To: Dr. Sarah Oman

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Subject: Implementation Memo

Introduction

The human-powered vehicle competition is an intercollegiate competition hosted by the American Society of Mechanical Engineers (ASME), where engineering students are encouraged to apply engineering principals learned to build a vehicle that is completely powered using human muscular strength. In this memo, four primary sections will be discussed. They are customer requirements, which will include a list of all customer requirements (CRs) provided by the client and the changes to those CRs made since the end of 476C. The engineering requirements section of this memo would list the engineering requirements that abide by the competition rules and customer requirements (ERs) with tolerances and discuss all changes made to the ERs between last semester now with reasons as to why these changes were made. This memo will also discuss the design changes made to the design's main/subsystems, where main systems include frame, roller cage, gear train, braking, ergonomics, and fairing. The subsystem includes components such as brake lighting and electrical components. Finally, the memo will cover the future of the project and go into the details of the manufacturing process, schedule and how these can accommodate capstone deliverables.

1 Customer Requirements (CRs)

The customer requirements listed below were directly derived from the list that was provided by the client. The CRs listed satisfy the objectives stated by the client and align with the rules and regulations provided by ASME. The main objective of the project is to manufacture a two-wheel recumbent bicycle that is fully operational and ensures the safety of the rider. Another goal provided by the client was that if the vehicle was presented at community and outreach demonstrations, it should be able to accommodate any rider.

Customer Requirements (CRs)

1. Cost within budget
2. Durable and Robust design
3. Reliable design
4. Safe to operate/rider protected in case of collision
5. Vehicle can reach high speeds
6. Vehicle must be light weight
7. Highly maneuverable
8. Contains cargo space
9. Unobstructed field of view
10. Aerodynamic
11. Fits different riders of varying heights and weights

The current set of customer requirements

There were no changes made to the customer requirements between last semester and now. The table below lists the CRs, description for each and their respective weights. The weight for each CR ranged from 1-5 where 1 being the least importance and 5, the highest importance.

Table 1: List of customer requirements ME486C

Customer Requirements	**Description**	**Weight**
Cost within budget	The manufacturing costs must be maintained under budget to ensure that all components are assembled within respective amounts allocated.	2
Durable and robust design	This requirement helps ensure that the vehicle is strong and is able to withstand any changes to the environment (weather, temperature or pressure)	5
Reliable	This requirement will help ensure that the vehicle is not only suitable and ready for competition but add to the safety of the vehicles operation to limit unwarranted issues for the operator.	5
Safe to operate/rider protected in case of collision	This is one of the most emphasized requirements provided by the client. The rider must be protected in the event of a roll over or crash. FEA and all safety testing must be completed before the competition.	5
Vehicle can reach high speeds	This requirement makes sure that the HPV is able to compete in the sprint and endurance events.	4
Vehicle must be light weight	This requirement will aid in other requirements such as safety, maneuverability and ability to reach high speeds.	4
Highly maneuverable	This requirement directly correlates to some of the competition guidelines for turning radius, braking and acceleration.	4
Vehicle has cargo space	This lesser important requirement is to ensure that the team is ready for whatever bonus cargo may be present during competition.	3
Unobstructed field of view	This major safety requirement will ensure that the operator has a full field of view during operation in order to analyze the track and avoid dangerous conditions.	4
Aerodynamic	This requirement will not only aid in the project's innovation, but also aid in allowing the vehicle to achieve maximum speeds with minimal effort for sprint competition.	4
Can fit riders of varying heights and weights	The team is required to come up with an ideal seating position, gearing position that can fit range riders with varying torso and leg lengths and is able to transfer maximum amount of energy to the shaft which in turn help increase the speed of the vehicle.	5

2 Engineering Requirements (ERs)

Table 2: Preliminary engineering requirements and target values

Engineering Requirement	Target Value
Weight	50 pounds
Frame Strength	Yield FOS > 1.5
Turning Radius	≤ 15 feet
Top Speed	45 MPH
Drag Coefficient	CD < 0.2
Innovation	Max Points
Cost	< $5000
Mount/Dismount Time	30 sec
Frontal Area	5 square feet
Ergonomic	Comfort for 2 hours

