Borehole Lining on the Moon

Lunar Mission One

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Contents

Abstract

Lunar Mission One aims to drill on the Moon with the hope to get an idea of it's history. Once drilling finishes, an archive of human life and the Earths geology will be placed down the borehole for future generations to find. This archive needs to be able to be found, so the borehole wall will need to be strengthened to prevent it collapsing.

The three methods proposed are laser vitrification of the rock, additive manufacture, or an expandable material. These methods have been compared in terms of mass, power consumption and their capability to strengthen the borehole wall.

The expandable material has been brought forward as a strong candidate as it produces a strong yet lightweight liner, it does not require nearly as much power as the other two methods, and is compact. The liner itself will have a similar structure to a medical stent as it is extremely lightweight yet strong. A concept of the lining unit has been made with technical drawings produced with possible dimensions.

1 Introduction

Lunar Mission One is a UK based Lunar Mission with both professors and students working on the project worldwide. It is a project funded by the public through a greatly successful Kickstarter campaign. It plans to perform deep drilling on the moon that will give light into the origin of the Moon. The project plans to leave an archive of human life at the bottom of the borehole once drilling is complete as a time capsule for generations to come. The archive will contain data from all aspects of life, from all the species of bugs and animals to the geology of the Earth.

The borehole needs to be lined with a protective material to ensure that the borehole will remain as a permanent fixture on the Moon. The liner and assembly needs to be lightweight, have a low power consumption and be strong . It is being lined to preserve the hole so that it will still be there for years to come allowing it to be found by future generations, otherwise it could crumble in on itself and bury the archive.

2 Design Specification

It is proposed that the borehole drilled will be 5cm in diameter, and the drill will bore 15cm at a time with the core sample being lifted to the surface between cycles.

The drill mass is limited to 10kg, so this will effect what lining method is chosen as certain designs can be heavier than others due to the number of parts required or the weight of the specific parts themselves.

There will also be no cooling liquid available to cool the parts, which will help to narrow down the choice as some methods produce a lot of heat that could be problematic if not removed from the borehole.

There will be limited power available, so this must also be taken into consideration when choosing a design. The craft will be powered by solar panels, which will have a maximum output of 500W.

3 Drilling Methods

There are two main methods of creating a borehole, those two being Wireline and Auger drilling. Both methods yield the same results; but the equipment needed, speed and transport size are vastly different. Due to this it is important to compare the two methods and how they function to decide which should be chosen considering the task to be carried out. Also, it is key to compare the two as different methods of drilling will favour different methods of borehole lining, as certain combinations of drilling methods and lining methods could greatly reduce efficiency of the system.

Auger Drilling

Auger drilling works by having a drill head directly attached to a motor unit on the surface by a series of drive shafts. the drill head is connected to a section of drive shaft which drills until it reaches a depth equal to the length of one shaft, and at this point another section of drive shaft is connected, and the drill continues until it runs out of shaft; and the cycle repeats itself until the unit runs out of shafts to add.

A main advantage of this method is that if a deeper borehole is required, more drive shafts are attached. However, this advantage only applies where a direct source of shafts can be attained, which generally speaking would not be on the Moon. This method would not be as efficient or flexible on the moon as only a certain number of shafts can be transported, so an exact depth would need to be decided on, and the number of shafts calculated accordingly.

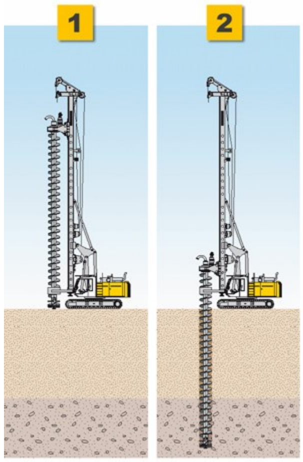


Figure 1: Auger Drilling

The mission plans to collect material samples in a solid and uncrushed form meaning a hollow drill will need to be used. This means the drill will need to be removed each cycle to collect the sample, which will be a slow and inefficient process for this method.

This design requires a drive motor on the surface to directly drive the drill head by shafts. This will increase the rotational velocity and torque of the drill bit as there are no major constraints on the size of the motor (The size will need to be reasonable to allow transport) when compared to wireline drilling. However, if an assembly for lining is to be placed above the drill head, it will need to be designed with an empty central column to allow the drive shaft to pass through which could complicate design for the liner assembly.

Wireline Drilling

Wireline drilling is the other main method of drilling used. It uses a main drill assembly that contains the drill bit, material collection, drive motor, Force on Bit unit and an anchor. This assembly is the part that creates and enters the borehole. It is connected to a surface assembly by wireline (hence the name) which contains the winch and any operating computers. The wireline is typically made from a main steel wire, with any cables or tubes wrapped around it that connect to the assembly, but an alternative for this could have the cables and tubes in the middle, and be wrapped with a strong metal mesh keeping the cables tight.

The main advantage of this method is that the assembly can be easily removed from the hole due to it simply being lowered by a cable and winch. This means that a material sample in the assembly can be removed easily and any liner can be replaced easily. Also, this means that the system is flexible, it can drill as deep or as shallow as necessary simply by altering the length of cable that is deployed.

