Drilling Technology – Report

An investigation into the utilization of Radioisotopic Thermoelectric Generators as the focal energy source amongst Space Engineering

Abstract

This report aims to guide us through the in depth analysis of how something as simple as lunar dust can have on the effects of the conventional solar panels, how something as unpretentious as lunar atmosphere can have an effect on the surface of the moon and how something such as nuclear power will be enhanced to a safe and secure state that is deemed utilizable in the space craft. Detailing out the engineering challenges that we face; from the sheer power that is necessary to power the space craft and the drill itself to the storage compartments that will aim to contain and control the radioactive decay that is constantly occurring. By doing in depth analysis of particular ailments that lie ahead, thorough study methods and research will be a major component of this report; the lunar atmospheric composition, the deterioration of individual solar cells from fragments of micrometeorites, the radioactive decay of an isotope and so forth. Here we summarize that nuclear power has a significant potential to be used frequently amongst space travel, and it is already being used in reality as of this moment.

Introduction

Forming a major role in the mission for data and archive storage upon the moon, the drilling technology will have to be developed to a degree of advanced modern technology and the process itself will be endorsed in an environment literally out of this world. Like many projects, the idea comes with both drawbacks and advantages. Questions will be answered and unanswered and the idea of rhetorical questioning will come into play; there is a list of endless factors that have to take into account in environmental, social and technological terms. This therefore would be a deemed a challenging and daunting task, however this opportunity will be the fuel to thrive humanity onwards.

The search for a newfound technology that will provide the power source for future space missions up to the moon is in a developing field where there is an immense potential for scientific breakthrough and advancements. As part of Lunar Mission One, a lunar project esteemed with such potential, regardless of how distant it is in the future or how little one's role may be, it still gives us the opportunity to partake in.

Lunar Mission One is an esteemed project that is funded a nd is available to everyone on a global scale, ranging greatly in age, gender, culture and background. The project's aim is to design a drill that is thoroughly capable of battling the environmental and geophysical territories on the lunar surface of the moon, and to drill 100 meters down into the borehole to then store small capsules containing an archive of Mankind's past history, as well as the present memories we are enduring.

What problems we may face

It is human nature for us to focus more on the problems, but that is what allows us to build a foundation towards our goal. Numerous questions remain in several areas:

- Power Source – How will the drill be powered? Obviously the lack of sunlight will indefinitely dismantle the idea of solar power, so how will we be able to power the drill using little cargo uptake and will it be efficient?
- Lunar Environment – In a different geophysical environment consisting of almost absolute zero temperatures and an unsettled variation of radiation throughout the moon, how will the drill be designed to counteract these issues?
- Control – Since communication via regular radio wave transmission will be limited, will there have to be a software system that can ensure consistent and reliable control of the drill?
- Drill Bit – The drill head itself will have to be specially designed to crack, crush and clear the rock in one rotary action; how will the drill aim to deliver this in such a confined space and environment?

Counteractive Ideas

Looking at a few of these problems gives us something to work upon and they may not all be as difficult as it sounds. We can consult and take inspiration from our history of drill engineering and see how it is developed overtime:

- Drill Engineering – The drills used on Earth are mainly used to extract resources deep into the crust of the Earth consisting of oil, gas and fossil fuels. These drills also have to comprehend a gruelling environment, and by seeing how they perform in those environments will enable us to tackle problems of similarity on the moon [1].
- Power Source – In order to use as little cargo uptake as possible and ensure an efficient process, the source of power will have to react in a restricted space yet deliver enough power towards the drill bit. An idea is that we can use radioactive reactions as a source of energy ie radioactive decay. Another common source is through liquid hydrogen. Although this liquid is mainly used for the propulsion of the rocket itself, could it also be used as a power source for the drill bit as well?

Chapter One - Engineering Challenges

Figure 1: A computer design of a drill with similar characteristics to that on the moon

The engineering challenges that we will be facing are amongst the most dissimilar and strenuous situations that we will be involved in compared to that of Earth. We know that the Moon's surface will not consist of the same elements or materials compared to Earth, so this is one of many factors to cause this variation. Other factors could involve the absence of particular molecules such as water or the lack of atmosphere that could help preserve specific minerals or rocks along with multiple other factors. So these issues that are laid out for us will alter have to alter of the drill structure so that it can be induced in a difficult and instable environment [1].

1.1 Power Source

The source of power to keep the drill running efficiently and methodically will be the ultimate challenge that I will face, along with the type of power that will be used. Whatever the potential or strength of the power source, it will need to be contained within a controlled container within the drill where it is not exposed to the harsh environment of the outer layer of the drill body. By researching individual methods thoroughly through from radioactive reactions ie nuclear power to the high fusion power reaction of liquid hydrogen and liquid oxygen, I will be able to come to evaluate and come to a conclusion as to which method would be deemed the most efficient and suitable.

