University of Alabama in Huntsville

LOUIS

Honors Capstone Projects and Theses

Honors College

4-29-2014

An Investigation of Drag on the Haack Series Nose Cones through Subsonic and Supersonic Mach Regimes

Chad O'Brien

Follow this and additional works at: https://louis.uah.edu/honors-capstones

Recommended Citation

O'Brien, Chad, "An Investigation of Drag on the Haack Series Nose Cones through Subsonic and Supersonic Mach Regimes" (2014). *Honors Capstone Projects and Theses*. 172.
https://louis.uah.edu/honors-capstones/172

This Thesis is brought to you for free and open access by the Honors College at LOUIS. It has been accepted for inclusion in Honors Capstone Projects and Theses by an authorized administrator of LOUIS.

NASA Human Exploration Rover Challenge Lunar Environment Adaptation

by

Darren Patrick O'Donnell

An Honors Capstone
submitted in partial fulfillment of the requirements
for the Honors Diploma
to

The Honors College
of
The University of Alabama in Huntsville

April 24, 2019

Honors Capstone Director: Dr. Paul Collopy
Professor of Industrial & Systems Engineering and Engineering Management

4/24/19

Student Date

4/25/19

Director Date

4/25/19

Department Chair Date

5/1/19

Honors College Dean Date

Honors Thesis Copyright Permission

This form must be signed by the student and submitted as a bound part of the thesis. In presenting this thesis in partial fulfillment of the requirements for Honors Diploma or Certificate from The University of Alabama in Huntsville, I agree that the Library of this University shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by my advisor or, in his/her absence, by the Chair of the Department, Director of the Program, or the Dean of the Honors College. It is also understood that due recognition shall be given to me and to The University of Alabama in Huntsville in any scholarly use which may be made of any material in this thesis.

Darren P. O'Donnell
Student Name

Student Signature

4/24/19
Date

NASA Human Exploration Rover Challenge Lunar Environment Adaptation

by
Darren Patrick O'Donnell

An Honors Capstone
submitted in partial fulfillment of the requirements
for the Honors Diploma
to

The Honors College
of
The University of Alabama in Huntsville

April 24, 2019

Honors Capstone Director: Dr. Paul Collopy
Professor of Industrial & Systems Engineering and Engineering Management

____
Student Date

____
Director Date

____
Department Chair Date

____
Honors College Dean Date

The National Aeronautics and Space Administration's (NASA) Human Exploration Rover Challenge (HERC) started in 1994 around the 25th anniversary of the first Apollo moon landing. Since then, the competition has encouraged students from around the world to develop their own 2-person rovers with some of the same guidelines and constraints that the original lunar roving vehicle had. Although many of these constraints help to show the importance for creative solutions, they do not always fully demonstrate the full leading importance to getting a rover onto the moon. The University of Alabama in Huntsville (UAH) entered two rovers into the competition in 2019, the focus will be around Team 1's design. This paper aims to discuss probable changes required to enable the team's challenge-ready buggy to function properly and efficiently on the lunar surface with consideration of environmental conditions and human factors. The primary areas of concern deal with the redesign of the frame to meet the requirements of an astronaut, the amount of oxygen supply that the astronaut would need if the buggy were to remain pedal powered, and the comparison of this oxygen supply to that of batteries if the buggy were to switch to an electric motor.

The first Apollo mission that brought and used the Lunar Roving Vehicle (LRV) was Apollo 15. The driver of the LRV was astronaut James B. Irwin, so this paper will be using the dimensions and information about his space suit primarily. The dimensions of the LRV itself can be seen in figure 1, where it is approximately 72 inches from tire to tire, and 122 inches from front to back. What is not pictured is how the LRV folds, and it does so in order to fit within the small confines of the lunar module.[1]

