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ÚSTAV AUTOMOBILNÍHO A DOPRAVNÍHO INŽENÝRSTVÍ

CONCEPTUAL DESIGN OF A MANNED MOBILE LUNAR HABITAT (VEHICLE)

KONCEPČNÍ NÁVRH MOBILNÍHO LUNÁRNÍHO HABITATU (VOZIDLA) S LIDSKOU POSÁDKOU

BACHELOR'S THESIS
BAKALÁŘSKÁ PRÁCE

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Brno 2023

Zadání bakalářské práce

Ústav:	Ústav automobilního a dopravního inženýrství
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Ředitel ústavu Vám v souladu se zákonem č.111/1998 o vysokých školách a se Studijním a zkušebním řádem VUT v Brně určuje následující téma bakalářské práce:

Koncepční návrh mobilního lunárního habitatu (vozidla) s lidskou posádkou

Stručná charakteristika problematiky úkolu:

Začíná nová éra pilotovaných letů na Měsíc. Otevírá ji série misí programu Artemis (I až VI). Důležitým technickým prostředkem těchto misí jsou autonomní mobilní kolové habitaty (vozidla) pro transport posádek na povrchu Měsíce. Tato vozidla by měla být tvořena přetlakovým interiérem poskytujícím plnou ochranu před vnějším extrémním prostředím, tj. úplnou absencí atmosféry, extrémními teplotami, mikrometeority, atp. Vozidlo by mělo poskytovat vysoký vnitřní komfort bez nutnosti používat přetlakový skafandr. Musí být vybaveno systémy zajišťujícími stabilní vnitřní přetlak, dýchatelnou atmosféru, tepelný komfort, ochranu proti mikrometeoritům, atp.

Cíle bakalářské práce:

Cílem bakalářské práce je provést koncepční návrh autonomního mobilního kolového habitatu (vozidla) pro transport posádek na povrchu Měsíce. Vozidlo bude určeno pro přepravu jedné nebo dvou osob a nákladu o objemu alespoň 1 m3. Pohon vozidla bude elektrický. Dojezd bude alespoň 100 km. Pro ovládání vozidla lze využít prostředky virtuální reality. Důležitým hlediskem návrhu je skladnost vozidla při přepravě v raketovém nosiči. Vstup do vozidla bude primárně zabezpečen prostřednictvím skafandru připojeného k vozidlu přes připojovací port.

Seznam doporučené literatury:

https://en.wikipedia.org/wiki/Space_Exploration_Vehicle.
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Brno 2023

Termín odevzdání bakalářské práce je stanoven časovým plánem akademického roku 2022/23

V Brně, dne

L. S.

prof. Ing. Josef Štětina, Ph.D.
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ABSTRAKT

Bakalářská práce se zabývá konstrukcí lunárního vozidla. V práci jsou popsány případy reálného použití lunárního vozidla. Dála se práce zabývá konstrukcí podvozku lunárního vozidla. Úkolem konstrukční části je návrh ideálního podvozku pro měsíční povrch s důrazem na hmotnost a jednoduchost provedení. Konstrukční řešení jsou následně podrobena analýze za účelem dosáhnutí efektivních výsledků.

KLÍČOVÁ SLOVA

Kyklop, Habitat, Podvozek, Materiál, Tlumení, Analýza

ABSTRACT

The bachelor’s thesis deals with the construction of the lunar vehicle. The work describes cases of real use of the lunar vehicle. Further work deals with the construction of the chassis of the lunar vehicle. The task of the structural part is to design an ideal chassis for the lunar surface with an emphasis on weigh and simplicity of design. Design solutions are subsequently subjected to analysis in order to achieve effective results.

KEYWORDS

Cyclop, Habitat, Chassis, Analysis, Material, Damping

BIBLIOGRAFICKÁ CITACE

MIKEŠ, Adam. *Koncepční návrh mobilního lunárního habitatu (vozidla) s lidskou posádkou*. Brno, 2023. Dostupné také z: https://www.vut.cz/studenti/zav-prace/detail/149869. Bakalářská práce. Vysoké učení technické v Brně, Fakulta strojního inženýrství, Ústav automobilního a dopravního inženýrství. Vedoucí práce Vratislav Šálený.

ČESTNÉ PROHLÁŠENÍ

Prohlašuji, že tato práce je mým původním dílem, zpracoval jsem ji samostatně pod vedením Ing. Vratislava Šáleného Ph.D. a s použitím informačních zdrojů uvedených v seznamu.

V Brně dne 24. května 2023 ……..……..…………………………………………..

Adam Mikeš

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CONTENT

INTRODUCTION

This research and design bachelor thesis deals with the design of a lunar vehicle. Lunar module is an essential part of any future space cape for cases of fast planetary transfers. Its design must meet the given requirements of loading and operation in a different environment than on earth.

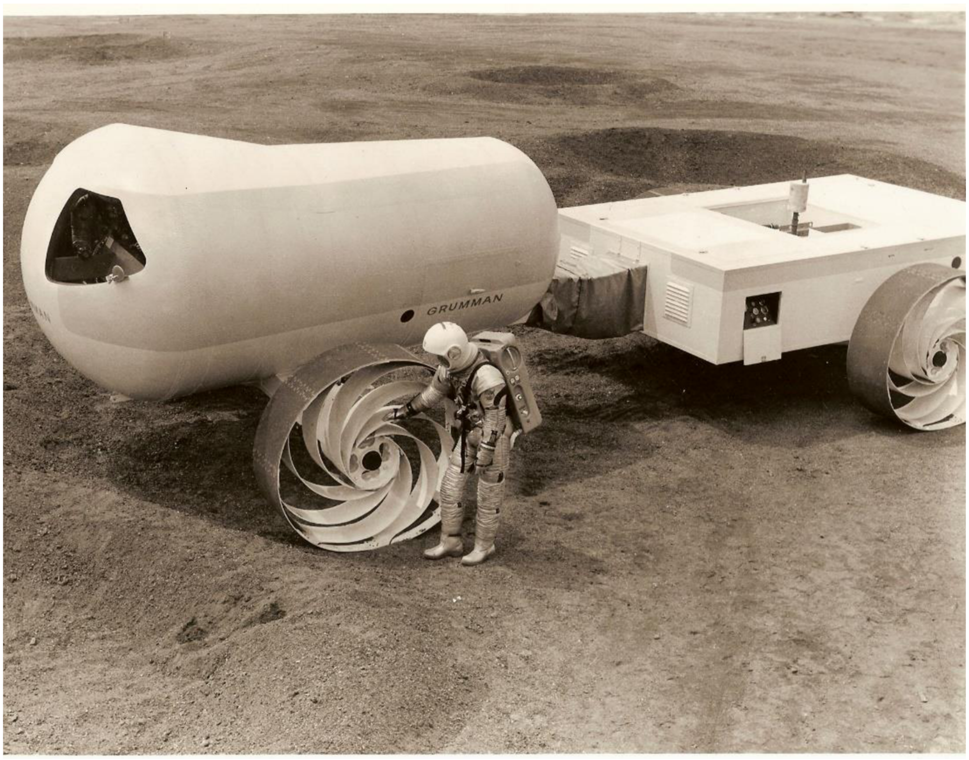
1 LUNAR VEHICLE

1.1 TARGET AREA OF USE

The lunar rover design of this work is intended for the Artemis 1-6 flights, which will be tasked with detailed exploration of the lunar surface. The Cyclops rover concept should facilitate the exploration of the lunar landscape and its subsequent settlement. To introduce the target area of the design, the vehicle design is presented in the following sections.

1.2 HISTORY

To better understand the present and future of lunar vehicles. We'll have to look to history. Since ancient times, people have wanted to see the moon. That's why they've thought about how to get to our nearest cosmic neighbour and navigate on its surface. But it took many years before mankind could develop new technologies and materials to make this journey possible. This was in the second half of the 20th century, when the US and the then USSR were competing for lunar primacy. Both sides began to develop the first concepts for lunar vehicles that would traverse the lunar landscape, manned or unmanned. Engineers had to deal with vehicle design in a completely different environment than they had been used to. And so it's no wonder that the first designs look more like something out of the realm of SCI-FI movies than a car designed to move on the moon. Among the most famous companies to take on this task were Boeing and Grumman. Both companies produced countless designs. Some of the designs were too bold, such as the XD31414 prototype from Grumman. (pic.1)



Picture 1 XD31414 prototype [32]

But there were also more realistic concepts from the same company. For example, this prototype (pic.2), which was to become the official lunar vehicle for the Apollo flights. It was until Ferenc Pavlics came to Verner Von Braun's office. However, he did not come alone, but a smaller version of his lunar rover design entered the office with him. Verner Von Braun was so impressed and intrigued by this design that he gave the green light to the project. The production was undertaken by the American company Boeing which began building the Lunar Roving Vehicle (LRV) at the Kent, Wash., facility in 1969, and the first vehicle was delivered just 17 months after the contract was signed.

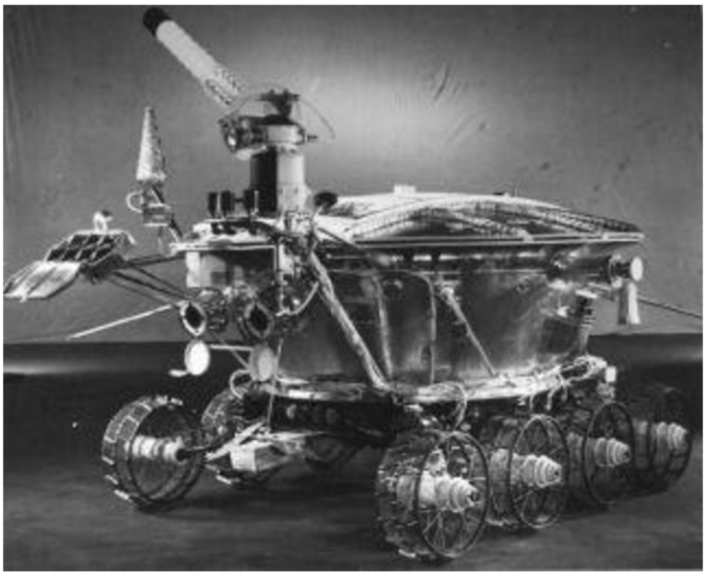
It looked like a golf cart, or a stripped-down dune buggy, but was an engineering marvel. Equipped with a colour television camera able to send images back to Earth via satellite, it travelled about 10 mph (16 kph), carried four times its own weight and had woven piano-wire mesh-like wheels to negotiate the strange lunar surface. An LRV travelled to the moon folded up and stuffed into a small storage space on the side of the Lunar Module on Apollo missions 15, 16 and 17.

The Lunar Roving Vehicles gave the astronauts the ability to do three times the amount of work done on the earlier voyages. The battery-powered vehicles operated faultlessly in temperatures ranging from minus 200 degrees Fahrenheit (minus 128 degrees Celsius) to more 200 degrees Fahrenheit (93 degrees Celsius). After the Apollo program ended, the moon cars were left parked on the surface, awaiting the next generation of astronauts. [1]

The legacy of the LRV, however, extended back to Earth, where its technology helped evolve the motorized wheelchairs that today provide many people with a way of negotiating around this world.

Picture 2 The Lunar Roving Vehicle [33]

Not to be one-sided, it is polite to mention the Soviet design of a lunar vehicle, which was conceived as an autonomous unmanned vehicle. Its name was Lunokhod 1 It was the first successful rover to explore another world. It arrived on the Moon on November 17, 1970, on the Luna 17 landing module. It was controlled remotely by operators in the Soviet Union and travelled more than 10 kilometres in just 10 months. By comparison, the Mars rover Opportunity took approximately six years to reach the same milestone. [2]



Picture 3 Lunokhod 1 [34]

After the end of the Cold War, the two sides began working together to develop new rovers, but none were designed for manned missions with humans on board. The most famous rovers were the successor to Lunokhod 1, Lunokhod 2. After that, interest in rover exploration of the moon waned for many years, and humanity focused more on exploring the planet Mars. Here it is worth mentioning the rover Sojourner, which started exploring the planet Mars in 1997. It was followed by the pair Spirit and Opportunity in 2004.

Picture 4 Opportunity [35]

1.3 PARTICIPATION, CLOSE WAKEFULNESS

In terms of presence, the Curiosity rovers are currently active, exploring Mars, and the Chinese rovers YUTU-1 and YUTU-2 are exploring the far side of the moon. But the biggest success so far is the Perseverance rover, which is the largest remotely operated rover on an alien surface to date.

Picture 5 Perseverance [36]

As far as crewed rovers are concerned, after 50 years, the drive to put a man on the moon is reawakening and with-it new designs for a lunar vehicle. Again, we have a lot of concepts. For example, the JAXA rover (Pic.6).

Picture 6 Jaxa moon rover [37]

Or the giant collaboration of Lockheed Martin, General Motors, Northrop Grumman, Lunar Outpost, AVL, Michelin who are working together to build the LTV. However, LER has the highest probability of success so far. Which was a great template for the Cyclops lunar rover.

