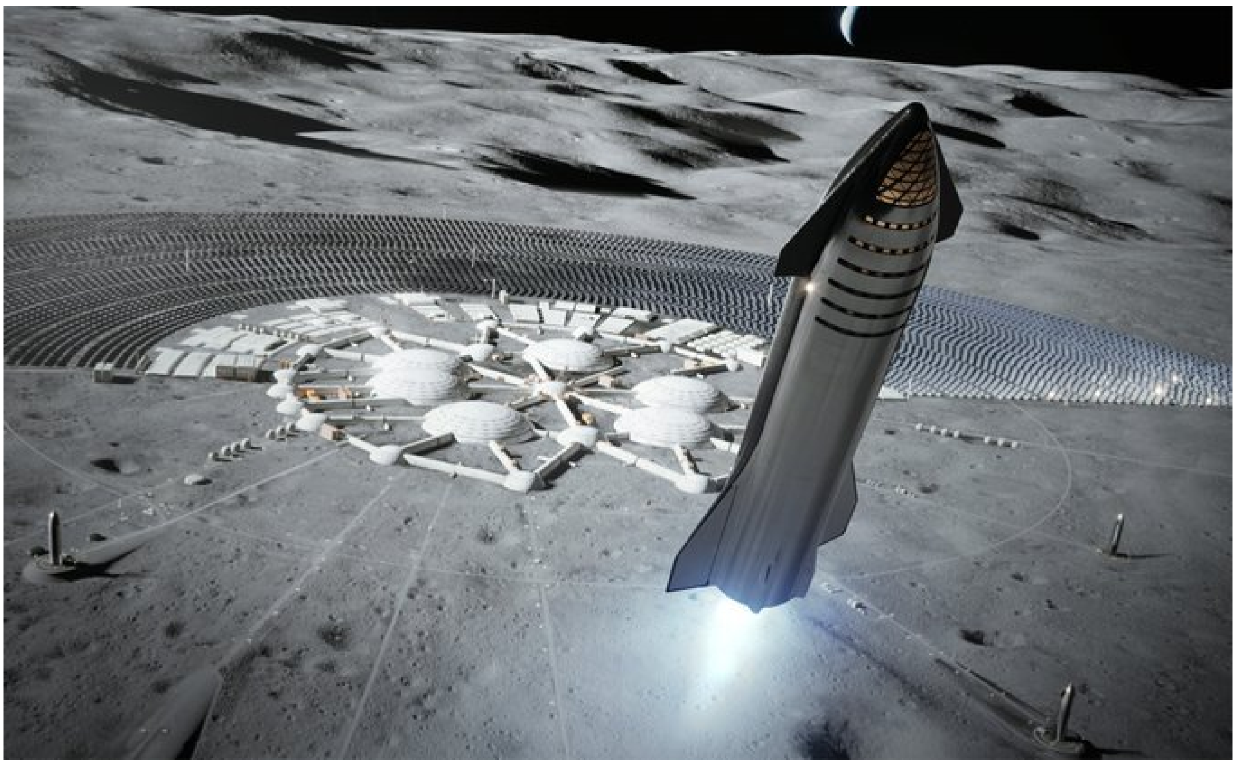
What's the best way to build landing pads on the moon?

May 11 2022, by Matt Williams



Artist's rendering of a Starship taking off from a lunar base. Credit: SpaceX

In the near future, NASA, the European Space Agency (ESA), China, and Roscosmos all mount crewed missions to the moon. This will constitute the first time astronauts have walked on the lunar surface since the Apollo era. But unlike the "race to the moon," the goal of these programs is not to get there first and leave only a few experiments and landers behind (i.e., "footprints and flags" missions), but to establish a sustained human presence on the lunar surface. This means creating habitats on the surface and in orbit that can be used by rotating crews.

While NASA and other space agencies intend to leverage local resources as much as possible—a process known as in-situ resource utilization (ISRU)—creating lunar bases will still require lots of materials and machinery to be shipped from Earth. In a recent study, Philip Metzger and Greg Autry reviewed the cost and energy consumption of building landing pads on the lunar surface. After considering various construction methods, they determined that a combination of additive manufacturing and polymer infusion was the most efficient and cost-effective means.

Philip Metzger is an associate scientist with the Florida Space Institute (FSI) at the University of Central Florida (UCF), a former senior research physicist at NASA's Kennedy Space Center (KSC), and the co-founder of the KSC Swamp Works. Greg Autry is a clinical professor of Space Leadership, Policy, and Business with the Thunderbird School of Global Management at Arizona State University (ASU) and the Chair of the Commercial Space Transportation Advisory Committee (COMSTAC) Safety Working Group at the Federal Aviation Administration (FAA).