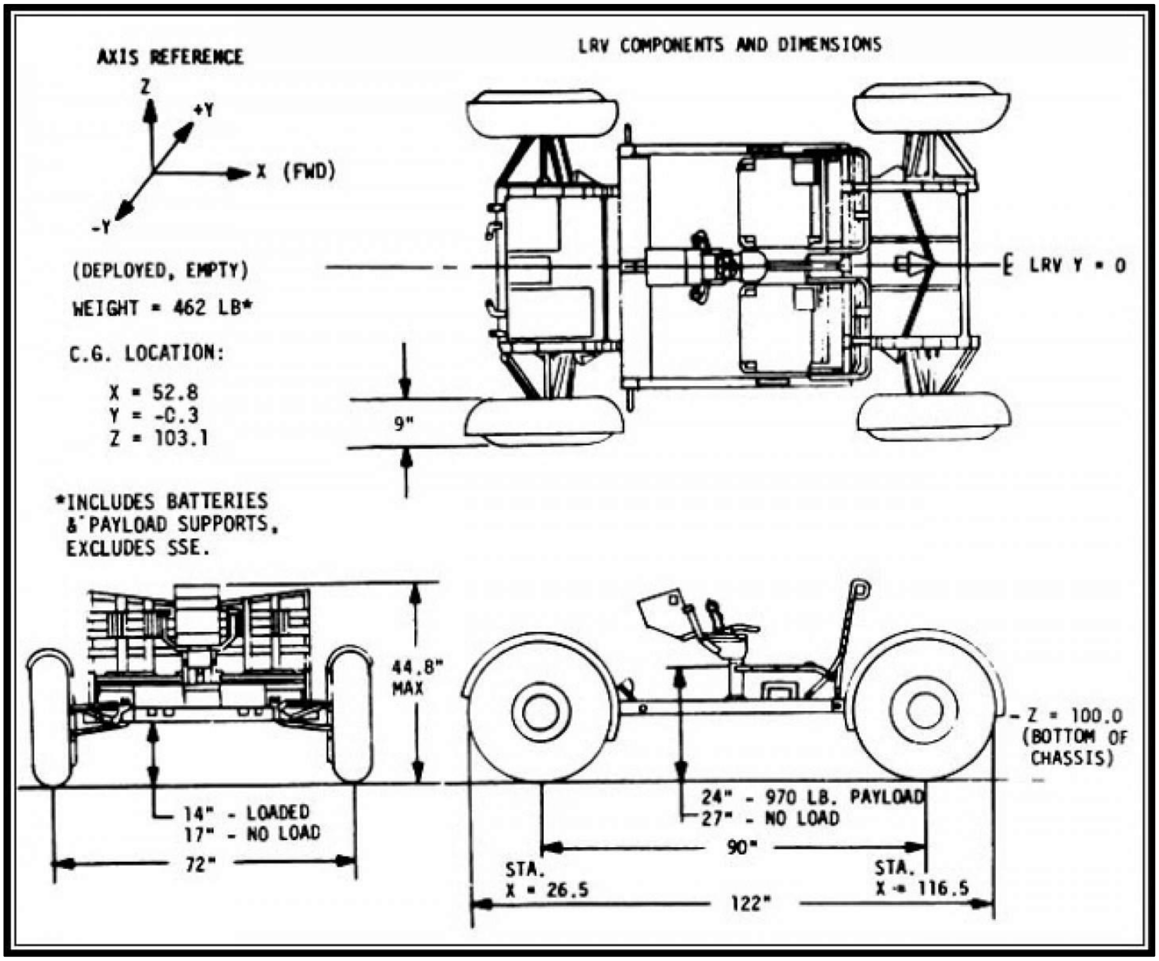

Figure 1. Dimensions of NASA's LRV[1]

UAH's Team 1, the Norse Horse on the Course Force (NHCF) – named such as their rover's name is Alsvior, a mythical horse from Nordic mythology that pulled the sun across the sky – produced a rover that is also capable of folding up to fit within a small space; defined by the NASA HERC guidelines as a 5 x 5 x 5ft cube.[2] The unfolded dimensions of the rover Alsvior can be seen in figures 2, 3, and 4. NHCF's length and wheel base are both smaller than that of the LRV at 56.9 inches wide and 90 inches long. This size allows the buggy to fold and still fit within the 5ft cubic volume required, without having to add on intricate mechanisms and allowing for quick deployment on the course.

