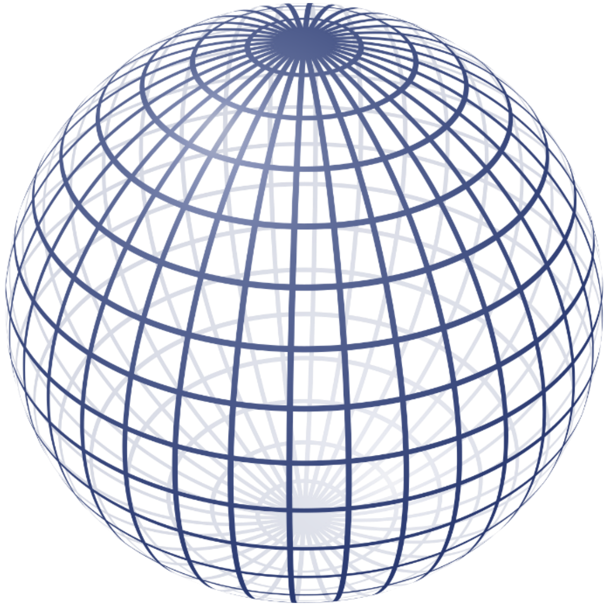
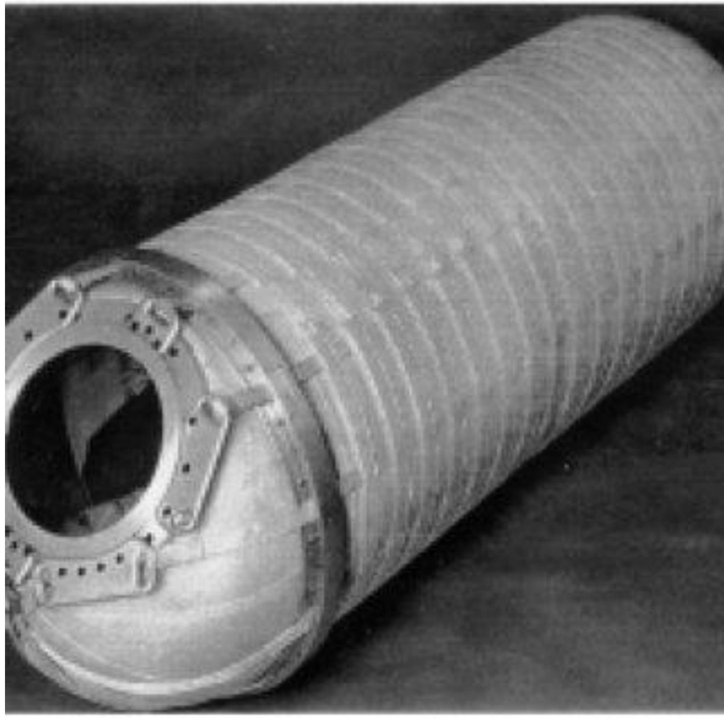
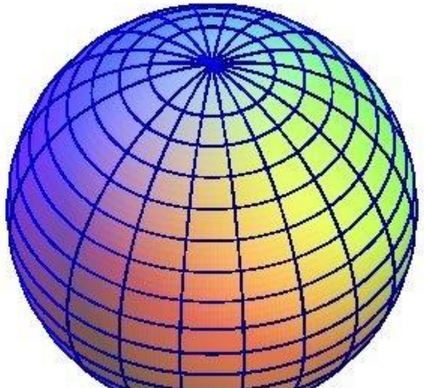




