Overcoming the ”Tyranny of Water”
Using Electrical Power to Replace Rocket Fuel in Moon-wide Operations

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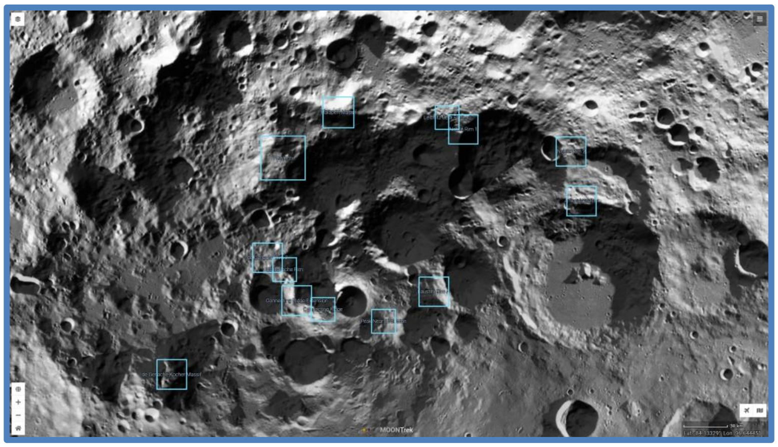
The Problem of Water Dependency

The progress of future lunar operations will be paced by the supply of rocket fuel that must either be transported to the moon or created there via mining and subsequent processing—either option involves high cost and daunting logistics. Many papers have been published describing the complexity and cost of lunar mining of water as a source of hydrogen and oxygen to supply rocket fuel. Even if successful, however, the needed lunar ice is only present in the perpetually shadowed craters near the South Pole (see Figure 1), a small fraction of the total area of the moon.



Courtesy of NASA

Figure 1. The Artemis regions near the South Pole.

This paper proposes an alternative solution—that intralunar transportation and low-mass moon-to-Earth transfers could be accomplished without rocket fuel by applying sustainable electrical power to centrifugal machines—with reduction in costs, risk, and complexity.

The centrifugal approach does not constrain the location of a robotic lunar outpost to a source of water; it can operate autonomously at any location on the front or back face of the moon. Networks of such outposts could be linked by centrifugal machines, to transfer cargo from anywhere on the moon to anywhere else, within a day.

The All-electric Centrifugal Propulsion Alternative

We suggest applying electromagnetic propulsion technologies to create the needed velocities without use of fuel. Using solar or nuclear power, we drive a rotary mechanism (Figure 2) to accelerate projectiles to the needed velocity to move them from place to place on the moon (Figure 3), or to bring cargo from the moon to Earth. The environmental and safety considerations of such lunar launch instead of rocketry are compelling.

This alternative does not achieve all that mining for fuel does. Namely, we cannot do any in-space maneuvering, only launch from the surface. We cannot, for instance, refuel lunar spacecraft. If. for one of these cargo missions. post-launch maneuvers are needed, the fuel for those must be part of the launched projectile and still supplied from somewhere. The centrifugal propulsion solution eliminates or mitigates fuel for some applications, but certainly not all.

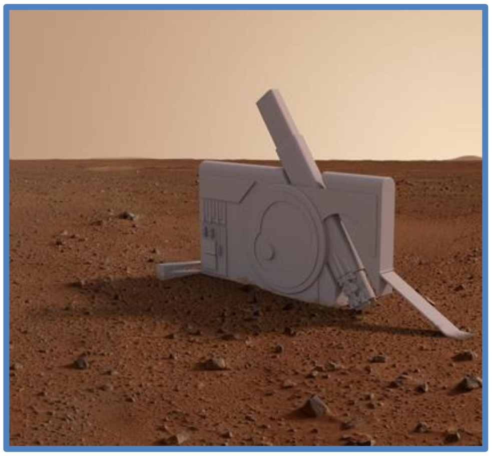


Figure 2. Artist's concept of a centrifugal propulsion device.

The use of centrifugal launchers equipped with the needed solar or nuclear power systems has attractiveness because it does not require expendables to propel and so no complex rocket fuel production and handling is needed. The common denominator of these missions is conversion of electrical to kinetic energy. The needed energy per launch is a function of the payload mass, the system electrical efficiency, and the velocity. The needed power is a function of the unit energy times the launch cadence. This process has been brought to a high level of efficiency by the electric vehicle industry.