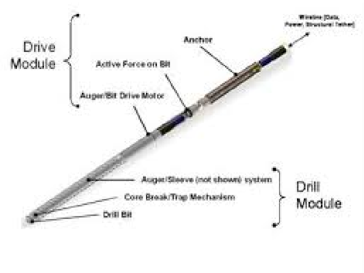


Figure 2: NASA Wireline Drill

A disadvantage to this method is that the drill isn't driven from a motor on the surface, but instead a motor within the drill assembly. This means that the size of the motor is limited by the diameter of the borehole, causing a great reduction in power and torque to the drill head when compared to Auger Drilling. This isn't as big as a factor as it seems when comparing the two methods as NASA created a wireline drill for use on the moon, which is a functional and successful design.

Due to the wireline being non-rigid, it cannot make the assembly rotate, and therefore it cannot prevent the assembly from rotating. This rotation may be incurred if the drill head snags, it will 'kick' and could cause the whole assembly to rotate, which would result in the wireline becoming tangled, damaged, or even ripped. A system will need to be put in place to to keep the assembly stable while the drill is engaged.

Comparison of Drilling Methods

The advantages and disadvantages of the two methods should be compared as this shows which method will work better in practice when considering the environment it will function in.

Auger drilling allows for a larger motor, therefore more power to the drill head meaning the drill will not only be faster, but will find it easier to cut through harder materials. However, many drilling companies use wireline drills without problems, so this isn't an issue.

Wireline drills can be deployed and retracted quicker, allowing for a faster cycle time compared to auger drilling.

It is stated on the Lunar Mission Website that Wireline drilling technology will be used on the mission. This method is lightweight, compact and it allows for quick and efficient cycles of the drill to allow quick core collection.

4 Proposed Methods of Lining

Three methods were proposed in the brief, those being Laser vitrifcation/sintering, Additive Manufacture or Expandable Material. These methods should be compared and the advantages and disadvantages discussed to allow for a method to be chosen, along with a method of drilling that compliments the lining method chosen.

Laser Vitrification

This method uses lasers to heat the material, which turns it from an uneven and rough surface to a smooth and stable surface that the drill assembly can pass down without any material chipping off and falling onto the assembly. The material is superheated by the laser turning it into a liquid state, then cooled back into a solid, glass-like material. This process happens within a fraction of a second, so there is no chance of any of the superheated liquid dripping onto the drill assembly and causing damage.

An advantage to this method is that there is no lining material required, is does not add any extra material to the borehole wall to provide support. This is a large advantage it has over other methods due to the fact it will cut down the weight of the craft as it does not need to carry any material. Also, it will reduce cycle time, meaning the drill process will be faster as there is no liner that needs to be replaced each cycle.

Due to the material being superheated (well over 100^oC), there will be a great amount of heat present in the borehole. This may be problematic if the assembly isn't cooled effectively, and with a lack of cooling liquid this could be problematic.

Multiple lasers will need to be used in an array to provide 360^o coverage. This could be done various different ways.

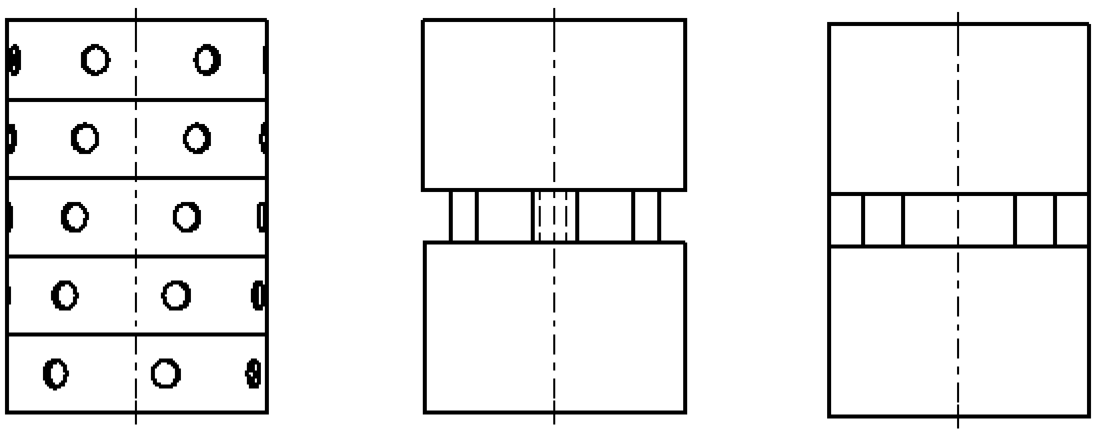


Figure 3: Laser Designs

The left drawing shows the design needed if lasers are used, however this is only a portion of the assembly and it would need to be twice as tall to get full coverage, requiring roughly 70 lasers in total. The middle drawing shows how a single laser and an optic block could be used to create a 360^o beam, but support beams (which are necessary so the assembly is not weak) would block certain areas. The final design would work best as it provides full coverage and uses 4 separate lasers each with their own optics to widen the beam.

Additive Manufacture

As the name suggests, material is added to the borehole wall to provide support. This method is similar to to 3D printing as filament is extruded onto the surface, except this is done around 360^o rather than a single plane. A filament is fed down to the assembly through a tube which is heated and melted, then fed through slits onto the borehole wall where it hardens and forms a solid layer on the wall.

The advantage to this method as it provides a strong and secure cylindrical tube that the drill assembly can operate in, with no chance of any material falling in from the sides.

