How to build a Moon base cheaply

With interests in establishing a base on the Moon on the rise again, while some look at how to get there, others look at how to stay there – for the long term. Alexander Mayboroda, an advocate for space colonisation, guides us through the technological challenges faced by those hoping to establish a base on the Moon and ways to get around the spiralling cost associated with such an endeavour.

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Almost half a century has passed since man first visited the Moon. However, most projects for creating humanity's outpost on the Moon never made it past the drawing board due to their expensive implementation. In a 2009 study, the Center for Strategic and International Studies suggested a lunar base would cost $35 billion to construct and $7.35 billion a year to maintain. It is clear therefore that until the cost of space access is lowered the situation with building a base on the Moon is unlikely to change.

Considering the current level of rocket and other space technology development, it is more profitable to create industrial facilities on asteroids compared to the Moon. Private companies that have declared plans to mine platinoids and rare metals outside of Earth are looking at asteroids first. There is far less interest in business plans to mine resources on the Moon. At the same time, it takes a week to get to the Moon and back, whereas visiting an NEA group asteroid takes years. From an investment point of view, due to the possibility of quick equipment depreciation, mining on the Moon is potentially more lucrative than mining an asteroid.

Aside from providing a stunning backdrop to the night sky that has wowed humanity for thousands of years, the Moon has many valuable resources; just like an asteroid, it is home to metals that are rare on Earth and both uranium and platinum-based metals can be found there. It is somewhat macabre, but it can also be thought of as an asteroid cemetery of sorts, as for billions of years, asteroids that contained metals have bombarded the Moon's surface. Essentially there is no real need to chase asteroids and waste years on a lengthy trip, it's enough to simply look under the regolith surface of the Moon for metal asteroid fragments – and in order to do that a base is needed.

The true cost

If the cost of delivering cargo to the Moon becomes equal to the cost of cargo delivery to asteroids, the shorter travel distance to the Moon and, respectively, the quicker returns (100 times quicker on average), will make mining on the Moon appealing to investors. Luckily, the technology that would make this possible already exists and a method to deliver goods without rocket deceleration has already been tried successfully.

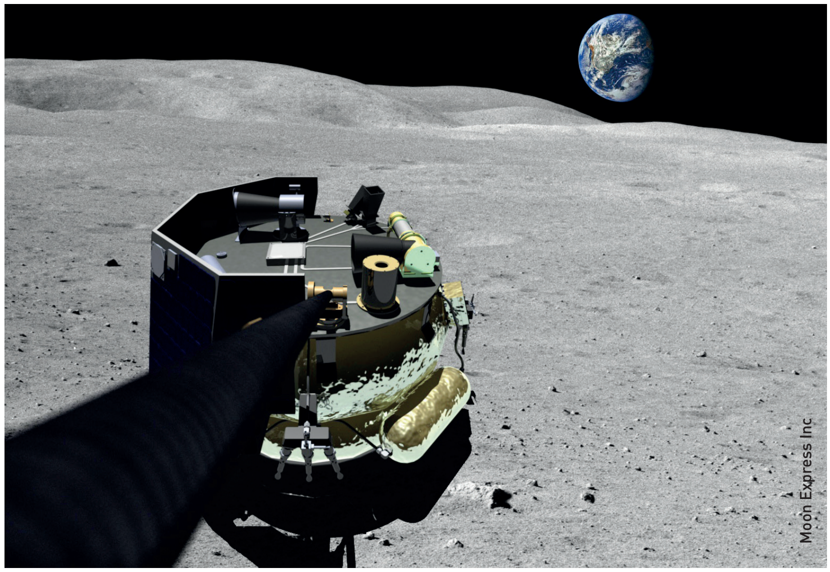
The first cargo shipment delivered to the Moon was the metal 'USSR' ball, dropped by the Luna-2 soviet spacecraft. The landing was hard but that made it energetically efficient in comparison to a soft landing that occurs through rocket engine deceleration. A hard landing occurs at a speed of around 2500-3000 m/second. In effect, it can be thought of as a crash, during which the cargo melts and partially evaporates. However, a hard landing is preferential for two simple reasons; the design allows for an increased storage capacity over soft-landing by three to five times, thus decreasing the cost of delivery by 70-80%.

Nonetheless, up until recently and perhaps to be expected, only soft landings have been considered for spacecraft despite the higher cost, as the stored rocket fuel significantly decreases the available cargo space in the rocket. In addition, the cost for the landing module needed for such a delivery system is also high. But how necessary is it to find a way for soft-landing delivery of cargo when building a base? Does all cargo that requires the use of heavy rockets need to be delivered in this expensive manner? With an outlay of $15-30 billion for the creation of one such rocket, perhaps a more cost-effective solution can be found.