Liquid Hydrogen and Oxygen

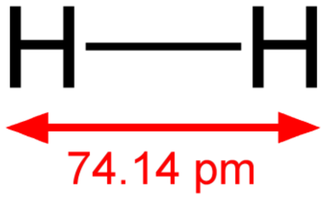


Figure 2: Diagram of hydrogen at a liquefied state on a molecular level

Liquid Hydrogen is a very abundant and efficient way of spacecraft propulsion. It is frequently applied as a rocket fuel within the internal combustion cell of the engine itself, but current ongoing research tries to combine the useful properties and elements of liquid hydrogen towards automotive manufacturing where it could be a potential replacement for petrol and other fuels.

Liquid Hydrogen itself comes as a very small supply on Earth due to its high volatility with other elements, so essentially LH needs to be converted to a liquefied form so that there is a larger volume available for fuelling the drill and that it will also take up less space at a constant temperature and pressure compared to a gas, where the molecules are further apart and so will take up more space thus increasing costs [1]. We know for a fact that hydrogen itself is an odourless, colourless and non-toxic gas that will be completely harmless to organisms. However in order to convert hydrogen to a liquid form, this will need to be stored at an extremely low temperature almost close to absolute zero ie -273°C and below 33 Kelvin (<-240°C) [4].

Because of this extremely low temperature, the LH cannot be stored in a normal way compared to other liquids. It will have to be cryogenically stored in a thermally insulated specialized container that will ultimately prevent any possible leaks or contamination from occurring allowing the LH to retain its extremely low temperature. However it is also a hazardous and risky element to contain in a liquefied form [5]. Liquefaction of LH involves multiple stages:

- Firstly, pure hydrogen gas is compressed to a very high pressure whilst simultaneously increasing the temperature as the molecules are at a closer distance to one another; as a part of the ideal gas law, the molecules collide into each other at a greater frequency and exerting a greater force upon another [5]. Pure hydrogen is specifically used to reduce any impurities to prevent any errors in the reactions as the impurities could solidify and interrupt the reaction process [5].
- Secondly the hot pressurized gas is then passed between two heat exchangers which consists of liquid nitrogen, rapidly lowering the temperature to a cryogenic state [5].
- Finally the once highly pressurized gas is now at a temperature close to absolute zero where it will be carefully throttled into a container for storage. The LH itself can cause a very destructive response if it is provoked by any hazards, for example a lit flame nearby [5].

Now since we have a covered overview background of liquid hydrogen, we can attempt to apply its useful properties to the drill itself. On a spacecraft, the LH is stored in a very large fuel container with an approximate volume of around 900,000 gallons ie 34 million liters so the energy produced is enormous [4]. But if we are able to build a similar replica of the container but of a smaller size and place it onto a section of the drill, then the energy required to power

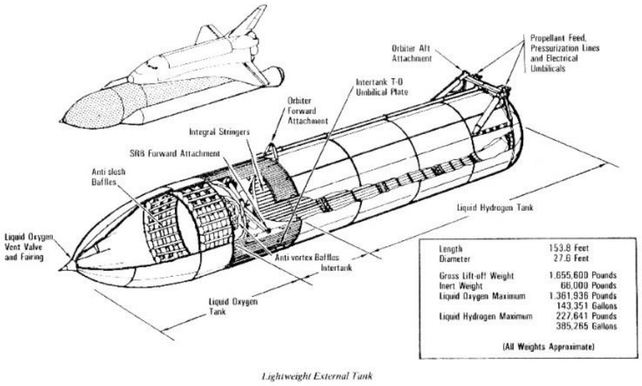


Figure 3: In depth diagram of the individual sections to the fuel tank of the rocket

I have endorsed myself thorough research by trying to find accurate values necessary to calculate the amount of thrust power needed for a spacecraft to launch itself from Earth. Although this might seem unsimilar and strange at first because of the fact that I'm calculating the thrust power of the space craft from Earth, I can use these values to compare the scale of that to a drill power needed on the moon. Using the General Thrust Equation, I am able to calculate the Force ie thrust necessary to launch the spacecraft and I will be using to separate points to start; Liquid Oxygen and Liquid Hydrogen as their density differs which will alter the overall result of the equation [6].

$$\dot{m} = \rho V A$$

The 'm with the dot' stands for the mass flow rate. Because the material of liquid hydrogen is of course liquid, this greatly determines the equation we would use. If the hydrogen were in a gas state, we would be able to use the Ideal Gas Law equation consisting of PV=nRT [6]. However, the mass of the liquid would differ to that the mass of the gas as well as a solid. This is because we are trying to keep track of the mass of the fluid which is uncontrollably and constantly flowing and moving throughout. So therefore we calculate the mass flow rate; this is the amount of mass moved over a plane over a period of time. It is not simply the mass of the fluid itself, but rather the mass per unit time (kg^{-1} m^{-3}) [6]. The dot notation above the *m* is used frequently by mathematicians to represent the variable per unit time, hence why it is very important. *ρ* stands for the density (g^{-1} cm^{-3}), *v* is the velocity of the fluid (m^{-1}) *and A is the area (m^{-2})* [6].