However, this method produces a lot of heat, which could cause problems to the drill assembly when not cooled. Also, the assembly will need to be coated with a special coating that prevents the printed material from sticking to the assembly as well as the borehole wall, as this will prevent the whole assembly moving. Products currently exist that are applied to 3D print-beds to ease separation, but this does not prevent all adhesion, there will still be some present so the assembly will still stick in place.

If this method was used, a similar array will need to be used as the first design from the Laser Vitrificaton section, as print heads are typically circular and can only print in one direction. A funnel design could be used to guide the material into a wider arc and onto the borehole wall.

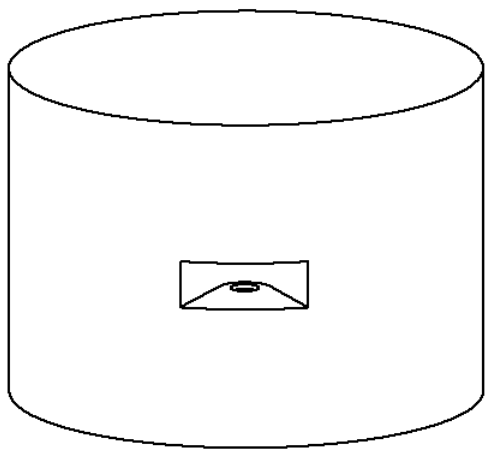


Figure 4: Extruder with funnel (inverted)

The design opposite shows what the funnel would look like, with the small circle inside of it being the extruder. The melted filament will come out of the extruder and fill up the funnel, which will push it outwards and spread it out as the only way for the material to keep flowing is out through the opening and onto the borehole wall. This may not work as intended as some material may not travel outwards so will solidify. The drill will not be drilling constantly as it will need to surface to get rid of the material it has excavated, and during this point the material still in the funnel will solidify.

Expandable Material

The final method proposed uses a flexible yet sturdy material to line the borehole wall. The material is transported down the hole on the assembly, then expanded against the wall to prevent material falling onto the assembly. This method requires the liner section to hold the liner while transporting it down the borehole, and a system in place to push the liner outwards, or a system to release the material if it is self expanding.

The liner itself will need to keep it's rigidity when expanded, so stretching out a plastic cylinder will not work as this will weaken it's structure, meaning it might buckle under load when it is preventing material from falling in the borehole. An example of a self expanding liner is a piece of sheet metal, rolled to create a cylinder. For this to work there needs to be a gap in the cylinder, and a section where the metal overlaps. The sheet also needs to be fairly thick to provide enough resistance to spring back to a larger diameter.

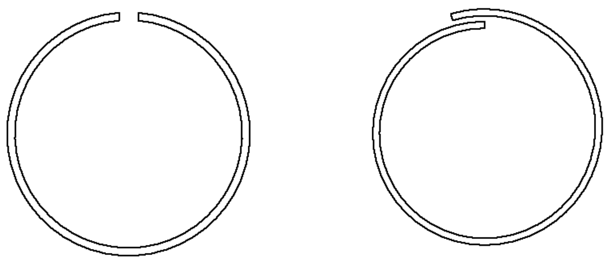


Figure 5: Coil under normal conditions and Compressed Coil

A large benefit to using a design like this is that it can expand itself. There is no need for a mechanism to aid the expansion of the liner, only a mechanism to hold the liner in place while it is transported down the borehole. However, although this is a great advantage, there are a few major disadvantages that this method has. One being that when the coil expands, it could exert a large force on the borehole wall which could create cracks making the whole borehole unstable. This could be problematic if these cracks open and the material behind the liner starts to crumble away, which in time will cause the liners to become uneven meaning drilling cannot continue.

An expandable mesh could be used, as it will not stretch but just open up, so no loss of rigidity of the liner. This is a better method as it would be lighter in transport compared to a solid steel design. This method will not cause damage to the borehole wall as it it expanded outwards by a mechanism in the lining unit. A liner similar to a medical stent could be plausible.

For liners that aren't self expanding, the liner could be expanded by an inflatable balloon/bag around the main assembly, that sits between the assembly and the liner. It would require some sort of compressor to inflate the balloon when needed. Another method possible would use tabs that extend outwards to expand the liner.

Comparison of Lining Methods

Laser vitrification is very useful as it will not limit the drill depth in anyway, it can drill as deep as required. It does not add any material to the borehole wall so is the most compact in transport. However, the large amount of heat produced by the lasers is a problem as there will not be any cooling liquid to remove this heat, which makes this method unsuitable as this heat may damage the drill. A laser array would make the assembly unnecessarily large so this is not a viable method. Also, Since the power available is limited there will be a limit on the number of lasers or the power of the lasers which may cause the cycle time to be increased or the method to work incorrectly.

The advantage that the additive manufacture method has over the other methods is that it produces a solid barrier that will ensure the hole cannot collapse. This method produces the strongest liner, as the liner will solidify into a hard and rigid solid. This method also produces a lot of heat, as multiple heating elements will need to operate simultaneously. As well as this, there would need to be an array of print heads to give full coverage, around the borehole wall, which would clutter the design and make it too complicated. The funnel concept would not work as the filament would solidify in the funnels between print cycles causing blockages. This method could also use a lot of power which could reduce the number of print heads and therefore limit the length of section that can be lined at a time.