From the ground up

A lot has changed in the last 50 years with the appearance of additive technology i.e. the process in which digital 3D design data is used to build up a component in layers by depositing material. This negates the need, as some project developers claim, to deliver assembled equipment to space bases.

If the extraction of raw materials is streamlined, 3D printers will be able to print



▲ An artist illustration of the Moon Express MX-1 lunar lander on the surface of the Moon after a soft landing. The California-based company is one of three selected by NASA for its Lunar Cargo Transportation and Landing by Soft Touchdown (CATALYST) initiative to advance lander capabilities that will enable delivery of payloads to the lunar surface.

habitation and technological modules, rocket engines, fuel tanks and spacecraft in situ – wherever that may be in space. Thus the cost of cargo delivery will decrease. However, in order to build a base using local materials, equipment that will be able to extract metal, silicon and oxygen from the surrounding regolith, must first be delivered to the Moon.

One way to do this is to transport the necessary raw components from Earth via the hard-landing method to provide the materials to be used by 3D printers on the Moon. Once built, resources extracted from the Moon can then be used to construct everything else. In this proposal, only the parts necessary for printing base units and equipment necessary to receive and collect materials delivered from Earth would need to be sent in a controlled soft-landing scenario. Simple materials such as water and hydrocarbons, necessary as chemical reductant agents for metals and rocket fuel, as well as aluminium, titanium and other metals do not need to be delivered using this costly method and delivery via a hard landing would be sufficient.

However, implementing and controlling a hard landing is not that easy. If the cargo is made up of spheres, much like the Luna-2 sphere, after the explosion on impact the cargo would be dissipated over a large area. As a result, it would be impossible to collect most of the cargo. It is possible to prevent this explosive dissipation in a number of ways and, as long as the materials are collected and accumulated for future use, the cheaper delivery option would suffice.

One of the simplest methods used with a hard-landing involves the use of arrow or rod-shaped

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cargo portions, similar to 'Rods from God' high-precision space weaponry. Objects of this shape act like a cumulative charge spray when faced with a barrier. Upon hitting the ground, the arrow-shaped parts of the cargo, provided that the mass, form, speed and material of the cargo were chosen correctly, should enter the ground at such a depth that their partial explosive evaporation will take the form of a 'closed-cavern camouflet', without the outside dispersement of the main material mass. A camouflet, in military science, is an artificial cavern created by an explosion. If the explosion reaches the surface it is then termed a crater.

This method can be conveniently used to deliver various metals to the location of the future base construction. Other, easily sublimated materials pose a difficulty however as any gases, for example, will escape the camouflet through the entry hole.

The second method of hard-landing cargo delivery is based on the creation of hermetically sealed camouflets in the ground. This is possible if the target is hit precisely, with an error margin that does not exceed 1-2 m. In this case, a hermetic ring is built on the ground or on a side of a hill, that is embedded into the ground and has a diameter of 2-4 m. The ring covers the potential landing area for the cargo and has a closable hatch that remains open until the cargo lands in the trapping ring. After the cargo has entered the ground, the ring hatch is closed, thus hermetically sealing the entrance to the camouflet.

This method has the advantage of being able to deliver materials such as water and other easily evaporated liquids, including cryogenic ones - such as oxygen, hydrogen, chloride, fluoride and some hydrocarbons - with relative ease. In this instance, polyethylene tubes can be used as containers for such liquids.

A further option to consider when developing cargo delivery technology for hard-landings on the Moon, is the use of regolith-filled shells. The shells would also have a closable hatch, so that the entrance port is closed and the gases contained. Such 'collectors' offer added improvements including ease of material retrieval and ease of preparation of next cargo delivery, as well as the potential use of generated heat.

A lasting impact

The part of a collector that could be delivered from Earth, such as the container, can be made of highly durable materials such as aramid, instead of metal. The container would be tube-shaped, with both ends sealed off and would be mounted on a sledding mechanism or on landing wheels, or a similar mechanism with a low materials-output ratio. It would have a volume of 80 cubic meters and a total mass (when empty) of 1 tonne. Taking into account the mass of the cargo catcher and density of the regolith only the 1 tonne container has to be delivered from Earth.