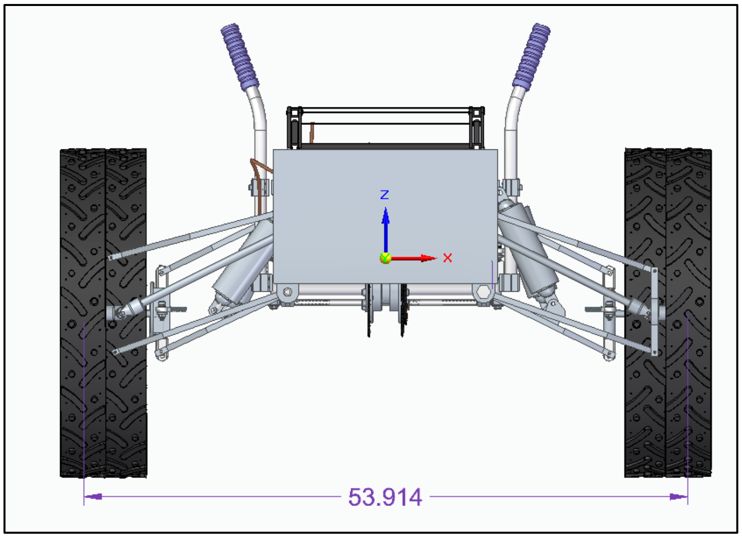

Figure 2. Dimension of outer, rear wheelbase – rear view of Alsvior.

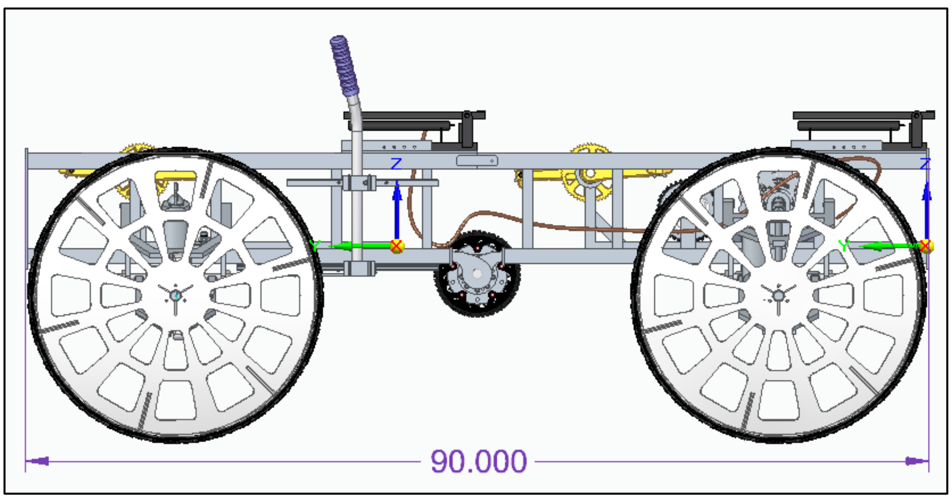

Figure 3. Length of Alsvior, left view

Although Alsvior meets all the requirements for the NASA HERC, these guidelines do not account for any of the extra dimensioning issues that come with a pressurized suit. Using the information from the Smithsonian National Air and Space Museum on James Irwin's space suit, the dimensional requirements for Alsvior change drastically, as the seats that work great for the

NHCF drivers do not even remotely seat an astronaut in a pressure suit. The approximate dimensions for the suit are 153.7cm tall by 120.65cm wide, or 60.5in by 47.5in.[3]

The current design for Alsvior is one that houses all of the drive train, seats, and riders on the inside of the rectangular frame. The idea was to increase safety and avoid having any potential collisions injure the legs of the drivers, as the course had obstacles such as trees and standing concrete slabs. This design is incapable of housing an astronaut in a pressure suit. Figure 4 shows how the aluminum bars would have to greatly widen to fit the astronaut at a minimum. Even this change would be extremely restrictive, if the astronaut(s) were required to pedal to power the rover.