An expandable liner would provide a light weight liner that is secure and stable. The liners will not take up a considerable amount of space as they are smaller in transport. This method requires a system to expand the liner, which could be either an inflatable balloon or extendable tabs. This method won't be as complicated as the other two methods, and it does not produce heat, or require as much power to operate. This method is the most suitable in theory as it is lightweight and simple. This design works best with wireline drilling, as the method requires the drill to surface each cycle to replace the liner, so wireline will be the quickest and most efficient for this. This method does not require much power at all, only needing a small amount to enable the solenoid for a few seconds each cycle.

The additive material method doesn't rely on any technologies to be developed such as complicated print heads or more powerful and efficient lasers, and it is the easiest method to demonstrate.

5 Designing the Liner and Assembly

The liner method chosen is the expandable material due to it's strong yet lightweight structure, so a liner needs to be designed as well as the assembly that will extend it. This design could either be an expandable balloon that wraps around the assembly, or extendable tabs.

Liner

The liner needs to be light, so a design similar in structure to a medical stent would work. Stents are used to open up blood clots by being expanded against the clot and pushing it outwards, so something similar to this could work to line the borehole. They are made out of metal wire that is formed into a cylinder of mesh. They are designed so that they can be stretched without losing their rigidity.

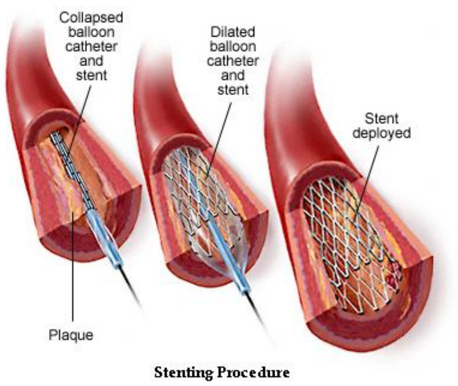


Figure 6: Medical Stent Cycle

the medical stent is transported through veins/arteries on a catheter with a balloon in between the two. The balloon is inflated which expands the stent and opens the blockage. The image shows the size increase of the stent, with it still retaining rigidity and holding it's shape. The balloon works here as it is necessary due to the small diameter of the catheter, as in this situation it is too small to use the retractable tab design. However, the retractable tab design would work better on the drill liner assembly, as the diameter of the drill is large enough to house it, and if the balloon were to burst if it was used, there would be no way to fix it as it would require human interaction to fix.

The stent would need to be altered slightly to make it suitable. It would need to be a lot larger, and it won't need to expand as much as a medical stent, as there won't be that much of a difference between the borehole diameter and the assembly diameter. This allows for the stent to be a lot stronger as it does not need to be as expandable. It will also need to be wrapped in a sheet of plastic, to ensure that material cannot fall through between the gaps and cause issues.

This method is more suitable than others as it is lightweight but still provides a strong barrier. it could also be transported very small, then expanded slightly to fit over the assembly, then expanded for a final time against the borehole wall. This will allow more liner sections to be transported, allowing a deeper hole to be drilled.

Liner Assembly

The liner assembly needs to contain a system that can expand the liner, a mechanical solution would be best. Solenoids could be used to push out the tabs, like so;

This design has a solenoid connected directly to the tab to extend it. This is the simplest design possible, but it limits the size of the solenoid as it's maximum length is roughly the radius of the assembly. With the same idea, the maximum length of the solenoid could be doubled by putting the solenoids for each tab at different levels within the liner assembly.

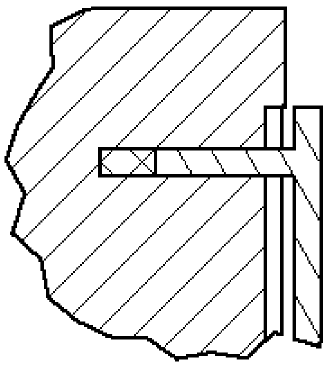


Figure 7: Concept 1

The design could be changed to allow the solenoids to be even bigger by making them vertical and putting a sloped surface against the tab legs. This still uses eight solenoids.

This design is better than the previous design as the length of the solenoid is not limited by the diameter of the drill, it can be as long as required, however the longer the solenoid the longer the lining assembly.

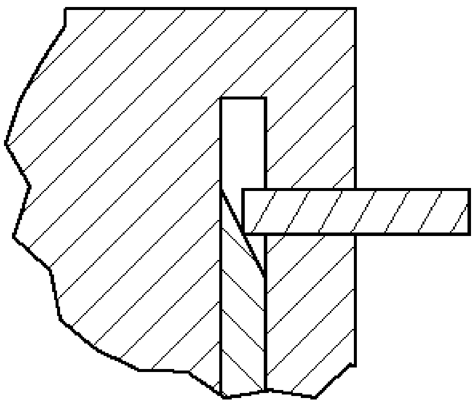


Figure 8: Concept 2

An improvement to this design is instead of having 8 separate solenoids and shafts, a single, central shaft could be used to push out all eight tab legs at once.

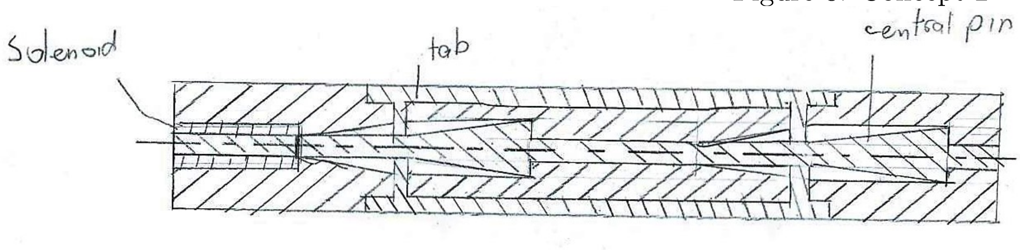


Figure 9: Concept of design

The diameter of the borehole will be 5cm, so the diameter of the assembly will be roughly 4cm, to allow for it to slide down the wireline assembly. It is planned that the drill will move down 15cm at a time, so the length of the tab will need to be just over 15cm, and the full liner assembly around 20 cm or so.

