# Team 1116:

# How many rocket launches from Mahia Peninsula would it take to establish a lunar colony?

## Introduction:

The Moon is a frontier that humanity has aspired to reach for many years. A prominent topic in much of science fiction and the discussion regarding the future of space exploration is the establishment of space colonies, and one on the moon is a very logical first step. Many companies and visionaries are funding and developing modules and spacecraft that will make this dream of a moon-base a reality.

## Summary:

The establishment of a lunar colony would require the formation of a permanent habitat, with aid provided from the Earth in the form of food and other resources until the moon colony is able to become self-sustaining. Our method resembles other leading methods of establishing space colonies, including sending basic necessary resources and equipment first, including the permanent habitation, and then humans, to organise and set up the necessities of the colony.

***We have managed to calculate an estimation of 73 rocket launches in order to establish a basic colony on the moon.***

## Definition Of Problem:

Here we have chosen how we interpret each term used in the question in order to solve the problem.

- **'Rocket launches'** - as we are uncertain of the types of rockets that can be produced in the future, we have decided to limit our calculations to rockets that have currently been produced or are in development.
- **'Mahia Peninsula'** - Currently the Mahia Peninsula does not have large enough facilities to launch the large rockets we wish to use so we assume that the launch site will be upgraded fittingly before we start launching the rockets.
- **'Lunar colony'** - This is the formation of a permanent community of people on the moon. We decided there would have to be 160 people[1], as this would be a genetically stable population. Also, more people may come from Earth later to help expand the colony. This colony should be close to self-sustaining - be able to produce food and get water without aid from Earth, however Earth will send resources to the moon to help expand the colony, such as more habitation modules and more people. We

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[1] https://www.newscientist.com/article/dn1936-magic-number-for-space-pioneers-calculated/

decided this as the goal here is to **simply establish the colony, not completely finalise it.**

## *Assumptions:*

1. Assume that all rockets that can be used for this project are ones that either exist already or are in development. This is because, while new rockets will be designed that are more efficient than the previous, it is unreliable to guess how these improvements will impact the project.
2. Assume that funding is unlimited, to allow the most optimal number of rockets to be sent.
3. Everybody is vegetarian (or will be given a vegetarian diet on the moon) in order to cut on the food requirements.
4. As many sophisticated habitats are merely prototypes, full specifications and details either have not been researched or have not been released to the public. Because of this we are using a complete model based on the 2006 research paper, referenced later in the report.
5. We assume that the unlimited funding will allow us to upgrade the Mahia peninsula to support the launch of a the NASA SLS rockets.
6. We were unable to find the exact mass for communication equipment, so we have estimated the mass of the communication devices and other peripheral large equipment for deviced beyond our knowledge to be less than or about 100T.
7. Basic equipment requirements for each astronaut on a space mission will be applied to all colonists, so we assume that each will have a set of astronaut gear complete with an oxygen tank for initial needs when landing on the moon.

# *(Part 1) Rockets:*

We have assessed multiple choices for a rocket that will put a payload into LEO (low earth orbit). The rockets that are intended for launch from Mahia are the **RocketLab Electron** rockets, which are in no way near feasible for such a large operation such as this. The Electron has a nominal payload of 150kg and is not yet able to do manned missions[2]. We assume that with the funding to start such a colony, we are able to upgrade the launch facility to one that can launch the **NASA SLS rockets**. These are much more feasible and efficient. We will use the SLS Block 2 cargo for the majority of the cargo, and then the SLS block 1B crew or the SLS block 1 for crew. Each crew craft can carry 4 members. **The SLS block 2 Cargo has a payload capacity of 130T**, and the **Block 1b crew has a payload capacity of ~40T not including 4 crew members.**[3][4] Furthermore we have accounted for the carrying volume of the rockets, which is significantly larger than the issue of the total

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[2] https://www.rocketlabusa.com/launch/dedicated/#Plug

