NORTHERN ARIZONA UNIVERSITY
College of Engineering, Forestry & Natural Sciences

Northern Arizona University

NASA Human Exploration Vehicle Competition

Report One: Background Report

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1 Introduction

This vehicle is being designed to participate in the NASA Human Exploration Rover competition. The objective of this project is to design and build a vehicle that can navigate a multitude of terrains through a half-mile course.. The sponsors' that are interested in this project are NASA, along with the Society of Automotive Engineers advisor (SAE), Dr. John Tester. Their interest comes from the want to be able to cross the predicted terrains of planet Mars, and to aid with their design for the actual prototype. The completion of this project will provide a working prototype of a design that will suit their needs, as well as become a possible design for future NASA missions.

1.1 Project Description

Following is the original project description provided by the sponsor:

"NASA Human Exploration Rover Challenge revolves around NASA's plans to explore planets, moons and asteroids across the solar system. The project is to design, construct, test and race mobility devices–lightweight, human-powered rovers–capable of performing in the varied, demanding environments to be explored. The challenge will focus on designing, constructing and testing technologies for mobility devices to perform in these different environments."

1.2 Original System

This project involves a completely new design for a Human Exploration Rover. This project is not a revision build that focuses on the improvement of one aspect of the vehicle, because of this, we used other designs, products, and projects to help us better understand the design challenges. With no previous or original system to reference, we used projects such as the Human Powered Vehicle (HPV), along with consumer products such as a recumbent bicycle, a quad-cycle, and a tandem bike. The comparison and usefulness of each system will be discussed alter in the report.

Quadra-cycle, HPV, recumbent, and tandem

2 Requirements

This section begins with a description of the requirements outlined by the customer. The customer requirements are then weighted numerically, with higher numbers signifying a more important requirement. Also included are target objectives, which are not substantial requirements that necessitate a weighting, which indicates goals that the team aims to meet. Customer requirements and target objectives are compiled into a House of Quality along with corresponding weight ratings. This section may refer to the design objective as a vehicle or a rover, which are synonymous ways of describing the design objective.

2.1 Customer Requirements

The customer requires that the team build a vehicle that is solely human powered and propelled around the test course by two students – one female and one male. Tires on the vehicle cannot be inflatable or pneumatic. The vehicle must be sturdy enough with wheel technology able to traverse large obstacles, provide traction and support on soft, hard, rough and smooth surfaces, and cross cracks, crevasses and ruts. The vehicle must be able to do this on flat or inclined surfaces from a moving or static start. All wheels must be covered with dust abatement devices, or fenders, sufficient to mitigate the hazard of flying debris.

To verify ship-ability, the vehicle must be easily deconstructed to fit within a cubical container of sides measuring five feet. The vehicle must be lightweight and portable, such that collapsed shipping configuration can be lifted by the two drivers and carried 20 feet without contacting the ground.

Assembled, the vehicle is constrained to a width no greater than five feet, with no restrictions on length or height. The ground clearance of the vehicle at its lowest surface must be no less than 15 inches. The turning radius of the vehicle can be no greater than 15 feet. The vehicle is required to have a specific set of accessories, which may be real or simulated during testing. They include a high-gain antenna, a national or institution flag, two batteries, a video camera and an electronic control panel. To address safety concerns, the vehicle seats must have adequate restraints to secure the driver. Furthermore, all sharp edges and geometries must be guarded or eliminated.

2.2 House of Quality

This section briefly discusses the HoQ that is attached with this report. The HoQ consists of 17 customer requirements (CRs) each weighted by the importance of its inclusion in the final design. The two most important characteristics of the design are that the vehicle is human powered, and can be easily transported. Cargo space is limited during space travel, so having a light compact design will be more desirable for NASA. To view the rest of the CRs, see the HoQ attached.

3 EXISTING DESIGNS

The following section lays out the preliminary research for the Mars Human Powered Vehicle project. Research was conducted to ensure preventable mistakes are avoided. Below, the research is divided into sub-categories in order to establish the alternative areas to learn about human powered vehicles. The system level and subsystem level sections divide the key areas of focus in order to better understand what the research was focused at studying.