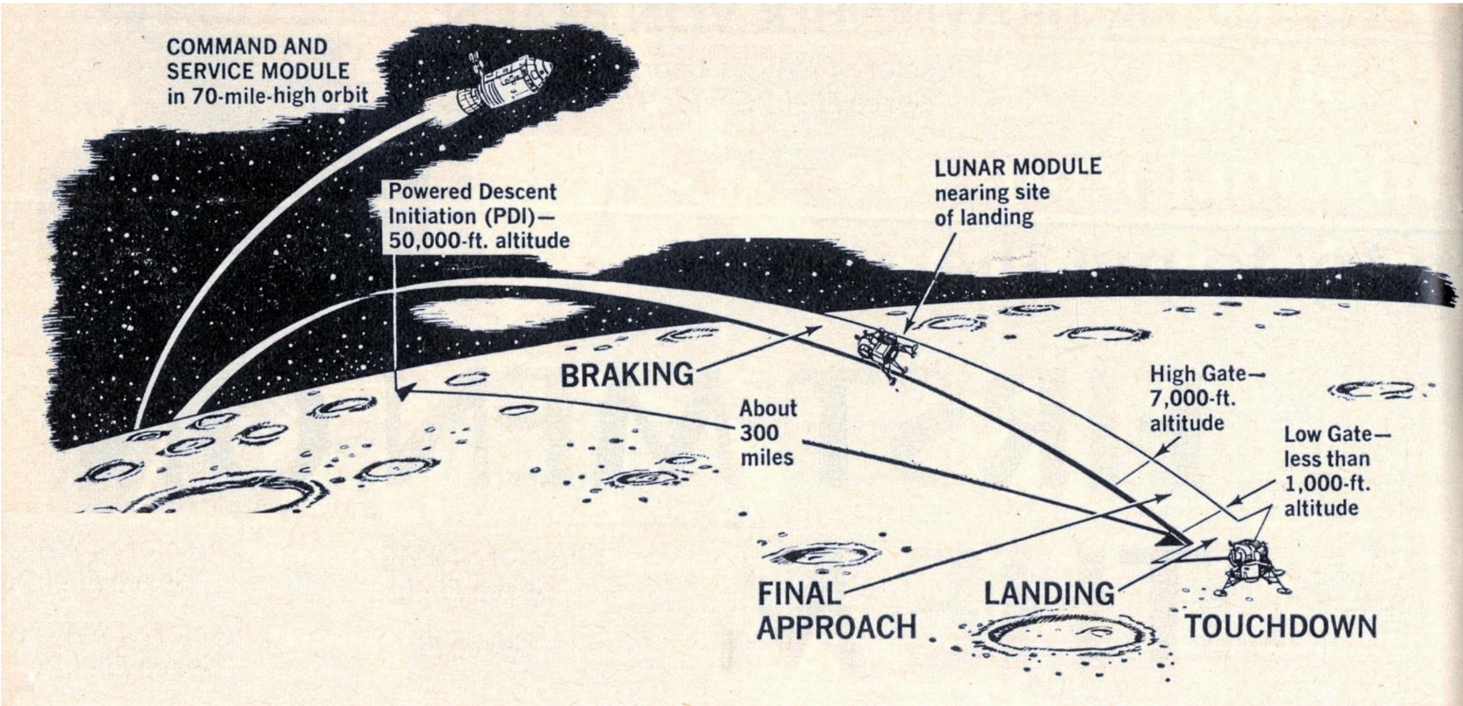
Lunar Supply Pods

Using the friction of the lunar surface to slow down supply pods filled with durable goods. The end goal is to save mass, fuel and money for landing crew supplies on the Moon and Mars.



Soft Landing

I'm sure that everyone would agree that when we land people on the moon, they need to land relatively softly. Since the moon doesn't have any air that we could use to slow the craft down or to give lift with wings, NASA used the engines of the Apollo Lunar Lander to slow the vehicle down from orbital speed to zero and also to touch down lightly. 2/3 of the launch mass of the Lunar Lander was fuel so the crew could slow the space craft down from orbital speed and land softly. Some of the fuel and mass was also for taking off and getting back up to orbit to dock with the command module.



Some supplies are more durable than others

- I think that we could also agree that not everything needs to be landed softly. Some durable things like tools or food packets or water could be landed with a much bigger bump without damaging the supplies as long as the container remains intact (its hard to damage water). Just like a golf ball can be slowed from 200 mph to a stop as it bounces and rolls through the grass and sand, we should be able to use the sand and soil of the lunar surface to slow a supply pod to a stop instead of using fuel. The faster the container hits the ground (without breaking open), the more **<u>fuel and mass could be saved</u>** from slowing the container down. If less mass for fuel is required more supplies could be sent.
- The question is how hard can you allow a supply container to run into the ground without it breaking open?
- And a second question, how much fuel and mass can be saved by hitting the ground faster?