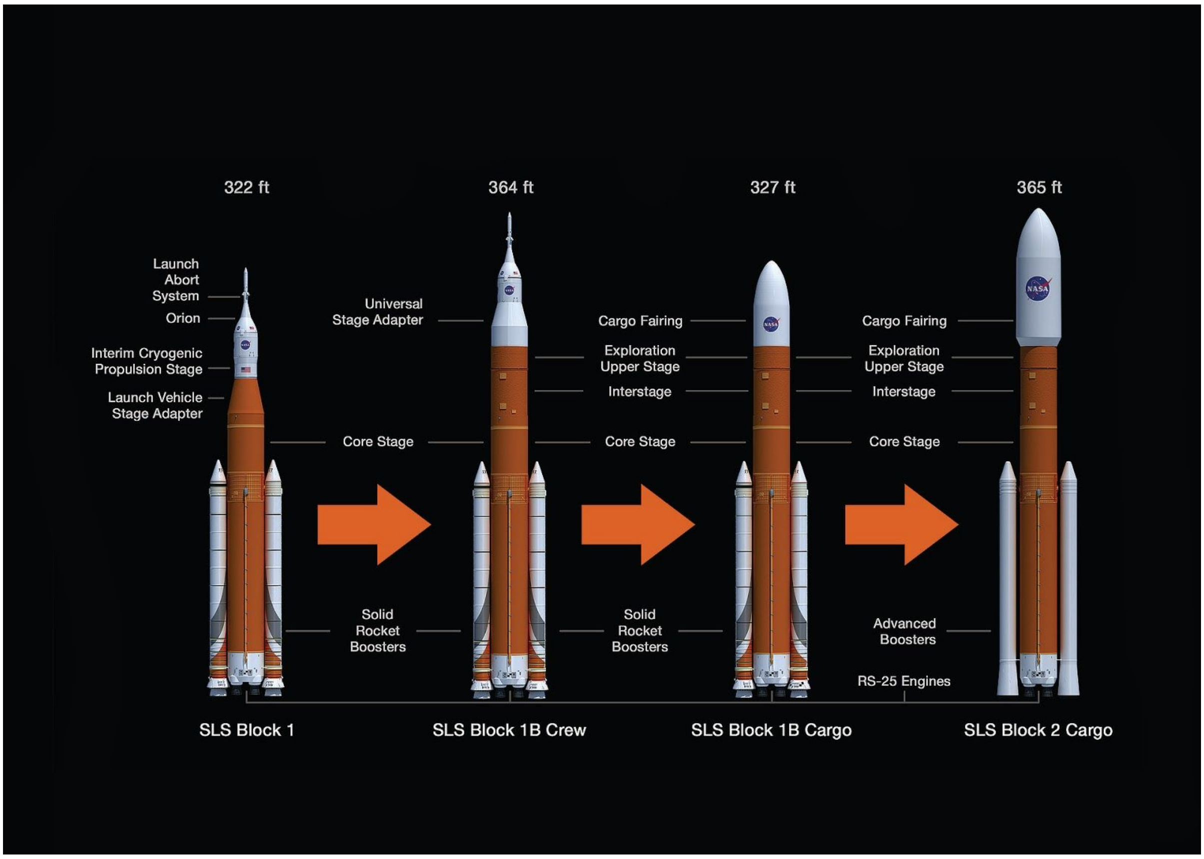
[3] http://www.boeing.com/assets/pdf/defense-space/space/sls/docs/sls_mission_booklet_jan_2014.pdf

[4] https://www.nasa.gov/sites/default/files/files/Creech_SLS_Deep_Space.pdf

mass they can carry, so the actual volume of the rockets is not an issue for sending supplies to the moon.

**For 160 people, we need to send 40 rockets.** This is a limitation, as in endeavouring to put an entire colony on the moon, one would design a spacecraft that will be solely made to transport people *en masse*, but we do not have such a craft at the moment, so we must do this calculation with what exists, which is the Orion capsule. This may dock at a base in the Lagrangian point between the moon and the earth, the ISS, or go straight to the moon. In all situations however, a launch must be made for every 4 people.