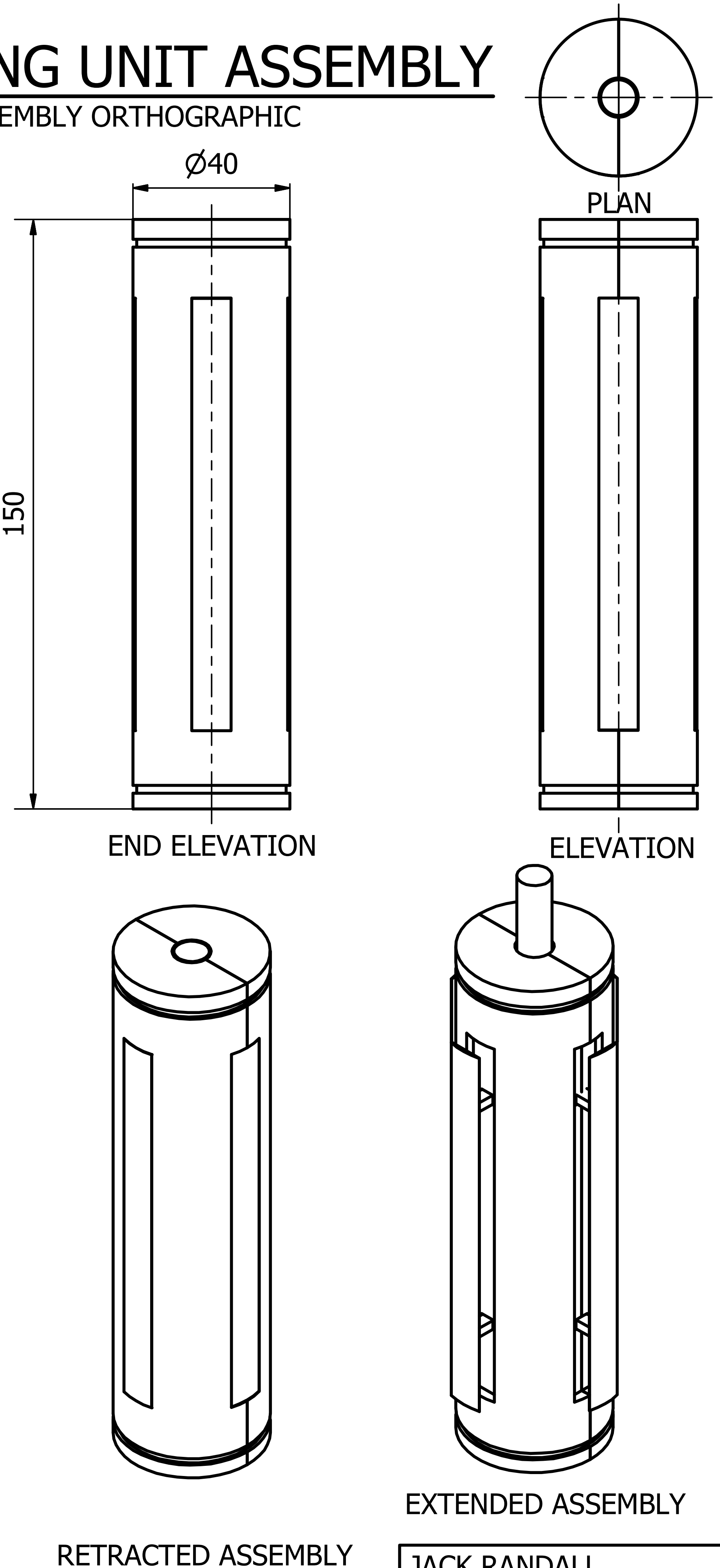
6 Materials

The assembly needs to be made of a lightweight yet strong and durable material. A suitable material would be aluminium of high grade, as it is relatively cheap and abundant. It is lightweight yet strong so would be suitable.

However, graphene, a recent discovery is a carbon based material that is much stronger, and much lighter. It is similar in structure to graphite, but the 'sheets' are much thinner, only being 1 atom thick. using pure graphene would not work, it would be incredibly strong, but also incredibly expensive due to it being such a recent development and the amount needed. Using graphene composite materials would be a better solution as it lowers cost as it reduces the amount needed, but it still will be stronger than conventional materials.