LER concept enables a mobile form of exploration that can provide the astronauts' main mode of transportation, and – unlike the unpressurized Apollo lunar rover – also allow them to work on long excursions without the restrictions imposed by spacesuits. The pressurized cabin has a suitport that allows the crew to get into their spacesuits and out of the vehicle faster than before, enabling multiple, short moonwalks, as an alternative to one, long moonwalk. The adaptable vehicle features pivoting wheels that enable "crab style" sideways movement to help the rover maneuver over difficult terrain. Its tilt-able cockpit provides the drivers the best possible view of the terrain ahead. Early concepts also call for an exercise bike that allows crew to exercise while charging the vehicle's batteries. Each rover consists of a mobility chassis and a small, pressurized cabin module. These two components could be delivered to the lunar surface pre-integrated or as separate elements. Astronauts can drive the mobility chassis without the pressurized cabin, by riding in rotating turrets while wearing spacesuits; the chassis can also be used to carry cargo. The modular design allows various tools – winches, cable reels, backhoes, cranes and bulldozer blades – to be attached for special missions. And the chassis can pick up and reposition solar-powered charging stations, communication relays and scientific [3]

Picture 7 LER [38]

Range of Exploration

The presence of two or more LERs on the lunar surface would extend that potential range to more than 150 miles in any direction, greatly increasing the scientific opportunities during lunar missions. Even in the midst of challenging terrain, emergency shelter and support can be less than an hour away. [3]

Astronaut Protection

The greatest risk to explorers on the lunar surface is that posed by unanticipated solar particle events. With a heavily shielded cabin, the Lunar Electric Rover doubles as a storm shelter. The rapidly accessible, pressurized, radiation-hard safe haven can sustain and protect exploring crew members for up to 72 hours against solar particle events, acute suit malfunctions and other medical emergencies. The radiation shielding in the LER cabin provides protection that the Apollo crew did not have on their unpressurized rover (or even in their Lander). [3]

Rapid Ingress/Egress

The LER system's suitport concept allows astronauts to go out for a moonwalk at almost a moment's notice. The suitport will allow the crew to enter and exit their spacesuits without bringing the suit inside, keeping the internal space mostly free of dust and reducing wear-and-tear on the suits. It also minimizes the loss of air inside the cabin when it is depressurized for moonwalks, extending sortie durations by helping the LER to make the most of its resources.[3]

Field Science Capability

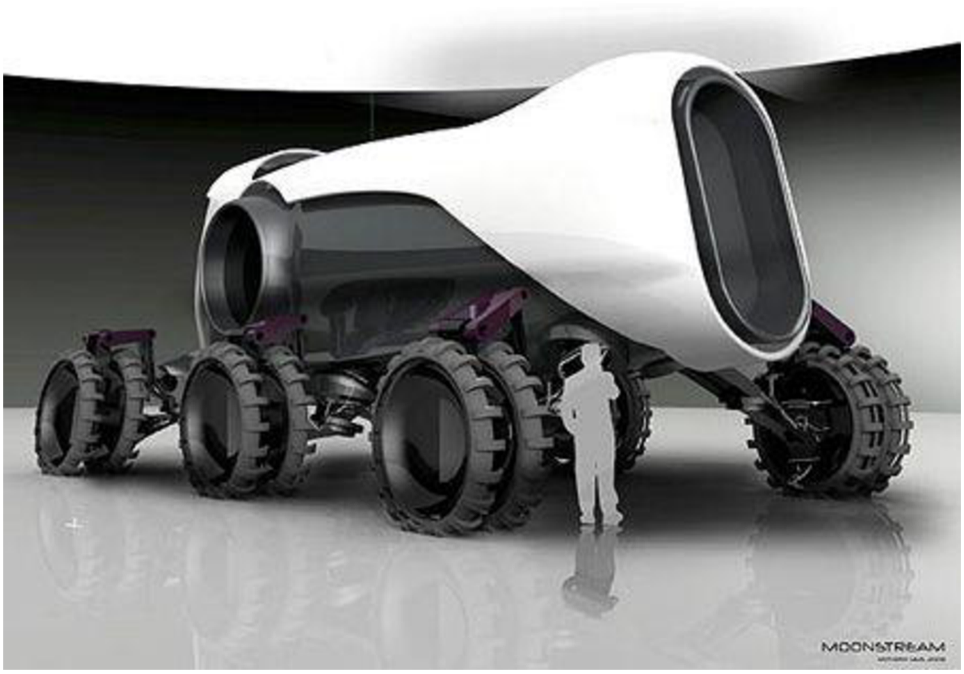
By combining a pressurized cabin with a suitport, the LER gives crew members the unprecedented flexibility of being able to easily switch between working in plain clothes or spacesuits. Although astronauts may want to exit the vehicle to take a closer look at something outside, activities requiring fine manipulation and unfettered visual access are best performed without the confines of a bulky gloves and helmets. Being able to sit comfortably in a cabin and look at geologic formations without the continuous exertion of suited walking enables better use of computers, maps and dialogue between crew members. The cabin can also serve as a rolling science lab for studying samples. [3]

Extended Range on the Moon and Earth

Like electric cars here at home, the Lunar Electric Rover will rely on batteries to travel. NASA is developing batteries that weigh less and provide more power than those currently being used in earthly automobiles. The same technology that will someday allow astronauts to see more of the moon could also lead to better, more efficient transportation for the rest of us, as well. Electric commuter vehicles, electric off-road vehicles, electric transport trucks, and electric construction equipment may one day benefit from NASA's battery innovations [3]

1.4 DISTANT FUTURE

As far as the distant future is concerned, we can only guess at the trend of vehicles, whether lunar or those destined for alien planets. Countless unrealistic and realistic looking rovers are being built. For example, Nasa (Pic.8) which gives us a glimpse of what lunar rovers might look like in 50 years or more.



Picture 8 design of futures pace rover [39]

2 LUNAR VEHICLE CYCLOP

2.1 KEY DESCRIPTION.

The Cyclops moon car is designed to be faster and safer than any previous moon car. In order to achieve the best results, existing space vehicles were used, from which I drew information.

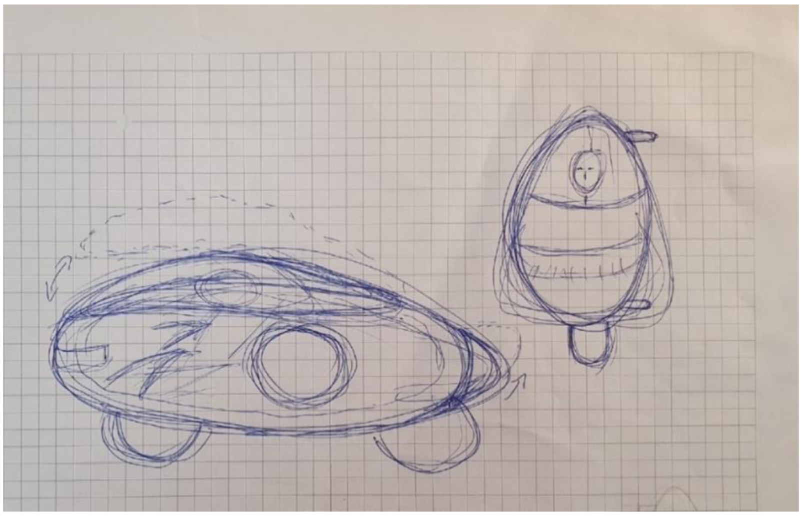
2.2 PARAMETERS OF THE VEHICLE

Length (unfolded)	4500mm
Length(folded)	1700mm
Driven axles	Eight-wheel drive
Maximum range	300km
Maximum speed (rough terrain)	30km/h
Maximum speed (level ground)	60km/h
Storage capacity	1500L
Maximum permissible weight	2 t
Turning radius	3 m

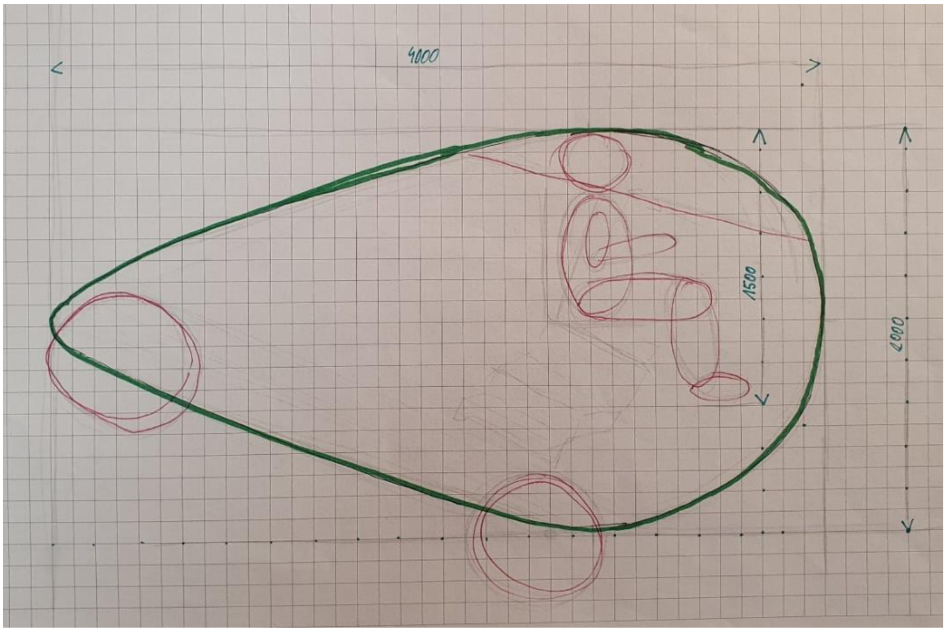
Table number 1 Parameters of the vehicle

2.3 DRAFT

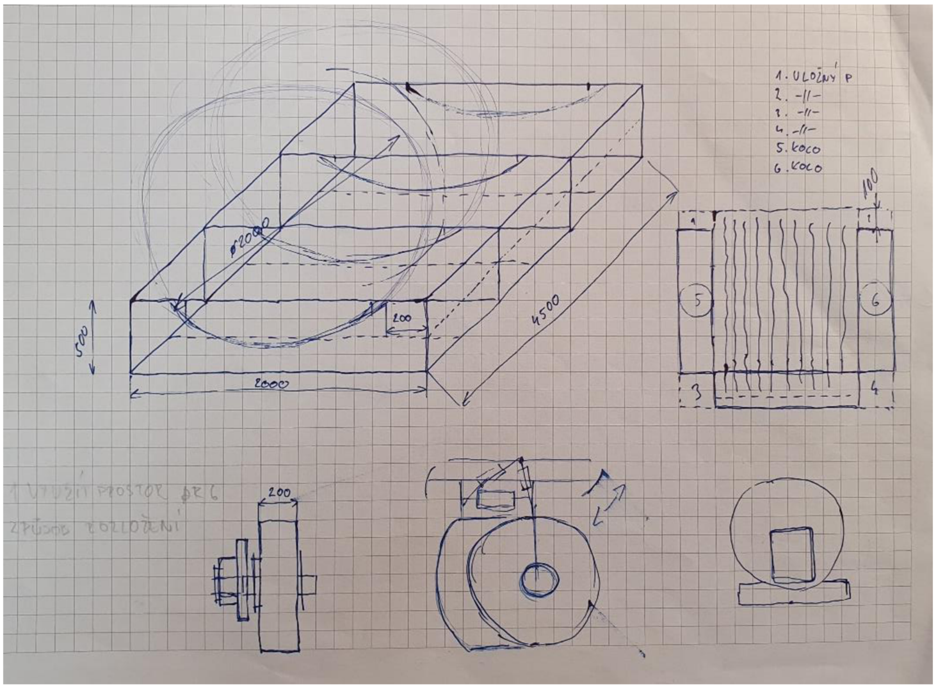
The original designs for the lunar vehicle were very clumsy. However, we can note the evolution of the lunar car from an egg-shaped, two-wheeled vehicle to a full-fledged rover.



Picture 9 draft 1.



Picture 10 draft 2.



Picture 11 draft 3

In order to create the Cyclop lunar vehicle, it was necessary to take inspiration from existing vehicles. The biggest model was the LTV.

The LTV lunar vehicle is currently the best and largest lunar vehicle ever created, which is why I chose it as a model. The LTV track on Cyclop can be seen in the shape of the cabin, for example. Or the similar concept of the wheels. When designing the Cyclop vehicle, I decided to split the development into 2 parts. The living section and the chassis.

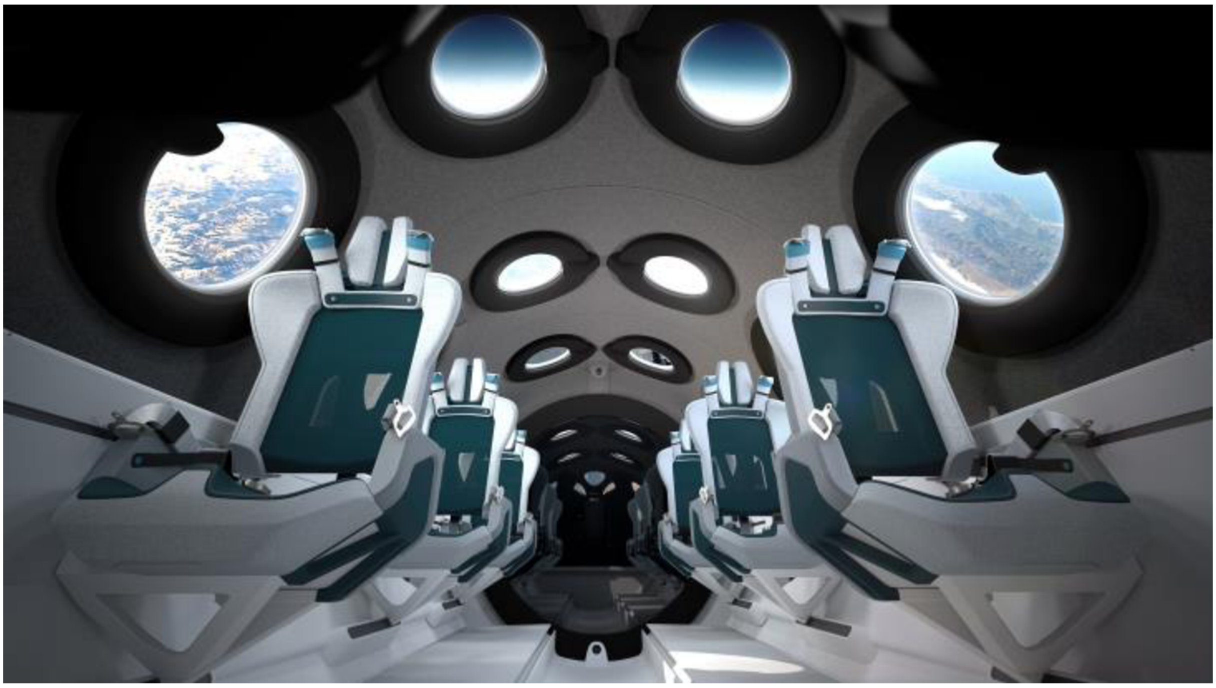
2.4 CONSTRUCTION

To make the description of the overall design of the Cyclops vehicle clearer, I have divided it into two basic divisions. The living area and the chassis.