**40 launches will give a potential payload transfer of ~1600T.**



## (Part 2) Resources:

In order to colonise the moon, the people living there will need many resources from Earth that are difficult or impossible to obtain from the moon itself. These resources are for the survival of the colonists and keep the crops alive.

***Essential resources include:***

- Food
- Water
- Oxygen
- Nitrogen

- Carbon Dioxide
- Clothing
- Medical resources

## *Food:*

In order to ensure that the colonists have enough food for their time on the moon, it is obvious that a **sustainable and renewable supply is needed**, however **this will take time to grow** (such as potatoes taking 10 weeks, with this being one of the faster growing plants) **so it will be important to bring enough initial food to last until the crops can readily supply for the colonists**. We have found that most crops we would realistically grow will be ready for harvest within a year of being planted, with a fair amount of crops giving food beforehand.

Therefore we can safely presume that **one year's worth of food for the colonists will be necessary to last them until they can sustain themselves**, allowing some excess food leftover as some crops will be producing during this time. Our research found that one American will eat approximately 905 kg[5] of food in one year. **This means we need to bring 144,800 kg of food to last all 160 people for the whole year.**

After considering the mass of all of the food we must bring, we looked into the mass of the seeds that would be necessary to grow enough food for the colony. We found that the mass of the seeds was on the scale of grams, were the heaviest plant seeds can have around 5-10 seeds per gram, such as beans or corn, whereas lots of plants such as cauliflower and tomatoes can have hundreds of seeds per gram. **Therefore it is reasonable to assume that the mass of the seeds to supply the colony will be negligible** as the total mass wont need to be more than 50 kg to have enough redundancy.

Additionally, we found that experiments funded by NASA that show lunar soil can somewhat be used to grow crops, with the main danger being that the crops may have too high of an iron or mercury levels, however these issues can be solved by growing violets in the soil to absorb these toxins. **This means we can utilise the lunar soil on the surface**. However, in order to ensure that the plants grow sufficiently, a beginning set of compost will be needed to grow them, as human waste compost needs to be treated for about one month before it can be applied. Therefore we will do one initial compost layer before using human waste. **On average, 2 inches of compost layering is necessary for growing crops**. We found that **0.01 hectares is enough to support 1 person**[6], so we will need about **1.6 hectares for the total 160 colonists.** This means we will be needing 640 $m^3$ of compost to be sent to the moon. The density of compost is 650 $kgm^{-3}$, so this means **we need 416 tonnes of compost to be sent to the moon.**

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[5] http://www.npr.org/sections/thesalt/2011/12/31/144478009/the-average-american-ate-literally-a-ton-this-year

[6] *The New Organic Grower* (Eliot Coleman)

In terms of growing the produce for the crops, **we will use the RASSOR (explained later) to supply the water for the crops**. We also found that human waste, when treated, can be used as compost for growing the crops. This allows easy and renewable compost to be readily available. Finally, simple crop rotation can be used to ensure the soil remains rich in the nutrients needed to grow our crops. **After considering these details we have found that no further weight needs to be accounted for in terms of what needs to be sent for sufficient food production (the actual facilities for growing crops is accounted for later in the document).**

## *Water and Gases:*

Initially, it seems to be impossible to obtain water and enough oxygen from the moon itself, however NASA has an excavator in development; the RASSOR excavator. **It is able to obtain water and oxygen from the ice at the poles**. When completed, we assume it will be able to obtain the necessary gases and water requirements for the people living there. Humans require about 550 litres[7] of pure oxygen per day, which is approximately 0.79kg of oxygen. The **RASSOR excavator is able to produce 2,555kg[8] of oxygen in 16 hours,** which is clearly enough to support life for the inhabitants of the lunar colony. In addition to this, **the RASSOR excavator will weigh a maximum of 50kg**, making its weight negligible when considering its transport to the moon, however it being present ensures that the people living on the moon will have sufficient water and gases. More than one of the RASSOR excavators will be needed, **and 20 will be taken** so the colonists have enough for use and for redundancy. But this still only has a **mass of 1.0 tonne, so it will not have a significant impact on the total mass being sent**. The excavators will be sent ahead of time, and will be set up by the first astronauts to arrive. The system required for ventilation is included within the habitat mass, therefore we do not have to consider it.