3.1 Design Research

The research for the Mars human powered vehicles comes from the following areas: personal experience, internet research, the Northern Arizona University SAE club (Students of Automotive Engineer), NASA Curiosity engineers and prior internship bike research. The areas of research are broken up into categories to show the various forms of research. The key focus when collecting the data was to evaluate systems and subsystems that the team will encounter in the designing and construction of the vehicle.

3.1.1 Personal Experience

Personal experience includes the experience of all the team members. This experience comes from our own personal interactions with vehicles, whether human powered or motorized, throughout our engineering experience. This experience ranges from repairing and restoring bicycles to fixing cars. The team experience is important in the design and construction of the Mars Rover vehicles. This experience is important for understanding proper materials and the manufacturing of parts and subsystems.

3.1.2 Internet Research

The internet research includes processes and information from various industries including bike shops, motorcycles manufactures, automotive industries, and engineering companies. A large influence in changing the paradigm of the problem came from the competing teams that have pictures on the NASA website [1]. It is important when viewing the competitor's designs to not begin creating vehicles that operate similarly, but to approach it with the goal of learning of possible routes for subsystems. Additional internet research was done with the SAE, but is explained in the following section.

3.1.3 Northern Arizona University SAE

The Northern Arizona University chapter of SAE is one of the project's most valuable resources. All members of the Mars Exploration Rover team are new associates of the organization and are learning about the vast resources of the SAE organization. Such resources include fellow peers within the program, senior engineering professors, machine shop capabilities, and a library with automotive resources of such as the SAE magazines. The importance of SAE is that the chapter heads have decades of experience in automotive vehicles, design, and testing.

3.1.4 Prior Internship Bike Research

Two of the team members, Greg and Josh, spent a summer interning at a Flagstaff small business shop. This internship allowed months of hands on experience creating a bicycle-like vehicle. Lessons included control, safety, and steering.

3.1.5 NASA Curiosity Engineer

The lead engineer of the Mars Curiosity rover will be in contact with the team leader to help explain challenges and issues that NASA Curiosity group had when designing their multi-million dollar rover. This resource will be most for educational purposes with a small possibility of design help.

3.2 System Level

[Use this section to discuss existing designs (besides, for re-engineering projects, the original system when the project began) that address requirements relevant to your project at the system level. For example, if you were designing a race car, one would use this section to describe entire race cars meeting similar or related requirements. If you were re-engineering an inventory management system, you would give an overall description of each of several inventory management systems. List at least three system-level designs and add more as necessary. Cite the sources from which the designs were identified, including your own benchmarking results, if appropriate. Use this section to describe the rationale for your selection of the systems described in the following subsections.]

[Include in Background Report and all subsequent reports.]

3.2.1 Existing Design #1: Quad-Cycle

The quad-cycle can be a one or two person bike with four wheels. Pros of this design are that it is stable, can easily carry two passengers, has plenty of storage space, and is all terrain capable. Cons are that the frame has a small profile, it appears that the weight is off center and wheel axels appear to be fragile. The quad-cycle cannot navigate large obstacles and currently has no dust abatement fenders. It is unknown if this design has a 15 foot turn radius or if the undercarriage height is at least 15 inches. This design satisfies the requirements of transporting two people, store accessories, less than five feet in width, and can be easily collapsed down into a 5-by-5-by-5 container.

3.2.2 Existing Design #2: NAU Human Powered Vehicle

Northern Arizona University's Human Powered Vehicle performed well at last year's competition. Pros of the HPV are that it is lightweight, aerodynamic, and fast. However, it cannot go over large obstacles, cannot accommodate two riders, has no storage space, extremely poor turn radius, cannot be collapsed down, it is too low to the ground, and it can't hold required accessories. This design can be carried by two riders.

3.2.3 Existing Design #3: Recumbent Bike

A recumbent bike is similar to NAU's Human Powered Vehicle. Recumbent bikes excel at stability, turning radius, are lightweight, and have the potential for storage space. However, a recumbent bike is too low to the ground, it cannot hold two people, cannot collapse into a 5x5x5 box, and cannot traverse over large obstacles, and it has inflatable tires.