LINING UNIT ASSEMBLY

FULL ASSEMBLY ORTHOGRAPHIC

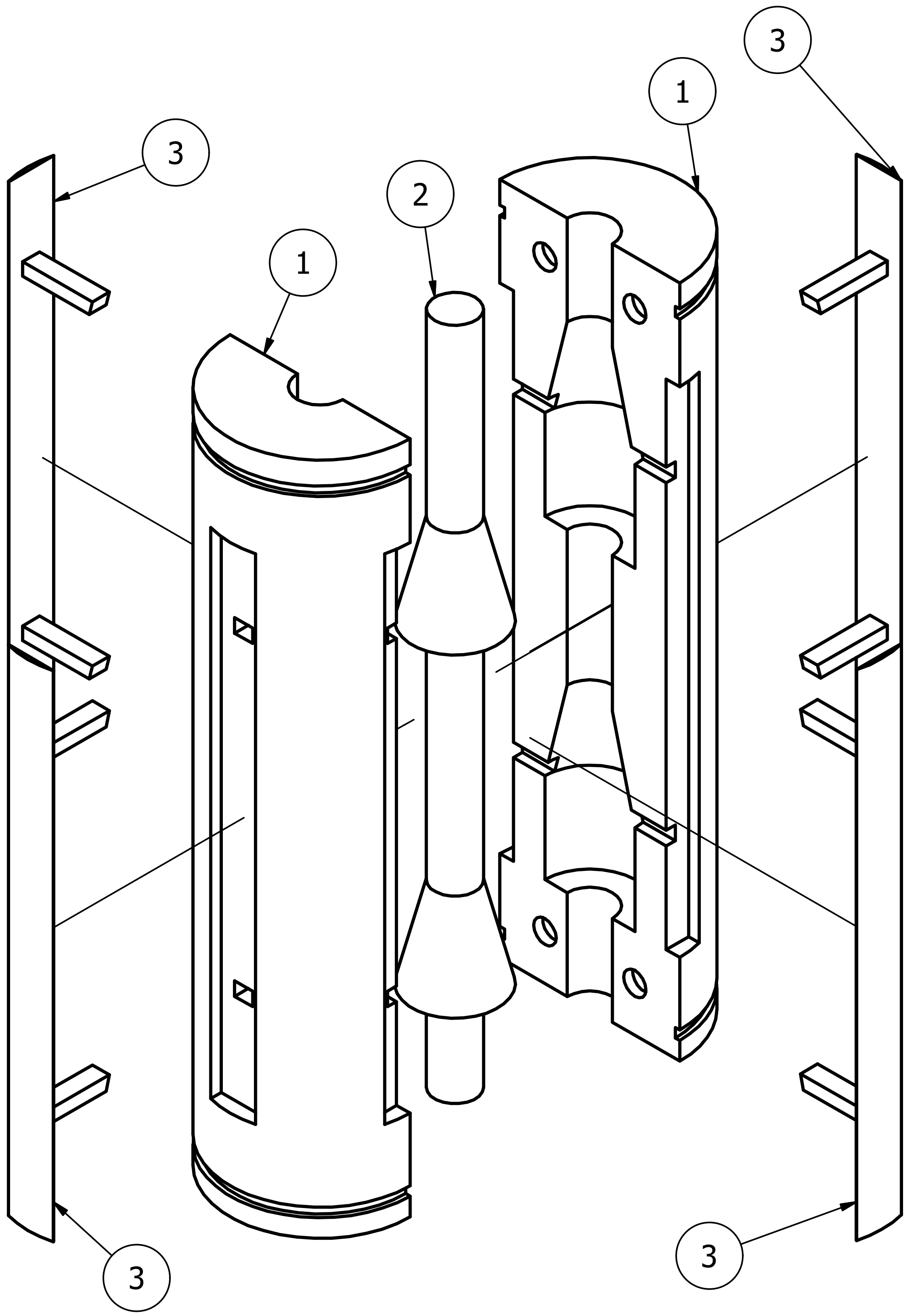


This dimension should be roughly 200mm

All dimensions in mm

JACK RANDALL
SANQUHAR ACADEMY

FULL ASSEMBLY EXPLODED VIEW



PARTS LIST		
ITEM	QTY	PART NUMBER
1	2	Body Half
2	1	Central Pin
3	4	Tab