High velocity impacts

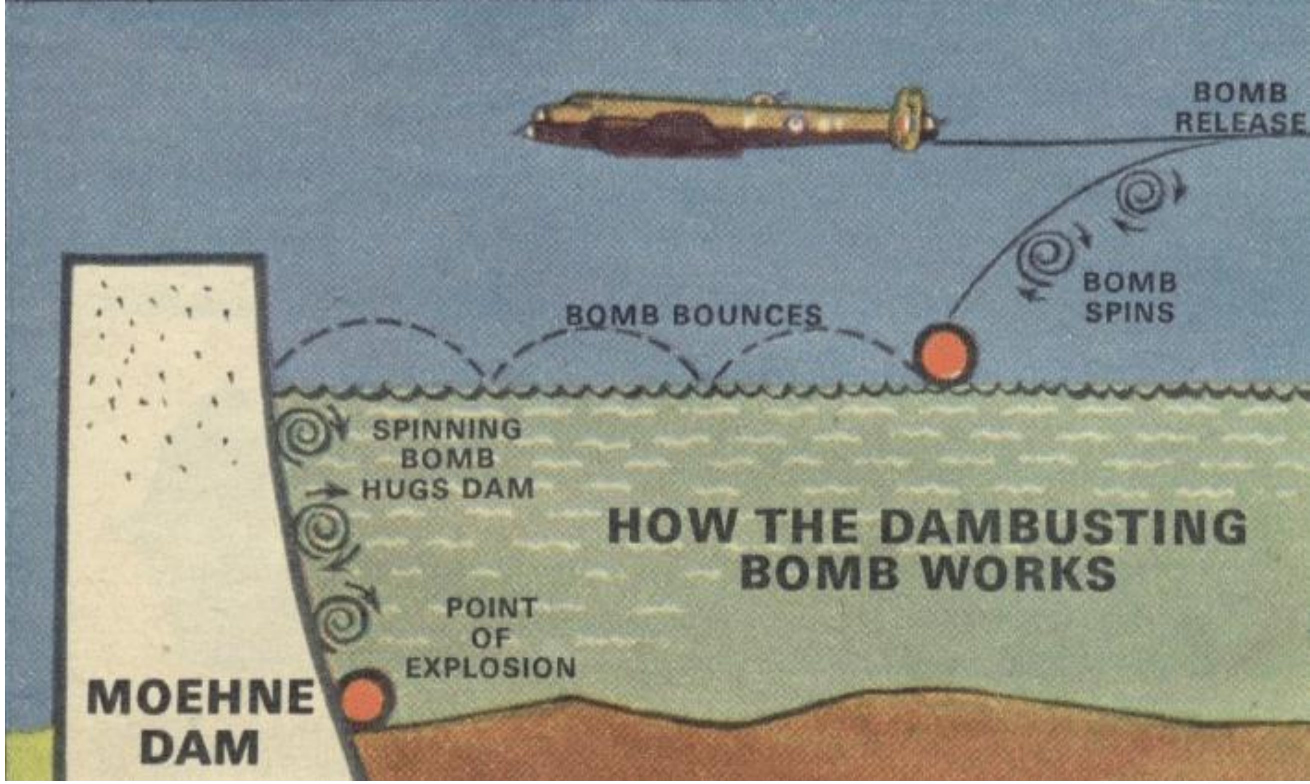
- For the first question—in WWII the allied forces dropped hundreds of thousands of bombs on Germany. 70% which exploded and did their job. However as much as 30% did not explode but struck the ground and remained intact and operational. This is after being dropped from between 10,000 and 20,000 feet. These bombs hit the ground at nearly a 90 degree angle and at almost 1000 miles/hour (**447 m/s**).
- If WWII engineers can drop a bomb and it not explode by accident, it seems that today's engineers should be able to drop a supply pod filled with water and food onto the surface of the moon at the same speeds without it exploding and the supplies would be usable.





Dam Busters—another example

There are some similarities with this idea to the Dam Buster of WWII where bomber planes would drop spherical or cylindrical bombs that would bounce across the lake until they slowed and bumped into the dam, sunk down in the water and exploded at an appropriate depth to damage the dam. They were dropped at low altitudes at speeds over 300 mph without exploding. There would be several differences from the dam busters of course.   NASA supply pods for the moon would not contain explosives that might detonate on impact but they could be coming down at much faster speeds and would be hitting sand and rocks instead of water. The whole point is to use friction with the ground over a long distance to slow down the supply pod to save mass of fuel, engines and structure to increase the amount of supply mass that can be placed on the Lunar or Martian surface.



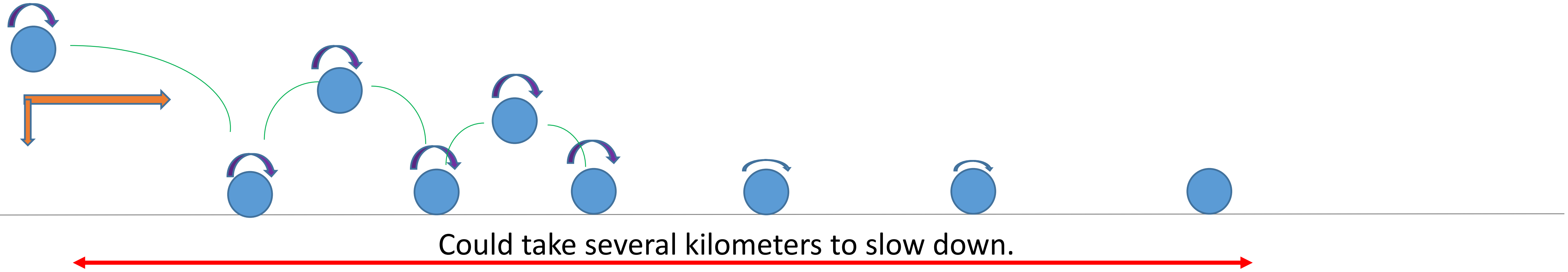
Lunar Supply Pod Mission:

Not all supplies to the moon need to be placed gently onto the surface. Water, food, nuts, bolts….supplies that are unlikely to get damaged by touching down harder can handle a rougher delivery as long as the pod doesn't break open.   Placing materials on the moon costs around $1.2 million per pound. If we can cut down on the amount of mass we have to send that isn't supplies (fuel, engines, landing gear), we will be able to send more supplies for less cost and have less trash on the moon.