Efficiency is measured at every step of the transformation process: from the transfer of electricity from the grid to the car (via a charging station or directly), to its transformation from alternating current (AC) to direct current (DC), to battery energy storage, through its reconversion into AC, and, finally, the efficiency of the mechanical motor itself. For electric cars, efficiencies of around 70 percent (electrical power input to kinetic energy at the wheels output) is considered normal. For our purposes, most of these steps can be eliminated, further increasing system efficiency. A multiparameter chart for such intralunar operations is shown in Figure 3. The "wrap-around" quad chart shows the relationships among the primary parameters for launches occurring once per hour:

- Upper left – Solar Array Size versus Output Energy (at 25 percent efficiency)
- Upper right – Launch Velocity versus Output Energy
- Lower right – Launch Velocity versus Flight Distance
- Lower left – Flight Time versus Flight Distance

The orange, red, and blue lines show parametric connectivity for flights of 500, 1000, and 1500 km.

Flights occurring at rates of more or less than once per hour and payloads more or less than 25 kg can easily be extrapolated from the charts.

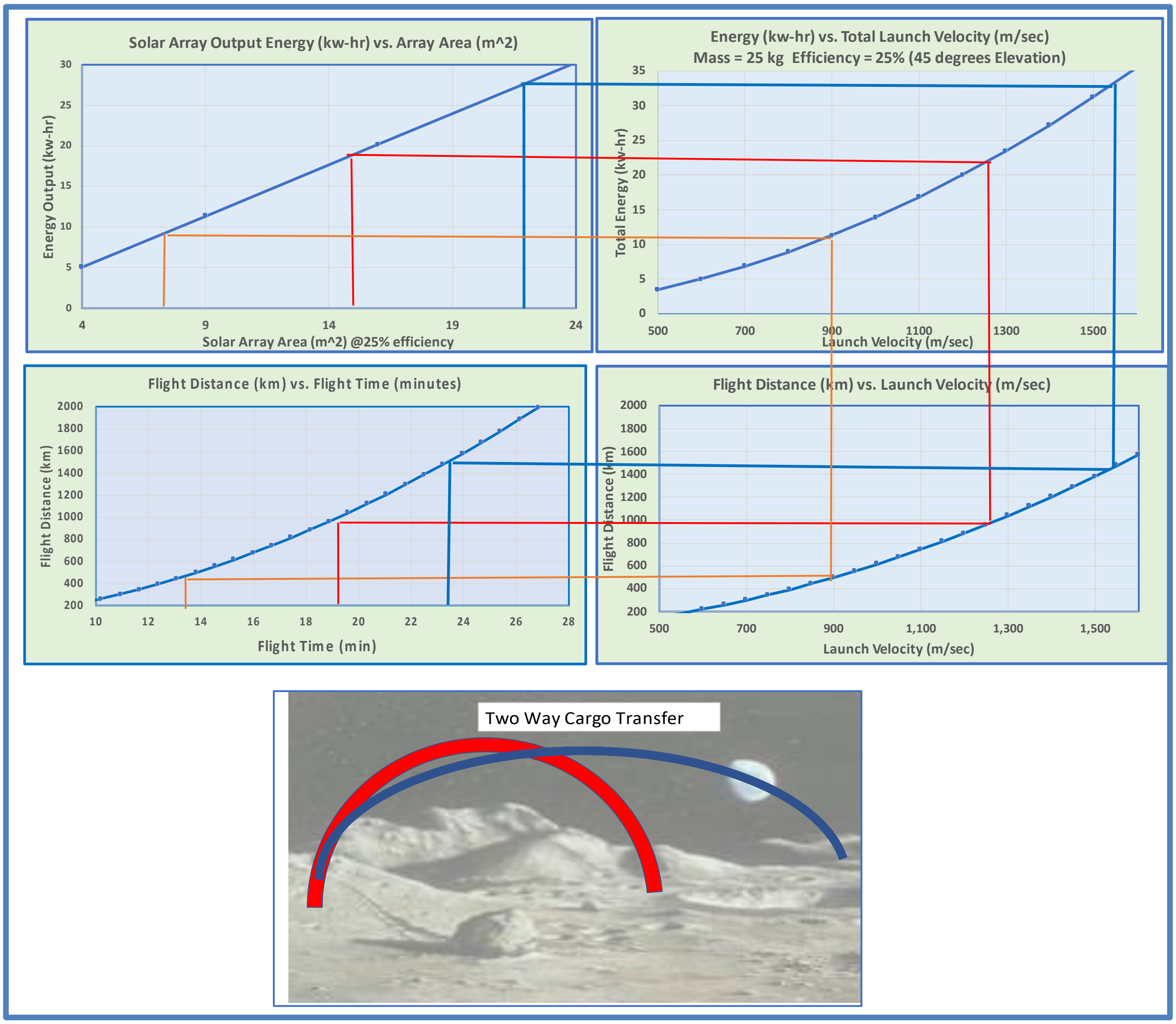


Figure 3. Representative parameters for 25 kg projectile vs. flight distance.