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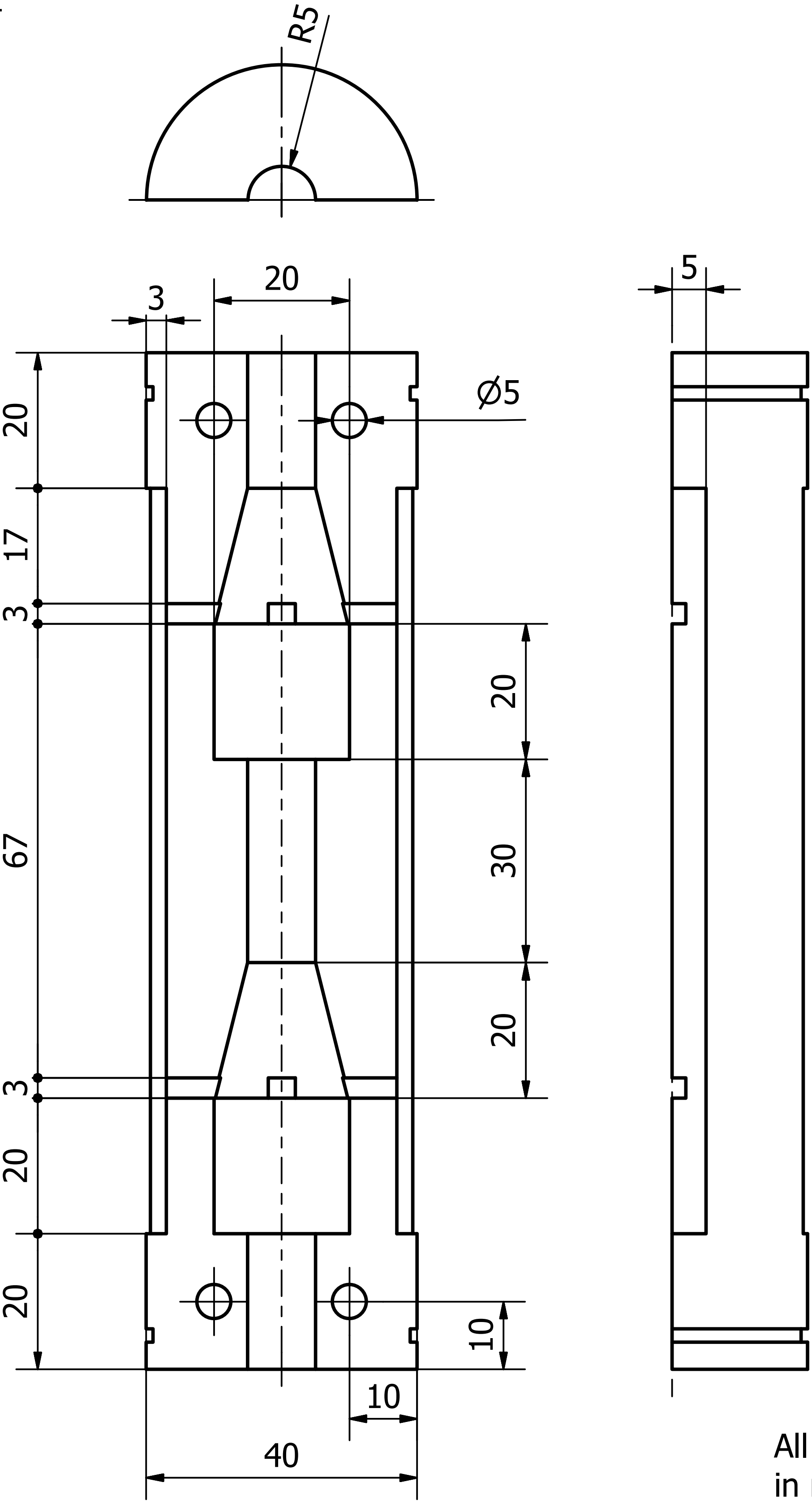
Main Body Half

Scale 1:1



All dimensions in mm

Vertical sizes are not correct for the real design, the design was shortened so the design would fit on to the page

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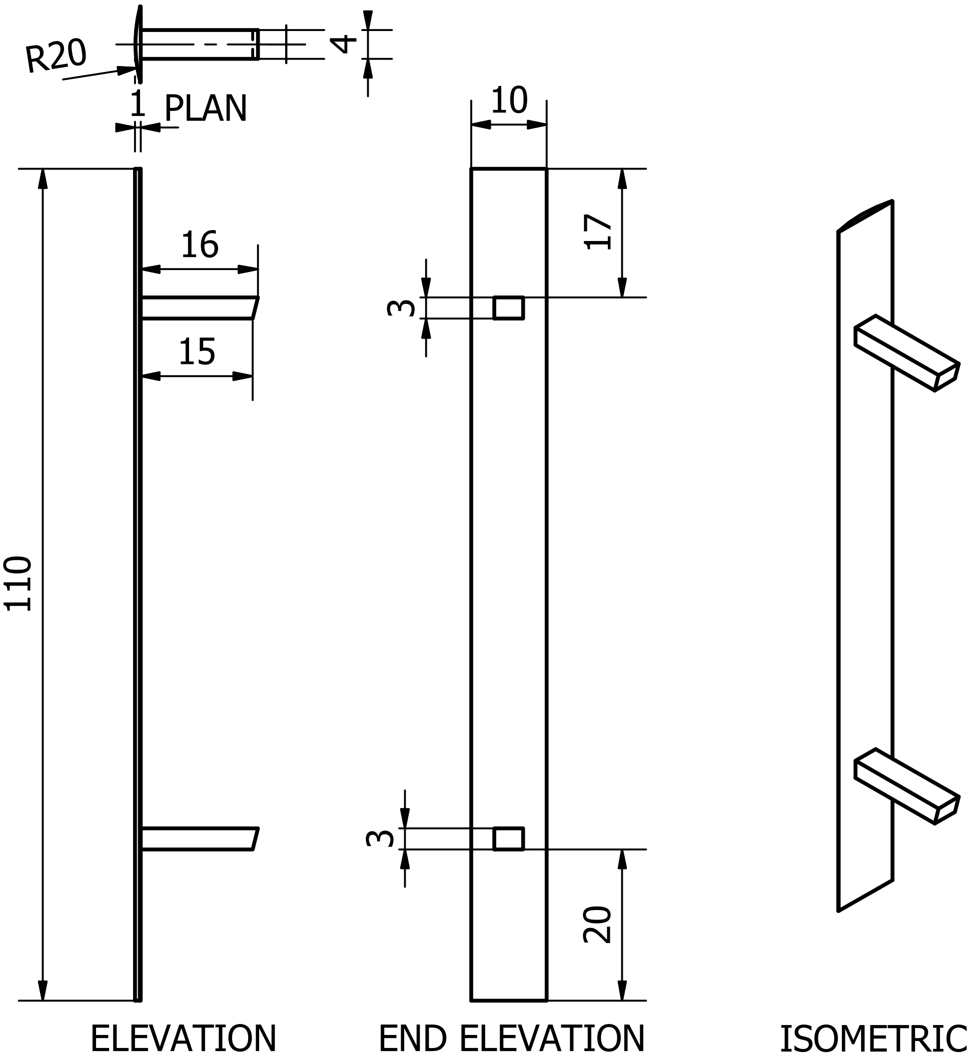
Individual Parts

