Spring 2021 HPVC Exhibition Capstone

Final Testing Report

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ME 486C – 21Spr06
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DISCLAIMER

EXECUTIVE SUMMARY

Northern Arizona University requires all senior mechanical engineering students to undergo a yearlong Capstone Design program. This final design course utilizes all the skills and techniques taught in the first three Design4Practice programs. Our team of four were selected to take part in the Human Powered Vehicle competition, which has been a well-established capstone team managed by our client, Professor Perry Wood. Without sacrificing the design intent, the project scope switched during ME 476C to focus on safety for young drivers. All major components of a human powered vehicle on a design intended for younger students to captivate an engagement in engineering principles.

Figure 1 - Final Design

Figure 2 - Side View of Final Design

Figures 1 and 2 show the final state of design, fully assembled. Since the project scope shifted focus from competition to education and inspiration for younger students, the testing process is crucial to ensure proper safety measures are proven sufficient. This final report contains the documentation for each engineering requirement that the team's design meets and proof of testing.

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REQUIREMENTS

This section outlines the list of Customer Requirements (CRs) and Engineering Requirements (ERs) the team has fulfilled during the project. This section will also outline the change of scope from competition HPV to a safety and inspiration drive HPV. Lastly, this section will also outline criteria and justification for the Engineer Requirements obtained.

1.1 Customer Requirements (CRs)

Professor Wood approved the list of CRs in Table 1 for the team to design to in the project. This tale was generated to prioritize safety to educate and inspire young students of general engineering concepts.

Table 1: Customer Requirements

RANK	CUSTOMER REQUIREMENTS (CR'S)	DESCRIPTIONS
1	Safety	Includes roll cage integration and secure seating.
2	Stability	HPV will not tip over through a sharp turn. Will also ride upright at slow speeds.
3	Operation age (5-13 years of age)	HPV can be driven by Kindergarteners through 8th graders.
4	Educational	Includes components that students can visually learn from.
5	Ease of operation	Low difficulty to operate. Includes foot pedals/brakes and hand steering.
6	Transportable	Lightweight to transport over long commutes. Can fit in a truck bed to transport places where it cannot drive.
7	Rollover protection	3- or 4-point roll-cage to ensure safety in the case of an operator accident that tips the HPV.
8	Manufacturability	Materials used are compatible and feasible to manufacture within a college students' budget.

1.2 Engineering Requirements (ERs)

The team quantified and defined ERs based on the definitions of each CR in Table 2. These ERs are what need to be tested to validate the team has sufficiently designed a human powered vehicle for students 5-13 years of age.

Table 2: Engineering Requirements

ENGINEERING REQUIREMENTS	
BRAKING DISTANCE (≤ 8 METERS)	COST (≤ $1,600)
MINIMUM OF 3 WHEELS	GEAR RATIO (3:1)
SEAT-TO-PEDAL DISTANCE (50 CM ADJUSTABILITY RANGE)	TURN RADIUS (≤ 8 METERS)
VOLUME (MUST FIT 6.5' X 5.5' TRUCK BED)	TENSILE STRENGTH (250-560MPa)
WEIGHT (≤ 45 KG)	

2 Testing Documentation

The following contains the completion of all testing procedures for this project. This section is divided by engineering requirements followed by its respective test. Each requirement includes any resources used, locations, and/or the schedule of the tests throughout the semester.

2.1 Test 1: Braking Distance (Target: ≤ 8 meters ± 1 meter)

At increments of 3 mph, the team used markers to signal the driver to actuate the brakes and measured the distance from the marker to the vehicle. The ER states that at a speed of 20 mph the vehicle must come to a complete stop within 8 meters. The team tested for every increment to find the maximum stopping distance was 1.5 meters traveling at 10 mph and 4 meters traveling at 20 mph.

Figure 3 - Brake Distance Test Apparatus

2.1.1 Test 1: Objective

The team prioritized that the brakes should be sensitive enough for an emergency stop, without the brakes feeling aggressive. This test is crucial for the safety of the driver and anyone around the vehicle.

