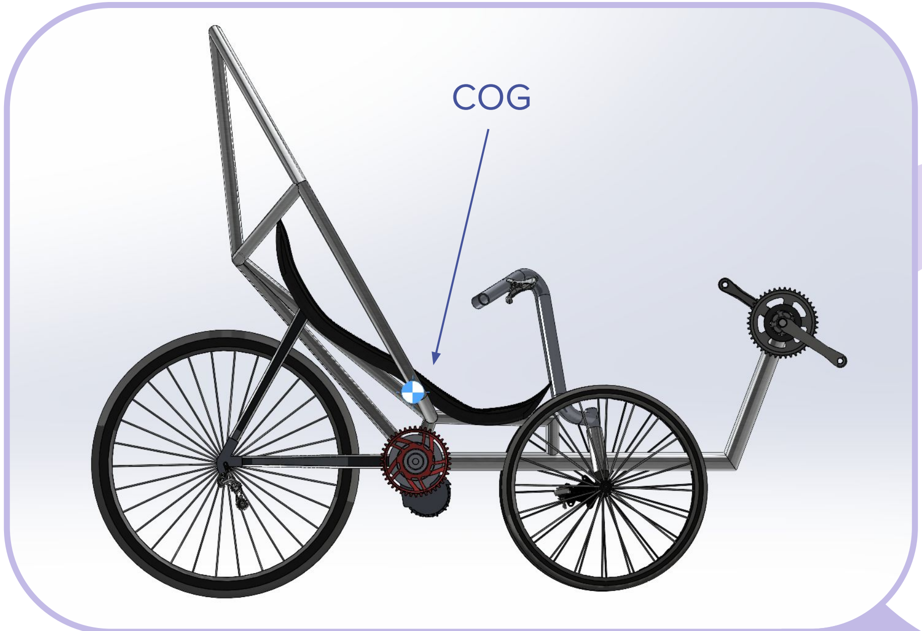
Enclosed compartment; battery will slide in and out

48V battery (verified via multimeter)

Battery → E-stop → Motor

Courtesy of polycase

Final Assembly



Total Weight = 63 Pounds
(Able to be handled by 2 people✔)

Frame Manufacturing Plans

Revise drawings for ease of cutting and welding

Specify cut angles and provide overall dimensions

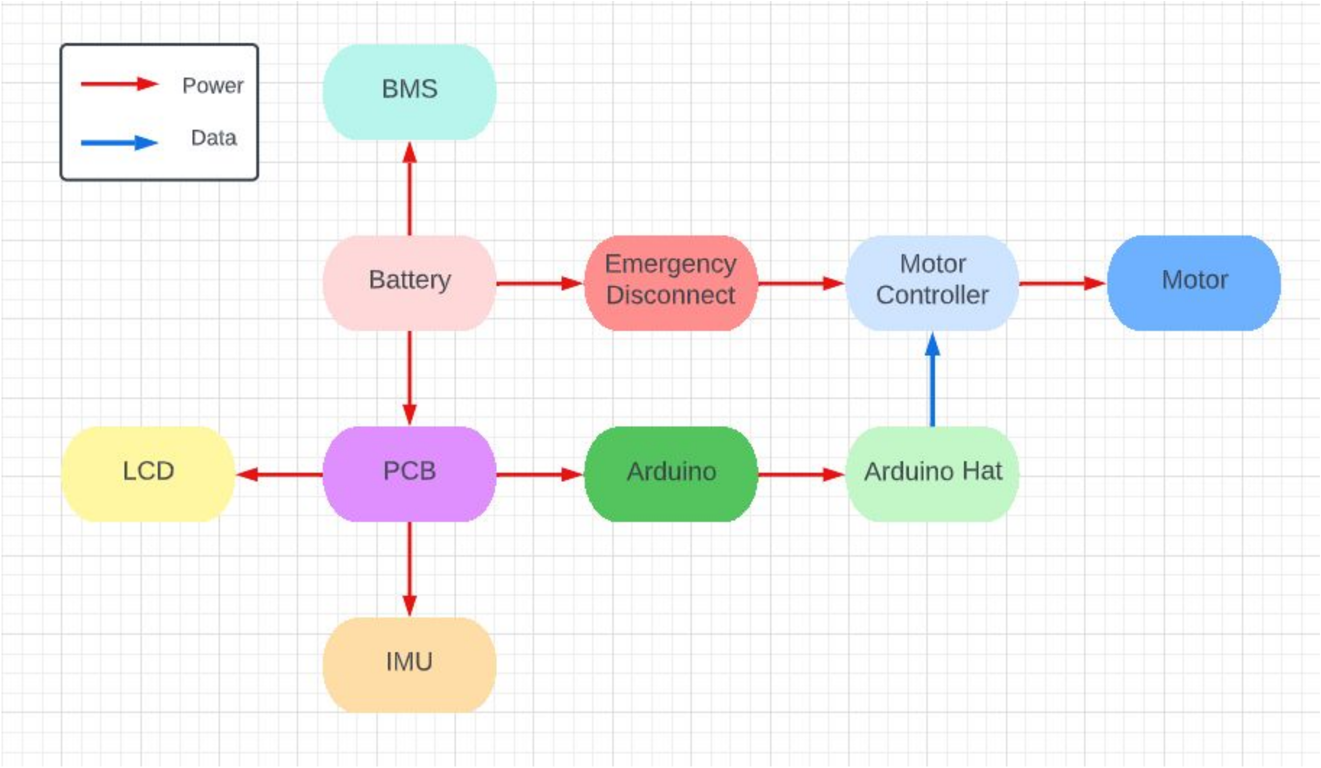
Assembly Plans

Install rear wheel and steering assemblies

Install drivetrain components to test and adjust as needed

Install seat, harness, brakes and battery to test vehicle

Electrical System Breakdown



Preliminary Concerns

Bike Frame Design:
Continue FEA to determine the best tube size for the frame, apply mounts for seat & harness

Drivetrain:
Optimize mounting point for the motor to avoid interference with the seat, determine front derailleur mounting solution (braze-on or clamp)

Brakes:
Finalize the rotor selection and determine whether to use one brake lever versus two independent levers

Steering:
Find optimal placement of tie rods and connection points

Presentor(s): Daniel Jang, Anisha Jayasekara, David Lozano, and Sophia Shannon

Final Concerns

Bike Frame Manufacturing:
The frame may get done before April 1, 2023.

Drivetrain:
Optimizing performance from the drivetrain by installing and tuning components

Brakes:
Need to verify speed and braking required to pitch over the vehicle

Steering:
Ergonomics for extended periods of riding

Future Recommendations

- Use a material that can be manufactured on campus; reduce outsourcing as much as possible.
- Majority of the team start on the frame so it may be manufactured by end of Fall Quarter.
- Possible Innovations: rear swing arm, front suspension, fairing, and regenerative braking
- Utilize flow chart to improve workflow
- Keep better documentation of project additions and changes

Year Two Outlook

- Optimize & Manufacture Design
- Reorganize Team & Workflow Structure

THANK YOU

Questions?

References

References

ASME Human Powered Vehicle Competition 2023 Rulebook

Design of Human Powered Vehicle by Mark Archibald

HPVC Design with Fairing 2021

Jetrike

Polycase

The University of Akron Human Powered Vehicle Competition Team Report

UWM HPVC Project