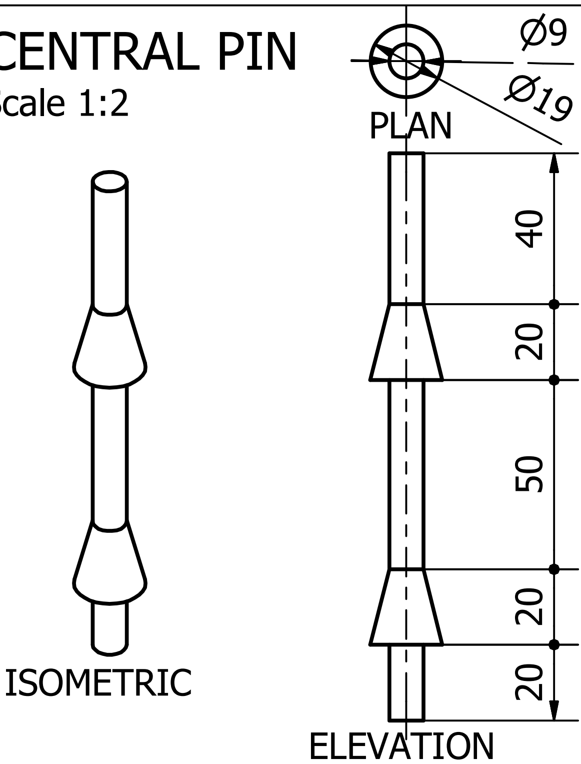
All dimensions in mm

TAB
Scale 1:1

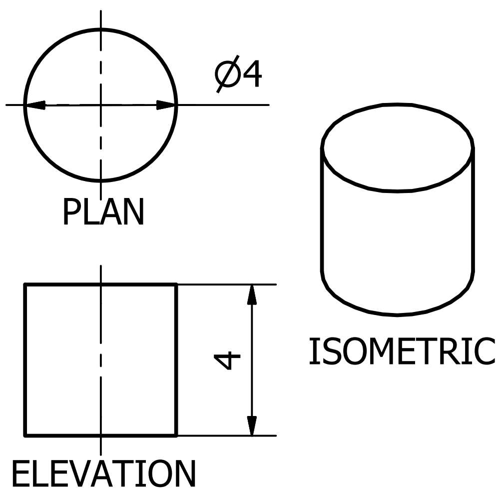
This dimension should be roughly 150mm



CENTRAL PIN
Scale 1:2



PIN
Scale 5:1



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8 Justification of Design/Method

The design made suits the specification for the following reasons;

Power - The only component that requires power in the assembly is the solenoid to push the central pin up and down, meaning that this method would use a lot less power than the other two methods which would need to operate multiple components simultaneously.

Mass - The difference in mass between the assemblies will be negligible if the same material is used. However, the the liner for this method will be heavier than the laser method, as it adds no material to the borehole wall. The difference in mass of liner between the expandable material and additive manufacture methods will be negligible.

Heat - The heat resistance of all three methods will be the same if the same materials are used for construction so this is not a comparable factor. However, this method will not produce heat which is a strong reason for choosing this method. Since the temperature at the lower depths could be as high as 500^oC, it would not be reasonable to add more heat into the borehole which could cause damage to the drill or liner assembly.

For the design to function correctly, rubber bands could be placed around the tabs to ensure they retract on a concept model, but on an actual prototype small springs between the tab and the assembly would work.

9 Evaluation

The design created is plausible as it adheres to all the points in the specification. However, the other methods may be just as effective if new technology was designed, such as lasers that are more efficient than current ones. A rotating array could be designed to keep the number of lasers needed to a minimum, but this would still require more efficient lasers as a large quantity will need to be used. A similar concept could be applied to the additive manufacture method, with a rotating array of print heads to cover the full borehole.

The expandable material method is the easiest to demonstrate as it is a simple design that does not rely on new technology. it may be useful to further explore the other two methods in depth and consider any new technologies.

10 Sources

Figures

Figure 1 - Auger bit - Liebherr - https://www.liebherr.com/shared/media/construction-machinery/deep-foundation/content/liebherr-endlosschneckenbohren-cfa-continuous-flight-auger-drilling-zoom.jpg

Figure 2 - NASA Wireline Drill - NASA - http://www.lpi.usra.edu/meetings/LEA/whitepapers/McNamaralunar$_{e}xploration_{a}bstract.pdf$

Figure 3 - Laser Designs - Produced in Autodesk Inventor 2016

Figure 4 - Extruder with Funnel - Produced in Autodesk Inventor 2016

Figure 5 - Coil under normal conditions and Compressed Coil - Produced in Autodesk Inventor 2016

Figure 6 - Medical Stent Cycle - Drug Recall Lawyer Blog - http://www.drugrecalllawyerblog.com/files/2013/01/Stent-01-28-10.jpg

Figure 7 and 8 - Concept 1 and 2 - Produced in Autodesk Inventor 2016

All technical drawings produced in Autodesk Inventor 2016

Information

Information from Sections 1 and 2 taken from Lunar Mission One website - https://lunarmissionone.com/