2.4.1 LIVING AREA

Inner part

The overall interior is created using Kevlar fibre which will be sewn into the outer part. This interior is expanded by "inflating" the habitat. The inner part consists of two sections which are separated by sliding doors. The reason why the habitat is divided into 2 sections is for purely hygienic reasons. This is because the module is divided into a living section and a working section, where contamination could occur that we don't want to transfer to the living section. The whole habitat can then be traversed by means of a middle path, which has a dimension of 1 meter, which is sufficient for one or two persons to move around the habitat in peace. In the first section is the living area. In this section there is a space for driving a car, which also serves as a bed for the astronaut. Here it was necessary to solve the security of the astronaut in case of impact. Thus, I chose a tested seat, which is located in Spaceship Two (pic.12).



Picture 12 seats in Spaceship two [40]

Seats can be customized to each individual, thanks to its form-fitting design. The seats are made of aluminium and carbon fibre, as well as foam and a knit fabric made by Under Armour — which also makes the spacesuits the customers will wear.

Each seat has a five-point harness, so passengers are tightly secured during flight. The buckles are each designed to be readily available, so customers can easily return to their seats after floating in space. [4]

The next task was to solve the storage space in the habitat. Storage space is very important in space travel because spacecraft are designed to carry various equipment, supplies, and payloads that are essential for mission success. These items may include, but are not limited to, food, water, air, scientific instruments, communication systems, and propulsion systems.

Because the spacecraft travels in a vacuum and is isolated from outside resources, it must carry everything needed to sustain the crew and complete the mission. This means that the storage space must be carefully planned and managed to ensure that everything needed for the mission is contained while maintaining the safety and efficiency of the spacecraft.

In addition, the storage space must be designed to withstand the harsh conditions in space, such as extreme temperatures, radiation and microgravity. The materials used for storage must be lightweight, durable and able to withstand degradation due to exposure to space radiation.

Overall, storage facilities are a critical part of space exploration and are essential for the success of any space mission.

Opposite the control station is the section where the food is stored. The food will be served wrapped and pre-prepared on the ground; a similar concept to the MRE is envisaged. The Meal, Ready-To-Eat (MRE) is designed to sustain an individual engaged in heavy activity when normal food service facilities are not available. The MRE is a totally self-contained operational ration consisting of a full meal packed in a flexible meal bag. The full bag is lightweight and fits easily into field clothing pockets. Each meal bag contains an entrée, and a variety of other components as may be seen in the table of Menus. [5]

The last important thing that can be found in both the living and working area are hooks and elastic bands on the walls, which are then used to attach various objects directly to the wall of the habitat. Throughout the section there is then plenty of storage material that the astronaut can use to store other material. Once the doors are pushed open, they are made of Polyetherimide. The reason I chose this material is as follows Polyetherimide is an amorphous polymer that ranges from amber to transparent in colour. This is important to note, as the thermoplastic offers limited colourability. PEI is frequently used as a substitute for metal in various applications due to its favourable strength-to-weight ratio. [6]

That brings us to the part called technical. Just outside the door are 2 drinking water tanks. Each tank is designed to hold 45 litres of drinking water. Considering that usually an astronaut in space uses around 3 litres of water per day altogether for drinking, hygiene and cleaning. [7]

Thus, we find that the astronaut has the possibility of a regular supply of liquid water for a maximum of 30 days. Then if we could filter the water from the astronaut's urine, we'd get to an even higher number. However, the concept of this vehicle does not envisage that.

However, the reservoirs will be stored and not accessed from this part of the habitat to prevent contamination of the water with lunar rigolith. The water from them is routed using plastic soft tubes to the habitation area, where the astronaut will be able to dispose of it as he or she sees fit. I took the "camel bag" as a model for the design solution for water transport, which also works on a similar principle, only on a smaller scale than I need. There will be a toilet next to the tank, this will be used to perform small and large needs. I have chosen the UVMS toilet. The toilet was designed to address astronaut feedback about comfort and ease of use.

It also features a 65% smaller and 40% lighter build than the current space station toilet. Improved integration with other components of the space station water system will aid in recycling more urine, which, yes, the astronauts do drink after it is filtered and processed.

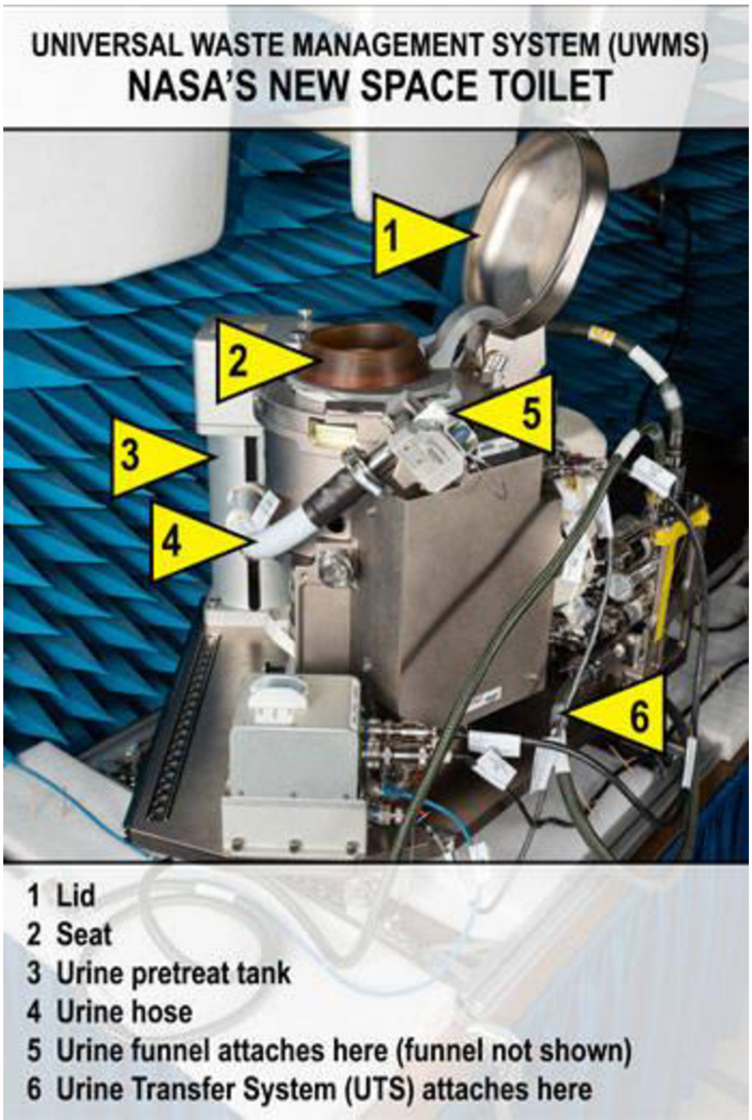
In the cyclops lunar vehicle this toilet is used as follows:

In the low of gravity, space toilets use air flow to pull urine and feces away from the body and into the proper receptacles. A new feature of the UWMS is the automatic start of air flow when the toilet lid is lifted, which also helps with odor control. By popular (astronaut) demand, it also includes a more ergonomic design requiring less clean-up and maintenance time, with corrosion-resistant, durable parts to reduce the likelihood of maintenance outside of the set schedule. Less time spent on plumbing means more time for the crew to spend on science and other high-priority exploration focused tasks.

The crew use a specially shaped funnel and hose for urine and the seat for bowel movements. The funnel and seat can be used simultaneously, reflecting feedback from female astronauts. The UWMS seat may look uncomfortably small and pointy, but in microgravity it’s ideal. It provides ideal body contact to make sure everything goes where it should.

The UWMS includes foot restraints and handholds for astronauts to keep themselves from floating away. Everyone positions themselves differently while “going,” and consistent astronaut feedback indicated that the traditional thigh straps were a hassle.

Toilet paper, wipes, and gloves are disposed of in water-tight bags. Solid waste in individual water-tight bags is compacted in a removable fecal storage canister. A small number of fecal canisters are returned to Earth for evaluation, but most are loaded into a cargo ship that burns up on re-entry through Earth’s atmosphere. Currently, fecal waste is not processed for water recovery, but NASA is studying this capability. In space, every part of the water cycle is key for survival and advances in technology can make a pivotal difference in mission efficiency and success. As we prepare to return humans to the Moon with Artemis and look forward to the first human mission to Mars, life support systems will play a major role in keeping our astronauts healthy and safe as they live, work, and learn farther from Earth than ever before. [8]



Picture 13 UWMS [41]

Across from the toilet is a storage area that holds cleaning supplies or material that is not as susceptible to contamination by the lunar rigolith that the astronaut will be trying to avoid. The reason it should be avoided is simple, it may contain certain substances that could be potentially harmful.

The main reason lunar dust could be problematic is its fine and pungent nature. The dust particles on the moon's surface are usually very small and have edges that could cause respiratory and eye irritation. If it were to enter the lungs, it could cause similar problems to other types of fine dust, such as silica dust.

Another potential problem is possible contamination of lunar dust by chemicals present on the surface of the Moon. For example, there may be trace amounts of heavy metals or other substances that could be toxic or carcinogenic. These chemicals could pose a risk if inhaled or absorbed through the skin.

Because lunar dust has been exposed to vacuum and extreme temperature conditions for long periods of time, it could also contain microorganisms that are different from those found on Earth. If these microorganisms have pathogenic properties, they could potentially cause infection or other health problems.

Fresh air is an integral part of survival on the moon, oxygen cylinders will be stored in both the living and technical sections in the locations marked in the picture. About the total embrace of 600 L.

The amount of oxygen a person needs per day varies depending on various factors such as age, physical activity and health. It is usually expressed in litres per minute (L/min) and then converted to daily consumption.

The average adult consumes approximately 5 to 8 litres of oxygen per minute at rest. If we assume that the person is asleep or at rest for 24 hours, we can calculate the daily oxygen consumption.

Daily oxygen consumption = (average oxygen consumption per minute) x (number of minutes per day).

Suppose the average oxygen consumption is 6 litres per minute. Then we can calculate the daily consumption:

Daily oxygen consumption = 6 L/min x 1440 minutes = 8640 litres of oxygen per day [9].

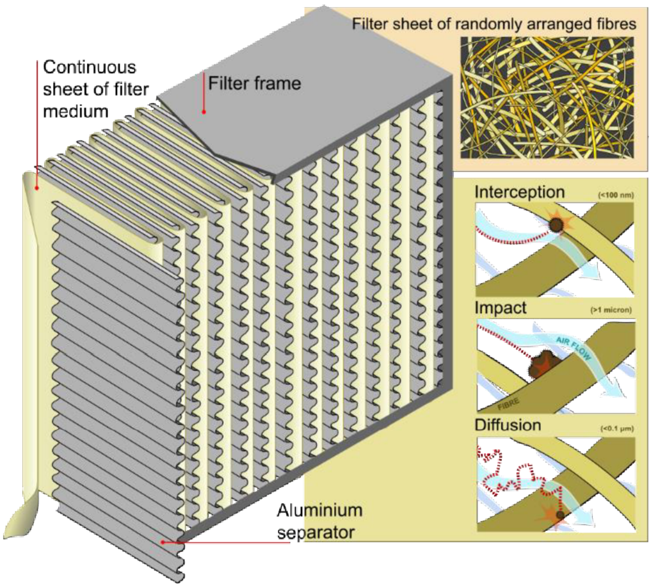
To prevent the astronaut from suffocating, a pair of filters are installed in the Cyclops vehicle, which are also used on the International Space Station.

The first filter is a **Hepa filter**. This type of air filter can theoretically remove at least 99.97 % of dust, pollen, mold, bacteria, and any airborne particles with a size of 0.3 microns (μm). The diameter specification of 0.3 microns responds to the worst case; the most penetrating particle size (MPPS). Particles that are larger or smaller are trapped with even higher efficiency. Using the worst-case particle size results in the worst-case efficiency rating, for example 99.97% or better for all particle sizes.

According to the Environmental Protection Agency (EPA), “HEPA is a type of pleated mechanical air filter. It is an acronym for "high efficiency particulate air [filter]" (as officially defined by the U.S. Dept. of Energy).

Originally, HEPA filters were secretly developed by the military because of their use for chemical, biological, and radiological defense purposes. “Following World War II, the Atomic Energy Commission (AEC) chose the military's HEPA filters as their principal device for particle removal in all exhaust air systems of nuclear facilities.” (Department of Energy, DOE) HEPA filters were first used in the Manhattan Project to prevent the spread of airborne radioactive contaminants and later commercialized in the 1950s.