Table 3: Updated engineering requirements and target values

Engineering Requirement	Target Value
Weight	< 50 pounds
Frame Strength	2 < Yield FOS < 4
Turning Radius	≤ 15 feet +0, -3ft
Top Speed	> 45 MPH
Drag Coefficient	CD < 0.2 +/- .1
Innovation	Max Points
Cost	< $3000
Mount/Dismount Time	< 30 sec +/-5 sec
Frontal Area	≤ 5 square feet
Ergonomic	Comfort for 2 hours +/- 15 min

2.1 ER #1: Weight

2.1.1 Weight = < 50

Based on research on prior HPVs built by NAU and other universities, we found that most of the competitive vehicles were below this weight and we desired to maintain a weight less than or equal to those designs. Additionally, the less weight incorporated into the vehicle the more efficient the operator can use his/her energy.

2.1.2 Weight +/- 5 lbs.

This tolerance was decided based on the fact that if it was deemed necessary additional material for any unforeseen issue, the team would be able to add it as necessary. However, it is very unlikely to require the addition of more than five pounds of material.

2.2 ER #2: Frame Strength

2.2.1 Frame Strength = 3

Originally, a yield factor of safety (YFOS) was deemed to be adequate at 1.5. However, after thorough consideration this was raised to a minimum of 2 and maximum of 4. The minimum was determined because there are no expectations any serious impact forces apart from the weight of the operator. The competition is held on relatively smooth surfaces where there should not be any possibilities for aggressive bumps or potholes in the road. The maximum value of four came from the desire to save materials which is important for both cost and for acquisition.

2.2.2 Frame Strength Tolerance +/- 1

Through careful study of the loads likely to be encountered in a road bicycle situation, it was deemed safe by the team to have a minimum YFOS of two. Based on understanding of the competition, there will be no portions of off-road travel or any sudden shock loads that should be encountered. However. Due to the competitive nature and because we only have one opportunity to construct a working HPV, a high YFOS of four was deemed reasonable in order to mitigate the risk of frame failure.

2.3 ER #3 Turning Radius

2.1.3 Turning Radius Target = 15ft

The competition incorporates a maneuverability component where the vehicle must complete a six-meter turn. In order to stay within that it was decided that a radius of 15 would be more than adequate, provide an extra degree of maneuverability, but not compromise the stability of the vehicle.

2.3.2 Turning Radius - Tolerance +0, -3 ft

Due to the proximity of the target turning radius to the maximum, it was determined that our tolerance should not be allowed to go over 15 ft at all.

2.4 ER #4: Top Speed

2.4.1 Top Speed Target = 45 mph

In order to maintain a competitive nature for the competition and improve the chances of performing well in the sprint and endurance components of the competition, the vehicle should be capable of at least 45 miles per hour on flat and level ground.

2.4.2 Top Speed Tolerance > 45 mph

While the top speed of the vehicle will dictate its ability to be competitive, the only limiting factor desired by the team is the athletic capability of the team members. Therefore, if the vehicle can attain speeds of over 45 miles per hour without adding significant cost or weight, then it will only benefit the performance.

2.5 ER #5: Drag Coefficient

2.5.1 Drag Coefficient Target = .2

The drag coefficient was determined based on the analysis of previous vehicles as well as the available data for standard unfaired cyclists. The drag coefficient of .2 will provide better aerodynamic properties than an unfaired vehicle.

2.5.2 Drag Coefficient Tolerance +/- .1

The tolerance for drag coefficient was decided at this value because, obviously, there would be no downside to being more aerodynamic. However, there is a possibility that the test results done in the wind tunnel might not necessarily translate perfectly to the application. Additionally, it will be very difficult to test the drag coefficient once the fairing has been fully constructed.

2.6 ER #6: Innovation

2.6.1 Innovation Target = Maximize Points

Ideally, based on the customer requirement to get maximum points on the design report, it was decided that the team aim for very high values in creativity and innovation. The team hopes that the unique fairing design and gear train will aid in maximizing points for innovation.