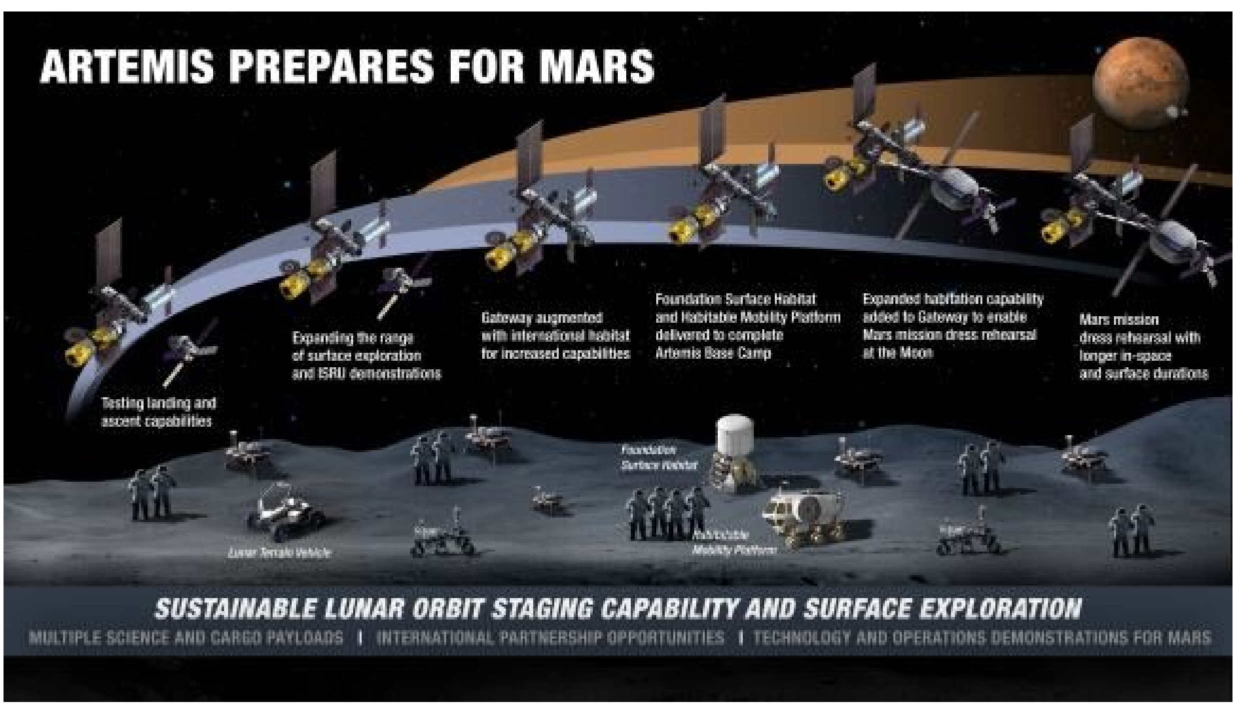
For their study, Metzger and Autry examined different methods for building landing pads on the lunar surface. Each method was evaluated based on three major factors: the need to ship large amounts of mass from Earth, the level of energy consumption on the lunar surface, and the time it would take to finish construction. Each of these factors contributes (directly or indirectly) to the overall cost of lunar activities.

Among their findings, Metzger and Autry determined that two variables are the most important when evaluating in-space construction methods: transportation costs and the delays imposed by the construction process.

As Metzger explained to Universe Today via email:

"I was surprised that the complexity and reliability of the construction process did not play a larger role. A complex system will need about 50% more up-front investment to make it as reliable as the simpler methods, and a 50% cost increase sounds like a lot, but compared to the cost of lunar transportation and the loss of value if you delay doing things on the moon, it turns out that 50% more development cost is utterly inconsequential.

"So if you invent a more complex method of doing things, and that method is faster and lower mass than previous methods, then it is worth it. That goes against our natural tendency as space technologists. We think keeping things simpler is better, and we think when we are operating far away on the moon, it is even more important to keep things simple. But when we look at it from an economic perspective, that feeling doesn't turn out to be true. In the economic environment of lunar operations, higher technology is worth the greater up-front investment."