Today, most HEPA filters are made from a mixture of glass fibers that are interlaced. Particles are captured in one of four ways: direct impacting, interception, diffusion, or sieving.
Direct Impacting: Large particles travel in a straight line, collide, and are trapped.
Interception: Particles collide with fibers and remain attached to the fibers.
Diffusion: As smaller particles travel, they collide with the fiber and are captured.
Sieving: Occurs when the particle is too large to fit in between the fiber's spaces. [10]



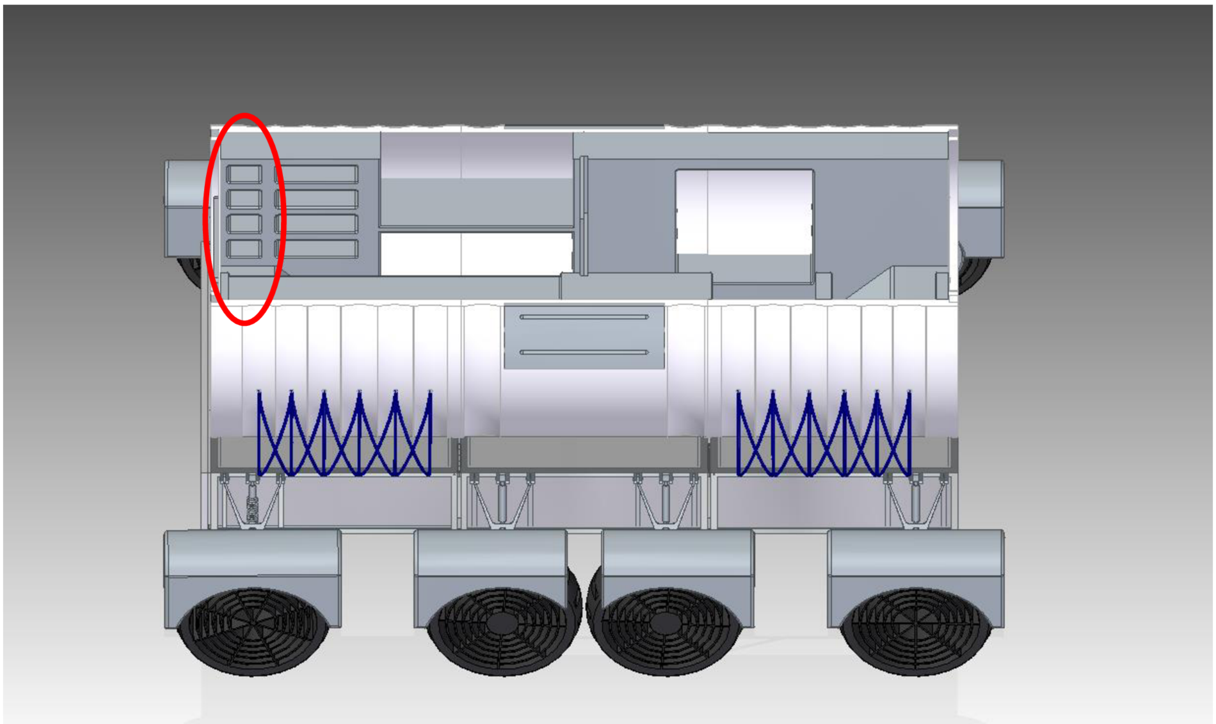
Picture 14 HEPA filter [42]

The second filter is the **charcoal filter**, which serves as a filter for liquids.

Carbon filters trap odors through a process called adsorption, which occurs when molecules attach to the outside of a surface, rather than being soaked into it. The more porous the activated carbon, the better, as this will increase the amount of surface space available for contaminants to latch onto when air passes through the filter. [11]

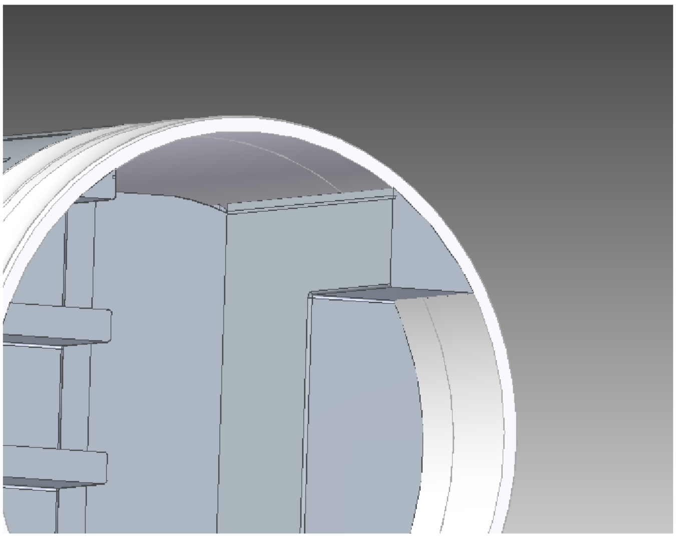
Picture 15 charcoal filter [43]

These filters are then placed in the marked positions (pic. 16).



Picture 16 location of filters

Led stripes are used to illuminate the entire interior of the habitat, which are excellent in terms of storage and durability. There are four strips of LED light strips in the habitat (pic.17). The primary colour will be white. In case the astronaut decides on a different colour he will be able to change it using the controller. Additional lighting can be found near the astronaut's driver's seat. This lighting will be used for better visibility when the astronaut is grazing and also when reading the manuals, which will be written on paper and not on a tablet.

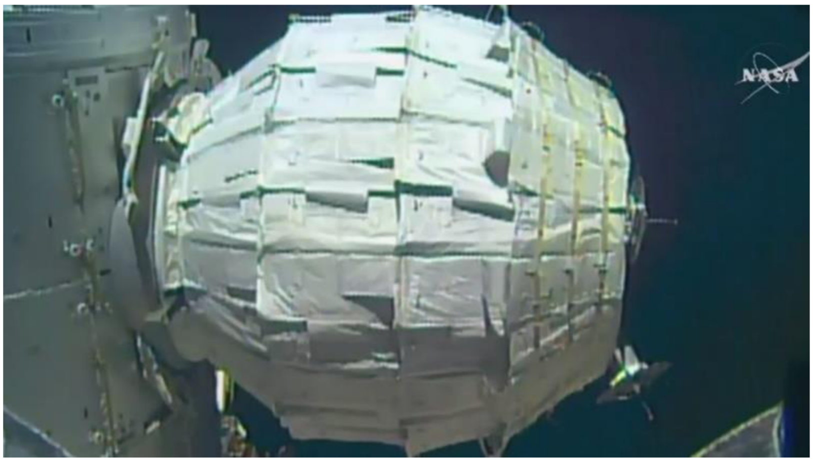


Picture17 LED stripes

Outer part

The outer part is inspired by the Bigelow module on ISS. The Bigelow Expandable Activity Module BEAM (pic.18.) is an expandable habitat technology demonstration for the International Space Station. Expandable habitats greatly decrease the amount of transport volume for future space missions. These “expandables” require minimal payload volume on a rocket but expand after being deployed in space to potentially provide a comfortable area for astronauts to live and work. They also provide a varying degree of protection from solar and cosmic radiation, space debris, atomic oxygen, ultraviolet radiation and other elements of the space environment. [12]

The material proposed for the construction of the habitat is the same as for the beam module and is Vectran. VECTRAN is a high-performance multifilament Kuraray yarn spun from a polymer with liquid crystals. The fiber is five times stronger than steel and offers a unique combination of superior properties. It is the fiber of choice where others fall short in performance. [13]

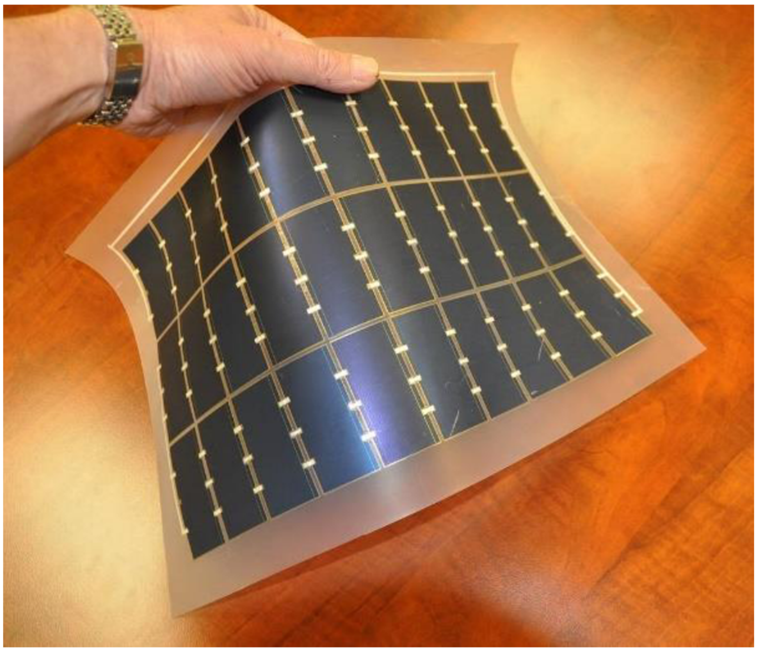


Picture 18 BEAM [44]

As far as compliance is concerned, it will be 1:3, so the module will measure 1500mm in length at the time of landing and 4500mm after deployment.

Only the side parts of the habitat are unfolded, which are made of vektran material. The middle part is made of titanium. Titan is chemical element, a silvery gray metal of Group 4 (IVb) of the periodic table. Titanium is a lightweight, high-strength, low-corrosion structural metal and is used in alloy form for parts in high-speed aircraft [14] and that's why I used it to build the middle part of the habitat.

In the front and back of the habitat, solar panels are incorporated, these will be flexible. Traditional solar panels used to power satellites can be bulky with heavy panels folded together using mechanical hinges. Smaller and lighter than traditional solar panels, flexible solar array consists of a flexible material containing photovoltaic cells to convert light into electricity. Being flexible, the solar array could roll or snap using carbon fiber composite booms to deploy solar panels without the aid of motors, making it lighter and less expensive than current solar array designs. [15]

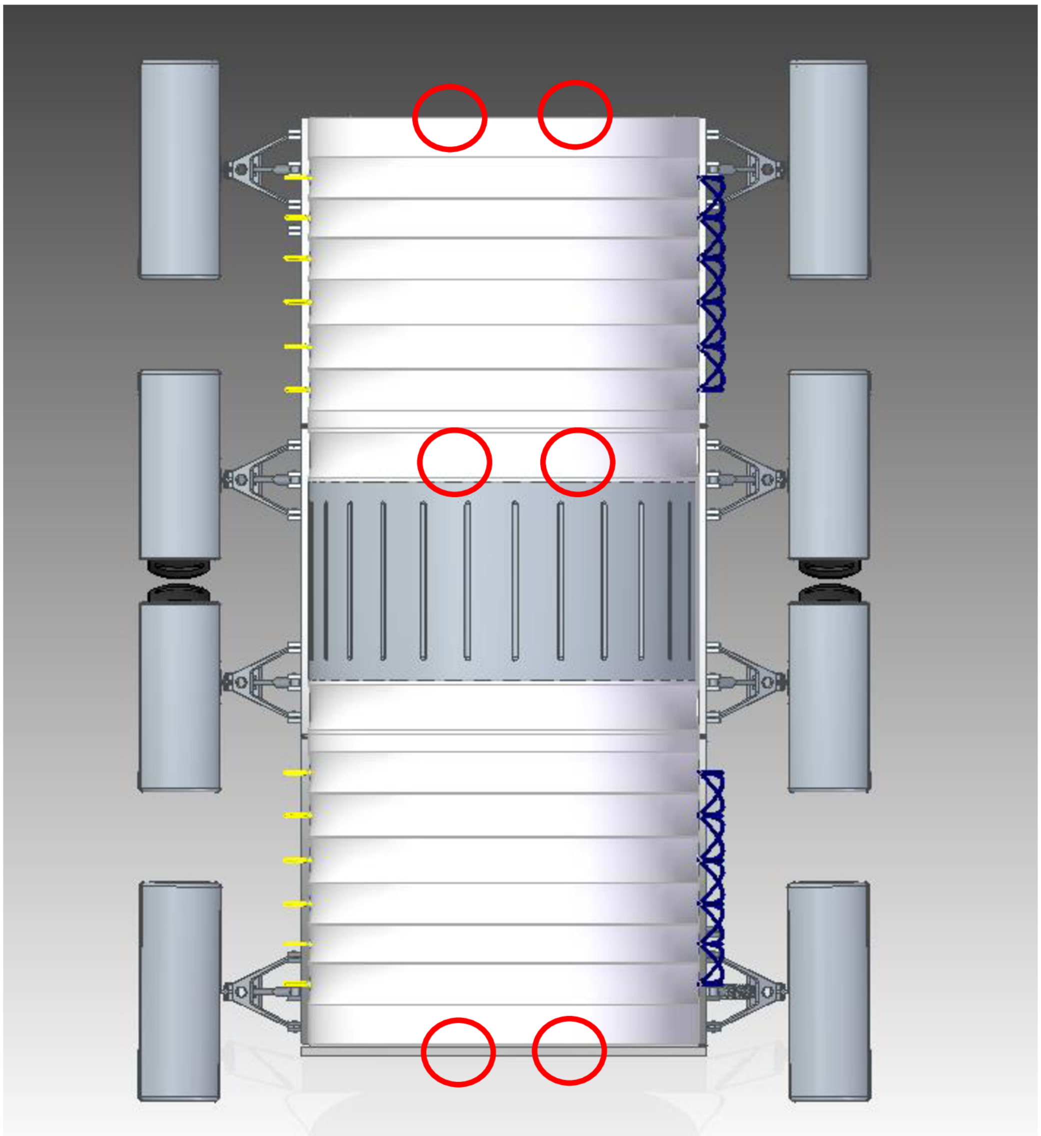


Picture19 solar panel [45]

In addition to the solar panels, these parts also incorporate lugs for the ropes that attach the inflatable habitat to the chassis. The top part of the habitat is used to place cameras that will be used to transmit images to the VR goggles for the astronaut while driving the car. The total number of cameras is 6 and they are placed all over the habitat (pic.20). They are placed on the upper parts of the habitat for better visibility, and mainly for protection from bouncing rocks while driving. I chose the GoPro HERO 11 mini black as my camera. I chose it for the following reasons Hero 11 Black can record 5.3K video at 60 fps and includes a new ability to shoot in 10-bit colour. GoPro's proprietary Super View mode is now known as Hyper View—enabling a wide-angle 16:9 capture with a great 5K resolution boost. Still image capture has jumped from 23 megapixels to 27, which is a welcomed change for GoPro fans of still photography. Even slo-mo has been refurbished with a bump up to 4K.

