TEAM 1003

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

Abstract

With the great degree of freedom presented in the question, some variables were specified in order to give a satisfactory answer. A colonist population of 160 with 14.7% chance of genetic drift, found by a computer simulation over 34 generations; inhabiting lava tubes within the Marius Hills in inflatable habitats; sustained on greenhouse modules; oxygen and water provided through the reduction of ilmenite; and energy provided by solar panels. 229 Falcon Heavy rockets were needed to establish a lunar colony. Initially 12 colonists would be dispatched to set up operations and habitats; a space station would be set up for the purposes of sustainability; and, furthermore, the choice of using the Mahia Peninsula would result in an additional 5 rockets. Due to estimations and assumptions, uncertainty in this number could range by 10%.

Introduction

Given the open nature of the question, key terms were defined as follows:

"Lunar" was assumed to refer to the Earth's moon, rather than the moon of any other planet.[1]

"Colony" was given to be "a body of people living in a new territory but retaining ties with the parent state".[2] By this definition, there was not a requirement for the lunar colony to be entirely self-sustainable, nor isolated; there was potential for rockets to continue being sent between the moon and the earth. However, in considering possible motivations for establishing a colony on the moon — for research or habitation —, alongside costs of continuously providing shuttles, sustainability was a desirable factor.

Similarly, although the question required only the number of rockets to "establish" a space colony, a degree of sustainability was assumed to be practical.

[1] https://www.merriam-webster.com/dictionary/lunar
[2] https://www.merriam-webster.com/dictionary/colony

The degree of technology, particularly that which pertained to “rocket”, was assumed to be around, although in some cases, more advanced than, present-day technology. This assumption was made because the uncertainty that arose with changes to future technology was too great — it would be too simple to say, ‘there would be a rocket in the future capable of carrying 160 amount of passengers’. For these reasons, the Falcon Heavy and the Dragon v2 rocket and spacecraft [3](respectively), were considered to be the main methods of transport in this report. Given this, there were still some assumptions made regarding the technology of surviving on the moon, though they were based on research of others substantiated to varying degrees.

For some cases a heavy object was too heavy for a falcon H. To circumvent this problem we created a Falcon SH which is just a falcon H with another 2 Falcon 9s attached, giving it the capacity to carry 31,000 kgs into lunar orbit.

Calculating estimated load capability of the rockets going into lunar orbit
SpaceX does not give Lunar orbit load so we had to figure it out using the average ratio between LEO, GEO and Lunar Orbit of rockets that we know[4].

	A	B	C	D	E	F	G	H	I
1		LEO	GEO	Lunar Orbit			Ratio 1:2	Ratio 2:3	Ratio 1:3
2	Delta II	6,000	2,171	1,508			2.76370336	1.43965517	3.97877984
3	Delta 4H	23,040	13,130	9,000			1.75476009	1.45888889	2.56
4	Delta 4M	8,120	4,210	2,722			1.92874109	1.54665687	2.98310066
5	Delta 7420	3,185	1,110	804			2.86936937	1.38059701	3.96144279
6	Atlas 5(HLV)	25,000	12,650	9,000			1.97628458	1.40555556	2.77777778
7									
8							2.2585717	1.4462707	3.25222021
9									
10	Falcon heavy	54,400	22,200	15349.8235	.=C10/H8		2.45045045	1.4462707	3.54401469
11	Falcon heavy	54,400	22,200	16727.0346	.=B11/I8		2.45045045	1.32719281	3.25222021
12	Falcon heavy	54,400	22,200	16038.4291	.=(D10+D11)/2		2.45045045	1.38417547	3.39185339
13									
14	Falcon heavy	63,800	26,700	18461.2742	.=C10/H8		2.38951311	1.4462707	3.4558828
15	Falcon heavy	63,800	26,700	19617.3678	.=B11/I8		2.38951311	1.36103887	3.25222021
16	Falcon heavy	63,800	26,700	19039.321	.=(D14+D15)/2		2.38951311	1.40236094	3.35095984
17									
18	Falcon SH	109,400	43,300	29939.0702	.=C10/H8		2.52655889	1.4462707	3.6540881
19	Falcon SH	109,400	43,300	33638.5585	.=B11/I8		2.52655889	1.2872133	3.25222021
20	Falcon SH	109,400	43,300	31788.8144	.=(D18+D19)/2		2.52655889	1.36211434	3.44146211
21									

