NORTHERN ARIZONA UNIVERSITY
Mechanical Engineering

[21Sp06]
[ASMEHPVC]

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From: Spring HPVC (Abel Aldape, Preston Berchtold, Martín Dorantes, Trent Todd)

Date: 10/01/21

Subject: Implementation Memo

1 Introduction

Northern Arizona University requires all senior mechanical engineering students to undergo a year-long Capstone Design project. 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.

Due to scheduling conflicts with the ASME competition, our client decided upon a new direction for our design. The human-powered vehicle would now be designed for the use of children from the age ranges of 5-13 years old. This vehicle would be taken to neighboring schools and allow kids to ride around and experience a fully developed project.

The scope of the project changed during the first semester of the capstone course. Since then, our customer requirements of safety, stability, ease of operation, adjustability, and transportability have been kept consistent from the change of scope. The client also established multiple constraints including a three-wheel design, and the inclusion of a roll cage for additional safety. In the first semester of capstone, it was determined that our design will be a recumbent tadpole tricycle (two wheels in front one in back) with indirect steering, a rear-wheel-drive chain system, three caliper breaking devices, a four-point roll cage, and ergonomic values that determine the angles at which the body is oriented within the device. Figure 1 below shows the team's first prototype, constructed of PVC pipe at the end of the first semester of capstone.

Figure 1- PVC Prototype

Entering the second semester of capstone, our team and client found it reasonable not to change our list of customer requirements. The sections below reflect our current design changes, successes, challenges, and a breakdown of future work. Our CAD drawing from semester one is shown below. It is important to note significant changes have been made during semester two to improve the overall efficiency of the design as construction and testing are underway by the time of this memo submission.

Figure 2- 1st Semester CAD Drawing

2 Customer Requirements (CRs)

After the scope of the project changed from competitive to inspirational/educational, the team revisited prior customer requirements (CRs) and engineering requirements (ERs) to fit the new project goals set by the client. Table 1 displays the new list of CRs in order of highest ranking, incorporating all the project requirements provided by the client. The new table was generated with safety in mind to educate and inspire young students into pursuing an education in engineering in their future. Client Wood approved the ranked table during semester one. There has been no need to make any changes or updates since the Preliminary Report from ME 476C.

Table 1 - Ranked List of Customer Requirements

RANK	CUSTOMER REQUIREMENTS (CR'S)	DESCRIPTIONS
1	Safety	Includes seat belt 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.

3 Engineering Requirements (ERs)

The team declared ERs in ME 476C, shown in Table 2, after client and advisor approval to dive into quantifiable aspects for each of the declared CRs. One ER has been updated since last semester to better reflect the team's budget of $1,500. The motivation behind each ER comes from the relationship between each CR and the quantifiable engineering trait. The team focused on the "how" and the "why" behind transporting a young student on the HPV. Each ER has targets and tolerances included in their respective section breakdown.

Table 2 - Engineering Requirements

ENGINEERING REQUIREMENTS	
BRAKING DISTANCE (WITHIN 8 METERS)	Cost under $1,500
MINIMUM OF 3 WHEELS	Gear ratio (3:1 or 4:1 typically seen in bicycles)
SEAT-TO-PEDAL DISTANCE (50 CM ADJUSTABILITY RANGE)	Turn radius (within 8 meters)
VOLUME (NO MORE THAN 5.2 CUBIC METERS)	Tensile strength (250-560MPa)
Weight (no more than 45 kg)	

3.1 ER #1: Braking Distance

3.1.1 ER #1: Braking Distance: Target ≤ 8 meters

To incorporate a safe and steady stop, the team decided a total maximum stopping distance to be within 8 meters after brake levers have been initiated. The decision came from initial research done in ME 476C of what average distances designs came to a stop in past competition projects.