2.6.2 Innovation Tolerance Undetermined

Due to unforeseen challenges regarding material acquisition, budget planning, and the cancellation of the physical ASME E-Fest, it is now a priority to complete the basic systems of the vehicle. Innovative systems will be completed as time and material allows.

2.7 ER #7: Cost

2.7.1 Cost Target = $3000

In order to meet the budget challenges, this value was changed from the prior $5000. This will be completed by performing all manufacturing and fabrication "in house". Based on research of previous teams that were able to do fundraising, the amount of money raised was very minimal, ($100-$150). The most reliable source of cost savings for the team will be donations and sponsorships.

2.7.2 Cost Tolerance = +/- $500

Due to the 40% reduction in target cost, it would be reasonable to ask an additional $500 from the university in order to fund this project should it be required. If more costs can be cut without sacrifice of performance, then it will be done.

2.8 ER #8: Mount/Dismount Time

2.8.1 Mounting/Dismounting Time Target = 30 seconds

In the competition there are events where the operator will begin the race outside of the vehicle and will have to quickly mount and dismount again to secure a payload. With the additional requirement of a safety harness, the goal is to have the rider be able to get into the faired or unfaired vehicle and secure his/her harness and make any necessary adjustments quickly and efficiently.

2.8.2 Mounting/Dismounting Time Tolerance +/- 5 seconds

The addition of five seconds to mount and dismount will not have a significant impact on the overall placement in the two-hour long endurance race.

2.9 ER #9: Frontal Area

2.9.1 Frontal Area Target = 5 square feet

In order to achieve a low drag coefficient and conserve materials on the fairing design, the total frontal area should be kept to a minimum. However, not too small such that it creates close confines and inhibits operator ability to mount and dismount the vehicle in an effective and efficient manner.

2.9.2 Frontal Area Tolerance = +0, -1 square foot

Ideally, the frontal area should not exceed five square feet for the purposes of aerodynamics and the design of the fairing. However, if the frontal area is slightly smaller it should still be spacious enough to allow proper use.

2.10 ER #10: Ergonomics

2.10.1 Ergonomics Target = Two-hour riding comfort

The endurance race is a two-hour long race. Assuming all mechanical systems are performing correctly, the limiting factor for performance will be based upon the operator's physical fitness. In order to ensure the rider can consistently perform well, an emphasis must be placed on comfort for the duration of the race. This includes the seating position, the material of the seat, the positioning of steering controls and pedals.

2.10.2 Ergonomic Tolerance +/- 15 minutes

Realistically, there is no reason why the vehicle could not be comfortable for a longer period of time, however, for the scope of this project and the expected service time, there is no need to overdesign comfort which will only serve to waste precious time and resources. Each team member agreed that if it was necessary, each could sustain being uncomfortable for the last 15 minutes of the race and would still be able to perform adequately.

3 Design Changes

Throughout the design process of the human powered vehicle, there have been multiple design changes that have taken place. These changes are due to functionality, the availability of resources, or to ensure maximum performance. The team is still expecting to experience more design changes as the project progresses due to challenges that will be unforeseen. The design changes to the vehicle involve the following.