Using the equation above gives the mass of the fluid, but now we can apply the mass to Newton's famous equation –> F=ma. The gravitational field strength of the moon comes to 1.6N and using the mass we calculated, we find the force ie thrust power necessary to launch the spacecraft. Now into the mathematics, here are some values to start us off [7][8][9].

Liquid Hydrogen Values

Tank size containing the LH:

Diameter = 331 Inches – 840.74 cm – 8.41m

Length = 1160 Inches – 2946cm – 29.5m

Density = 0.07 g^{-1} cm^{-3} – 70 kg^{-1} m^{-3}

Liquid Oxygen Values

Tank size containing the LO:

Diameter = 331 Inches – 840.74 cm – 8.41m

Length = 592 Inches – 1498.6cm – 15.0m

Density = 1.141 kg^{-1} m^{-3} - 1141 kg^{-1} m^{-3}

Please refer to the Appendix for the full hand written calculations.

Solar and Nuclear Power

The form of solar power is often the most useful as well as common form of energy that is used amongst space crafts, in fact if not all of them have been reliant on this type of power. Making sure we use the terms power and energy correctly; power is the measure of how quickly energy itself can be transferred and is essentially the work done per unit time. Energy is however the amount of capacity able to do work. Upon Earth, solar power has been developing to become an increasingly efficient method of converting light into electricity and is something that can be continuously renewable and long lasting. Within the solar panels are solar cells which consist of a semi conductive material that performs that photovoltaic effect.

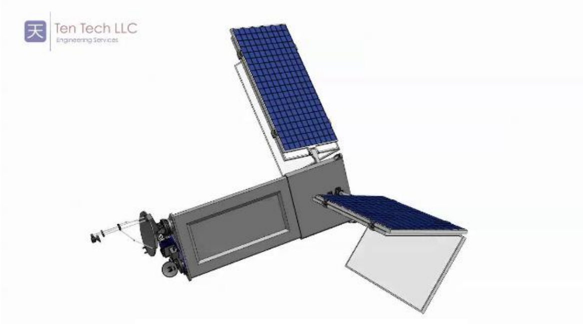


Figure 4: Solar Panel design on a satellite

This photovoltaic effect firstly comprises of the photoelectric effect – this is the emission of electrons from a metal surface as a response to the exposure of incident light shining upon it. When a ray of sunlight shines upon a metal surface [12]; the ray itself isn't made up of one strand of light, it is composed of wave packets called photons which are contained within the electromagnetic spectrum; the sunlight therefore is in the region of ultraviolet radiation due to its wavelength of $n\text{x}10^{-8}$ [11].

The photons that are shined upon the surface will collide with the free electrons from the metal material with a certain amount of energy, called the threshold frequency – the minimum amount of kinetic energy of the photon to allow photoelectron emission to occur without any additional energy required. Once the collision occurs, kinetic, heat and other forms of energy are transferred to emit the electron from the surface, which requires a minimum amount of energy in order to emit the electron, called the work function. The value of the work function will vary as the depths of some electrons may be deeper in the metal itself, thus requiring a greater work function. The whole process of photoelectric emission is then followed by an electrochemical process where crystallized atoms that are ionized in a series are then used to generate an electrical current [11][12].

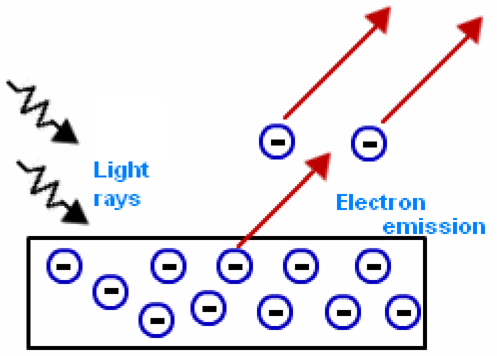


Figure 5: Diagram detailing photoelectric emission

Amongst space crafts, no ordinary solar panel is installed on it. The panels are specifically designed and engineered to enable the spacecraft to retain its maneuverability and essentially keep it 'working' altogether and the process of the photovoltaic effect is a revolutionary way of being able to generate electricity [12].

The space craft will reach beyond the Earths uppermost layer in the atmosphere and into space - i.e. the exosphere is the furthest atmospheric layer on Earth before it gradually fades into the vacuum of space, rising any distance $600<x<10{,}000$ km above the Earth's surface; it is also where the International Space Station orbits within [13]. Once it passes the exosphere, solar cells (special term – photovoltaic cells) will begin to peak in terms of functioning. The photovoltaic cells are closely packed together on the side of the spacecraft that is fully exposed to the sunlight and also has a very large surface area, thus gaining and absorbing as much possible sunlight as you can bearing in mind that there is ever so much electricity that can be generated due to limitations ie this would be the size of the space craft itself [11][12]. The photovoltaic cells are organized in a complex structural manner in which some cells are ever so slightly curved, allowing the sunlight to sometimes focus on specific areas.