3.2.4 Existing Design #4: Tandem Bike

The tandem bike is a bicycle built so two people can ride single file while peddling on the same gear train. They are typically lightweight, fast, have a minimized turning radius, and can navigate over large obstacles. Tandem bikes do not have storage space, cannot collapse, and cannot carry required accessories.

3.3 Subsystem Level

3.3.1 Subsystem #1: Wheels

The effectiveness of the wheels will be a factor in how much force is needed to overcome various terrain in the competition. Durable wheels with good traction that do not require air are necessary if the team wants to do well at the competition. The design could have the best brakes, steering and frame, but if the wheels do not propel the vehicle forward when a force is applied, everything will fall apart.

3.3.1.1 Existing Design #1: Rubber Wheels

The common wheels are standard rubber, inflated wheels. They are good for traversing rough terrain are easy to transport and light enough to have spares on board the vehicle. These wheels can traverse large obstacles with the proper propulsion, they have decent traction, and provides some support over soft, hard, and rough surfaces. The cons of these wheels are that they need to be inflated, there are no dust abatement devices, and they can where down quickly.

3.3.1.2 Existing Design #2: Solid Rubber Wheels

Solid rubber wheels are the same as the previous design, except that they need no inflation. The life span of these wheels are long with very minimal maintenance if any. The problem with these wheels are that they are heavy and difficult to purchase.

3.3.1.3 Existing Design #3: 3D Printed Wheels

3D printed wheels of a new design by Dr. Tester have the potential to be very effective. The problem with this wheel choice, is that he has not chosen to explain their exact specifications, but plans to debrief us upon request.

3.3.1.4 Existing Design #4: Solid Aluminum Wheels

Solid aluminum wheels are another option. These are currently what the Mars Curiosity Rover uses. These wheels are long lasting and greatly exceed the amount of payload they can support when compared to similar designs. The problem with this choice is the added weight, the high cost of material/machining, and the low amount of grip on solid surfaces (no dirt).

3.3.2 Subsystem #2: Braking

As important as propulsion is, braking is equally important. The vehicle needs to brake well to be able to maneuver the terrain and obstacles present at the competition. A good braking system will increase handling around turns as well as protect the drivers and the vehicle is there is a need to come to an abrupt stop.

3.3.2.1 Existing Design #1: Disk Brakes

Disk brakes are very common on bicycles. Pros of disk brakes are the durability, no rim wear/tear, long lasting, resistant to mud/water, and stronger than rim brakes. Cons of disk brakes are the added stress to the spokes, they heat up quickly, require readjustment, and cause torsional stress on the wheels. Disk brakes are relatively standard and provide good control over the vehicle.

3.3.2.2 Existing Design #2: Pad Brakes

Pad brakes are simple, but effective brakes. These brakes allow for easy assembly and low design times. They can be found on most low quality brakes due to their low cost. The problems with them are that they have long distance and ware quickly. Replacing these brakes requires an entirely new assembly, which is not feasible for NASA applications.

3.3.2.3 Existing Design #3: Reverse Gearing Brakes

Reverse gearing breaks are common on cruiser bicycles. This is the quickest build system as it is simply making it so that any backwards pedaling slows the tires and ultimately the vehicle. Some problems include: possibly tire damage, unstable stopping, can hurt the drivers if pedaling fast enough, and low stopping time.

3.3.2.4 Existing Design #4: Drum Brakes

Drum brakes are very common. These can be found on most vehicles today and all older vehicles. The design of the mechanism allows for long life cycles with dependent results. A major problem is that a small version of these brakes has not been found as would be needed for the project.

3.3.3 Subsystem #3: Steering

Having good wheels and great brakes will not mean anything if the drivers cannot steer the vehicle. Steering is essential in any vehicle, especially any space-faring vehicles. The operators of this bike need to be able to dictate where the bike goes when. Steering in combination with propulsion and brakes are what make the vehicle useful. However, if the steering is lacking, no amount of propulsion will help the drivers reach their destination if the vehicle cannot be controlled.

3.3.3.1 Existing Design #1: Stem-Wheel

The Quad-Cycle uses a stem-wheel steering apparatus. A steering wheel connected to the stem turns the wheels to steer the vehicle. The exact turning radius is unknown. A stem-wheel design is more familiar to most riders. It provides optimal control of the vehicle without sacrificing functionality.