2.1.2 Test 1: Resources Required

The team used leftover parts as markers to signal the driver to brake. Measuring tape was used for recording the distance. Helmets and body pads were worn in the case of an accident. The test was performed in the Machine Shop parking lot. Figure 3 shows the test set up as the cone signals when to pull the brake levers and measure the distance between the vehicle and the cone.

2.1.3 Test 1: Schedule

This was the last test completed by the team. After everything was assembled was when the team could test the braking system while driving.

2.2 Test 2: 3-wheel design

The tadpole trike design fulfills the requirement of 3 wheels. Instead, the team tested the durability of the vehicle by driving off-course, making sharp turns, and tipping it over.

Figure 4 - Off-course Downhill Test

Figure 5 - Off-course Uphill Test

Figure 6 - Tip Over

2.2.1 Test 2: Objective

By driving off-course, the team can see the effect of evasive maneuvers on the chain and wheels. This was verified, shown in Figures 4 & 5, that the vehicle can handle mild off-road terrain. There was an initial worry about the height the derailer sits at. This test showed that there was no environmental impact on the derailer. Making sharp turns will show the team if the steering alignment deforms or reevaluate any other issues that arise. The tip over test was to show that rolling was a difficult task, promoting driver safety. Figure 6 shows how much tip the trike needs before being taken by gravity.

2.2.2 Test 2: Resources Required

No resources were needed for this test other than the completed vehicle assembly. A tire pump was at the ready but unnecessary for the test.

2.2.3 Test 2: Schedule

The requirement was fulfilled in ME 476C when the team proposed the tadpole design. This test came towards the last few weeks of the semester due to needing the complete assembly for the stability of the vehicle.

2.3 Test 3: Seat adjustability (Target: 50 cm adjustability ± 10 cm)

The ER states that there must be 50 cm of adjustability within the seat for differently sized children. The test conducted was shortening and extending all adjustable components. The seat bracket slides linearly along the frame and the back rest adjusts rotationally to give a total adjustability of 51 cm.

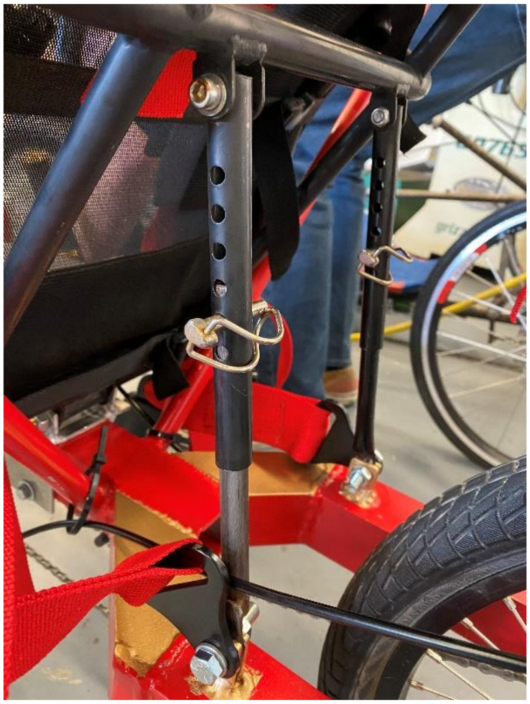

Figure 7 - Height Adjustability

Figure 8 - Axial Adjustability

2.3.1 Test 3: Objective

The purpose of having an adjustable seat is to comfortably fit children across wide age ranges (5-13 years). Friends of team members helped to see how taller children would fit on the vehicle compared to shorter children. Figures 7 and 8 show that there are multiple components of adjustability on the vehicle. There is axial adjustability along the beam, held together by clamps. The height adjusts using pins and a bolt acting as a hinge to allow different angles of the seat.

2.3.2 Test 3: Resources Required

Friends of different heights were the only resources needed to perform validation that the adjustability range is wide enough to comfortably fit children to operate. Younger students at neighboring elementary or middle schools can also be used to validate the range.