Space Station

We will be building a space station that orbits the moon. This station will be identical to the one that orbits the earth as of November 2001 when it had 5 modules and could support 3-4 people. This station will allow the use of the Altair spacecraft which can ferry people to and from the space station. People can then be picked up from the space station by one of the Dragons which can take them back to earth. Each return trip of the Altair (to the moon and back to the space station) will require roughly 19,000 kgs of fuel, meaning one rocket launch

[3] http://www.spacex.com/

[4] http://space.skyrocket.de/directories/launcher_usa.htm

from earth. 2 of the modules will need to be transported using Falcon SHs and the other 3 can be transported using Falcon Hs.

Derivation

Impact of choice of Mahia:
We see that the latitude of the launch site will impact the change in velocity required to get into orbit. This means that as the latitude increases, the payload which can be carried will decrease. This has the implication of Mahia being in a location which results in a lower possible payload, which will later be taken into account when determining the final amount of rockets.

The term v_f, the velocity which the rocket must reach, is affected by the latitude of the launch site. As the absolute distance from the equator increases, the rotational speed of the earth decreases:

$$Tangential\ Speed = \frac{2\pi \times r_{earth}}{Sidereal\ Rotational\ Period} \times cos(latitude)$$

At the equator, this would be equal to:

$$Tangential\ Speed = \frac{2\pi \times 6371000}{86164} \times cos(0) \approxeq 465ms^{-1}$$

Whereas at Mahia Peninsula, at 39.16 degrees south of latitude, it is:

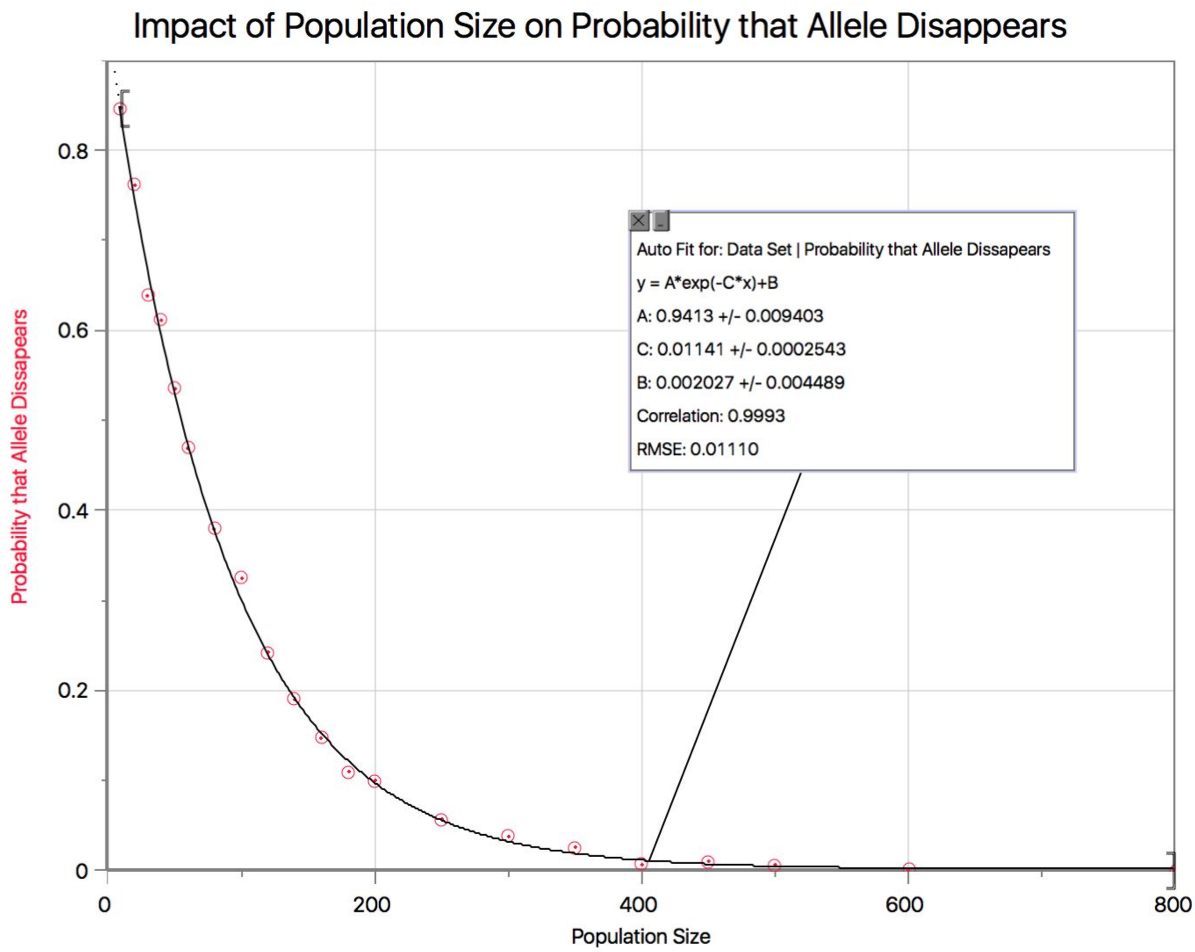
$$Tangential\ Speed = \frac{2\pi \times 6371000}{86164} \times cos(39.16) \approxeq 360ms^{-1}$$

This difference of approximately 105 meters per second means that less payload will be able to be carried in these rockets, as they have less rotational speed to assist them.

Requirements for the colony:

Population
The number of colonists used was 160 people (cite by NASA in the book *Interstellar Travel and Multi-Generational Space Ship)*. The lower the number of colonists sent meant a higher likelihood of genetic disorders arising should breeding between colonists occur. Reproduction was assumed under the basis of 'some degree of sustainability' for the colony to survive more than one generation.

In order to determine the amount of people that would be necessary to support a genetically healthy population on the moon, a model was developed within the Microsoft Excel spreadsheet software. This was used to simulate the probability that a given allele would disappear from the population after a given number of generations. In order to obtain the data, the probability was averaged across a sample of approximately 800 populations, over 34 generations. An explanation of the workings of the model is provided below. The findings demonstrate that, at the proposed colony size of 160, the chance that a given allele will disappear is equal to 14.7%. This was determined to be an acceptable risk. In order to have the risk much closer to zero, a population of approximately 600 would be necessary. This was shown by the exponential curve fit in the graph below. Intuitively, the probability tends to zero as the population increases.



The model[5] works by binomial probability distribution B(2N, p), 2N being the total number of alleles for diploid organisms and p being the probability of the allele appearing. The data below shows separate populations and their frequencies of having the initial allele in their subsequent generations. Due to the random nature of genetics, 50 populations were modelled at the same time for 34 generations and the final probability that the gene disappeared was the proportion of populations that had lost the gene.

The modelled allele was assumed to be relatively uncommon, with a 0.1 probability of it appearing in a given individual. This assumption was made because only the less common alleles would exhibit genetic drift.