Preliminary assessment shows that up to 100 kg of materials can be thrown into one such catcher trap during a single mission. The rod-shaped cargo enters the trap through one of the container sides (the rod itself contains cryogenic liquids). The rod breaks the membrane or the net

► In coming years, government-sponsored and private-sector spacecraft will land on the Moon. This image shows a resource prospector carrying a Regolith and Environment Science and Oxygen and Lunar Volatile Extraction (RESOLVE) experiment, intended to find, characterise and map ice and other substances in almost permanently shadowed areas.

at the entry side of the collector container, which serves as a temporary wall for the regolith inside the container, goes through the mass of sand and slows down deep inside the catcher environment.

The explosive evaporation of the cargo is balanced by the massive and loose regolith. After this, the quick-acting lock is activated and all the gaseous product is hermetically sealed. The gas cools and is pumped out of the container into the bases' storage containers. Then, a new membrane or net is installed instead of the pierced one (or the existing membrane is patched up), the regolith is loosened or partially replaced, the lock is opened, and the collection container is once again ready for use.

Another type of membrane container is the mobile container. Such a system can receive cargo from the space vehicle that throws the cargo out into a container area with a target error margin of tens or hundreds of metres. These rods would have lidar radar detection markings, allowing the cargo's location to be calculated as they land vertically on the Moon. The collector container will then proceed to move to the landing point for cargo interception.

This method uses small collectors with the receiving opening of about half a metre and water or high-boiling hydrocarbons are used as the braking environment. A mechanical lock and an aerodynamic porthole are used for hermetic sealing. An aerodynamic porthole or window is a gaseous curtain that prevents the buffer zone materials, such as gases, aerosols and liquids, from leaking out into the outside vacuum. At the same time, the aerodynamic window allows for raw materials in the form of threads, bands or thin gas tubes to enter the chamber. Streams of materials that enter the chamber at the speed of 1700 to 2000 m/s, interact with the buffer zone, pulverize, brake and, mixing with the chamber environment, give off heat, after which they are separated and pumped into storage tanks. The window works only when the cargo arrives in the collection chamber of the collector, when the mechanical hatch lock is open.

Cargo-carrying spacecraft that can aim the cargo with precision from orbit and into the Moon collectors will naturally be specialised based on the type of cargo they are transporting. To ensure a successful delivery, the modules have a guidance system and a rocket propulsion system to aim the cargo block at the collector prior to send off, and to turn the sending block away after the cargo has been discharged.

Upper-stage rockets of cargo-carrying spacecraft could crash on the lunar surface in order to not add to the space debris cloud that already surrounds the Earth. However, if the payload mass is chosen appropriately, the boosters retain enough fuel to make it possible to lower the speed in perigee after circling the Moon and on the approach to Earth, and to enter low Earth orbit. In this case, the low cost of cargo delivery to the Moon is complemented by the possibility to use upper-stage rockets multiple times – it's cheaper to re-fuel them in low Earth orbit than to launch new boosters from Earth. The first stages could thus provide 15-20 repeat booster trips, with the potential of increasing that number to 100-200 trips.

The method, called Moontrap Technology, uses collectors that are not only useful for transport but also for technological production. Explosive processes in regolith, when hydrogen, hydrocarbon, carbon, chloride and fluoride enter the collector, create a regenerative reaction that produces iron, titanium, nickel, other metals and silicon.

Asteroids have their uses too

The regolith on many asteroids, including the martian moons Phobos and Deimos, is rich in carbon and possibly hydrocarbon. Carbon is necessary to release metals and oxygen from regolith.

It is much easier to deliver carbon to the Moon from Phobos or Deimos or other asteroids than from the Earth. In some places where hydrocarbon will fall, gas deposits, such as CO, CO_2 and H_2O will also appear along with metals. These deposits can be used in later stages as rocket fuel components.

Accordingly, a lunar transfer point would be beneficial for not only providing resources for Earth or a base on the Moon but also for facilitating the delivery of asteroid resources. The return of derived materials to space (for example, for building space power stations and refueling stations) also becomes cheaper thanks to orbitally based collectors. Orbital collectors will thus decrease the cost of cargo delivery by 95-99% not only from the Moon but also from Earth. ■

Considering the current level of rocket and other space technology development, it is more profitable to create industrial facilities on asteroids instead of on the Moon

About the author

Alexander Mayboroda is director of AVANTA-Consulting, Russia. He is a former director of Microgravitatcia research and Technology Centre, which worked under the aegis of the USSR Space Federation and the Research and Technology Society of the USSR on non-rocket space transport systems and using microgravity for industrial purposes. He also holds a number of international patents relating to inventions in space transport.