The purpose of the supply pod is to decrease the <u>**mass**</u> used to get supplies to the Moon without breaking open:

- Minimize the amount of fuel needed to slow down the supplies
- Decrease the amount of landing gear
- Decrease the amount of materials left on the moon

Lunar Supply Pod bouncing and rolling to a stop on the moon before being picked up/transported by a SEV with some kind of tool.



Could take several kilometers to slow down.

We expect that, just like a golfer can aim a ball pretty close to a hole, NASA would be able to aim a supply pod within ½ mile radius of where the astronaut could pick it up. But this still means that it may be too far for astronauts to walk to and it will be too heavy for them to move by hand or foot. We will need to use the SEV to bring it back to the Lunar Base. This means we will need some kind of tool either on the front or the back of the SEV that could pick it up, drag it or roll it to the Lunar Base---This is another project.

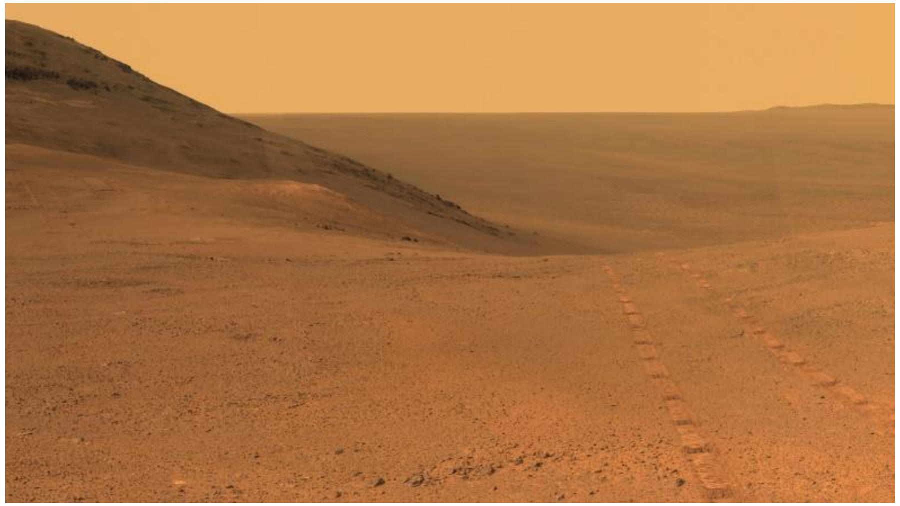
Lunar Supply Pods—computer modeling

Problem:

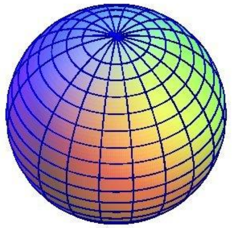
NASA is being asked to make a Lunar Base for a permanent human presence on the moon. To supply food, water and day to day durable equipment to a Lunar Base we need to develop another method of landing supplies that doesn't leave expensive rocket engines and fuel tanks on the surface every time the astronauts need something. Since there isn't air around the moon that would allow us to use heat shields, airfoils or parachutes, is it possible to slow down supply pods without engines and fuel but instead roll across the sand.

Objective:

Develop a computer model that will provide information demonstrating at what speeds a supply pod of food, water and other essentials could be dropped onto the lunar surface and the pod survive the impact and rolling without the supplies being burned up from over heating, turned into mush or scattered across the surface.