[5] http://scienceandmathacademy.com/academics/srt2/assignments/genetic_drift_simulation.pdf

N	800		Generation	Pop1	Pop2	Pop3	Pop4	Pop5	Pop6	Pop7	Pop8	Pop9	Pop10	Pop11	Pop12	Pop13	Pop14	Pop15	Pop16	Pop17	Pop18	Pop19	Pop20	Pop21	Pop22	Pop23
p	0.1		0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
				0.1	0.1	0.10375	0.1075	0.1175	0.094375	0.108125	0.110625	0.10375	0.11	0.105	0.104375	0.095	0.105	0.101875	0.096875	0.121875	0.096875	0.09125	0.101875	0.109375	0.0925	0.104375
				0.108125	0.1075	0.09375	0.105625	0.119375	0.10375	0.1175	0.125625	0.091875	0.106875	0.11125	0.096875	0.094375	0.10125	0.106875	0.095	0.116875	0.0975	0.086875	0.109375	0.1	0.09	0.0925
				0.106875	0.103125	0.09625	0.106875	0.12375	0.109375	0.123125	0.1275	0.10375	0.108125	0.11875	0.094375	0.09125	0.098125	0.113125	0.090625	0.1075	0.088125	0.0825	0.105	0.094375	0.09375	0.079375
				0.10375	0.11	0.1125	0.110625	0.111875	0.109375	0.121875	0.118125	0.0975	0.104375	0.120625	0.085625	0.1	0.0975	0.114375	0.091875	0.12125	0.091875	0.086875	0.103125	0.0925	0.09625	0.075625
				0.09	0.100625	0.115625	0.125625	0.101875	0.1125	0.12	0.111875	0.105625	0.105	0.12125	0.0925	0.10875	0.098125	0.135	0.084375	0.125	0.095	0.08625	0.118125	0.105625	0.083125	0.083125
				0.09875	0.105625	0.123125	0.115	0.09625	0.13125	0.12	0.101875	0.09625	0.100625	0.118125	0.093125	0.108125	0.0975	0.133125	0.085	0.11625	0.09375	0.08	0.113125	0.1075	0.08375	0.086875
				0.099375	0.095	0.126875	0.111875	0.10875	0.125625	0.12375	0.0975	0.104375	0.1	0.1175	0.086875	0.105	0.09875	0.139375	0.084375	0.115625	0.090625	0.0875	0.10875	0.11	0.089375	0.071875
				0.10625	0.0975	0.1225	0.130625	0.118125	0.129375	0.121875	0.096875	0.0975	0.09625	0.1175	0.08	0.0975	0.105625	0.126875	0.0925	0.125625	0.091875	0.094375	0.101875	0.125	0.10625	0.075
				0.1025	0.10625	0.11875	0.119375	0.119375	0.138125	0.13625	0.109375	0.09625	0.1075	0.106875	0.074375	0.090625	0.09875	0.13875	0.085625	0.129375	0.08375	0.095625	0.104375	0.11875	0.109375	0.076875
Average prob to fixation				0.105	0.110625	0.133125	0.123125	0.118125	0.131875	0.12875	0.11875	0.0925	0.104375	0.109375	0.065625	0.090625	0.10875	0.149375	0.086875	0.135	0.073125	0.105	0.098125	0.114375	0.095625	0.079375
0				0.100625	0.095	0.138125	0.12875	0.1325	0.145625	0.1225	0.1225	0.1025	0.114375	0.11375	0.07625	0.091875	0.111875	0.155625	0.09125	0.144375	0.08125	0.09125	0.0975	0.121875	0.105625	0.079375
				0.106875	0.096875	0.134375	0.11625	0.1375	0.155625	0.12875	0.115625	0.101875	0.114375	0.1175	0.075625	0.099375	0.111875	0.16	0.0925	0.139375	0.07	0.09125	0.09625	0.131875	0.1	0.0925
Average prob to dissapearing				0.120625	0.095	0.1325	0.12375	0.13625	0.166875	0.1225	0.1175	0.098125	0.115625	0.113125	0.06625	0.100625	0.09875	0.1575	0.09375	0.140625	0.07375	0.11	0.095	0.13625	0.098125	0.094375
0				0.12	0.095625	0.128125	0.12125	0.135	0.17625	0.134375	0.105	0.100625	0.109375	0.118125	0.06125	0.09875	0.076875	0.14375	0.093125	0.1525	0.073125	0.104375	0.093125	0.139375	0.09125	0.0975
				0.125	0.1	0.12	0.116875	0.1425	0.17375	0.1325	0.1025	0.100625	0.10375	0.1175	0.065	0.10125	0.07375	0.146875	0.085625	0.145625	0.068125	0.0975	0.090625	0.153125	0.0825	0.104375
				0.1075	0.109375	0.130625	0.140625	0.1425	0.183125	0.123125	0.119375	0.086875	0.10625	0.11875	0.055	0.11375	0.066875	0.146875	0.090625	0.140625	0.078125	0.09625	0.08875	0.15625	0.079375	0.111875
	Probability gene dissapears			0.11	0.1175	0.145	0.15375	0.150625	0.193125	0.125	0.12125	0.085	0.10125	0.114375	0.053125	0.110625	0.068125	0.153125	0.08625	0.1525	0.078125	0.09125	0.100625	0.165	0.079375	0.115