2.3.3 Test 3: Schedule

The test came shortly after the seat was completed; after the pegs were welded on the frame and the seat was completely assembled.

2.4 Test 4: Volume (Target: Fit in 6.5' x 5.5' area)

For ease of transportation, the team quantified the limit of which area the vehicle can take up. The target dimensions come from the dimensions of a truck bed. The test fulfilled the requirement when length and width were defined in the SolidWorks model of the frame.

Figure 9 - Width Measurement (3')

Figure 10 - Length Measurement (6')

2.4.1 Test 4: Objective

The purpose of this ER is to make the transportability of the vehicle an easy task. The compact lightweight design makes loading the vehicle into a truck simple without the need to disassemble any components. Figures 9 and 10 show how small the area that the vehicle takes up is. The final design fits in a 6’ x 3’ area, well within the ER parameters.

2.4.2 Test 4: Resources Required

SolidWorks was the only resource needed to ensure our frame was to fit in a truck bed. The team also used a member’s truck to fit the vehicle into, passing the test with certainty.

2.4.3 Test 4: Schedule

This test came shortly after the wheels were assembled onto the frame. The wheels extended the vehicle’s length and width but were still contained within the limitations of the requirement.

2.5 Test 5: Cost Effective (Target: $1,200 ± $400)

During ME 476C the budget for the project was fluctuating based on the change in project scope. The team designed to $1,200 before getting into the Machine Shop. It was not until ME 486C that the team obtained a concrete budget of $1,600. After the team was able to recycle old parts from other HPV’s, the team landed at a total cost just under $600.

2.5.1 Test 5: Objective

There was no physical test to fulfill the requirement, but the usage of parts from past HPV’s aided in the cost-effective aspect of building the vehicle.

2.5.2 Test 5: Resources Required

Excel was used to keep the project budget and parts list organized. The steering and brakes were taken off a previous project and implemented onto this project. The budget in Appendix A shows the full parts list and cost breakdown.

2.5.3 Test 5: Schedule

This requirement was fulfilled when the team obtained an approved budget for the project and using recycled parts.

2.6 Test 6: Turn radius (Target: ≤ 8 meters ± 1 meter)

The turn radius test occurred in the middle of ME 486C, after the steering was implemented onto the frame. The calculations done in ME 476C theoretically proved the test would pass within a radius of 8 meters. Figure 11 below shows how this test was completed by using a measuring tape and positioning the trike in a full turn to measure the radius of a 180° turn, proved at 1.7 meters.

Figure 11 - Turn Radius Test

2.6.1 Test 6: Objective

The purpose of a limiting turn radius ensures comfortable riding. It is not ideal to make multiple turns to change directions in a vehicle. The ER is also meant to provide evasive maneuvering in the case that sharp turns must be made.

2.6.2 Test 6: Resources Required

As shown in Figure 11, the test was done in the Machine Shop parking lot using only measuring tape. During the assembly process, the team found that shortening the steering tie rods gave a greater turning angle with the initial clearance allowed from the grips to the seat.

2.6.3 Test 6: Schedule

The turn test was performed during the middle of the ME 486C semester. The team retested the requirement again after the seat was assembled onto the frame.

2.7 Test 7: Material Properties (Target: 400 MPa ± 150 MPa)

The preliminary research helped the team select the material used for the project. Maintaining the idea of a robust lightweight design led the team to selecting 6061 aluminum alloy. The analysis performed showed no deformations in the central beam as loads were applied to the area where the seat bracket mounts. The alloy has a tensile strength of 290 MPa, which falls between the given boundaries and tolerance.

2.7.1 Test 7: Objective

Each member of the team has sat in the assembled vehicle; no cracks were yielded as the frame is supported. The test is meant to show that a lightweight alloy can have incredible reaction support if chosen correctly. The alloy also aided in keeping the trike as light as possible.