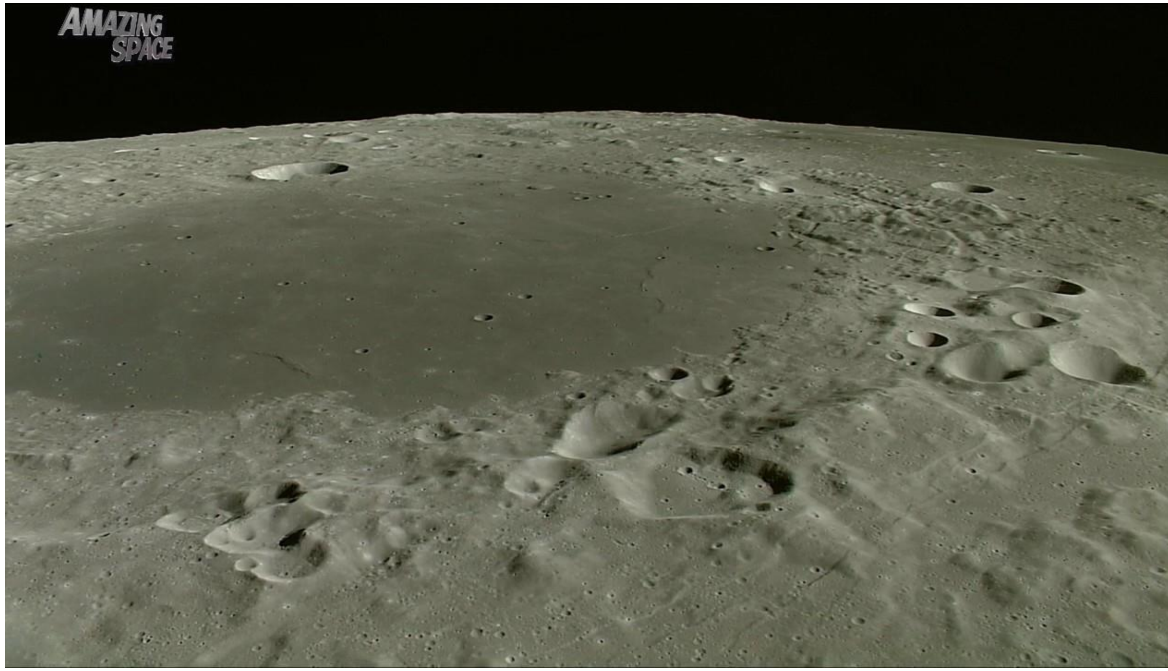


Some of the variables will include:



- Mass of container and contents
- Strength of container
- Velocity at touchdown
- Angle of contact with the surface
- Surface particle size—sand to gravel to rocks to boulders
- Undulation of the surface
- Coefficient of restitution of pod
- Internal and external dampening of container affects the restitution of pod
- Spin of pod—forward or backward

How far will a lunar supply pod roll when it touches down on the moon?



- <u>Physics Equations to start with</u>
- Work = F x d
- Energy = Work/time
- $F_{friction} = \mu m g_{moon}$
- $KE = ½ mv^2$
- When the ball touches the surface of the moon, it is at its maximum kinetic energy, there is no potential energy. If we pretend that the supply pod doesn't bounce and it just rolls on a flat sandy surface, the friction of the sand on the ball will be the only force slowing it down.
- $KE = ½ mv^2 = Work/time = F_{friction} \times d/t = \mu m g_{moon}\, d/t$
- $½ mv^2 = \mu m g_{moon}\, d/t$
- Notice that the mass falls out of the equation.
- $½ v^2 t = \mu g_{moon}\, d$
- $v^2 t/2\mu g_{moon} = d$

Assume a touch down velocity = 447m/s
This makes it a question of just time and distance

Left over parts on the surface = $$$$ wasted

The Moon and Mars both have plenty of open spaces. Because Mars has wind and dust storms, the Martian surface is smoothed out more than the moon's making it more likely that we could find a relatively even surface to roll to a stop. The less fuel, engines and landing structure used for placing those supplies on the lunar surface, the more supplies NASA can outfit our crews for success—and maybe with less expense.

The main objective of the Supply Pods is to maximize the amount of materials that are needed by the astronauts and to minimize the amount of wasted materials and mass sent to the base. On a lunar base, left over landers, engines, fuel tanks all become trash that the astronauts will have to maneuver around when they are doing their day to day work. The less wasted material on the surface, the more work the crews can get done. Some sensitive equipment and people will need to touchdown at gentle speeds. But that is not needed by everything. By having specific supplies land at higher speeds, we can increase the amount of delivered supplies per launch from Earth and decrease the amount of high tech materials that will eventually clutter the surface and impede activities and operations.

Martian surface as seen by Curiosity Rover

Apollo 17 crew leaving behind decent module. The Apollo program left seven lunar landers and components on the moon after serving their purpose. Used components and parts will be in the way of normal operations.