10	0.8464373			0.1075	0.113125	0.146875	0.151875	0.153125	0.18125	0.119375	0.115625	0.0875	0.101875	0.11125	0.04375	0.11625	0.068125	0.154375	0.0825	0.14875	0.0875	0.078125	0.10125	0.151875	0.079375	0.11125
20	0.7616708			0.1275	0.110625	0.145625	0.148125	0.146875	0.19125	0.12625	0.115625	0.09375	0.126875	0.11875	0.046875	0.116875	0.068125	0.154375	0.089375	0.13625	0.08125	0.0825	0.10875	0.149375	0.069375	0.11625
30	0.6388206			0.134375	0.119375	0.138125	0.14	0.1475	0.200625	0.109375	0.118125	0.095625	0.126875	0.115625	0.041875	0.1225	0.065625	0.160625	0.090625	0.15	0.0775	0.085	0.09625	0.13375	0.06625	0.121875
40	0.6117936			0.131875	0.111875	0.130625	0.130625	0.14	0.188125	0.1075	0.119375	0.094375	0.12875	0.11125	0.0475	0.123125	0.06875	0.17625	0.089375	0.159375	0.075625	0.08625	0.08625	0.13	0.068125	0.113125
50	0.5356265			0.119375	0.115	0.126875	0.134375	0.1375	0.18625	0.099375	0.1	0.09875	0.11125	0.115625	0.04625	0.124375	0.07125	0.196875	0.080625	0.1525	0.07	0.0925	0.086875	0.13875	0.064375	0.1175
60	0.4692875			0.119375	0.115	0.135625	0.14125	0.135625	0.191875	0.10375	0.104375	0.100625	0.101875	0.12	0.04125	0.140625	0.059375	0.203125	0.07875	0.138125	0.07125	0.085625	0.093125	0.1425	0.056875	0.121875
80	0.3796069			0.121875	0.113125	0.14	0.131875	0.14375	0.209375	0.09125	0.1	0.099375	0.089375	0.11375	0.041875	0.146875	0.058125	0.2025	0.064375	0.138125	0.06	0.08625	0.100625	0.14625	0.064375	0.12625
100	0.3255528			0.1275	0.104375	0.141875	0.14625	0.155625	0.21	0.094375	0.095625	0.101875	0.08875	0.09875	0.04125	0.14875	0.059375	0.194375	0.056875	0.13	0.06	0.081875	0.116875	0.1375	0.073125	0.116875
120	0.2420147			0.124375	0.1125	0.141875	0.138125	0.141875	0.195625	0.094375	0.09125	0.0925	0.079375	0.095	0.04	0.155	0.053125	0.213125	0.045	0.144375	0.058125	0.0775	0.11875	0.140625	0.080625	0.11
140	0.1904177			0.105	0.12375	0.131875	0.130625	0.1425	0.194375	0.09875	0.08625	0.095	0.075	0.085625	0.045625	0.15125	0.058125	0.19625	0.0475	0.158125	0.058125	0.07125	0.128125	0.144375	0.07125	0.1075
160	0.1474201			0.10875	0.12125	0.133125	0.134375	0.143125	0.20125	0.098125	0.0975	0.100625	0.06625	0.0675	0.05375	0.14125	0.056875	0.20125	0.05625	0.15875	0.05625	0.07375	0.120625	0.154375	0.0775	0.103125
180	0.1093366			0.1075	0.12625	0.133125	0.15875	0.1625	0.21625	0.09875	0.098125	0.09375	0.061875	0.07	0.05625	0.1475	0.051875	0.19	0.05125	0.144375	0.076875	0.076875	0.11125	0.15375	0.081875	0.105625
200	0.0995086			0.10125	0.105	0.1325	0.15	0.1675	0.2175	0.096875	0.09	0.09	0.06375	0.074375	0.055625	0.140625	0.041875	0.2125	0.05125	0.1325	0.081875	0.0675	0.106875	0.1575	0.095625	0.098125
250	0.0565111			0.103125	0.096875	0.116875	0.14125	0.1475	0.238125	0.09	0.086875	0.085	0.06	0.07125	0.065	0.133125	0.04375	0.2125	0.05375	0.13625	0.0725	0.07	0.108125	0.166875	0.108125	0.096875
300	0.0380835			0.100625	0.090625	0.124375	0.1375	0.155	0.23125	0.083125	0.090625	0.094375	0.060625	0.070625	0.070625	0.1475	0.053125	0.205625	0.0625	0.134375	0.0675	0.0625	0.10125	0.160625	0.110625	0.086875
350	0.0257985			0.088125	0.09	0.111875	0.14375	0.154375	0.245	0.08375	0.076875	0.09875	0.069375	0.070625	0.07375	0.1525	0.05125	0.216875	0.065625	0.13	0.070625	0.0625	0.10625	0.1525	0.11625	0.088125
400	0.007371			0.0875	0.085625	0.12125	0.139375	0.146875	0.25375	0.093125	0.06375	0.095625	0.07375	0.0775	0.076875	0.144375	0.050625	0.216875	0.0675	0.13125	0.0575	0.06375	0.10875	0.14625	0.113125	0.088125
450	*0.009828*																									
500	0.0061425																									
600	0.0012285																									
1000	0																									