3.1 Design Iteration 1: Frame Alteration

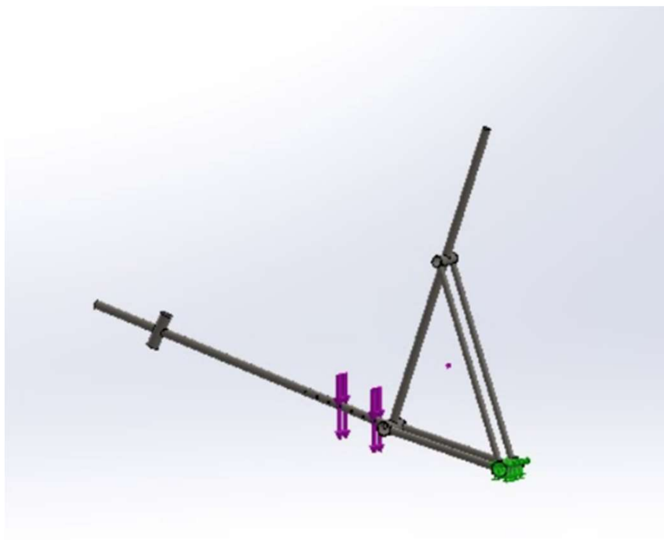

Figure 1: Frame iteration 2

This frame iteration was by far the simplest of the many ideas considered, however after careful consideration it was decided that the roll bar should be consolidated into the upward tube for seat and harness mounting in order to reduce the overall use of material. This design is a much better use of space and allows additional options for mounting hardware, accessories, and most importantly, the fairing.

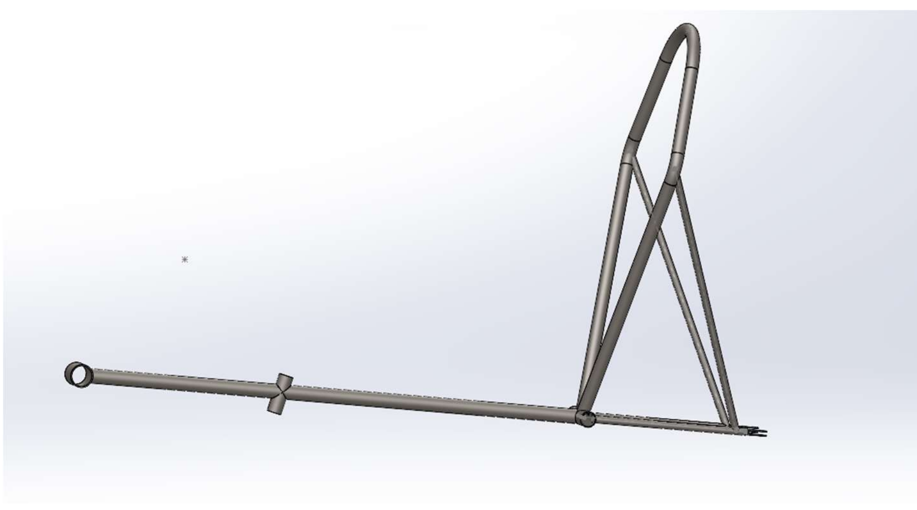

Figure 2: Frame iteration 3

With the addition of the roll bar, the frame does become more complex to fabricate but with the knowledge that the team possesses of this process, it is not likely to slow progress significantly. Another benefit of this bar is that it allows the operator to have his/her shoulders tucked farther back into the tube if they so choose. This allows for more weight to be distributed to the rear tire.

3.2 Design Iteration 2: Fairing Design

The fairing design has been dynamically changing throughout the life of this project. The team's initial thoughts on fairings featured many ideas such as half, full, and even no fairing on the vehicle. After speaking with our client, Mr. Perry, he mentioned that having a fairing could be an advantageous feature of our design that could help with performance as well as innovation for the design competition. Figure 3 below is our initial fairing design.

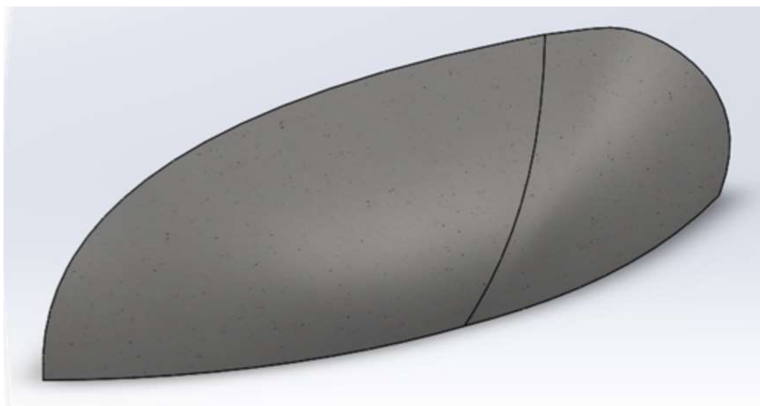

Figure 3: Initial fairing design

Using ANSYS Fluent, the team determined a coefficient of drag of 0.162 using general air pressure and density conditions at a wind speed of 17 meters per second. A second design was also analyzed under the same conditions. This design is shown below in Figure 4.