Figure 6: Solar panel structure upon long distance travelling space craft

Solar power as of this moment seems the most obvious choice no doubt, however to fully divert all our energy towards this would be risky and deem us oblivious to the other possible ways of generating electricity; we wouldn't be using the other resources we have to the maximum. To rely on solar power alone would not be long lasting and inefficient simply because sunlight is not accessible at every point in the universe at a constant intensity; the varying light intensities would result in electrical fluctuations so acute that it will cause an inability for the space craft to be consistently powered. However, it is not just science that determines and limits what we can do. Economic factors also maintain a strong role in solar power. The most efficient solar powers will often be the most expensive and to have them adjusted and installed onto the sun-exposed side will further raise costs.

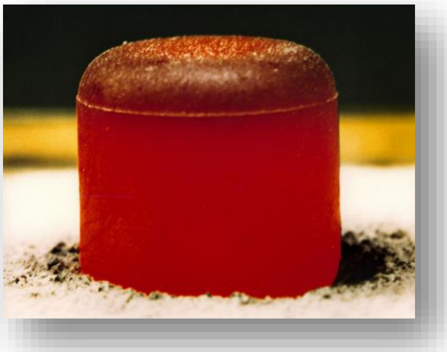


Figure 8: A heated block of radioactive Plutonium-238

Another issue is that the side exposed to the sun will start to gain a positive charge as the electrons are emitted away from the solar panel surface ie ionization. The more electrons that are emitted, the less electrons there will be remained in the surface. So of course the electrons are supplied from a replenishing source such as a battery as a form of neutralization. Now that this is sorted, there is also another issue. Since the constant photoelectric emission forms a positive charge on the sun-exposed side, this leaves the other dark side to be negatively charge as there is no photoelectric emission occurring. This will cause an imbalance discharge throughout the spacecraft which may damage the functioning of electric equipment's and components.

As the space craft moves further out towards the moon, the strength of the solar radiation may begin to dissipate and weaken due to the increased extent of the distance from the sun. In order to keep the power of the space craft working, the efficiency of the solar power will need to be consistent and generate electricity sufficiently.

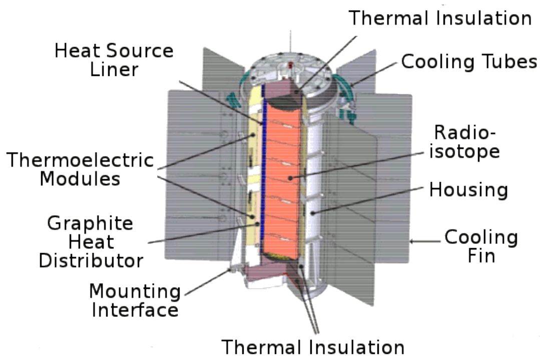


Figure 7: Diagram of the inner structure of the RTG

However since solar radiation weakens, how can the craft generate enough energy?

To answer this question, a Radioisotope Thermoelectric Generator (RTG) is a generator that converts the heat energy generated by the nuclear decay of plutonium-238 into electrical energy, storing them in capsules called thermocouples [10]. This is an incredibly efficient way of generating electricity in an environment that will have weakened solar radiation as well as daringly low temperatures, and the process will therefore undergo the Seebeck Effect – this is just simply the direct conversion of heat energy to electrical energy involving two separate materials [14]. Thermocouples involve a phenomenon that involves two electrical conductors each of different material at different and distant temperatures, generating a voltage only a few microvolt's per Kelvin. So the whole Seebeck effect is essentially mainly responsible for the behavior of the thermocouples and any slight temperature fluctuation (to the thousandth of a degree Celsius) can alter the control of electrical current to the space craft.

Thermocouples are very common in everyday electrical devices that require a constant monitoring of the regulation of their temperatures; this would include refrigerators, air conditioners etc. Since the energy is stored in the thermocouples, they need to be correctly insulated to prevent energy loss through the material; ideally lead and graphite sheets are used for insulation. Within the space craft, the thermocouples assist the transfer of heat energy into electrical energy [10][14].

Radioisotope Thermoelectric Generators (RTG's) use the radioactive isotope Plutonium-238 (stored in the form of Plutonium Oxide– PuO_2) due its low shielding requirements ie only 25mm of lead needed for the insulation of this isotope thus making it cost effective as weight is reduced as compared to other isotopic materials [14]. It also has a half-life of 87.7 years - half-life being the amount of time it takes for the number of nuclei in an isotope to halve, so the longer the half-life, the longer the material will last. Initially the RTG's may seem like it will undergo a process similar to that of nuclear reactors that one may have heard about, however it is a very dissimilar process. In nuclear reactors, nuclear fission is often the most common process; it involves the bombardment of neutrons upon the atoms, causing them to split and so the energy derived from this is incredibly immense [14].