For practicality, to reduce the number of necessary rocket launches, the number 160 was used with this risk taken into account.

Oxygen and water

The reduction of ilmenite by hydrogen, molten silicate electrolysis, fluxed molten silicate electrolysis, and vapor phase pyrolysis[6], were all tested to be viable methods of generating oxygen on the moon.

Most of the systems used recycled products, ameliorating the need to transport hazardous or explosive chemicals to the moon. For instance, the reduction of ilmenite by hydrogen produces water, which is then electrolysed to hydrogen gas and oxygen, the oxygen being used to sustain the colonists while the hydrogen is reused for reduction.

The water produced is also used as the primary source of water for the colony. The table below shows that a 200 tonne plant would produce 1000 tonnes of oxygen per year. Given we have 160 people using 0.84[7] kg oxygen a day we need $160 * 0.84 * 365 = 49056\, kg$ or 49 tonnes. This leaves most of the plant unused. As the plant is producing 1000 tonnes of oxygen per year, it must be producing at least 2250 tonnes water in the previous step. Therefore we will only be using 110.25 tonnes of this water and so there will be 2140 tonnes of water left, more than enough to satisfy the water requirement of 167 tonnes per year ($160 * 28.63 * 365$) plus 351 tonnes for the greenhouse module (27 modules at 26 tonnes water every two years per module)