3.1.2 ER #1: Braking Distance: Tolerance: ± 1 meter

It is important to have a brake distance far enough to come to a complete stop safely, yet not have a sudden-short brake distance that will throw the operator out of the vehicle when braking begins. The idea is to avoid the feeling of slamming the brakes while driving a car while still coming to a safe stop. This ideology led the team to have a tolerance of 1 meter to design to.

3.2 ER #2: 3 Wheel Design

3.2.1 ER #2: 3 Wheel Design: Target = 3 wheels

With the success of the 3-wheel design from the 2014 NAU team, our team decided it would be beneficial to stay along the same track. Client Wood also supported the decision, reinforcing the idea that designing a tricycle is safer for the driver by adding extra support to avoid tipping over.

3.2.2 ER #2: Wheel Design: Tolerance: + 1 wheel

There is no minimizing this ER due to the fact that children will be operating the vehicle. While most children develop the skill to operate a bicycle at young ages, there is still a risk compromising safety when mounting any human powered vehicle. The design decision is nonnegotiable, as the team and client have agreed upon no less than 3 wheels on the project design.

3.3 ER #3: Seat Adjustability

3.3.1 ER #3: Seat Adjustability: Target = 50-centimeter adjustability

Children come in all sorts of shapes and sizes, and the team does not want to exclude any child from the opportunity to learn more about engineering concepts from this project. During preliminary research, the team found that the average heights of children between 5 and 13 years of age was about 45 centimeters. The team thought the range was too low due to the angle the children will be sitting in, which is why the target was adjusted up to 50 centimeters.

3.3.2 ER #3: Seat Adjustability: Tolerance: ± 10 centimeters

To incorporate the initial finding of 45-centimeter range, the team decided to design to a larger tolerance of 10 centimeters, in the rare case of a taller or shorter child in comparison to the rest of the data in their age group.

3.4 ER #4: Volume

3.4.1 ER #4: Volume: Target ≤ 5.2 cubic meters

During preliminary research, the team found that the average volume of tricycles fell around 6 cubic meters for adult designs. With child height data and average dimensions of existing tricycles, the team concluded 5.2 cubic meters was a fair target to aim for in the design.

3.4.2 ER #4: Volume: Tolerance: ± 0.5 cubic meters

Following the same ideology for the seat adjustability ER for various child heights, the team determined to have a tolerance of 0.5 cubic meters included with our design. When constructing the first PVC prototype during ME 476C, the team visually saw that having a volumetric tolerance will only help the team and taller or shorter children ride the tricycle.

3.5 ER #5: Cost under $1,600

3.5.1 ER #5: Cost under $1,600: Target = $1,400

The team struggled to get a solid budget in place during ME 476C due to not participating in the ASME competition. Funding came from ASME in past projects so this posed an issue for the team designing a project for elementary and middle schools. Our team put together a list of materials and vendor quotes to get an estimate of what our design would cost. Our budget liaison found our design should end up around $1,400 if we were to build from scratch.

3.5.2 ER #5: Cost under $1,600: Tolerance: ± $200

Client Wood approved the team of using scrap material from some past projects that were no longer being used. The change helped the team tremendously by reducing part costs. The team believes the proposed design will not land close to the initial proposed budget, saving money and recycling our resources.

3.6 ER #6: Gear Ratio

3.6.1 ER #6: Gear Ratio: Target = 3:1

Gear ratios in bicycles have been either 3:1 or 4:1, as found in preliminary research. Our drive train lead intends to keep consistent with a 3:1 ratio to keep an effective and simple design.

3.6.2 ER #6: Gear Ratio: Tolerance: +1

The team's design intent is to keep the actuating systems as simple as possible, to promote the core engineering concepts to younger students. This requirement allows the team to have a tolerance going up to a 4:1 gear ratio, if absolutely needed.

3.7 ER #7: Turn Radius

3.7.1 ER #7: Turn Radius: Target ≤ 8 meters

The team found that it is a requirement to have a turn radius of 8 meters or less in the ASME competition. It was decided not to change this aspect in our design, as there is no real benefit to shortening the turn radius for a sharper turn in a design intended for children.