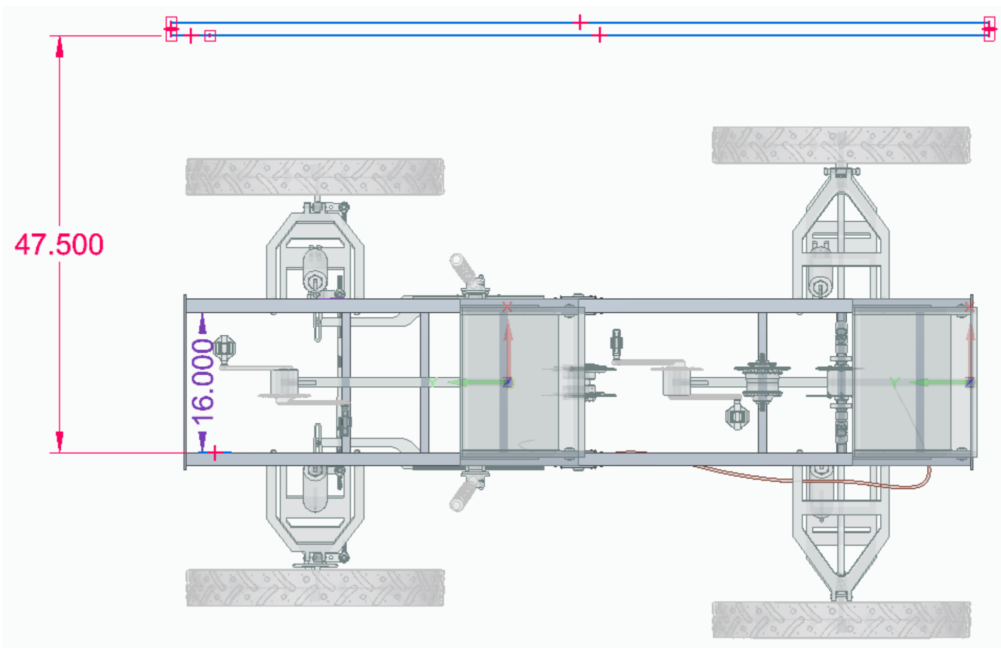

Figure 4. Demonstration of required dimensional change to accommodate a pressure suit

This change to the rover layout would require a redesign on the suspension and A-arms as well, or perhaps a more intricate folding mechanism that would allow the buggy to collapse inward, as well as from front to back, in order to maintain a folded volume no greater than five cubic feet. A popular option that would still fit with the theme of the HERC would be to remove the containing aluminum bars, and run them down the centerline of the buggy, attaching the drivetrain and seats to it. This allows for a much greater degree of freedom of the legs – and issue the NHCF had while testing – as well as removing some weight that is essentially doubled by having the mirrored aluminum frame.

Assuming this redesign of the frame is plausible, there are a few other considerations to note: this design lacks fenders. In the previous year of the NASA HERC, fenders were a requirement for all rovers, this year they were not, so the NHCF as well as most other teams simply neglected to include them for simplicities sake. These fenders are extremely important on the lunar surface to reduce the amount of dust thrown up that can cause problems with systems, especially to the space suits. “It was found that the effects could be sorted into nine categories: vision obscuration, false instrument readings, dust coating and contamination, loss of traction, clogging of mechanisms, abrasion, thermal control problems, seal failures, and inhalation and irritation.”[4] Before the LRV could even be launched, testing had to be done on the moon after Apollo 11 had landed in order to ensure that the fenders would sufficiently contain the dust. This is because there was no real way to have previously studied the behavior of the dust in low gravity, in a vacuum. There were numerous and ever-present problems with the dust build up – it caused most Velcro to be rendered useless, generated poor sensor readings, caused damages to seals and abrasions to equipment. The dust is such a problem that in the Apollo 17 Technical Debriefing, Gene Cernan said, “I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust.”[4] The importance of the fenders cannot be overstated and covering the wheels to a maximum is a must.

The design for the fenders needs to be able to compensate for motion in the wheel, so it will need to likely be attached to the upper A-arms on all 4 sets of wheels. The more of the wheel that the fender manages to cover, the better, so at least to top half of the wheel should be covered. There is not much room to have the fender extend over the outside wall of the wheel, or the rover may break over the volume constraint; however, the fender should still be designed as an almost full plate on the inside of the wheels, so as to block as much dust as possible from affecting the internal systems of the rover.

Assuming the fenders can properly shield the drive train from becoming clogged with lunar dust, an astronaut still must find a way to pedal the buggy in order to power it. The first problem encountered here involves the immobility of the space suit. In fact, because of how difficult and time consuming it was to try and operate the LRV in the space suit, the astronauts did not even attempt to fasten the seatbelts provided, and instead drove the rover slower than 5kph to avoid being thrown off the rover.[5] However, for the sake of this paper, it is assumed that the astronaut will not be hindered significantly by the suit or the frame of the rover, and the focus will be on their oxygen usage, and how that would affect the carry weight of the rover and themselves.