2.7.2 Test 7: Resources Required

The assembly of the wheels to the frame is needed prior to conducting this test. There are no other physical resources needed to fulfill the requirement as the calculations from ME 476C prove the alloy is suitable for the design intent.

2.7.3 Test 7: Schedule

The calculations have been completed and the second phase of the test occurred after the seat was completely assembled onto the vehicle.

2.8 Test 8: Weight (Target: ≤ 45 kg ± 5 kg)

A transportable HPV cannot be heavy beyond its ability to be lifted into a truck bed. The team was able to find total weight of what was built in SolidWorks, but that excludes the steering, sensor, Arduino, and any other miscellaneous parts assembled onto the frame. The frame alone only ended up weighing 6.5 kg with the total weight coming in at 27.2 kg which was more than the team was expecting but still well within the target range. Another important note is the weight ended up being perfectly distributed at each wheel with each scale showing 9 kg each.

Figure 12 - Weights

2.8.1 Test 8: Objective

From the material properties, the team was aware that the vehicle would fall under the limits defined by the ER. Weighing the miscellaneous parts separately aided in finding total weight and if any unnecessary parts were being used. This design is robust and lightweight. Figure 12 shows how the team was able to find the total weight of the design.

2.8.2 Test 8: Resources Required

SolidWorks was used when the complete CAD model was finished to find its respective weight. The team used a small scale to weigh all other necessary parts and combined the values for the total vehicle weight. After lifting it into a truck bed, the team was also able to determine that the weight was ideal for loading it to be transported.

2.8.3 Test 8: Schedule

The first phase of the test was completed after the SolidWorks assembly was finished. The second phase was completed after all other parts were together to be weighed.

2.9 Test 9: Gear ratios (Target: 3:1 or 4:1)

Gear ratios are important in limiting actuating systems in a design. Typically, gear ratios A and B of 3:1 or 4:1 are seen in bicycles, respectively. Dynamic calculations have been completed to ensure either ratios A or B will satisfy the ratio requirement. The team has designed to a 4:1 ratio to help in the propulsion of the vehicle using the least amount of human power to preserve energy.

2.9.1 Test 9: Objective

A visible validation test was done when after the completed assembly. If the gear ratios were incomplete, the HPV would not operate in the manner intended, and the team would have to review the state of the design as needed. This was not the case; the calculations were physically proven during the assembly process.

2.9.2 Test 9: Resources Required

Excel was used to keep calculations organized in the case that revisions were necessary. The team rated their power input after starting to move the vehicle to determine the ease of propulsion.

2.9.3 Test 9: Schedule

The calculations have proven the gear ratio of 3:1 is suitable for the intended design. The physical rating of propulsion occurred after the final assembly had been built to ensure low power input from the driver. Unexpected issues implementing the drivetrain and lack of proper tooling did end up postponing testing by a day.

Table 3 - Testing Status of ERs

ENGINEERING REQUIREMENT	Status of Test
BRAKING DISTANCE (TARGET: ≤ 8 METERS ± 1 METER)	Met (1.5 m)
MINIMUM OF 3 WHEELS	Met (Trike)
SEAT-TO-PEDAL DISTANCE (TARGET: 50 CM ADJUSTABILITY ± 10 CM)	Met (51 cm)
VOLUME (TARGET MUST FIT 6.5' X 5.5' TRUCK BED)	Met (6' x 3'
WEIGHT (TARGET: ≤ 45 KG ± 5 KG)	Met (~12kg)
Cost (TARGET: ≤ $1,200 ± $400)	Met (~$600)
Gear Ratio (3:1 or 4:1)	Met (3:1)
Turn Radius (TARGET ≤ 8 METERS ± 1 METER)	Met (1.7 m)
Tensile Strength (250-560 MPa)	Met (290 MPa)

3 CONCLUSIONS

The result of this report is the validation of our design intent through the team's tests. After validating each ER through the team's testing results, the final design meets all Engineering Requirements. The documentation outlined above proves that this team has successfully designed and constructed a human powered vehicle that younger students can safely operate with ease. Table 3 is a concise visual overview of the testing procedures discussed above. Each requirement has been fulfilled in the scope of the project and within the boundaries and tolerances of required limits.