**There will be one early trip of 4 colonists sent to the moon** in order to set up one habitat for themselves, as well as setting up the excavators to store water. Each of the excavators have up to a **500 kg payload, therefore there can be up to 5000 kg of water stored if 10 excavators are used at the same time. 5000 kg of water will be enough for 4 people for 12.5 days, as 1 person's daily need of water for**

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[7] http://health.howstuffworks.com/human-body/systems/respiratory/question98.htm

[8] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20130008972.pdf

**sanitation and drinking is 100 L**[9]. Therefore, with each group of 4 astronauts brought up, 2 weeks of water should be brought up as well, which amounts to **5600 kg of water**, this is very small compared to other resources being taken up, such as the habitation, and therefore there will be space for it in the rockets. Furthermore, the **habitation has water recycling**, so this water will be sufficient for the colonists to survive while the excavators get more water. As more water is accumulated, crops can be planted and the community can become more self-sustaining.

## *Clothing:*

On average the total mass of clothing required, assuming that there are 80 females and 80 males, **would be around 1 tonne**. This has been calculated by using the average weight of types of clothing worn by the colonists. The average weights are as follows[10]:

| ***Male*** | ***Female*** |
|---|---|
| Shirt- 220 grams | Shirt- 110 grams |
| Underwear- 60 grams | Bra- 60 grams |
| Pants- 620 grams | Underwear- 30 grams |
| Socks- 60 grams | Jeans- 450 grams |
| Shoes- 800 grams | Flats- 340 grams |

Assuming that each colonist brings 10 shirts, 14 sets of underwear, 5 pairs of pants, 10 pairs of socks and 2 pairs of shoes, **the total mass would be 1036 kilograms**, approximately 1 tonne. This is **negligible** compared to the mass of the habitation and of the food required, and therefore we have not taken this into account in our final calculations.

## *Medical resources:*

A medical kit will be supplied to all personnel that is involved in the colonisation of the moon [11]. These, if any, has a negligible mass as each medical kit is of a very low weight. As time goes on and the expansion of the colony takes place, hospitals containing adequate medical supplies and technology will become available and self- sufficient, however we can **assume that it is not required for initial stages of colonisation**. All personnel, before embarking on the mission, should be medically examined in order to prevent or reduce any early medical complications that may occur e.g. diabetes, cancer and previous records of cardiovascular diseases. The hereditary tendencies of the subject's family should also be

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[9] http://everylittledrop.com.au/knowledge-center/how-much-water-does-a-person-need/

[10] http://www.cockeyed.com/science/weight/weight_menu.html

[11] https://airandspace.si.edu/exhibitions/apollo-to-the-moon/online/astronaut-life/medical-survival.cfm

examined, as if there are any serious diseases that the subject's family is particularly susceptible to, the subject should not be included into the mission.