Figure 4: Fairing Design Iteration 2

The second design iteration had a drag coefficient value of 0.26. This drag coefficient was greater than the initial design. Design iteration 2 features an open section of the fairing for the rider to mount the vehicle easier and be able to lower their feet to balance if needed. With the addition of an open section like this, there was more drag involved. With these learnings, the team created a third design iteration seen below in

Figure 5 which adds more paneling to the fairing closing as much of the cabin as possible to reduce drag effects while still maintaining the ability of the rider to lower their feet as needed.

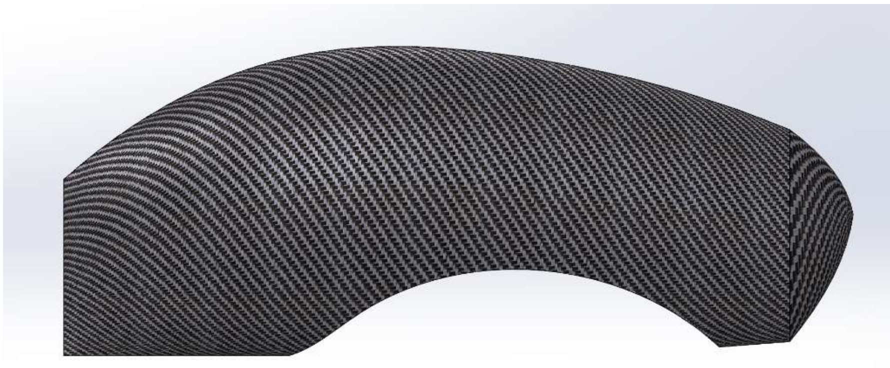

Figure 5: Fairing Design Iteration 3

With the E-Fest competition going virtual this year, there is a high possibility that the HPVC competition will not happen. This sets back our project and priorities. The team is continuing to conduct an analysis on fairing design and will be running real world wind tunnel testing using 3D printed models. Based on the results of that testing, the team will select a final design and have that design on hand in case we decide to build a fairing later on once conditions are better and a competition is held.

3.3 Design Iteration 3: Drive Train

The drive train is a major system within the design of the HPV, and the innovative gear box (Figure 6) that was designed for use as a component of the drive train was intended both to maximize innovation points as well as help maximize the potential top speed of the vehicle.

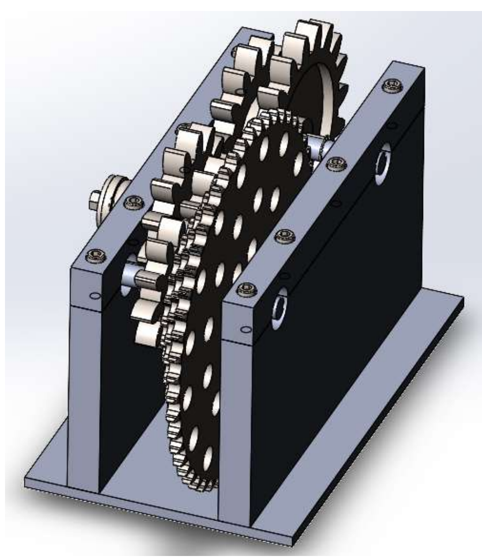

Figure 6: ME 476C Gear Box Design

While the team does plan on producing and integrating some iteration of the dual speed gear box prior to the 2021 E-Fest competition, given the remaining time and the status of the HPV, the team will be temporarily removing this sub-system from the design for the sake of completing the Capstone requirements. Some materials have been acquired for the manufacturing of the gear box and the updated design will be able to accept a future gear box of sorts with minimal changes. As time permits, the gear box will be re-evaluated as to whether or not it will be implemented prior to the completion of Capstone.