Sensor aside, the Hero 11 Black benefits from a stronger and tougher battery that is designed to withstand more extreme weather. Short and finicky battery life has plagued the Hero line for a while, and this improvement could not have come at a better time. [16]

In addition to these amazing technological features, the GoPro HERO 11 mini can transmit images to 3D glasses which fits this concept vehicle.



Picture 20 location of cameras

There is a circular LED light and a door at both ends of the habitat. LED lights are a popular choice for space missions for several reasons. First, they are highly energy efficient, which is very important in the resource-constrained environment of a spacecraft. Compared to traditional incandescent bulbs, they require less power to operate and produce less heat, which can help reduce overall power consumption and heat production on the spacecraft.

Another advantage of LED lights in space is their durability and long lifetime. They have a much longer lifespan than traditional incandescent bulbs and are not susceptible to the shock and vibration damage that can occur during launches and other space operations.

In addition, LED lights are highly customizable, so they can be tuned to specific wavelengths and colours. This can be useful when conducting experiments or creating specific lighting conditions for crew comfort and well-being.

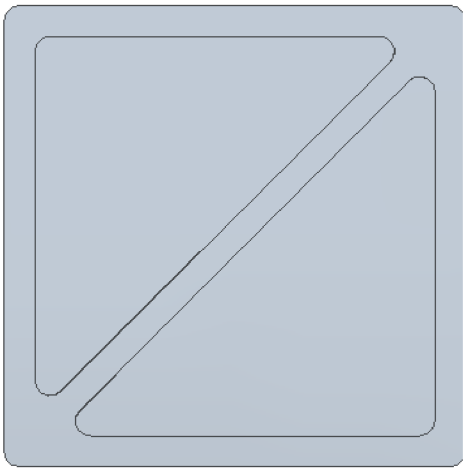
Finally, LED lights are very versatile and can be used in a variety of applications, from lighting the interior of a spacecraft to illuminating the exterior during spacewalks or other activities.

Overall, the energy efficiency, durability, longevity, customizability, and versatility of LED lights make them an excellent choice for space missions.

The doors are unified to the dimensions of the latest Artemis space suits (pic.21)

The method of attaching the suit to the frame is solved by means of an electromagnet and latches. The electromagnet is used to attach the suit to the frame in a lighter way, then the suit will be attached with the help of latches, which will keep the suit firmly in place and at the same time the electromagnet will not have to be on all the time.

In the realization of the frame for attaching the spacesuit and the window frame, 7075-T6 aluminum alloy is used.



Picture 21 doors

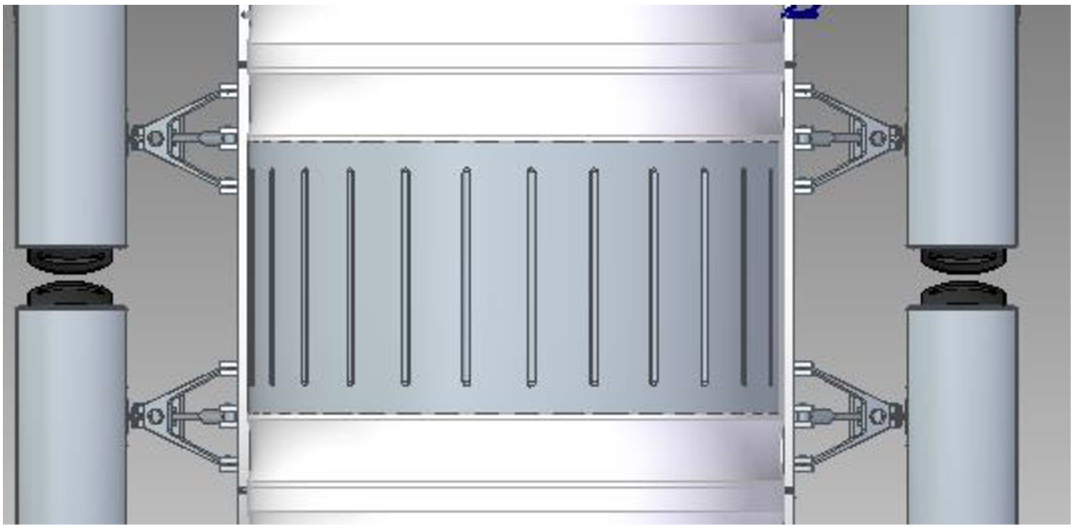
The same material is used for the window frame. As for the choice of material for the transparent part, fused silica is chosen. The workhorse transparent material for space missions from Apollo to the International Space Station has been fused silica due in part to its low density, low coefficient of expansion and optical quality. Despite its successful use, fused silica exhibits lower fracture toughness and impact resistance as compared to newer materials. Can these newer transparent ceramics lighten spacecraft window systems and might they be useful for applications such as phone screens? This presentation will compare recent optical ceramics to fused silica and demonstrate how weight can be saved. [17]

Then it was necessary to solve the heat dissipation so that the inside and outside of the habitat would not overheat. There are two thermal systems, passive and active, to prevent overheating. Passive heat systems use passive heat sinks that absorb heat and then emit it into space. These heat sinks typically use thermal conduction and radiation to dissipate heat. They are made of materials that have high thermal conductivity and are capable of rapidly removing heat from temperature-sensitive components of the satellite. In addition, white or otherwise reflective surfaces are placed on satellites to reflect solar radiation and reduce the heat load.

Active thermal systems are equipped with coolants that will circulate around the thermally sensitive components and will dissipate heat to heat sinks that will then radiate it to space. This process can be controlled by thermostats and control systems to ensure that the temperature on board the habitat is kept within the desired range.

The passive heat sink(pic.21) on the habitat roof will be made of aluminium, which has a high thermal conductivity. The surface of the habitat will be covered with white or gold reflective materials that reduce the absorption of solar radiation and thus reduce the heat load.

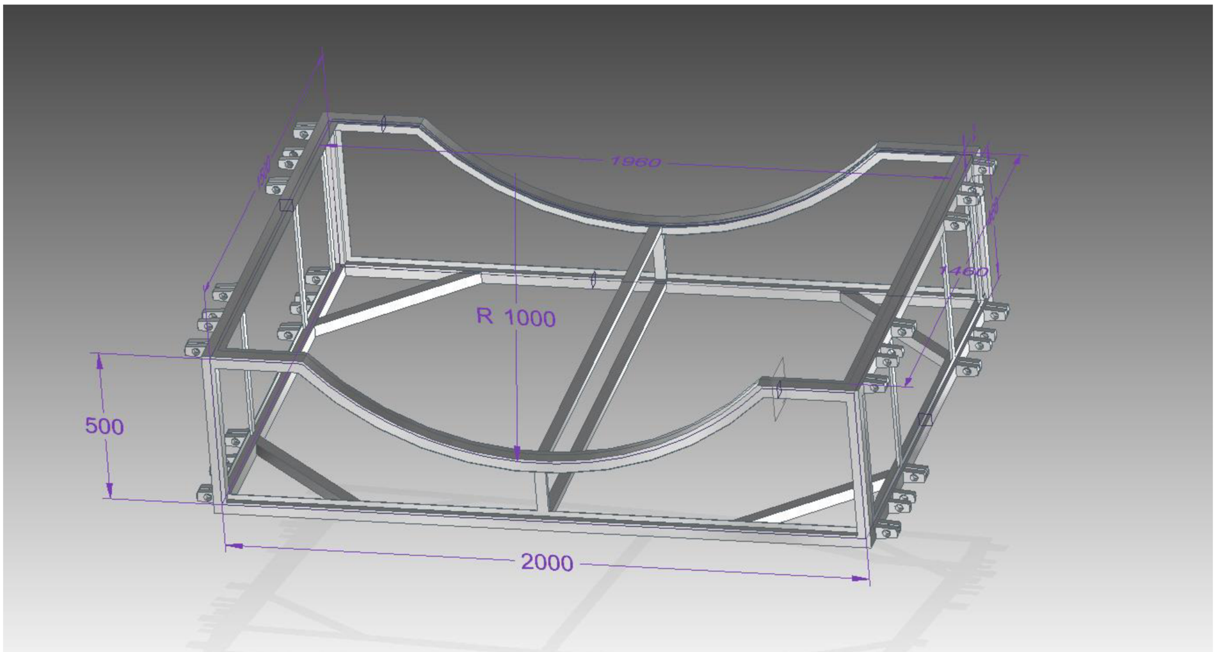
Active thermal systems in the habitat use coolants, ammonia, or perfluorocarbons. These fluids have a high heat capacity and are capable of rapidly removing heat from temperature-sensitive components of the satellite. In addition, the heat sinks are made of aluminium tubes that can efficiently transfer heat to the satellite surface where it is radiated into space.



Picture 22 passive heat sink

2.4.2 CHASSIS

The chassis consists of 3 parts. These parts are dimensionally identical. They will be 2000mm wide by 1500mm long and 500mm high. The only difference will be between the middle chassis and the side chassis. The middle section has an extra pair of wheel hangers because the middle section will have 2 extra wheels than the side chassis (pic. 22).

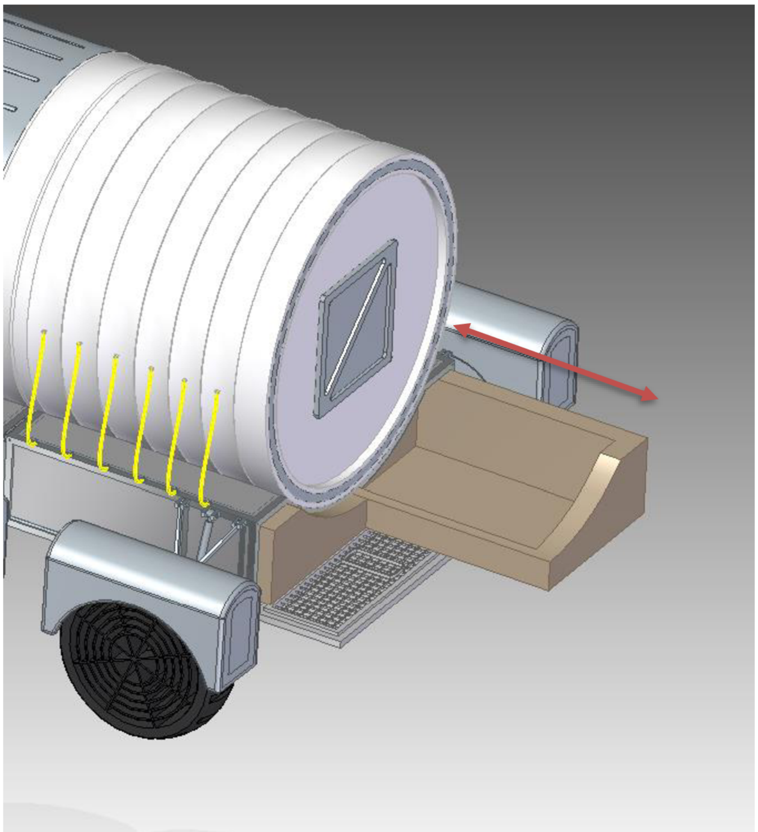


Picture 23 chassis

The chassis material of choice is 2219 aluminium, which was also used for the lunar vehicle chassis for the manned Apollo 15 to Apollo 17 missions. Aluminium Alloy 2219 is a high strength alloy which combines good machinability and good mechanical properties. 2219 is useful over a temperature range of -452°F to 600°F, is readily weldable and has good fracture toughness. In the T8 condition it is resistant to stress corrosion cracking. Aluminium 2219 is typically used in a range of aerospace applications such as high temperature structural applications including space booster and fuel tanks. [18]

As for the connection of these three chassis, the upper part is held by a hinge, which will also serve to open the whole structure. Once the chassis is in the unfolded state, the lower part is connected with screws. There are lugs on the side chassis for ropes that will firmly connect the inflatable habitat to the chassis.

As for the side chassis, they are supposed to hold two large containers (pic. 23), which will be used to store work tools that get dirty during work, and we really don't want a contaminated object with lunar soil to get or even be stored inside the habitat where the astronaut lives.



Picture 24 containers

The frame is reinforced with several elements to withstand greater loads, plus a spreader plate is added to the side and bottom.

The frame also contains a set of 16 sensors that are placed around its perimeter to assist the astronaut in traversing the rugged terrain by alerting him to an approaching obstacle with an audible signal. If the warning is not heeded, the sensors will automatically deploy an airbag hidden in the frame. For the sensors, I took inspiration from the Renault brand, which uses them extensively in its cars. More specifically, I chose the Renault Arkana. Here is a description of how the whole system works on this car, where this solution is also used on the Cyclops.

Operating principle of sensors

Ultrasonic sensors, indicated by arrows **1**, are fitted in the bumpers to measure the distance between the vehicle and an obstacle.
This measurement is indicated by beeps which become more frequent the closer you come to the obstacle, until they become a continuous beep when the vehicle is approximately 20 to 30 centimetres from the obstacle.
Depending on the configuration of the vehicle, the system detects obstacles to the front, the rear, and the sides of the vehicle.
The parking distance control system is only activated when the vehicle is driven at a speed below approximately 6 mph (10 km/h).
The function does not consider towing or carrying systems that are not recognised by the system. [19]

Picture 25 car sensors [46]

There is a grate in front of the containers. Which folds down if the space suit is attached to the habitat. In a frame that will consist of polyamide. Polyimide (PI) is an interesting material for space applications as it offers excellent thermal properties. [20]

The airbag is deployed. Airbags are inflatable cushions built that protect occupants from hitting the vehicle interior or objects outside the vehicle (for example, other vehicles or rocks) during a collision. [21]

It will fire if the sensors detect a collision with the body.