## *(Part 3) Habitation:*

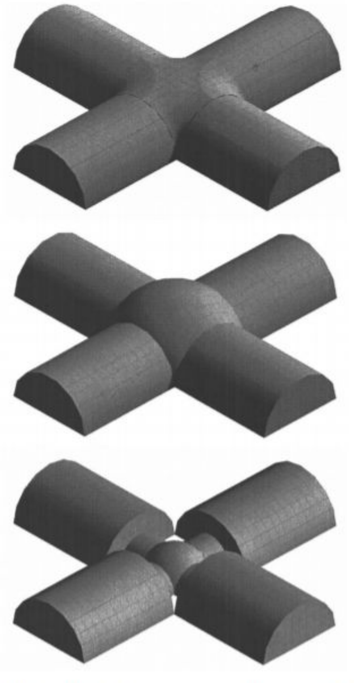

Fig. 26. Different solutions for a radial arrangement

Many ideas have been proposed for habitation on the moon, including living in craters, living underground, living on the surface, near the pole, and on the **dark side of the moon**. We first considered the location of the colony, and considering the necessity for water and essential gases such as oxygen, we **decided to locate the colony near the south pole**, as the south pole has water frozen in the form of ice, as well as gases, such as nitrogen, in the ice[12], which can then be obtained using the ROSSAR excavator.

For the habitat itself, there have been many prototypes and ideas suggested recently, however a research article published in 2006 assessed the various different ideas, materials, and shapes, and, with detailed mathematical models and calculations, designed a lunar habitat able to house 12 people and hold a common room, **so for approximately 160 people, the number of habitats required is 14**. In addition to this, **16000m$^2$ is required for the crops**. The habitats have a floor area of 500m$^2$, so approximately 40 more habitats are required, including walking area, for all the crops. **This gives a total of 54 habitats needed**. The estimated mass of each habitat is **90 tonnes**[13], so for 54 habitats, this is a total of **4860 tonnes**. The habitats can also be broken into 20 parts each. Each habitation can be set up by using a lightweight crane, with the weight for the crane negligible compared to the habitations themselves.

## *(Part 4) People:*

We have decided that the number of people that is required to be sent to the moon **will be 160 people,** which is the necessary amount for sufficient genetic diversity, to ensure there is no danger of inbreeding, thereby maintaining a healthy population[14].

**As stated by Part 1, the number of SLS Block 1b Crew rockets required to transport the lunar population will be 40.**

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[12] https://www.researchgate.net/profile/Niklas_Jaervstrat/publication/228918710_Design_and_Construction_for_Self-sufficiency_in_a_Lunar_Colony/links/09e41509598a23faa6000000.pdf

[13] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.503.9275&rep=rep1&type=pdf

[14] https://www.newscientist.com/article/dn1936-magic-number-for-space-pioneers-calculated/

# *(Part 5) Energy:*

Certain parts of the moon can be in the **dark for up to 14 days**[15], and so solar power seems to be a rather inefficient option for a self sustaining colony. We need a source that is more consistent and easy to maintain. This is why we have decided on **transporting multiple small fission reactors to suit power needs for the colony on the moon**. To model the power usage per capita, we have considered multiple strategies. It is difficult to compare the power consumption of an average person on earth to one on the lunar colony, as there is a lot more power used in things such as airlocks, air and water purification, heating etc. What we have done to create a reasonable comparison to astronauts on the moon was to see the energy consumption per capita of those on the ISS, as it has similar facilities and living amenities as a moon base would have.

*Total Power Consumption of the ISS: **75-90 kW**, average of **82.5kW**[16]*

*Power Consumption per person on the ISS:* 82.5/6 *(6 people on the ISS at the moment) = **13.75 kW/person***

*Power Consumption for a Moon Base of 160 people, **13.75 kW 130 =2200 kW***

We have decided to use a compact fission made for small scale use like on the moon or Mars called the **RAPID-L** (the L indication that this is the lunar model). This is a Japanese design that is able to produce **200kW.**[17] **It weighs 7.6 tons, and is 2.6m wide, and 6m deep.** The holes for the array will be excavated by the robots that have already been accounted for in terms of weight. **Helium-3 can be mined on the moon for fuel, and Lithium-6 will be taken up as a coolant**. These reactors last **for 10 years without refueling[18],** at which they will be at 80% efficiency. This is adequate for our model, until technology improves and updated technology is sent from earth.