The ESA’s concept for a habitat around the south pole of the moon known as the Lunar Village. Credit: ESA

They further found that the thickness of the pads, the thermal environment (which varies between the inner and outer pad), and the launch cadence of the lunar program were also important factors in establishing practical limits on construction time. In short, the cost-effectiveness of each method comes down to the cost per kilo of launching payloads and the speed of construction. They considered several based on the energy requirements and how this would vary depending on the thermal environment.

In particular, they considered recent innovations in additive manufacturing (3D printing) and ISRU, which have been the subject of research by NASA and the ESA for many years. When adapted to the lunar surface, methods include heating regolith with microwaves to create a molten ceramic (aka. "sintering") that is then printed out and solidifies on contact with the airless lunar environment, or adding a bonding agent to regolith (like cement or a polymer) to fashion "lunarcrete."

"Some methods require huge amounts of energy, which requires heavy energy systems on the moon. Other methods require many tons of binder brought from Earth at great expense. Still, others are very, very slow processes. We wanted to see how these different factors compare to each other when we look at it from an economic perspective.

"We converted everything into a real cost: the cost of transporting mass from Earth; the cost of energy delivered on the moon; the loss of economic value if we take a long time doing construction. Putting it all together, we could see which construction methods provide the best value to lunar operations."

They found that microwave sintering provided the best combination of low mass and high speed compared to other methods. This was particularly true for building the inner, the high-temperature zone of the lunar landing pad (where the take-off and landing rocket burns happen). This method is also the most favorable for constructing the outer, low-temperature zone if and when transportation costs are high.

However, in the event that transportation costs to the lunar face can be kept at $110 per kg (around $50 per lb), the most cost-effective method switched to polymer infusion. They also produced estimates on the overall cost of building the Artemis Base Camp ($229 million)—the surface habitat NASA intends to build around the South Pole-Aitken Basin. These were based on the caveat that transportation costs will drop from their current rate of $1 million per kg ($454,545 per lbs) to $300,000 per kg (~$136,360 per lbs).

Metzger said: "We found that the cost of building a landing pad during NASA's Artemis program is quite affordable—about the same cost as a NASA Discovery-class spacecraft ($300M). That is a tiny cost compared to many other elements of a human spaceflight program. For that cost, the program will create the first permanent facility constructed on another world, and it will also deliver the construction robots to the moon, so they can begin doing other tasks like building human habitats."

The Artemis Base Camp. Credit: NASA

These estimates drop to $130 million if transportation costs could be further reduced to $100,000 per kg ($45,455 per lbs) or to $47 million if they fall below $10,000 per kg ($4,545 per lb). Ultimately, Metzger and Autry demonstrated that a lunar base could be built affordably, and the price tag will depend on the extent to which launch costs continue to decline in the coming years. These findings are of particular significance given the number of space agencies looking to build outposts in the South Pole-Aitken Basin in this decade and the next.

In addition to the Artemis Base Camp, the ESA plans to create a permanent base known as the International Moon Village. As a spiritual successor to the International Space Station (ISS), this base would accommodate rotating crews of astronauts, long-duration stays, and science operations on the moon. Not long ago, representatives of the Chinese and Russian space programs came together to announce a shared vision for a lunar base—the International Lunar Research Station (ILRS).

In anticipation of the coming age of lunar exploration, NASA and other space agencies continue to research technologies that will allow for cost-effective construction on the moon. This includes an ISRU manufacturing process known as Regolith Adaptive Modification System (RAMs) pioneered by researchers at Texas A&M University. This process is focused on providing early-stage infrastructure that would facilitate the transportation of sintering or polymerization equipment.

There's also a lunar lander concept under development by Masten Space Systems with support from the Institute for Advanced Concepts (NIAC), Honeybee Robotics, Texas A&M, and the University of Central Florida (UCF). This concept incorporates a process known as the in-Flight

Alumina Spray Technique (FAST), where a lander injects aluminum particles into its landing thruster nozzles to fashion its own landing pad, which also mitigates the problem of lunar dust being kicked up.

In this decade and the next, humanity will be returning to the moon, this time to stay. Not only will multiple space agencies be sending astronauts, but commercial partners will be enlisted to provide payload and crew transportation services. Lunar tourists and even settlers may eventually follow, leading to a permanent human presence and the first generation of "Lunites" (or "Loonies").

This multinational effort is fostering innovation across multiple sectors and leading to applications for life here on Earth. After all, if we're going to ensure that humans can overcome the ecological problem we face on Earth and live in space, it requires that we be inventive.

More information: Philip T. Metzger, Greg W. Autry, The Cost of Lunar Landing Pads with a Trade Study of Construction Methods. arXiv:2205.00378v1 [econ.GN], arxiv.org/abs/2205.00378

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