Using a study from the UA National Library of Medicine National Institutes of Health, it is found that “minute ventilation during bicycle rides were on average 2.1 times higher than in the car,”[6] giving an approximation for making calculations based on the differences between driving the electric LRV and pedaling one. The original LRV was capable of traveling up to 40 miles, but the range was restricted to about six because of the limitations of the astronaut’s Life Support System (LSS) backpack. This six-mile distance allowed the astronauts to be able to walk back to the Lunar Module if the LRV became inoperable.[1] The LSS included The Portable Life Support System (PLSS) and the Oxygen Purge System (OPS)[7] which can be seen in figure 5.

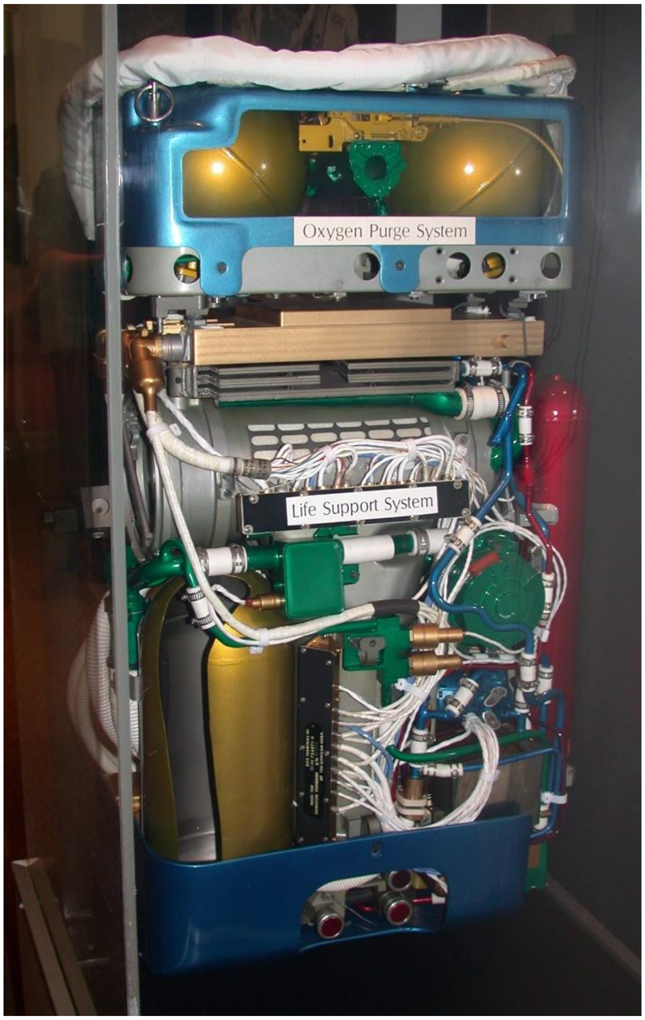

Figure 5. Internals of the Life Support Backpack[8]

The PLSS provided pure oxygen at about 3.7 PSI and provided an operational lifetime of up to 8 hours for the Apollo 15 through 17 missions, which was double the lifetime for the Apollo 11 through 14 missions.[8] This increase in duration came with an increase in weight as well, and the PLSS system weight approximately 129 pounds on earth, and about 21 lbs on the moon.[7]

Assuming that the study done on minute ventilation holds the same ratio for these otherworldly conditions, the 8-hour lifetime for an Extravehicular Activity (EVA) of the LSS is dropped to about 3.8 hours. In order to bring it back up to the full 8 hours again, more oxygen supply must be added. The main oxygen tanks could be edited to be larger and carry more oxygen, or the OPS could be increased, or more of them used. As it stood, the OPS could increase oxygen time under normal conditions by approximately 30 minutes. The OPS systems held 5.8 lbs of pure gaseous oxygen at 5800 PSI, and for the Apollo 15 – 17 missions, could be "stored separately on the Lunar Module and attached to the top of the PLSS via slide-in brackets for EVA assembly and use."[7] The fully charged OPS weighted about 40 pounds – which is only about 6.6 pounds on the moon.[7] Given the accessibility of the OPS to the space suit, and it's relative interchangeability, it would likely be easiest to carry several of these on the rover during pedaling excursions to increase oxygen supply.