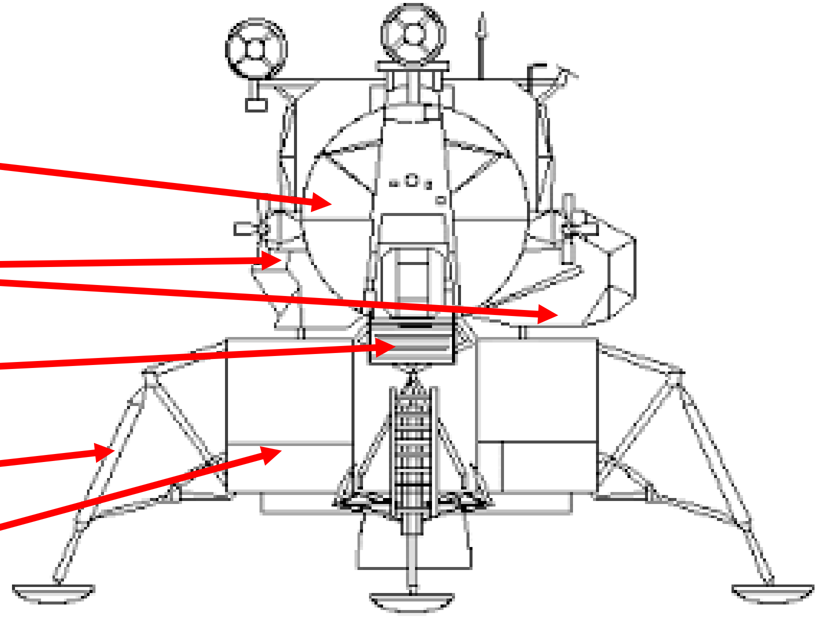
Supply limitations

- Assuming that we only want to send supplies without people to the moon there are several factors that determine how much can be sent on a single supply mission. The limitations for sending supplies to the moon start at the launch pad. How much mass can the rocket get into space and send it to the moon? This is controlled completely by the power of the available rockets. A Saturn V rocket could deliver 140,000 kg to Low Earth Orbit but it could only deliver 48,000 kg to the moon. Some of that is the Command Module and some is the Lunar Lander. The further away the payload is sent, the more fuel it takes to get it to the destination and the less supplies that can be sent.
- Another limitation comes from how much fuel, engines and support material is needed to slow down the craft with its supplies from its orbit around the moon and support the landing on the surface. The amount of fuel is determined by the type of engine and by the mass of the supplies and its containers.
- There are many factors that determine the ratio of supplies that can be landed to compared to the amount of materials to needed to land the supplies.
- Some of the factors include mass of the fuel, mass of the engine(s), landing support (legs). If we can cut down on the mass of these materials, we can send more supplies for the astronauts that are on the moon.

Part 1 of a thought experiment

Cost of putting material on the moon-------$1.8 million per kilogram

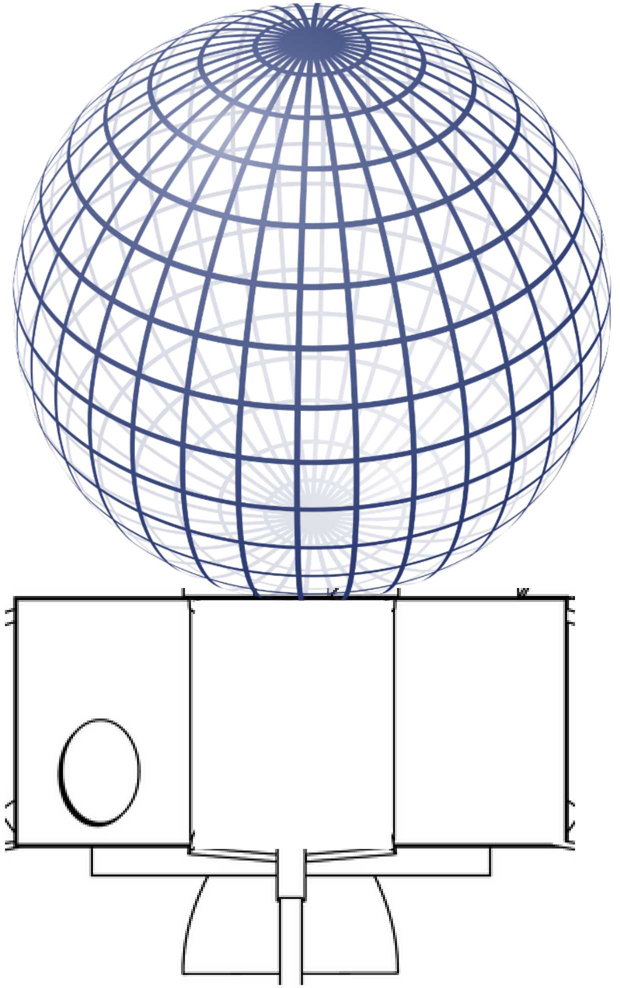
Apollo Lunar Lander materials	Mass (kg)
Crew and Crew Supplies	360
Ascent fuel	2136
Ascent engine	82
Landing legs	220
Fuel for Decent	8,804
Total mass of Apollo Lunar lander	15,227 kg



To land the crew and supplies softly, the Lunar Lander needed nearly all of its fuel for decent. The Apollo 11 had only a few seconds left of fuel when they touched down.