A solar power supply (with 25 percent efficiency) is illuminated for half of the 28-day lunar cycle anywhere on the moon. The figures assume a 25 percent efficiency in converting battery-stored power into kinetic energy. For operations during the 14 Earth-days lunar night, we either use a nuclear power source instead of solar cells, or include storage batteries. The typical weight for electric vehicle automobile lithium-ion storage batteries is approximately 30 kg/kw-hr. The chart shows that each launch of a 25 kg payload at a 1,500 km range requires 750 kg of batteries. Improving the conversion efficiency from 25 percent would reduce the battery weight accordingly.

To allow continuous operations, not dependent on the sunlight cycle, we can use a nuclear power system. Figure 4 illustrates a candidate nuclear power source being developed by NASA—this would eliminate the need for large batteries for lunar night operations.

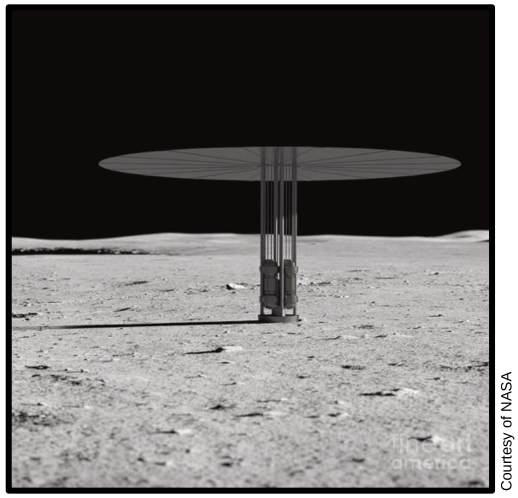


Figure 4. Alternative to solar arrays—NASA image of 40 kW lunar nuclear power generator.

Of course, “What goes up…,” so there has to be consideration of the landing dynamics—the launch velocity at 45° elevation will be identical to the landing velocity (assuming the same surface altitude). So, we postulate adaption of the classical trampoline (Figure 5), sized to accommodate the likely landing dispersion ellipse (perhaps 0.1 percent of the flight distance) to provide a soft landing.

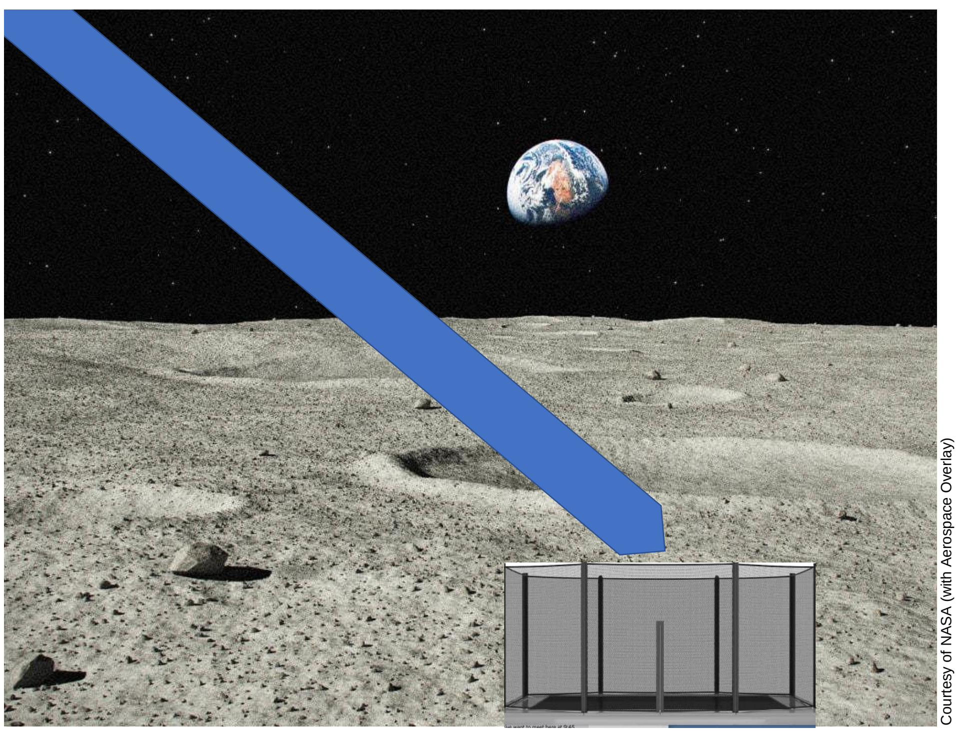


Figure 5. Trampoline concept for the landing zone.