Because the normal EVA time is 8 hours, which gets reduced to approximately 3.8 while cycling, several OPS need to be added. The normal 30-minute extension that each OPS would give gets reduced by almost half because of the increased minute ventilation, it will take about 18 total OPS systems to counteract the oxygen usage of pedal power. This would equate to an approximate weight of 118.8 additional pounds on the moon, or 720 additional pounds on earth – which is considerable given the cost per pound to launch something into space is approximately $10,000.[9] This suggests that using pedal power in its current state would cost 7.2 million dollars in launching oxygen equipment alone. Calculations are shown below in figure 6.

$$3.8\,hr + \frac{30\,min}{2.1} * \frac{1\,hr}{60\,min} * (\#\,of\,OPS) = 8hr$$

$$(\#\,of\,OPS) = 17.6 = 18$$

$$18 * 40lbs = 720\,lbs$$

$$720\,lbs * \frac{\$10{,}000}{lb} = \$7.2\,million$$

Figure 6. Equations showing the process of finding the number of OPS needed to recreate the total EVA time, and the approximate cost it would take to launch that equipment.

To counter this proposition, perhaps it would weigh less, and cost less, to refit the rover with an electric motor instead of pedals. The original LRV had each wheel individually powered by an electric motor that only output one quarter-horsepower each. This resulted in a total of one horsepower and allowed the vehicle a top speed of 13kph on a smooth surface[1], though as mentioned before, they never exceeded 5kph.

The UAH college of Engineering actually produced a 3rd, electric buggy in 2019, however it was not to be used in competition. Instead it was a request from NASA in order to prototype the beginnings of a different sort of HERC. The design for this rover would be most compatible with Alsvior, and so it will be used for comparison.

The original LRV used two 36-volt batteries to power the entire system, which included things like steering and sensors, that weighed 59.5 lbs each.[5] The UAH Electric buggy (E-B), is powered by a large series of much smaller batteries, lithium magnesium graphite HE2 18650 batteries. Each of these weighs only a fraction of a pound, but there are 252 of them, so they total up to be 26.67 lbs.[10] The electric motor on the E-B weighs about 28 lbs and has a max horsepower of 15, while being able to reliably sustain 8 horsepower. This is a significant advantage over the LRV, and enables higher speeds, as well as the ability, if needed, to climb steeper hills, provided traction remains. The simplest way to implement this motor on Alsvior would be similar to the E-B, as a rear mounted, and rear-only driving motor. This would be a slight disadvantage on the 4-wheel drive that the LRV provided, but the extra horsepower will likely make up for this. Mounting it as a rear-wheel drive allows for the removal of the pedals, most of the chains, and idle gears, which will bring down weight slightly. This results in an overall weight gain of about 51 lbs, which equates to $510,000 additional cost to launch it into space. This is an astronomically lower cost, and much more effective method of traversing the lunar surface.

With all of these weight considerations comes the decision on what kind of suspension to use. The LRV used a “double horizontal wishbone with upper and lower torsion bars and a damper unit between the chassis and upper wishbone”[11] which was “designed for a factor of safety of 1.5 based on a maximum gross weight LRV of 1500 lb.”[12] Which, with the 3-inch difference from loaded and unloaded, means approximately a stiffness of 500lb/in. The suspension currently equipped on Alsvior are each 1000 lbs/in.

To put this in perspective, the LRV weighed about 460 lbs on earth, and had 500 lbs/in suspension, and Alsvior weighed 315 lbs with 1000 lbs/in suspension.[11] The NHCF realized they had overdone the suspension stiffness already, so a redesign would be needed for that to begin with. Factoring in an additional 51 lbs for the motor sets Alsvior at 366 lbs. To try and match the LRV’s suspension ratio, Alsvior’s suspension stiffness would have to be lowered to approximately 407 lbs/in. This Earth based weight calculation may need to be slightly increased depending on the number of samples and equipment that will be collected on the lunar surface. This should have very little effect, however, as the lighter rover will balance out the equivalent sample size even with the lesser suspension stiffness. Alsvior, on the moon, will only weigh 60.5 lbs, which will allow for a significant load to be placed on it.