If an Apollo Lunar Lander were converted into an automated, soft landing vehicle and was used only to send supplies, around 2578 kg of supplies could be sent since ascent fuel, ascent engine, crew and crew supplies wouldn't be needed. (I'm sure there is more mass that could be removed…ladder, ramp, windows…)

Part 2 of thought experiment



If an Apollo Lunar Lander were converted to holding a supply pod (a sphere or cylinder that could roll to a stop) that could touch down at 447 m/s (similar to a WW II bomb casing), another 220 kg of supplies could be sent since the legs wouldn't be needed. But more importantly another **1000 kg** of supplies could be sent since we wouldn't be using fuel to slow down at the end.   This would allow for a total of around 4000 kg of supplies. (some mass would need to be added for the structure to hold).

Release the engine and tanks before touch down to allow the supply pod to roll and stop independently.

Of course it is easy to come up with a way to make a supply pod to stop quickly, just ram it hard into the ground. But that means that all of the kinetic energy of the fast moving projectile is converted into heating the contents of the supply pod and some into the ground.   Apollo used rocket thrust to slow the craft down more gently over time so the people weren't hurt. The objective of rolling across the surface, instead of slamming into the ground, is to convert the kinetic energy into heating the lunar sand over a longer distance instead of heating the supplies inside the pod.

Supply Pod Design

We are designing a shipping container that is going to impact the ground at a high velocity and then roll or slide to a stop. It will probably bounce a lot since the Moon's surface is heavily cratered. It would be easy to slow it down quickly—just run it into the ground. But that would mean that the container has to be that much stronger and sturdier. It also means the contents would have to be able to handle the forces.   The intention is to slow the pod down slowly so that the pod doesn't have to be a foot thick of steel or more and more supplies could be sent. The pod needs to stay on the surface as much as possible (not burrow into the ground or bounce a lot) so that it is easy to collect and bring back to the base.

Even though this is a new kind of container there are still many ideas from current shipping containers that could be valuable to learn from.   Sturdy and simple. Make the attachment points flush with the surface or fold into the surface so they are not damaged easily. Sturdy simple doors/ hatches. Versatile interiors for shipping a variety of objects. Most likely these pods to be cylindrical or spherical although some people are trying some different ideas that may have some value.

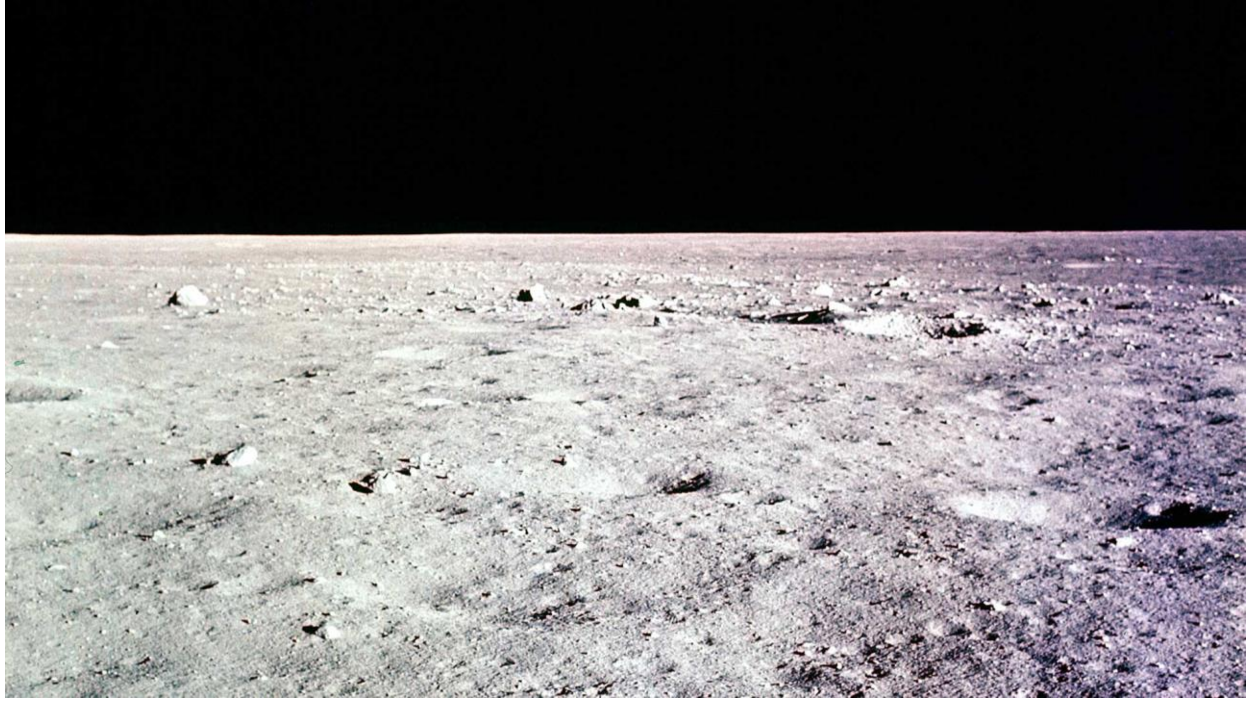
- Keep the Pod as simple and dumb as possible since it is being thrown against the ground. Don't expect that electrical or electronic components will work after contact.
- Needs to have a simple but sturdy mechanical hatch to get supplies into and out of.   It may be helpful to position the hatch so it gets less damage during impact, rolling, sliding. You could use a drill or other motor to assist with opening and closing.
- Needs to have some kind of attachment points so it can be picked up or moved once it has stopped rolling. These should be something that can survive the impact and abrasion of the lunar surface. Work with a Supply Pod Mover team to coordinate ideas if possible. Crew will have to be able to attach to them with their thick gloves on.
- Compartments to keep supplies from shifting. It may be helpful if these compartments could be reorganized to handle different shipments. Supply Pods will be bringing a wide variety of different materials and probably at the same time. This may include tanks of water, air, fuel, batteries, food, durable spare parts, clothing, nuts, bolts, hand tools.
- Expect that all the of pods coming to the Moon or Mars will be sealed to prevent dust from getting inside and jamming components. Some pods may not have air because they are carrying supplies for outside use.