For 2200 kW, 11 200 kW reactors are needed to meet demand. 15 will be taken for redundancy, so in total, **the mass of all the reactors is 114 T.**

# *(Part 6) Final Calculation:*

### Method of Colonisation

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[15] http://www.synapses.co.uk/astro/moon2.html

[16] http://www.edn.com/design/power-management/4427522/International-Space-Station--ISS--power-system

[17] https://inis.iaea.org/search/search.aspx?orig_q=RN:37002589
[18] https://inis.iaea.org/search/search.aspx?orig_q=RN:37002589

1. Send up resources in the SLS Block 2 Cargos
2. Send up people with some more cargo in the SLS Block 1B crews

### *Step 1:*

- The resources sent with the SLS Block 2 Cargos will include the compost, the food, the excavators, the nuclear reactors and some of the habitats
- 14 full habitats will be sent up in these rockets
- The remaining 40 habitats will be sent up with only 13 pieces of the 20 total pieces of each habitat

### *Step 2:*

- The crew are sent up in the SLS Block 1b Crews which each have payloads of about 40 T, therefore they will be sent up with the remaining 7 parts of the total 20 pieces of the 40 incomplete habitats already on the moon.
- In addition to this, they will each be sent up with 2 weeks worth of water which is 5.6 T.
- This in total is **31.5 + 5.6 = 37.1 T.**
- Personal belongings such as clothing can also be taken up in the remaining space.

### *Overall Calculation:*

- There needs to be **40 SLS Block 1B** crews sent up for all the colonists to reach the moon
- The remaining mass that needs to be taken up is the total mass of the nuclear reactors, compost, food, excavators and the portion of the habitats not taken up in the SLS Block 1B crews.
- The mass of the habitats that needs to be taken up is: $14 \times 90 + 40 \times 13 \times 4.5 = 3600\ T$
- The total mass in Cargo rockets is therefore: $3600 + 114\ (reactors) + 416\ (compost) + 145\ (food) + 1\ (excavators) = 4276\ T$
- Therefore $4276/130 = 32.89...$ so 33 Cargo rockets will be taken up
- This leaves 14 T of space in the Cargo rockets, and 116 T of space, total, in the Crew rockets, some of which will be used for communications equipment and for a lightweight crane to assemble the habitations

| ***Rocket number*** | ***Rocket type*** | ***Rocket capacity*** | ***Rocket payload*** | ***Crew*** | ***Total mass taken up*** |
|---|---|---|---|---|---|
| **1-33** | NASA SLS Block 2 cargo | 130 Metric tonnes each | Habitation equipment, crane, energy, compost, food, excavators, reactors | n/a | 4290T total empty capacity.<br>4276T for most cargo<br>14T of |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | communications equipment and related accessories |
| **34-73** | NASA SLS Block 1B crew | 40 Metric tonnes each | Habitation equipment, water | 4 | 1600T total empty capacity<br>1484T for habitation equipment and water<br>116T for communications equipment |

# Total: 73 rocket launches

## *Evaluation of conclusion:*

**The colonisation of the moon will be a monumental human event** that has been imagined for decades, unfortunately it is still a dream consisting only as plans and prototypes. Therefore, it is very difficult to calculate the number of rocket launches needed, especially as technology is developing at a very fast rate. It is likely that, if colonisation of the moon takes place several years in the future, the number of rockets needed will be much lower than what we have calculated, however **we have restricted ourselves to current rockets due to the uncertainty and lack of experimental rigour with predicting the future inexplicably.**

Also, the Mahia Peninsula is made to launch Electrons, **a rocket which does not carry any crew and can only have a payload of 150 kg.** If everything we planned above needed to be taken, **well over 30000 rockets will be needed only for the cargo.** This is clearly not feasible so our assumption that the Mahia Peninsula rocket station will be upgraded is very valid.

In conclusion, abiding with all stated assumptions and limitations, our final figure of 73 rocket launches from Mahia Peninsula seems, to us, a valid conclusion for such a problem. A major factor that would change the final figure is the development of a spacecraft specifically made for the transport of humans. This would create a very logical separation between the transport of people and the transport of equipment and will improve the efficiency of the entire process.