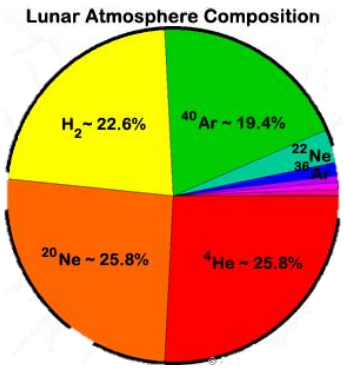


Figure 9: Composition of varying elements in the lunar atmosphere

However in the RTG's, most of the energy derived is from the natural radioactive emission of the isotopes. The emissions prove to be sufficient enough due to the high energy density of the isotope. For example for every gram, 0.54 Volts are generated therefore for every 1kg, 54 Volts are generated. To compare this to everyday objects, a car battery fully charged will be 12-13 Volts and so by scale, the isotope definitely proves so far to be the most efficient form of material used [14]. Other encouraging factors include the fact that is also a very stable isotope i.e. it is highly unlikely that it would destabilize and go out of control. Another factor consists of the lack of moving parts that associate with the body of the RTG ie without as many moving parts, the risk for the deterioration of the parts would vastly decrease thus reducing the possibility for problems to occur as well as dropping complexity and costs [14].

The space lander will weigh close to a ton when landed on the moon. Around 135kg will account for the payload i.e this will include the drilling equipment such as the drill bit as well as the robotic arm that will physically manoeuver the time capsules into the borehole. The whole drill itself will weigh a very light and approximate 10kg in which it is attached to a cable – the cable could be able to transfer electrical energy from the space lander to the drill itself as well as systems control for the drill. In order for the drill to function at full power, roughly 625 Watts are required. Given that the RTG will weigh around 60kg altogether, the Plutonium isotope will comprise of 7-9kg of the 60kg weight. 9kg of the isotope will produce 486 Watts of electrical energy at its natural state, but when it is in its reactive state, it will produce almost 4,500 Watts of heat energy, which can be directly converted to electrical energy for use in the drill [14].

Chapter Two – Lunar Complications

We know for a fact that the surface of the moon is completely dissimilar to that of Earth's; the lack of any atmospheric protection, the low strength of its magnetic field, the high visibility of crater's due to the lack of wind or erosion plus many other factors. These new challenges proves a necessary complication that we must overcome and deal with, reducing the possibility for any mistakes to occur whilst simultaneously creating new advanced technology that will assist us in these circumstances.

Atmosphere

During the previous times, there were many who thought that the moon's atmosphere virtually didn't exist or didn't consist of anything – essentially nothing. However during the Apollo missions from 1961 to 1972, the astronauts found that it did consist of some atmospheric material. Using the analogy that space itself is a vacuum (which it is), the Moon's atmosphere showed presence of Potassium, Sodium, Argon, Helium, Neon and scarce amounts of Hydrogen [15]. These elements found are considered to be very different to that of Earth's, in fact incredibly divergent and some not even found in the Earth's atmosphere. The Earth's atmosphere mainly entails that of Nitrogen, Oxygen, Hydrogen and Carbon along with other minor elements [16].

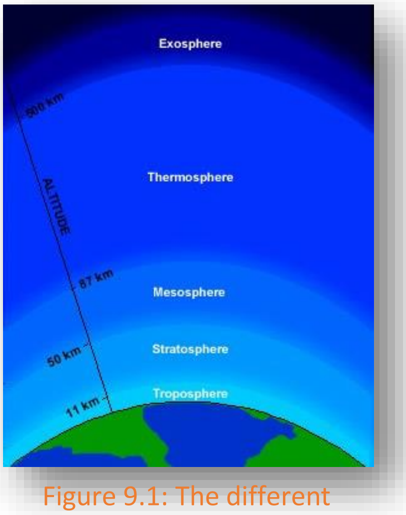


Figure 9.1: The different layers of the Earth's atmosphere

As of current research, there is little to describe how they got there in the first place. Nevertheless, what my idea takes account of is that the gases may have driven over from other areas of the universe or the galaxy via solar wind or micrometeorites that may have disembarked onto the Moon, with the Moon's electromagnetic field preventing it from resting upon the surface permanently; thus causing the field to only slightly form an exosphere consisting of those element's.