- The mission is to get as many supplies to the moon as cheaply as possible but safely. Try to maximize the space available by using smart materials and structures.
- I expect there will be at least two sizes—Small (2m in diameter) and Large (3m in diameter). They could be spherical or cylindrical. Expect the pods to be at least 2500 kg. You only need to design one but keep in mind it may be scaled up or down based on needs.
- We are trying to minimize the amount of wasted materials on the Moon and around the base. Is it possible to be able to use the pod for something else after being emptied? Not required, just something to think about.

How Fast?

447 m/s is around the speed that we know bombs have crashed into the ground and survived. However, the touch down speed could be slowed to nearly any speed using engines and fuel and then release the supply pod from the engine/tank. The supply pod would bounce onto the surface and roll to a stop and the engine/tank would land somewhere else. However, it may be possible to touch down at very high speeds and use little to no fuel. Escape velocity for the moon is around 2,386 miles per hour. That's very fast. And the orbital speed could be much faster depending on the orbit the supply pod could be placed in as it comes from Earth. However, depending on the materials for the pod and some other factors, it might be possible by adjusting the orbit of the supply pod so that perigee of the supply pod just barely kisses the ground at one of the long, flat maria basins of the moon so the payload skims across the sand like a stone skipping across the water. Using the friction of the sand to slow it down instead of fuel and engines.

This could be tested on Earth with a high-speed jet doing a low strafing release of a test supply pod filled with similar supplies and sensors. It seems like NASA might know of a long, flat, dry lakebed in California or Arizona that would be similar to a lunar maria or a Martian desert area. One of the main questions will be how much deceleration the supply pod materials can handle without being damaged.



Tips for Increasing the touch down speed and chances of survivability

There are a number of techniques that could aid in increasing the survivability of the supply pod including but not limited to:

•Touchdown on a downward slope going into the basin
•Forward spin on the supply pod—depending on how fast you want it to slow down or directing the bounce—forward spin would allow a slower deceleration and prevent **'decapitation'** of the pod at touch down
•External and Internal dampening mechanisms
•Planned breaking apart after impact
•Orbital tethers—have an orbital component that lowers the supply pod down closer to the surface by way of tether. When the supply pod gets close to the ground, release the connecting tether as it touches down on the surface, let it bounce and roll to a stop. The orbital component would get slung out to a higher lunar orbit and might be reusable once the tether was reeled back in.
•Inflated balloons similar to how JPL landed a Mars rover might be an option

Some of the Variables that need to be modeled:

- Mass of container and contents
- Velocity at touchdown
- Angle of contact with the surface
- Surface particle size—sand to gravel to rocks to boulders
- Undulation of the surface
- Coefficient of restitution of pod
- Spin of pod—forward or backward
- Strength of supply pod—key question—can the pod and supplies survive—the faster the touch down, the more mass saved in fuel and the more food for the crew.
- Internal or external dampening of supply pod
- Is there advantage to the pod being larger or smaller in terms of survivability
- *Although it is the goal to model all of these factors (and I expect there are more), modeling just some of these may give us an idea if this is possible.*

Existing simulator—may be helpful

- Some of you may play Kerbal Space which is a simulator game. It is possible you could do some of the design and testing work in Kerbal Space and it may give you some ideas although it is unlikely that it will fit all of our needs.
- It may give a method for demonstrating at least the visual of how some of it would work.

- https://www.kerbalspaceprogram.com/

Student supply pod concept from 2019

- Students from Oak Ridge High School in Texas suggested a cylindrical style supply pod with multiple compartments, air tanks and attachment points. They included some small thrusters for positioning and rotation before touch down. I don't know this is the right answer but I see many of the elements of what will be in a real supply pod.