Furthermore, the side chassis contains handles for hanging, to which a pair of wheels will be attached, each on one side.

Hanging

For the space car I chose the wish bone suspension.

Wishbone suspension is a type of independent wheel suspension often used on performance and sports cars. This type of suspension uses two arms or struts that are attached to the vehicle frame and the wheel hub. This configuration allows for greater control over the wheel geometry when driving, resulting in better vehicle handling and stability.

Wishbone suspension can come in a variety of variations, including single wishbone suspension, double wishbone suspension and multi-link suspension. In a single wishbone suspension, the arm is single and forms a Y-shape, with one end attached to the frame and the other to the wheel.

In a double wishbone suspension, two arms are placed on each side of the wheel and connected to different points on the frame. Multi-link suspension uses multiple arms and allows even more control over the geometry of the wheel.

Wishbone suspension is considered one of the best suspension types for performance vehicles because it allows for excellent handling and stability at high speeds and during steep maneuvers. However, due to its complex design, it can be more expensive to manufacture and maintain than other suspension types.

The main parts of the suspension are:

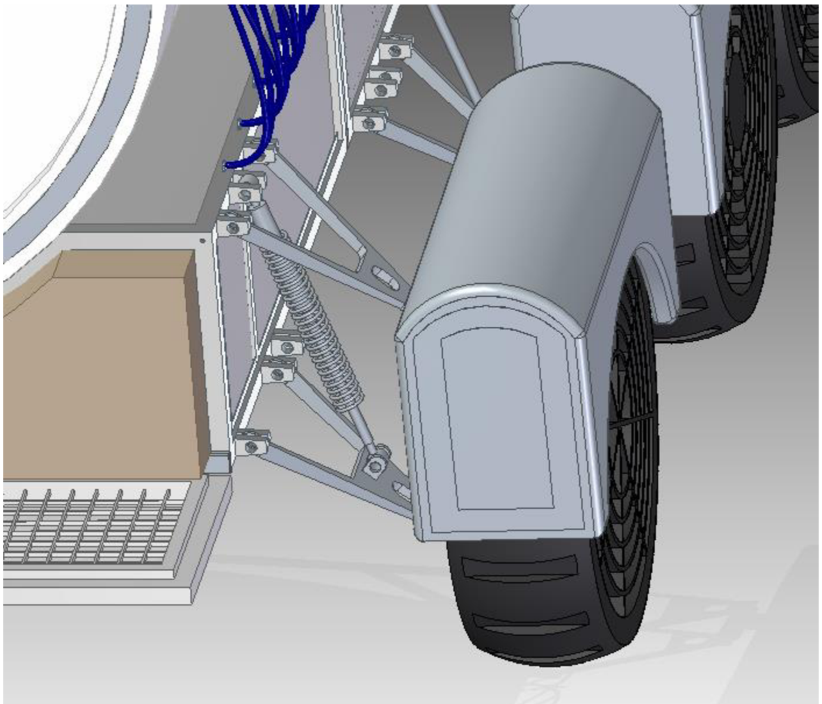
Shock absorbers: These components are used to absorb the shock and vibration that occurs when driving over uneven surfaces. The shock absorbers are located between the axle and the body of the vehicle.

The springs are located on each side of the shock absorbers and are used to store and release the energy that is generated when driving over bumps.

Arms and tie rods: The arms and tie rods are located between the axle and the bodywork and are used to maintain the correct wheel angle and to control axle movement.

Brake discs or drums: These components are located on the axles and are used to brake the vehicle.

Couplings and joints: Couplings and joints are the components that connect the various parts of the wheel suspension and allow them to move relative to each other



Picture 26 detail of hanging

The entire wheel suspension is designed for a smooth ride, good handling and safe braking. Each component must be designed and manufactured with great care and quality to ensure the reliability and safety of the vehicle.
As for the materials chosen for the suspension, the arms will be made of titanium. I have chosen titanium here primarily because of its unique properties such as high strength, light weight, excellent corrosion resistance and ability to withstand extreme temperatures.

Electric motor
Electric motors are used to power the Cyclops lunar vehicle. They are placed in each wheel, so the total number of electric motors is 8.I used Brushless DC motors which motors are the most predominant motors used for aerospace. [22]

A Brushless DC Electric Motor (BLDC) is an electric motor powered by a direct current voltage supply and commutated electronically instead of by brushes like in conventional DC motors. BLDC motors are more popular than the conventional DC motors nowadays, but the development of these type of motors has only been possible since the 1960s when semiconductor electronics were developed. [23]

I also chose it because of these advantages. The BLDC motor efficiency over that of a traditional brushed motor is another benefit of using a brushless motor. Brushless motors have an overall higher speed and torque and produce less noise than traditional brushed motors. They also run more efficiently and have little or no power loss, which is a problem that can accompany brushed motors due to increased friction caused by the brushes.
BLDC motors have reportedly hit 85 to 90 percent efficiency margins, which is higher than the standard brushed motors at 75 to 80 percent.

Brushless DC motors must also be electronically commutated, which means the motor is regulated by a control mechanism. That feature allows the 3-phase BLDC motor to change speeds at varying degrees along with the ability to quickly accelerate and decelerate to provide for the most efficient use of power and productivity when it comes to output. BLDC motors also typically weigh less than a brushed motor, but they have the ability to provide similar power outputs. [24]

Heat Shading

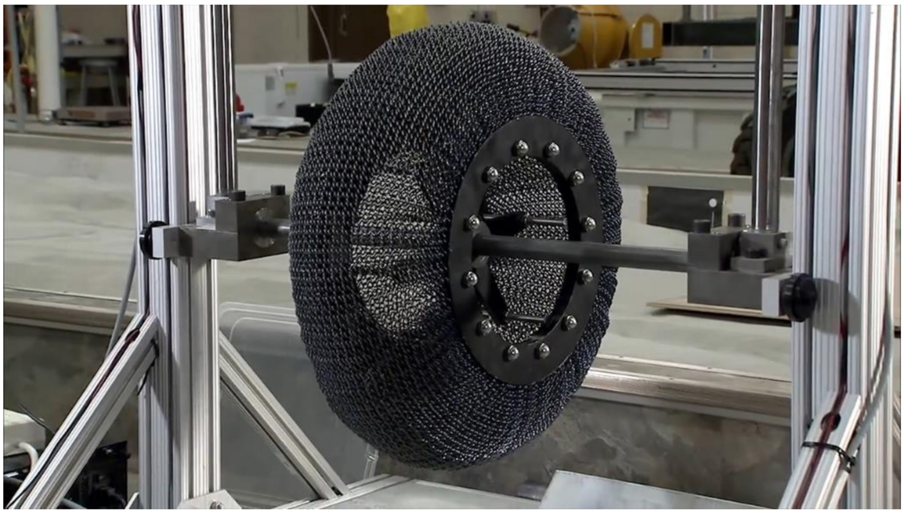
The shading of heat radiated from the sun also needs to be addressed. Therefore, to prevent the frame from overheating, a thin layer of mylar is applied to all its plates. Mylar(pic.27), also known as BoPET (Biaxially-oriented polyethylene terephthalate), is a polyester film made from stretched polyethylene terephthalate (PET) and is used for its high tensile strength, chemical and dimensional stability, transparency, reflectivity, gas and aroma barrier properties, and electrical insulation [25]

The reason I chose Mylar is that Nasa and the Aces use this material to shield the sun's rays from the astronaut's visor.

Picture 27 Mylar layer [47]

Wheel

When choosing the wheel, I used the wheel (pic.28), made of an ultra-flexible metal mesh, is designed to deform as it rolls over sharp rocks and other irregular features on the Martian surface and then snap back to its original shape. The idea of a chain mail-like tire isn't new. In 2009, NASA worked with Goodyear to create a wheel made of mesh woven from hundreds of coiled steel wires. The Spring Tire, as the wheel was dubbed, provided good traction and durability on soft sands and rock. But there was a problem: In tests at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, the steel wire mesh dented as it rolled over a simulated Martian landscape. Its main advantages include weight, good impact resistance and, last but not least, the ability to go fast. [31]



Picture 28 flexible wheel [48]

VR driving

When designing the control of the habitat, I was deciding between two control options. The first design was identical to the aforementioned vehicle (LTV), where the astronaut uses a joystick to control the vehicle and the viewports are used to see out. This concept has been tested, but it is completely inappropriate for the Cyclops vehicle. For one thing, the driver's seat is on the side of the vehicle, not in the middle, and it is an unnecessary weight increase and weakening of the structure, which would have to be strengthened because of the visors. So I went down the VR glasses route. These provide the following advantages: a realistic and intense experience that cannot be replaced by visors and, most importantly, the possibility to train driving the car on the ground in the same goggles, so it won't be a big shock for the astronaut when he drives on the moon. The goggles that are used are called Pimax 8K X(pic.29), which meet all the requirements in terms of resolution and weight.

Picture 29 Primax 8K X [49]

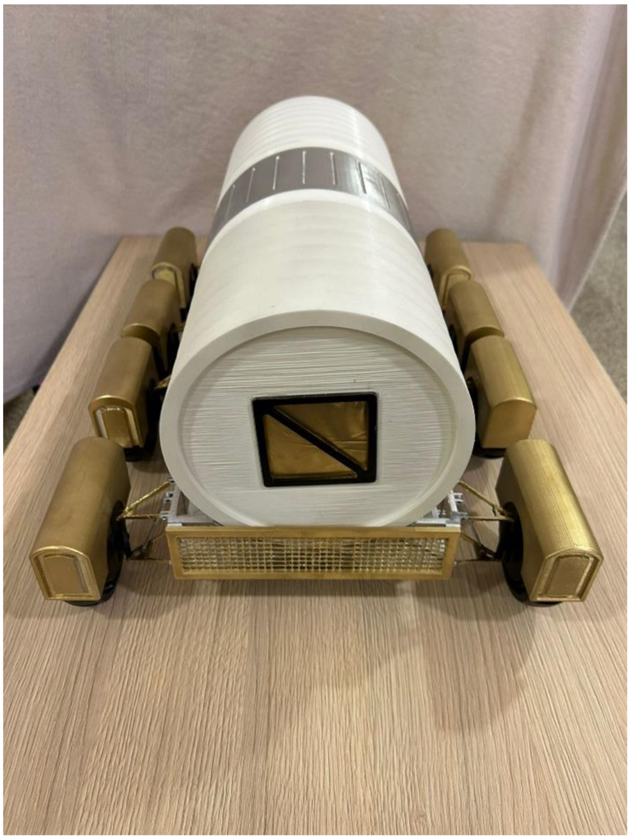
3 MODEL

3.1 3D MODEL IN SOLID EDGE

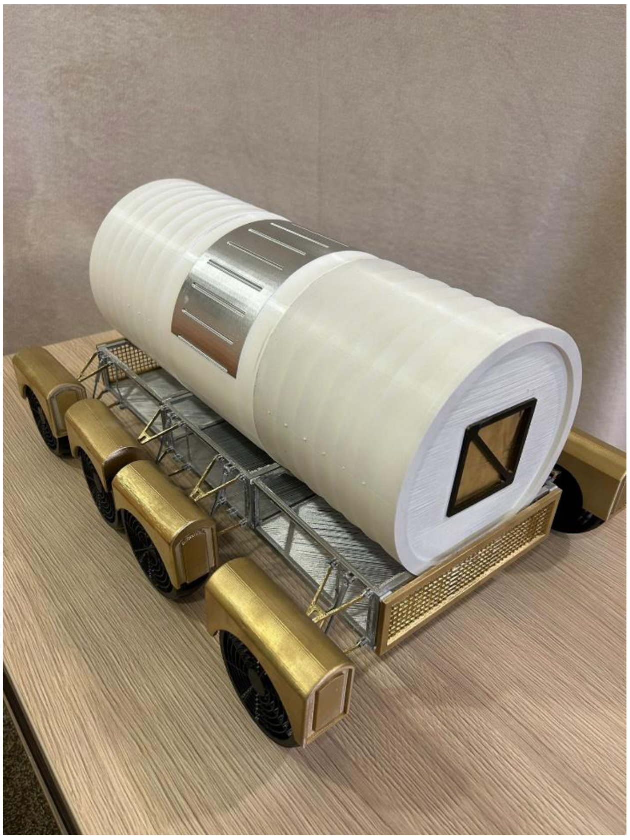
3D model of the Cyclops lunar car is created in solid edge st8. Total modelling time is over 500 hours. The model has a functional moving suspension and animations that simulate the unfolding of the car.