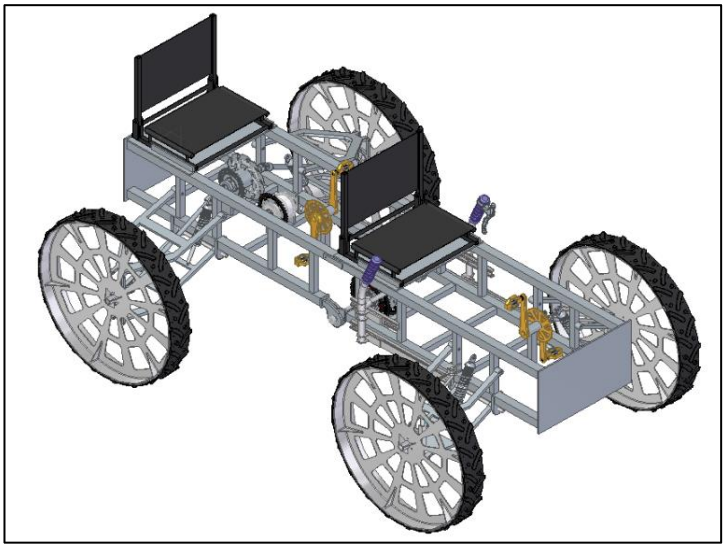

Figure 7. Alsvior Isometric View

In conclusion, there are a few major things that must change about Alsvior as it is in figure 7 before the buggy can be lunar-ready. The seating and general frame design must be changed or expanded to accommodate the pressure suit required for EVA's, and the wheels need to have high-coverage fenders installed over them. Critically, the pedaling system needs to be replaced by an electric motor, as the cost of oxygen to have an astronaut pedal their way across the lunar surface would be in the millions of additional costs, as well as not being very doable even in modern day pressure suits. Alsvior, with these changes, becomes a robust vehicle that would likely be capable of effectively roaming the lunar landscape and something of which the Norse Horse on the Course Force can be truly proud.

Bibliography

1. "Lunar Roving Vehicle (LRV)." Lunar Roving Vehicle (LRV) | National Air and Space Museum. Accessed April 1, 2019. https://airandspace.si.edu/explore-and-learn/topics/apollo/apollo-program/spacecraft/lrv.cfm.

2. *PDF*. Huntsville: National Aeronautics and Space Administration, October 2018. NASA Human Exploration Rover Challenge 2019 Guidebook

3. "Pressure Suit, A7-LB, Irwin, Apollo 15, Flown." National Air and Space Museum. June 08, 2018. Accessed April 1, 2019. https://airandspace.si.edu/collection-objects/pressure-suit-a7-lb-irwin-apollo-15-flown.

4. Gaier, James R. The Effects of Lunar Dust on EVA Systems During the Apollo Missions. March 2005. Report. Glenn Research Center, Cleveland.

5. Young, Anthony. *Lunar and Planetary Rovers: The Wheels of Apollo and the Quest for Mars*. New York: Springer, in Association with Praxis Publishing, 2007.

6. Zuurbier, Moniek, Gerard Hoek, Peter Van Den Hazel, and Bert Brunekreef. "Minute Ventilation of Cyclists, Car and Bus Passengers: An Experimental Study." *Environmental Health*8, no. 1 (2009). doi:10.1186/1476-069x-8-48.

7. Thomas, Kenneth S. "The Apollo Portable Life Support System." https://www.hq.nasa.gov/alsj/ALSJ-FlightPLSS.pdf.

8. Jones, E.m. "The Apollo 17 Lunar Surface Journal." *PLSS (Portable Life Support System)*, 1995. doi:10.2172/100030.

9. Dunbar, Brian. "Advanced Space Transportation Program Fact Sheet." NASA. Accessed April 1, 2019. https://www.nasa.gov/centers/marshall/news/background/facts/astp.html.

10. Youngdungpo-gu, Yoido-dong. Lithium Ion LG 18650HE2 2500mAh Product Specification. October 07, 2013. Raw data. Seoul.

11. Williams, David R. "The Apollo Lunar Roving Vehicle." NASA. Accessed April 1, 2019. https://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_lrv.html.

12. LRV Operations Handbook Appendix A (Performance Data). April 19, 1971. Raw data. Manned Spacecraft Center, Houston.