[6] http://www.uapress.arizona.edu/onlinebks/ResourcesNearEarthSpace/resources04.pdf
[7] https://www3.nd.edu/~cneal/CRN_Papers/Harper16_NS_LifeSupportLunarSettelment.pdf

TABLE VI
Mine and Plant Characteristics: 1000 Tonnes of Oxygen per Year

Processes	Ore (T/yr)		Plant Mass	Energy
	Raw	Process Troughput	(T)	(MWyr)
Ilmenite: High-Ti Mare				
Reduction with hydrogen	210, 000[a]	21, 000[b]	200	3
Reduction with CO	210, 000[a]	21, 000[b]	225	3.5
Reduction with methane	210, 000[a]	21, 000[b]	225	3.5
Mare or Highlands				
Glass reduction with H_2	160, 000[c]	80, 000[d]	200	4
Molten sil. electrolysis	5, 000[e]	5, 000[f]	70	3
Fluxed molten sil. electrol.	5, 000[e]	5, 000[f]	80	3.5
Vapor phase reduction	5, 000[e]	5, 000[f]	40	2
Ion (plasma) separation	5, 000[e]	5, 000[f]	40	2.5

[a] Assumes feedstock with 50 wt% ilmenite from an ore with 5% available ilmenite for a beneficiation factor of 10.
[b] Assumes approximately 90% conversion of ilmenite.
[c] Assumes soil with 25% glass beneficiated to 50% glass for a beneficiation factor of 2.
[d] Assumes 15% FeO in glass (= 3.35% O_2 in glass) and 75% conversion of FeO to Fe + $\frac{1}{2}O_2$.
[e] No beneficiation necessary.
[f] Assumes about 43 wt% O_2 in soil with 50% recovery.

Housing

The location of the proposed lunar colony is in the Marius Hills region of the moon[8]. This was selected due to its proximity to a lunar lava tube, which is a space under the lunar surface — this means that the colonists will be protected from meteorite impacts, solar radiation, and temperature variation, with the expected temperature being approximately -20°C[9]. To seal the lunar tube, an inflatable habitat will be used, which will provide a safe living environment.

A report by NASA has investigated the viability of such a habitat, and has designed a solution for 12 astronauts, with each having a mass of 16,300kg[10]. Therefore, with a population of 160 people, we would need to transport 14 habitats, which would be constructed within the Marius Hills lunar lava tunnels.

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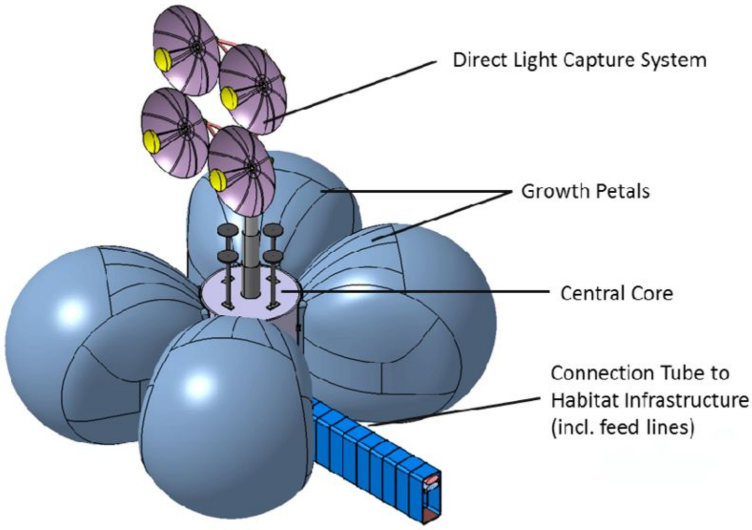
8 https://en.wikipedia.org/wiki/Marius_Hills
9 http://www.lpi.usra.edu/meetings/lpsc97/pdf/1023.PDF
10 http://www.nss.org/settlement/moon/library/LB2-303-InflatableHabitation.pdf

Source of food

The Greenhouse Module (GHM) provides a vegetarian diet for six colonists. Therefore, 27 will be required to service our colony of 160 colonists.