3.7.2 ER #7: Turn Radius: Tolerance: ± 1 meter

A tolerance of 1 meter was decided on in order to promote the design intent of avoiding sharp turns that would create a safety risk of tipping over.

3.8 ER #8: Tensile Strength

3.8.1 ER #8: Tensile Strength: Target = 250 MPa

The team wanted to design this tricycle to not crack under stress, with enforcement in the roll cage for extra safety. The team found that average bicycle alloys used have a tensile strength around 250 MPa.

3.8.2 ER #8: Tensile Strength: Tolerance: ± 150 MPa

Our team decided on using 6061 Aluminum alloy for the frame material. This alloy has a tensile strength of 110 MPa, which proves to hold our design intent through analysis of the frame under torsional stress conducted in SolidWorks.

3.9 ER #9: Weight

3.9.1 ER #9: Weight: Target ≤ 45 kilograms

As part of the agreement with Client Wood, the design must be transportable. This means the team must create a lightweight design that can be easily moved from school to school. Our team found it reasonable to construct a tricycle weighing no more than 45 kilograms (or ~100 pounds) by using hollow tubing for our frame to reduce overall density of the frame.

3.9.2 ER #9: Weight: Tolerance: ± 10 kilograms

Our team found a reasonable tolerance for this ER is 10 kilograms, after all subsystems and other integrations are added on. The team feels this target and tolerance have been overshot because of the hollow-frame design reducing weight and using recycled polymer materials instead of new metal.

4 Design Changes

The team has undergone several design changes to the roll cage design and body layout. These changes were to adjust minor dimensions and alter the fitting of parts. Design considerations were considered with safety of the driver and available manufacturing processes in mind.

4.1 Design Iteration 1: Change in roll cage

The team made altercations to the roll cage. In the previous design, the roll cage was a perfect semi-circle leading to a point. This previous design was chosen in efforts of minimizing damage in a roll over crash. Unfortunately, the team believed the elasticity of the aluminum and manufacturing tools available, this design would be unfeasible. Therefore, the team decided to use a series of sharp bends to round the metal for the roll cage. The altered design upheld the previous roll-over design while also being able to manufacture easily. These sharp bends allowed for a more controlled bending procedure while upholding the previous curved design. The change in SolidWorks can be seen below.

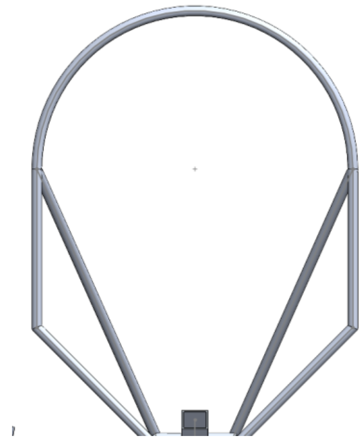

Figure 3 - Previous Roll Cage

Figure 4 - Current Roll Cage (Machined)

4.2 Design Iteration 2: Change in Design Length

Secondly, the team slightly modified the center frame for a shorter length. The team deemed this necessary as the driver could be slightly forward of the roll cage during use of the seat in the forward position. To uphold safety, the decided to trim an unnecessary length of frame in efforts of moving the roll cage forward three inches. This design change was minor and was decided before the team began building. Therefore, it had no impact on the current build of the project and could be modified with the current SolidWorks design.

4.3 Design Iteration 3: Change in Steering

The spindle system has changed to more closely follow the design of a previous project. Due to a limited time frame and manufacturing capabilities, the team is adopting the geometry from another HPV. The tricycle will still use the Ackerman steering method, and is expected to retain the turn radius design requirements.

4.4 Design Iteration 4: Change in Frame Fork

To keep a robust design in the frame, the team is revisiting the design of the rear fork. The revisions come from bending occurring in our previous design, and the manufacturing/material available. The team now intends to attach the roll cage on both ends of the fork instead of one, to reinforce the strength in both the frame and roll cage, and resist any torsion that may occur.