3D PRINTED MODEL

The model is printed on a 3D printer. The name of the 3D printer is Prusa i3 MK3S. The Original Prusa i3 MK3S+ is the latest version of the award-winning 3D printer. The MK3S version is enriched with a new Super PINDA probe, which allows for better calibration of the first layer. In addition, high quality bearings have been added and the printer has been slightly improved in various places to make it easier to fold and service. The MK3S+ incorporates all of the cumulative improvements from the entire MK3 life cycle. So you'll find a heated pad with removable flexible printing plates with PEI coating, as well as automatic Mesh Bed Levelling to compensate for uneven pads, a filament sensor, power loss recovery (called Power Panic) and a number of important safety features. And the printer is still wonderfully quiet. [26]



Picture 30 3D model



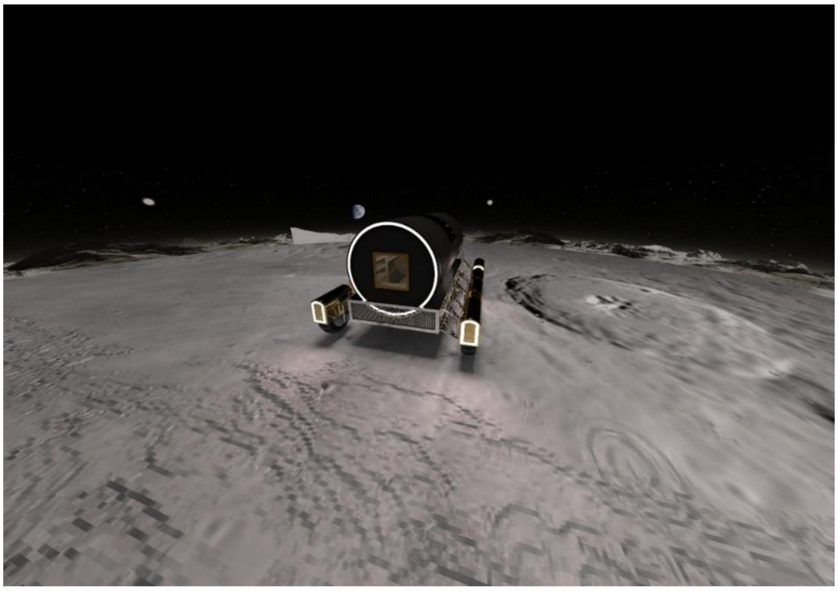
Picture 31 3D model

The chosen filament is white PLA. Polylactic Acid, commonly known as PLA, is one of the most popular materials used in desktop 3D printing. It is the default filament of choice for most extrusion-based 3D printers because it can be printed at a low temperature and does not require a heated bed. PLA is a great first material to use as you are learning about 3D printing because it is easy to print, very inexpensive, and creates parts that can be used for a wide variety of applications. It is also one of the most environmentally friendly filaments on the market today. Derived from crops such as corn and sugarcane, PLA is renewable and most importantly biodegradable. As a bonus, this also allows the plastic to give off a sweet aroma during printing. [27]

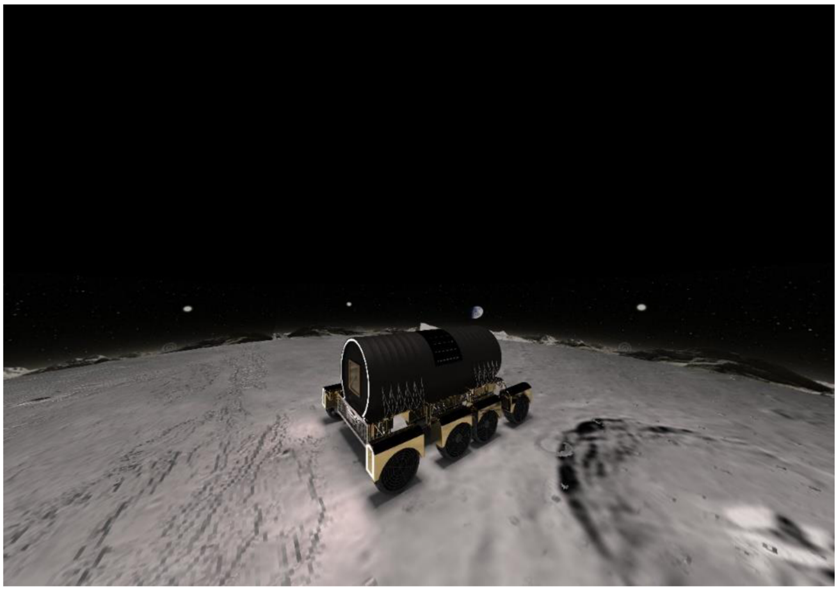
The printing thickness is 0.2mm. And the total printing time is 94 hours.

3.3 RENDERED MODEL

In pictures 32 and 33 you can see the final render of the Cyclops model. The render itself took thirty minutes.



Picture 32 rendered model 1.



Picture 33 rendered model 2.

3.0 KEYSHOT

I used the program Keyshot 9 to create the render.Keyshot is a real-time rendering application that can create amazing looking images from your 3D models that can be used throughout the product development process to make design decisions and quickly create variations of concepts for customer, production and marketing. The first designs weren't hilarious, but over time and by adding new things like lighting and moonscapes, the render became a nice advertisement for the Cyclops lunar vehicle The biggest problem when compositing in Keyshot was the lighting, which increased the rendering time by 30 minutes.[28]

3.1 SOLID EDGE

I chose solid edge to model a 3D model of a lunar car. Solid Edge is a 3D CAD, parametric feature and synchronous technology solid modeling software. It runs on Microsoft Windows and provides solid modeling, assembly modelling and 2D orthographic view functionality for mechanical designers. Through third party applications it has links to many other Product Lifecycle Management (PLM) technologies.

Originally developed and released by Intergraph in 1996 using the ACIS geometric modeling kernel, it changed to using the Parasolid kernel when it was purchased and further developed by UGS Corp in 1998. In 2007, UGS was acquired by the Automation & Drives Division of Siemens AG. UGS company was renamed Siemens Digital Industries Software on October 1, 2007.

Since September 2006, Siemens has also offered a free 2D version called Solid Edge 2D Drafting. Solid Edge is available in Design and Drafting, Foundation, Classic or Premium. The "Premium" package includes all of the features of "Classic" plus mechanical and electrical routing software, and engineering simulation capabilities for Computer Aided Engineering (CAE).[1]

Solid Edge is a direct competitor to SolidWorks, Creo, Inventor, IRONCAD, and others. [29]
The reason why I chose this program is as follows. I was interested in the clarity and compatibility with the Keyshot renderer.

3.2 VISUAL STUDIO CODE

Visual Studio Code (VS Code) is a popular integrated development environment (IDE) developed by Microsoft. It is a free and open-source code editor that is available for various operating systems, including Windows, macOS and Linux.

Visual Studio Code offers a wide range of features and extensions that allow programmers to write, debug, and maintain code in a variety of programming languages. Key features include syntax highlighting, code autocompletion, debugging, version management, and integration with versioning systems (such as Git), among others.

VS Code is popular among developers due to its simplicity, speed, and extensibility. Many development communities develop and share extensions for VS Code that allow you to customize and extend the editor's features to suit specific needs and languages.

3.3 ANSYS 2020

ANSYS 2020 is a version of the ANSYS software tool that is widely used for engineering simulation and analysis. ANSYS is a comprehensive simulation environment that allows engineers to model, simulate and analyze various physical phenomena and the behaviour of structures and systems.

This program offers a wide range of modules and tools that cover various engineering disciplines, including solid mechanics, fluid dynamics, electromagnetism, thermodynamics, airflow, optics, and more. Some of the most common ANSYS applications include stress and strain analysis, fluid flow, electromagnetic analysis, thermal analysis, and many more.

It also provides users with advanced tools for creating models, specifying material properties, setting boundary conditions, performing simulations, and visualizing results. This enables engineers to perform virtual testing and analysis before actual physical prototyping, which can reduce costs and speed product development.

ANSYS is widely used in various industries such as automotive, aerospace, energy, manufacturing, construction, healthcare and more. Each new release, such as ANSYS 2020, typically brings enhancements and new features that expand simulation and analysis capabilities.

Overall, Visual Studio Code is a powerful and popular software development tool that has become a favourite among many developers due to its flexibility and user experience.

4 LUNAR VEHICLE CONTROL

4.1 JOYSTICK

Since the early days, it has been used in space vehicles to control the thrusters of spacecraft, or to control the robotic arm of space shuttles. Space vehicles are no different. First of all, it is necessary to state what a joystick is. A joystick is a traditional input device that controls the movements of machines such as airplanes, video games, and motor vehicles. It is a basic device for controlling machine movement and is used to maneuver various types of equipment, including helicopters, cranes, spacecraft, and robots.

Joysticks are directional input devices that allow users to input controls by moving a handle or lever from side to side or up and down. The devices operate on the principle of potentiometers or variable resistors that identify the position, direction, and magnitude of the joystick movement.

The joystick was originally developed for military use in the early 20th century as a means of controlling the direction, altitude, and angle of an aircraft. It has since been adopted for a variety of applications that require precision, agility, and rapid response.

In short, a joystick is a device that allows users to control the movement of equipment and machines by moving a handle or bar from side to side or up and down. The device has a variety of applications, including games and simulations, flight and spacecraft control, and industrial equipment control. It is now commonly used as a controller in video games and simulations. [30]

And here's why I preferred a joystick to a conventional steering wheel. Multi-axis control: The joystick provides multi-axis control, which is important when moving in three dimensions, such as spatial simulators. Movement in space requires control of different axes (e.g. rotation, tilt, translation) and the joystick allows smooth control of all these movements.

Precision and sensitivity: the joystick allow fine and sensitive control, which is important when manoeuvring spacecraft over large distances. Precise direction, speed and intensity of movement are needed, and the joystick allows fine control in these aspects.

Ergonomics. For space simulators, which can be very large and offer many features, it is important to have a joystick that is comfortable and easy to use.

It should be noted that the steering wheel is typically used to control vehicles on the ground, such as cars, and is optimized for movement on the plane. A joystick, on the other hand, provides better control options in all three dimensions, making it more suitable for space simulators. In the end, however, the choice between joystick and steering wheel is subjective and depends on the user's individual preferences and needs.

4.2 GLASSES

For this project, the decision was between two types of VR glasses, each from a different company.

Oculus rift. I was attracted to these goggles because of their price, their design, and the fact that they have been tested for many years. Here are some of their advantages:

Virtual reality immersion: the Oculus Rift goggles provide an intense and immersive virtual reality experience. Users can literally find themselves in a virtual environment and explore and interact with the 3D worlds around them. This is ideal for gaming, exploring virtual environments and watching virtual reality videos.

High image quality: Oculus Rift glasses offer high image quality and detailed graphics. They have high-resolution displays that allow for a crisp and realistic view of the virtual environment. This is important for a natural and realistic experience.

Motion tracking system: Oculus Rift goggles are equipped with an advanced motion tracking system that allows tracking the user's movement in real time. This means that users can move their head and body and these movements are reflected in the virtual environment, adding to the sense of naturalness and interaction with the virtual world.

Community support.: This means there are plenty of resources, forums, and social groups where you can share experiences, find new games and apps, and get in touch with other people interested in virtual reality.

The second glasses that opposed in the selection are Primax 8K X. These glasses have the following list of advantages.

High resolution: Primax 8K X offer high image resolution, which creates a sharper and more detailed virtual reality view. With a resolution of 3840 x 2160 pixels per eye (7680 x 2160 pixels overall), they provide greater image finesse and accuracy.

Large field of view: Primax 8K X glasses have a wide field of view that brings a sense of full immersion in the virtual world. With 200 degrees diagonally, they cover a wider field of view than many other VR glasses.

Enhanced motion tracking: The Primax 8K X features advanced motion tracking that enables accurate and fast sensing of the user's movements. This is important for realistic interaction in virtual environments.

Upgradeable: Pimax offers the ability to upgrade Primax 8K X glasses with modules and accessories. This allows users to upgrade their glasses and customize them to their needs.

Compatibility: The Primax 8K X goggles are compatible with a variety of platforms and support a wide range of virtual reality games and applications. Users can enjoy content available on platforms such as SteamVR and Oculus.

It should be stressed that the selection and evaluation of VR glasses is a completely subjective matter. However, I chose the Primax 8K X goggles. For the following reasons:

Higher resolution: Primax 8K X have higher image resolution than Oculus Rift. With a resolution of 3840 x 2160 pixels per eye (7680 x 2160 pixels overall), they offer greater image finesse and detail.

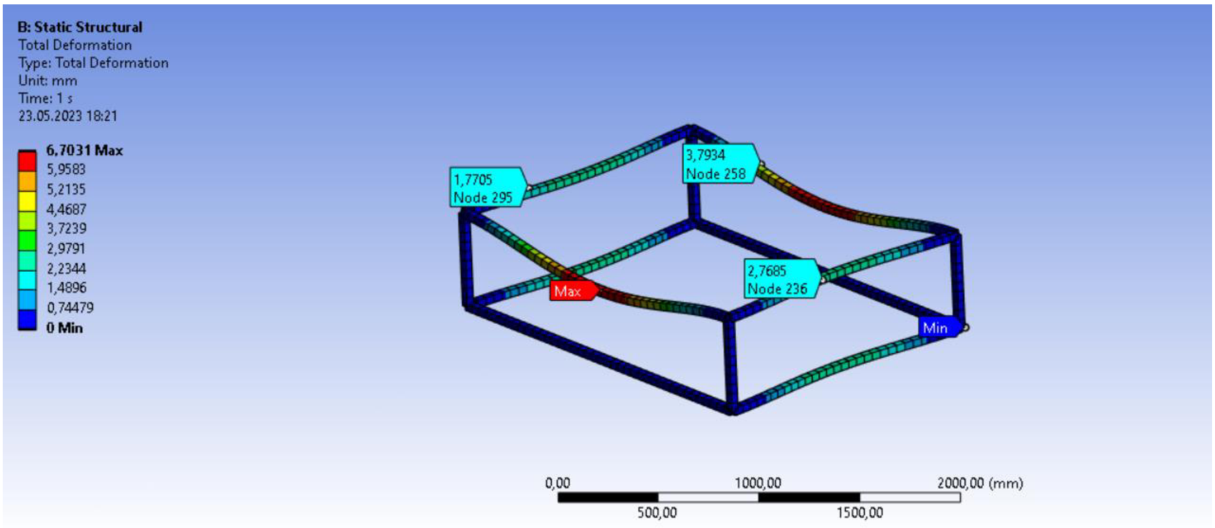
Larger field of view: Primax 8K X have a wider field of view than Oculus Rift, providing a wider field of view and improving the sense of immersion in the virtual environment.

Upgradability: Pimax offers the ability to upgrade Primax 8K X glasses with modules and accessories. This means that users can upgrade their glasses and customize them to their needs, for example by adding hand motion tracking or sound systems.