4 Future Work

Future work of the team includes testing the use of 1018 Steel tubing instead of the 4130 Steel tubing, as this was accidentally delivered. Several analysis tests will be done to ensure the total safety of the vehicle and the team will conclude from these tests whether the material on hand can be used. Further on, the team has parts in progress for other components including the drivetrain, ergonomics and steering. Any materials that have not yet been ordered, will be decided upon and bought within the next week. Final Analysis for the fairing will be completed on Friday, October 9th by 3D printing and testing in a wind tunnel. The team has discussed the deadline of Sunday, October 18th to have the basic final design completed and ready to test for riding capabilities. All updates and persons assigned to tasks can be seen in the Gantt Chart.

Human Powered Vehicle Fall 2020

NAU 2020 Capstone
Anuththare Alujjage, Allison Bedrin, Ryan Podell, Paolo Quattrociocchi, Samantha Robbins, Sebastian Ruvalcaba

Project Start: Mon, 8/10/2020
Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
HPVC Design Report				
Intro	Team	0%	9/25/20	10/19/20
Design	Team	0%	9/25/20	10/19/20
Analysis	Team	0%	9/25/20	10/19/20
Testing	Team	0%	9/25/20	10/19/20
Conclusion	Team	0%	9/25/20	10/19/20
Document Formalities	Team	0%	9/25/20	10/19/20
Editing	Team	0%	10/19/20	10/25/20
Turn in	Team	0%	10/26/20	10/26/20
Manufacture Trial Design				
Acquire PVC	Ryan	100%	8/10/20	8/16/20
Construct Initial Design	Team	100%	8/17/20	8/23/20
Reconstruct	Team	100%	8/25/20	9/4/20
Manufacture Final Design				
Sponsorships	Team	70%	8/10/20	10/26/20
Acquire Material	Team	70%	8/30/20	9/23/20
Analysis on new material	Paolo, Ryan	0%	9/23/20	9/27/20
Frame Construction	Paolo, Ryan	0%	9/23/20	10/4/20
Seat Components	Sebastian Ruvalcaba	0%	9/25/20	9/25/20
Attach Wheels	Allison Bedrin	0%	10/4/20	10/7/20
Attach Brakes	Samantha Robbins	0%	10/4/20	10/7/20
Fairing Analysis	Anu, Sebastian	0%	10/9/20	10/9/20
Assemble Steering	Samantha, Paolo, Anu	0%	10/4/20	10/14/20
Assemble Drive Train	Samantha, Ryan	0%	10/4/20	10/18/20
Assemble Harness	Ryan, Samantha	0%	10/4/20	10/18/20
Test	Team	0%	10/18/20	10/25/20
Deliver to Client	Team	0%	10/26/20	10/26/20
Compete	Team	0%	TBA	TBA

Figure 7: Gannt Chart

4.1 Further Design

At this point, the priority is placed on fabrication of the frame. All tube will be notched, and tack welded at the NAU Engineering Fabrication Shop and bending will be done at a small shop willing to help in Prescott, AZ. Once these steps are complete the rest of the welding will be completed after all team members check that all members have been oriented correctly. Once frame has been completed then attention can be shifted to fabrication and machining of the necessary drivetrain, steering, and brake components. There are plans to continue work on the fairing after the semester has ended and before the E-fest competition.

4.2 Schedule Breakdown

The overview for construction is in the above Gantt Chart. The team plans to construct the frame as soon as we receive the correct material, and the team expects this to be done by October 4th. The team also plans on testing out fairing designs in the wind tunnel by October 9th, and Anu and Sebastian are in charge of overseeing this process. Paolo and Ryan are in charge of overseeing the frame's completion. Next, the wheels and brakes of the design are expected to be assembled and attached to the frame by October 7th. Allison is in charge of the wheel process, and Sam is in charge of the brakes process. In addition to overseeing the brakes, Sam, Paolo, and Anu are in charge of overseeing the steering which is expected by October 14th. Consequently, Ryan and Sam are in charge of the drivetrain, and the plan is to have the drivetrain attached to the frame by October 18th.