The overall GHM system has a total mass of 86 tonnes. The power consumption during nominal operations is ~418 kW. The system requires 26 tonnes of water for an operation period of 655 earth days.

The inflatable petals are connected to the core with airlocks. Each of these compartmentalized growth areas provides optimum growth conditions for varying crops.

The core is split into three levels: Upper Level, Middle Level and Lower Level.
The Direct Light Capture System will be extended to the moon's surface, providing a power source for each greenhouse.

Food provided by each module for six colonist:

	Bread Wheat	Durum Wheat	Potato	Soybean	Rice	Total
Mass Produced per day (kg)	1.0	1.8	3.0	1.1	5.0	11.9

The greenhouse module has a total cultivation area of more than 650 m² [11].

[11] http://elib.dlr.de/110816/1/%5BOpen%20Agriculture%5D%20Greenhouse%20Module%20for%20Space%20System%20A%20Lunar%20Greenhouse%20Design%202017.pdf

The power consumption during nominal operations is ~418 kW (and ~40 kW during emergency/ hibernation mode)

Source of energy

Our power required for water and oxygen production is ~3MW per year and greenhouse production is 3.148E6, as calculated from figures mentioned previously under their respective headers. Approximate wattage produced by a modern solar panel would be 300W. Therefore, an approximate figure for the number of solar panels is 10494 panels.

Given this, the solar panels are assumed to be able to fit into gaps in some cargos of the rocket launches.

Rockets Needed

This system will involve Falcon Heavy rockets taking off from Mahia Peninsula with a Dragon V2 spacecraft for when people are being carried. It will travel to TLI, or trans-lunar injection orbit, where it will rendezvous with a space station orbiting the Moon.

Such a space station was decided to be established in the pursuit of sustainability; should there be travel to the moon in the future, a space station would be desirable.

The payload will be transferred from the Falcon Heavy rocket to the space station, where a system of rockets can be used to transfer it to the Lunar surface.

Initial	Initial food, water and air is 8 rockets.
People	Each Dragon 2 capsule can take 7 people[12]. As such, we will need 23 of these to transport our 160 colonists to the Moon. Also, 4 colonists will need to be transported to the space station by the altair. This will take 19,000 tonnes of fuel or 1 rocket launch.
Space Station	5 rockets, as it has five modules and it can only fit one onto each Falcon Heavy launch.
Habitation	With the mass of each habitation being 16,300kg, a separate launch will be required for each one. As we will need 14

[12] https://en.wikipedia.org/wiki/Dragon_2

	habitats, this will involve 14 launches which will transport these.
Agriculture	With each GHM weighing 86 tonnes, it will be separated into constituent parts to result in 162 launches.
Water and Oxygen	11, due to the mass of the extractors and volume constraints in the Falcon Heavy launch system
Total	After taking the above factors into account, we can conclude that we will need: $8 + 23 + 1 + 5 + 14 + 162 + 11 = 224$. Falcon Heavy rocket launches.

However, as discussed in the introduction, being launched from the Mahia Peninsula will have implications for the payload of the rockets. According to this answer[13], the impact of the change in latitude discussed in the introduction will lead to approximately 400kg less payload being able to be carried, per rocket. This means we have a discrepancy of $224 \times 400 = 89600kg$, which will result in an additional five launches, taking the final total to 229 launches. However, we estimate that there is an uncertainty in these calculations of 10%, meaning that there is a fair amount of variability in this final number.

13 https://space.stackexchange.com/questions/998/how-much-of-an-advantage-do-equator-proximal-launch-sites-provide?noredirect=1&lq=1