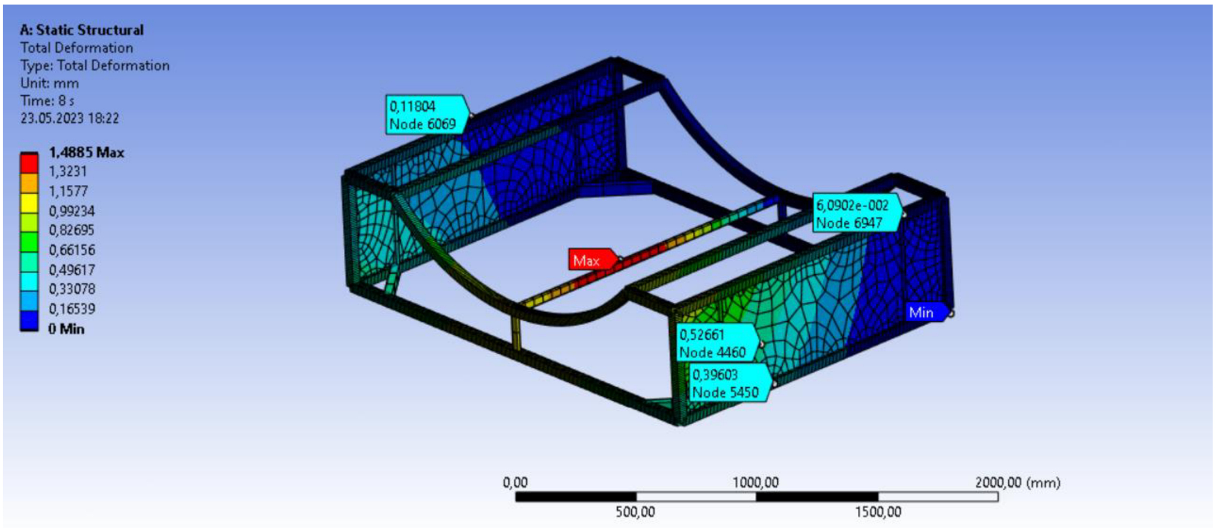
5 CHASSIS ANALYSIS

In Ansys it was observed how the forces from the suspension and the habitat deform the overall frame structure.

In the pictures we can notice the comparison of the original chassis (pic. 34) where the 1000N load caused much more total and maximum deformation compared to the reinforced chassis, which significantly reduced the total deformation and the maximum deformation was also reduced. Thus, it is clear that the new chassis (pic. 35) will meet all the requirements and an improvement can be seen.



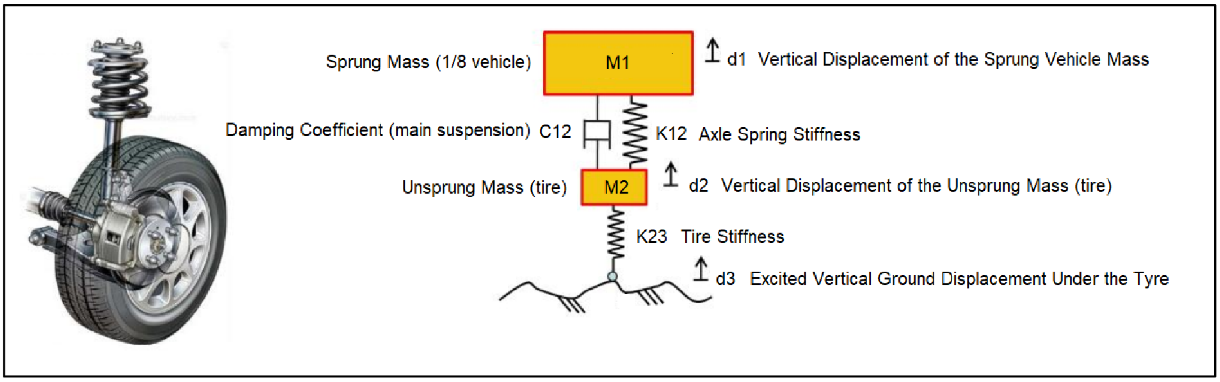
Picture 34 original chassis



Picture 35 reinforced chassis

6 ANALYSIS OF DAMPING

In this part, he researched the damping of the chassis suspension in order to achieve high speeds on the moon. In order to get the best data possible, visual studio code was used to write a program that plots damping graphs both on the ground and on the moon where there is less gravity.



Picture 36 basic model of dumping

Initial system configuration under static loading from gravity

$$k * u = F => k * d = m * g => d = \frac{m*g}{K} \quad (1)$$

$$d_1 = \frac{m_1 * g}{K_{12}} + d_2 \quad (2)$$

$$d_2 = \frac{(m_1 + m_2) * g}{K_{23}} \quad (3)$$

$$F_{g1} = M_1 * g \quad (4)$$

$$a_1 = \frac{F_{i12}}{m_1} + g => v_1 = v_1 + a_1 * \Delta t => d_1 = d_1 + v_1 * \Delta t \quad (5)$$

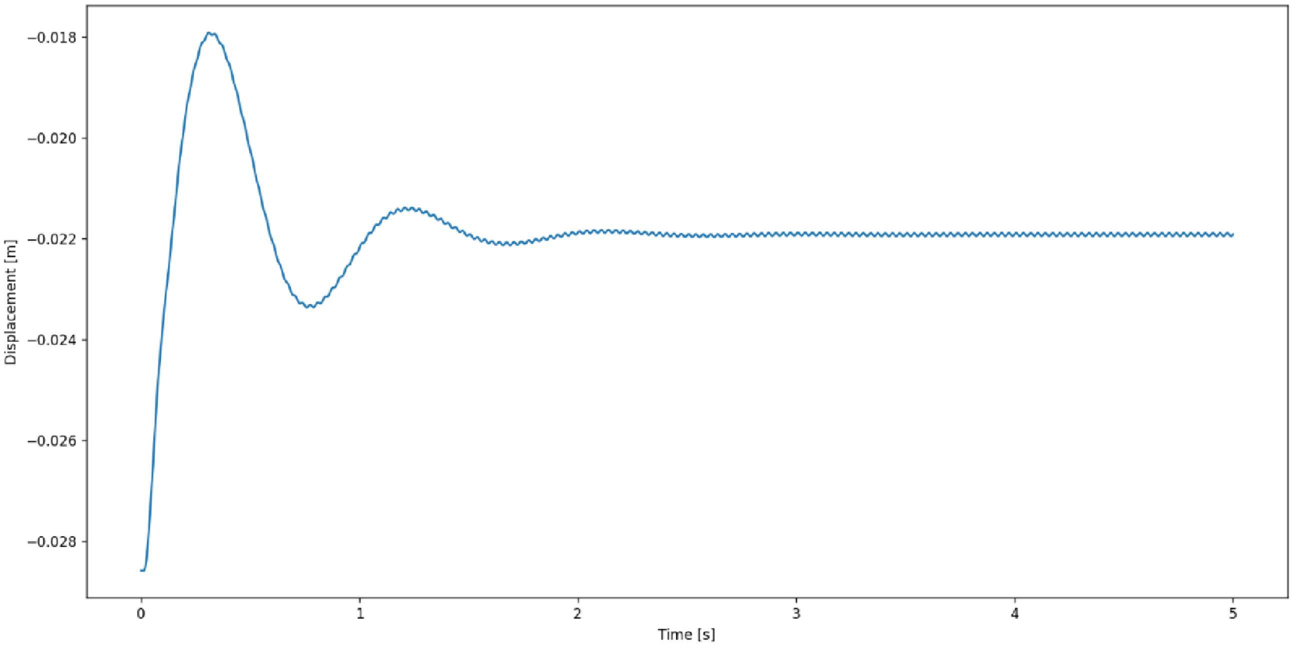
$$F_{i12} = c_{12} * (v_2 - v_1) + K_{12} * (d_2 - d_1) \quad (6)$$

$$F_{g2} = m_2 * g \quad (7)$$

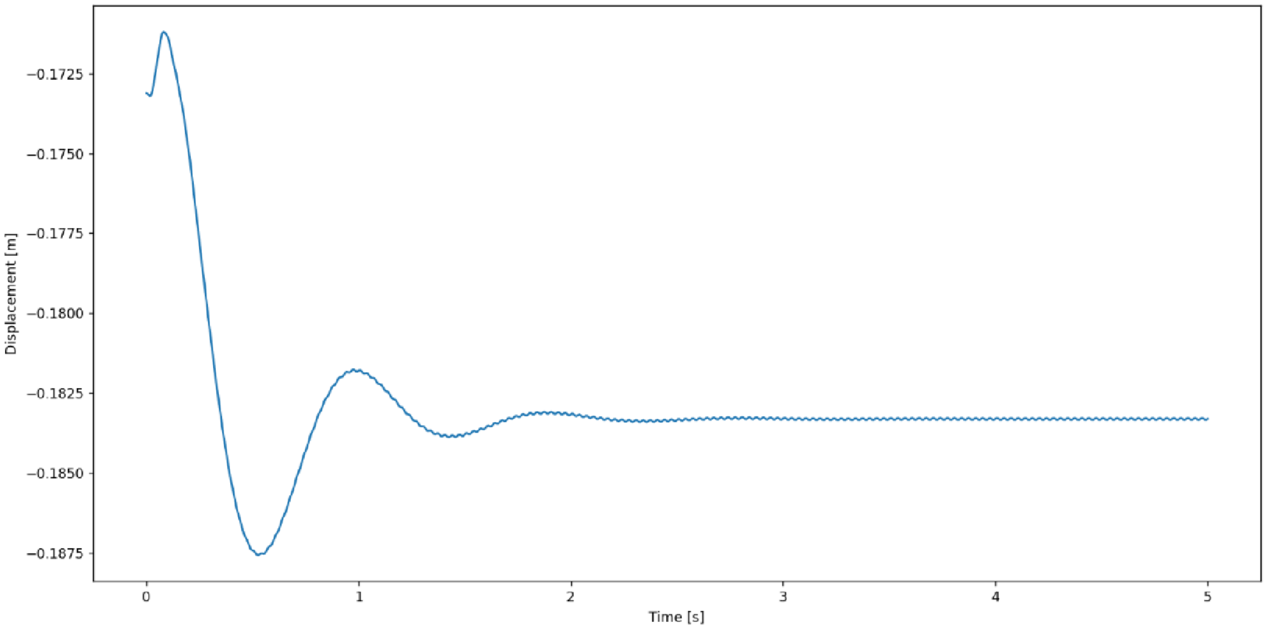
$$a_2 = \frac{-F_{i12} - F_{i23}}{m_2} + g => v_2 = v_2 + a_2 * \Delta t => d_2 = d_2 + v_2 * \Delta t \quad (8)$$

$$F_{i23} = c_{23} * (v_3 - v_2) + K_{23} * (d_3 - d_2) \quad (9)$$

$$d_3(t) = d + d * \sin(\omega * t + \frac{3}{2}\pi) \quad (10)$$



Picture 37 Moon graph



Picture 38 Earth graph

In the pictures we can see the damping process on the moon and on the ground. We can notice different features on the graph on the earth (pic. 38) and on the moon (pic.37), due to the heterogeneous conditions that prevail on both bodies.

CONCLUSION

This bachelor thesis deals with the structural design of a lunar vehicle and the tuning of the shock absorbers.

The research part of the bachelor thesis describes the history of lunar vehicles and its major milestones. A detailed description of the lunar vehicle Cyclop which was the model for this bachelor thesis is given.

In the bachelor thesis an analysis of the existing design of the lunar rover Cyclop is made.

In the main part of the bachelor thesis of the construction type, the procedure for the construction of a suitable lunar vehicle in the solid edge program is described. Furthermore, the shape of the chassis is considered in relation to the chassis stress analysis using the finite element method in Ansys. In the bachelor thesis, two main chassis that are modelled in solid edge are analysed and described. Furthermore, the main part discusses the setup of the wheel dampers in order to achieve ideal ride characteristics. The damping calculations are performed in visual studio code.

The output of the bachelor thesis is the structural design of a lunar vehicle that can accommodate one astronaut who will be able to survive there for more than a week. During this time he will be able to make ascents on the lunar landscape. Another output of this thesis is the debugging of the shock absorbers that make the vehicle

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LIST OF SYMBOLS USED

K	[-]	single element stiffness nut
F	[N]	Strength
d	[m]	maximum node displacement amplitude 3
m_3	[kg]	Concentrated mass at node 3 - not used
g	[ms-2]	gravitational acceleration
d_1	[m]	initial displacement of node 1
d_2	[m]	initial displacement of node 2
m_1	[kg]	Concentrated mass at node 1 - vehicle mass
K_{12}	[3.4E+4]	stiffness between nodes 1-2 axle suspension stiffness
m_2	[kg]	Concentrated mass at node 2 - axle mass
K_{23}	[3.4E+5]	stiffness between nodes 2-3 tyre stiffness
F_{g1}	[N]	Strength
a_1	[ms-2]	Acceleration
F_{i12}	[N]	Strength
v_1	[ms-1]	speed
Δt	[s]	time condition
c_{12}	[3.2E+3]	damping coefficient between nodes 1-2 axle suspension stiffness
v_2	[ms-1]	speed
F_{g2}	[kg·m-3]	Strength
a_2	[min-1]	Acceleration
F_{i23}	[min-1]	Strength
c_{23}	[0]	damping coefficient between nodes 2-3 tyre is not damped
d_3	[m]	initial displacement of node 3
Ω	[s-1]	angular frequency of excitation from the ground

LIST OF ABBREVIATIONS USED

BEAM	The Bielow expandable aktivity module
LED	Light emitting diode
LER	Lunar exploration rover
LRV …	Lunar roving vehicle
MRE	Mear ready to eat
PLA	Polyactic Acid
BoPET	Biaxially oriented polyethylene terephthalate
PI	Polyimide
UWMS	Universal waste management system

LIST OF ANNEXES

Annex 1: Exp_5s_Earth.c

Annex 2: Exp_5s_Moond.c