Think of a bathtub full of water and a large heavy spherical ball. Imagine the ball falling into the bathtub. We all know about the simple rule of buoyancy; an object will take up an amount of volume of a medium equal to its own volume, thus causing the level of the water to rise. Now think of the water as a vacuum, similar to that of space and the ball as a planet or moon. As the ball sinks, the water surrounds it. If you add ink or a denser liquid to the water (this represents the elements flowing around the universe), the ink would eventually surround the ball (the surrounding ink acts as the meagre atmosphere upon the moon). This analogy could help as a form of proving the possibility of how the elements got there. Another idea includes the fact that some of the elements may have been a product of radioactive α-decay from within the Moon's core, mostly that of helium and radon.

Gaseous Element in order of abundance	*Element Abundance in Moon's Atmosphere (Atoms per cm^3)*
Argon	20,000 – 100,000
Helium	5,000 - 30,000
Neon	20,000
Sodium	70
Potassium	17
Hydrogen	<17

Table 1: Abundance of elements upon the Moon [17]

Gaseous Elements in order of Abundance	Element Abundance in Earth's Atmosphere (part per million)
Nitrogen	780,900
Oxygen	209,500
Argon	9,300
Neon	18
Carbon	0.25 - 300
Hydrogen	0.5

Table 2: Abundance of elements upon the Earth [17]

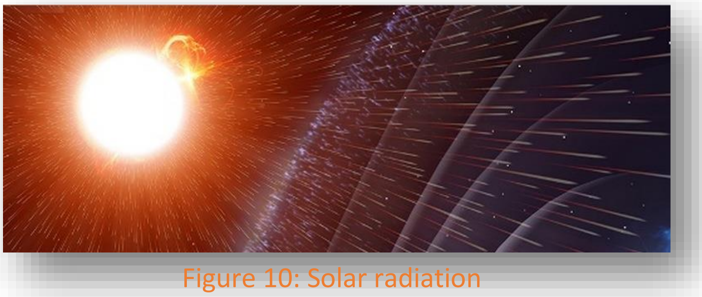


Figure 10: Solar radiation amongst the vacuum of space

So far, the gases that form the majority of the Moon's atmosphere prove to be adequately ineffective. The gases are of low density and are generally susceptible to foreign material from space approaching the Moon's surface whereas as opposed to the Earth's atmosphere, the several layers of the atmosphere each consisting of varying properties and elements are generally responsive to those foreign elements, which is why the Aurora Borealis occurs as well as the fiery entrance of spacecraft from space into Earth [16]. This can therefore leave the Moon exposed to cosmic rays from the sun as well as solar radiation. The cosmic rays can be a very dangerous phenomenon as when they collide into the Moon's surface, there is a secondary effect from the particles that will spray amongst the surface; this could penetrate the suit of an astronaut which can potentially put the person at risk of developing cancer or evolving sections of DNA to mutate [17].

Table 1 shows a heavy element abundance in Argon with an abundance of 20,000 to 100,000 atoms per cm^3; the measurement unit is not in parts per million due to the variation of densities amongst the space vacuum [17]. However in Table 2, Nitrogen is the most abundant element in the Earth's atmosphere by a far margin; measured in parts per million – for example, for every cubic meter, Nitrogen will take up to 78% of the cubic volume [17]. Nitrogen's abundance is of a greater extent than Oxygen; this is particularly due to the fact that Nitrogen is an extremely volatile material i.e it will not react with many other elements that essentially makes up the Earth's solid composition. Hydrogen seems to be the least abundant in both atmospheres which is surprising since it is the most abundant element (in all forms) in the universe, up to 90% of the space vacuum.

So in summary, the atmosphere will have very little effect on the drill itself to make a significant difference.

Lunar Dust

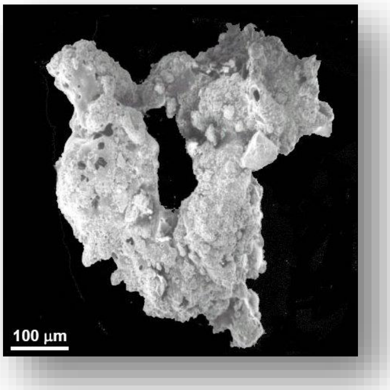


Figure 11: The molecular image of the lunar dust

Amongst the wide array of dilemmas we could possibly face, lunar dust lies as an important aspect. This dust is no ordinary dust however. The Lunar Dust is formed by the impact of micrometeorites composed of many metal oxides including that of Magnesium, Silicon, Iron, Calcium and other various metals. The dust itself on the moon was already unknown and unfamiliar to that of humans, until the Apollo missions provided evidence for its existence [18]. During the missions, the Astronauts discovered dusty material upon their suits and found that it was very difficult to decontaminate and remove due to the static attraction between the particles and the suit itself [19]. However, the major issue was that as the Astronaut suits were brought into the space craft, they were inhaled and this caused the Astronauts to have their health deteriorated, but not to the point of death. This risk and exposure of the dust can be significant towards human health if a colony were to form on the moon; breathing problems would greatly affect the health of a human.