APPENDICES

Appendix A - Budget

Purchased	PO#	Vendor	Item	Quantity/Size	Total Costs	Totals
						$1,600.00
9/3/21	1	Mayorgas	2"x 2" Hollow Square	10ft	$73.72	$1,526.28
9/3/21	1	Mayorgas	1.75" Round Tube	20ft	$42.58	$1,483.70
9/29/21	2	OnlineMetals	1.5" Hollow Tube	2ft	$44.10	$1,439.60
9/29/21	2	Amazon	Hall Effect Sensor	1x6pc	$12.91	$1,426.69
10/15/21	3	Amazon	Wire Brush Stainless Steel Wire Scratch Brush for Cleaning Rust	1x1pc	$13.05	$1,413.64
10/15/21	3	Amazon	OVIMAG Super Strong Neodymium Disc Magnets	1x5pc	$9.23	$1,404.41
10/15/21	3	Amazon	24PCS Sand Paper Variety Pack Sandpaper	1x24pc	$5.43	$1,398.98
10/15/21	3	Amazon	Rust-Oleum 7582838A2 Professional Primer Spray	1x2pcs	$15.18	$1,383.80
10/15/21	3	Amazon	Rust-Oleum 249127 Painter's Touch 2X Ultra Cover	1x1pc	$7.90	$1,375.90
10/15/21	3	Amazon	K01706 Krylon Spray Paint, Gold	1x1pc	$15.62	$1,360.28
10/15/21	3	Amazon	Rust-Oleum 271920 Gloss Cherry Red	1x4pcs	$6.82	$1,353.46
10/15/21	3	Amazon	Amazon Basics 9 Volt Everyday Alkaline Battery	1x1pc	$7.58	$1,345.88
10/15/21	3	Amazon	Mybecca Upholstery Foam Cushion Sheet High Density	1x1pc	$32.61	$1,313.27
10/15/21	3	Amazon	emma kites Black Ripstop Nylon Fabric	1x1pc	$9.73	$1,303.54
10/15/21	3	Amazon	Gorilla Super Glue with Brush & Nozzle	1x1pc	$6.49	$1,297.05
10/15/21	3	Amazon	Battery Powered LED Strip Lights, 24-Keys Remote Controlled	1x1pc	$18.37	$1,278.68
10/25/21	4	HomeCo	CDX Plywood.75"x2'x4'	1x1pc	$19.40	$1,259.28
10/25/21	4	Amazon	0.75" Lerox Tool	1x1pc	$10.37	$1,248.91
11/3/21	5	Amazon	4 Pack 20 Inch Bike Tubes with 2 Tire Levers	1x4pcs	$16.19	$1,232.72
11/3/21	5	Amazon	hooee Universal Bicycle Brake Cable Housing Kit for Mountain Bi	1x1pc	$10.86	$1,221.86
11/3/21	5	Amazon	TOPCABIN Bicycle Grips,Double Lock on Locking Bicycle Handleb	1x2pcs	$11.80	$1,210.06
11/3/21	5	Amazon	Sunlite Alloy Double MTN Lever	1x1pc	$22.35	$1,187.71
11/3/21	5	Amazon	AHEYHOM Bike Pedals 9/16 MTB Mountain Bike Peda	1x2pcs	$13.04	$1,174.67
11/3/21	5	Amazon	GANOPPER 170mm Crankset 32T	1x1pc	$59.80	$1,114.87
11/12/21	6	Amazon	Vbest life BB386 24mm Mountain Road Bike Press Fit Bearing	2x1pc	$52.40	$1,062.47
11/12/21	6	Amazon	ELEGOO UNO Project Super Starter Kit with Tutorial	1x1pc	$42.40	$1,020.07
					579.93	$1,020.07

Appendix B – Budget Breakdown of Costs