3.3.3.2 Existing Design #2: Pulley Mechanism

Pulley systems succeed in small designs and can allow for high torque in the vehicle control. The problem with this is that drivers require a long time to learn how to steer in order to grasp how to control the vehicle without damaging it.

3.3.3.3 Existing Design #3: Pull Bars

The NAU Human Powered Vehicle team, last year, integrated pull bars steering into their design and showed many advantages including: easy control of the system, able to be done in a very tight building area, and light weight. The problem is that the turning was sensitive and had a very small turning radius that they were not concerned with.

3.3.4 Subsystem #4: Frame

The frame is the key structure within the vehicle. All of the subsystems need to be compatible with the frame design. The material choice for the frame could change the weight from being 20lbs. to 40lbs. or more. The main three materials to choose from are 6061 aluminum, 6031 steel, and chromoly.

3.3.4.1 6061 Aluminum

Aluminum is a practical, light weight material used in most modern bike frames. This material allows for an inexpensive frame and low weight to strength ratio. The problem with aluminum is that it is difficult to weld, which is going to be the most prominent way to make a frame. Another problem is that it can get damaged quickly in testing applications

3.3.4.2 6031 Steel

6031 steel is one of the most available steels to find today. It is one of the strongest steels that can be purchased from any steel vender. This grade of steel can be welded by all forms of welding. The key issue is that this is a heavy material. The finished frame will also need to be heat treated if using this steel to cure and remove strength reductions caused by welding.

3.3.4.3 Chromoly

Chromoly is a four thousand series of steel. This steel is prominent in the automotive industry. This steel works well with welding as well and can be purchased from every steel vender. This is the most common steel an engineer can get a hold of for its machining, bending, and structural fabrication. The weight is less than 6031 steel and greater than the aluminum.

3.3.5 Subsystem #5: Propulsion

A good propulsion system is essential in any vehicle. Any vehicle can have the best tires, frame, brakes and steering, but without propulsion, it will not go anywhere. To complete the competition, the bike needs a good propulsion system the drivers can utilize to get the vehicle from start to finish.

3.3.5.1 Existing Design #1: Bicycle Drive-train System

The first design is a bicycle drivetrain. This design is a working and well tested method of transforming human foot power into movement. The benefit of going with a system such as this is that any bicycle system can be taken apart and manipulated for the rover's mechanism. The problem comes with a chain length and stability. The machine being designed needs to be able to withstand high torques to move heavy loads and typical bicycle chains are not the best in high torque situations.

3.3.5.2 Existing Design #2: Belt System

The second design is the belt system. This system is great with high torque scenarios and allows for error in the pedaling that is associated with quick jerks and turns on a tram. The problem with a belt system is the lengths and thickness of the belts as they are most commonly a set length and width and can be over-engineered for the design itself.

Appendix A

Customer Requirement	Weight	Engineering Requirement
1. Human Propelled	50	
2. No inflated wheels	30	
3. Wheels of adequate diameter to traverse obstacles	10	
4. Must be able to climb a grade	10	
5. Maintain traction through varying terrain	10	
7. All wheels require debris mitigation devices	10	
8. The rover must be narrow	10	
9. Collapse into a small space	30	
10. Able to be carried by two individuals	20	
11. Original design and build	40	
15. Able to seat two drivers, one of each gender	30	
Target(s), with Tolerance(s)		
Rover painted in school colors	LTE	
Mirrors	LTE	
Safety seat restraints	LTE	
High volumetric storage	LTE	
No sharp protrusions	LTE	
Built with campus equipment and resources	LTE	
	250	
Approval (print name, sign, and date):		
Team member 1: Joshua DeBenedetto		
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Team member 3: Joseph Andaya		
Team member 4: Kyle Carpentier		
Team member 5: Wilson January		
Team member 6: Joseph Annolino		

Figure 1: House of Quality

Works Cited

[1] National Aeronautics and Space Administration, *NASA Human Exploration Rover Challenge,* [online] 2014, http://www.nasa.gov/roverchallenge/realrovers/index.html#.VCR6SfldUQR (Accessed: 23 September 2014).

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