Moreover, the insulation and the further adding of protection from the potential damages that may occur will prove to be very costly. The dust proved to be ever so pervasive that during the Apollo missions, the lunar rock boxes that contained fragments of rock material from the moon had been contaminated and their vacuum had leaked [19]. Another issue was that whilst the astronauts re-entered the hatch for pressurization and decontamination, the opening door for the hatch had been ridden with small extracts of lunar dust which caused the amount of oxygen to be consumed to a higher amount [19]. Additional problems arose; the lunar dust had worn away the out layer fabric of the Astronaut's suits and this abrasiveness proved to further increase costs in developing ways to tackle this issue as well as the cost for the engineering design.

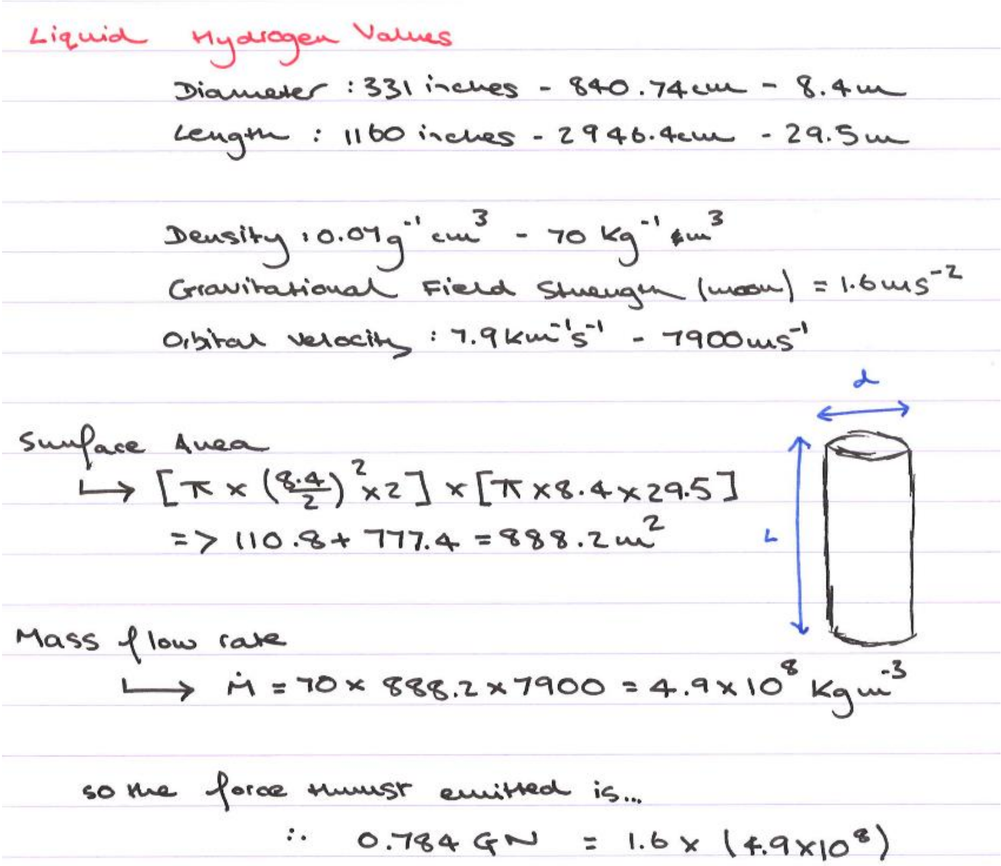
However the most detrimental aspect is its interference with the solar panels. The lunar soil forms up to 50% of the Moon's regolith (soil) and with certain features that occur between each individual dust particle is a buildup of static electricity due to extreme dryness amongst the surface. With the solar radiation weakening the electromagnetic field of the moon along with the dust interference, the solar panels face a tough challenge in counteracting these issues [20].

Summary

This report was commissioned to examine the utilization of Radioisotopic Thermoelectric Generators as the focal energy source amongst Space Engineering. From the thorough analysis of research that I have conducted, I was able to provide evidence that the use of RTG's can be deemed worthy and beneficial as a candidate for use as a fuel source in space crafts and can potentially assist with colonization on the moon far into the future. My main point that I am trying to demonstrate is that whilst solar power is very common amongst space crafts, if there are extenuating circumstances that can possibly pacify the functioning of solar power, then there is nothing to lean back on; there is no 'Plan B'. However the use of RTG's provide as a backup plan, as well as being a useful component to use alongside solar power, and that this energy gained can then be transferred via a heavily insulated but simple wire to the drill, ready for the mission itself. The combination of the two power sources can be used effectively and can alternate with one another, thus proving to be efficient in long lasting missions.

The lunar complications that were introduced to us deemed to play a key role, mainly that of lunar dust. From analysis, the lunar dust had the potential to severely damage the solar panels that are required to be on the outer layer of the space craft, leaving them vulnerable to this hazard. The RTG's however would be in the inner structure of the spacecraft, freeing them from the environmental dangers.