4.5 Design Iteration 5: Change in Seat Bracket

After looking at the initial design of the seat bracket, the team has decided to completely redesign how the seat will be mounted onto the frame. Figure 5 depicts how the team initially wanted the seat to be mounted, but decided a change was necessary to avoid too much stress in the weaker parts of the beam. After reviewing the other teams seat clamps, it was obvious better designs were available. While the frame is being welded together, the team is creating new ideas to construct a structurally ideal bracket without sacrificing alloy strength. The seat clamp will also be integrated with the seat obtained from a scrapped HPV.

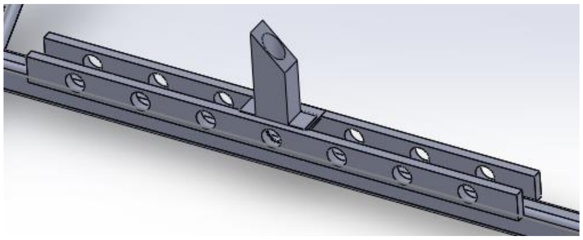

Figure 5 - Previous Seat Bracket Design

5 Future Work

The team's schedule is set up to meet deliverable deadlines without sacrificing design intent. There are major redesigns for the seat bracket and frame fork that are being worked out at the time of this memo submission. This section includes a breakdown of further designs and includes the team schedule and a plan outlining what each team member is doing to meet our deliverable deadlines.

5.1 Further Design

The team plans to continue manufacturing the child size HPV while redesigning the frame fork, steering system, and seat bracket design in SolidWorks. The team has plans to implement the steering system and drivetrain within the next few weeks as redesigns conclude. The team is planning to reuse old parts from past projects that Client Wood has given approval for the team to dismantle and take parts from, making future modifications effective and efficient for quick modifications.

After the steering and spindle designs have been established, the team plans to continue working on the brakes, seating dynamics, and implementing electronic software & hardware to the tricycle. The team anticipates modifications will be needed as troubleshooting the systems integrations begin. As construction continues, there is anticipation that the brakes and seating placement will need minor altercations.

5.2 Schedule Breakdown

The team reviewed and updated the schedule since ME 476C. The most iteration of the schedule is found in Table 3. During the time of this memo submission, the team is continuing the cutting and welding of the tricycle frame. The team believes to be slightly behind schedule based on what is presented below.

Table 3 - Schedule for ME 486C

2021 HPV Capstone Schedule		
Date Due	Assigment	Team Members Involved
10/1/2021	Website Check 1	Martin
	Prep frame stock	Trent + Abel
10/8/2021	Implementation Memo	All
	Purchase Remaining Material	Preston
	Welding, bending, notching	Trent + Abel
10/12/2021	Midpoint Presentation	All
	Begin Integration of systems	All
10/27/2021	Individual Analystical	Individual
	Iteration and problem solving	All
	Testing	All + Martin
11/5/2021	Hardward Review 2 + Website 2	All + Martin
11/7/2021	UGrad Registration	Abel
	Testing	All
	Begin Final Poster and Report	All
12/8/2021	Final Cad Package and BOM	All
12/8/2021	Final Poster	All
	Final Product Meeting	All
	Operation/Assembly Manual	All
	Client Handoff	All

The team had struggles surrounding the process of getting the first purchase order pushed through. Many delays caused setbacks for the team for some time preceding the first hardware review. While the team has made significant progress to catch up, the month of October is critical in constructing the tricycle so November can be devoted to systems integrations, testing, and problem-solving. Preston has been pushing purchase orders out to ensure materials arrive on time and can be integrated onto the design. Abel and Trent have been in the machine shop cutting, welding, and coping. Martin has been making modifications to planned testing procedures, updating the website constantly, and coding & gathering hardware materials for Arduino and Raspberry Pi integrations as the frame comes together. By the time hardware review 2 comes, the team anticipates having a fully constructed design with full capabilities to review in the machine shop with Dr. Willy.