Appendix


Liquid Hydrogen Values

Diameter : 331 inches - 840.74cm - 8.4m

Length : 1160 inches - 2946.4cm - 29.5m

Density : $0.07 g^{-1} cm^{3}$ - $70\ Kg^{-1} m^{3}$

Gravitational Field Strength (moon) = $1.6 ms^{-2}$

Orbital velocity : $7.9 km^{-1} s^{-1}$ - $7900 ms^{-1}$

Surface Area

$\hookrightarrow [\pi \times (\frac{8.4}{2})^2 \times 2] \times [\pi \times 8.4 \times 29.5]$

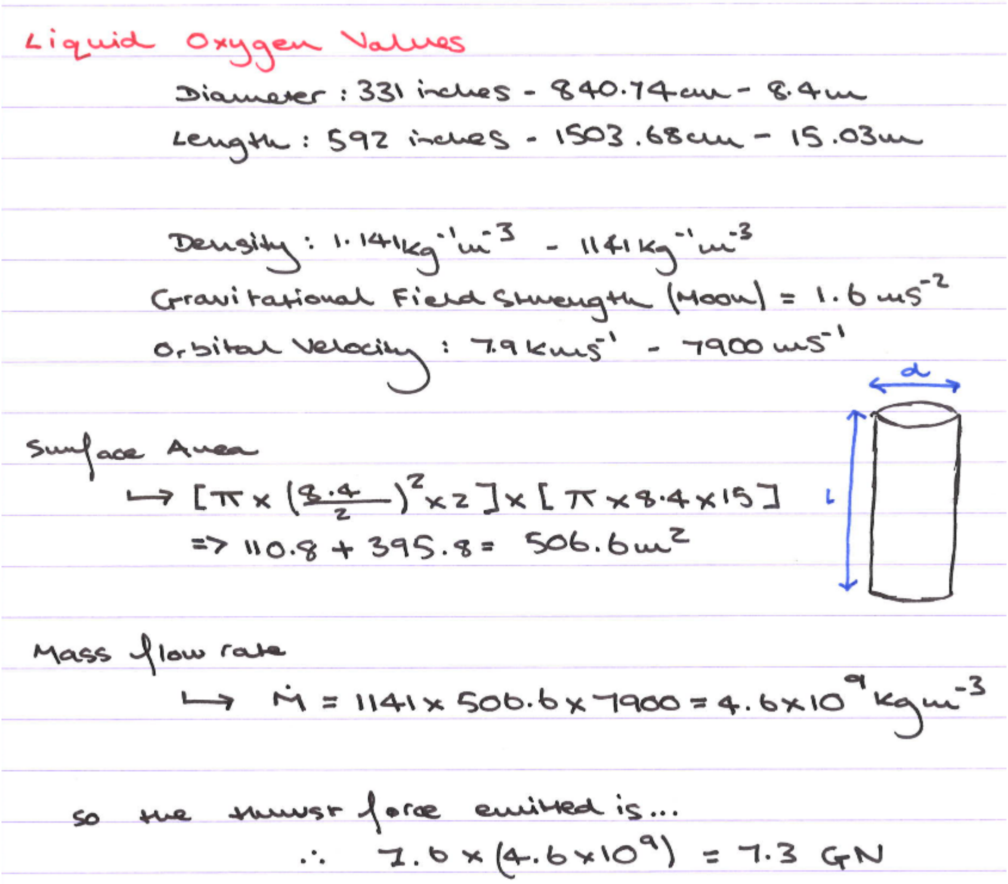
$\Rightarrow 110.8 + 777.4 = 888.2 m^2$

Mass flow rate

$\longrightarrow \dot{M} = 70 \times 888.2 \times 7900 = 4.9 \times 10^8\ Kgm^{-3}$

so the force thrust emitted is...

$\therefore\ 0.784\ GN = 1.6 \times (4.9 \times 10^8)$


Liquid Oxygen Values

Diameter : 331 inches - 840.74cm - 8.4m

Length : 592 inches - 1503.68cm - 15.03m

Density : $1.141 kg^{-1} m^{-3}$ - $1141 kg^{-1} m^{-3}$

Gravitational Field Strength (Moon) = $1.6 ms^{-2}$

Orbital Velocity : $7.9 kms^{-1}$ - $7900 ms^{-1}$

Surface Area

$\hookrightarrow [\pi \times (\frac{8.4}{2})^2 \times 2] \times [\pi \times 8.4 \times 15]$

$\Rightarrow 110.8 + 395.8 = 506.6 m^2$

Mass flow rate

$\hookrightarrow \dot{M} = 1141 \times 506.6 \times 7900 = 4.6 \times 10^9\ kgm^{-3}$

so the thrust force emitted is...

$\therefore\ 1.6 \times (4.6 \times 10^9) = 7.3\ GN$

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