This leads to consideration of incremental placement of stations to form the “Lunar Express Cargo Transportation Network”—"LunEx.” Each network node would contain a kinetic launcher, its power supply, a landing mechanism, and the robotics to collect incoming cargo and rapidly pass it on the launcher for onward transfer. The maximum interstation distance would be about 2,000 km to not exceed lunar escape velocity of about 2.5 km/sec.

In our example (Figure 6), we postulate major stations at 1,500 km distance and perhaps minor stations, as needed, for closer range support. As seen in Figure 3, for 1,500 km distance, the flight time is about 0.5 hours—so if the in-station transfer took another half hour, the cadence of launches could be about an hour (power dependent). As the lunar circumference is approximately 11,000 km, the maximum separation between a station sending cargo and one receiving it would be about 5,500 km, requiring some 4 hops of 1,500 km each. Such a network could therefore deliver cargo from any station to a distant station in less than 4 hours.

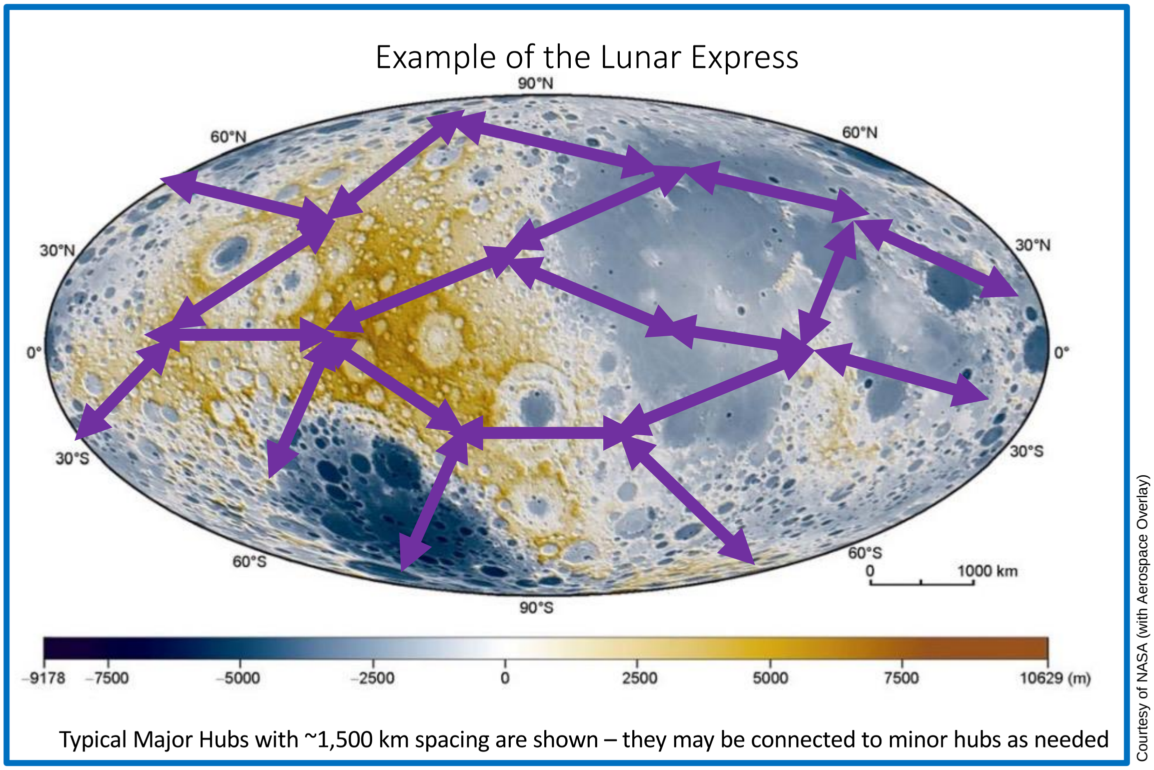


Figure 6. Hypothetical lunar express network of stations and links.

Flights from the Moon to Earth

We modeled notional flights to understand the geometric and time-related possibilities and constraints of moon-to-Earth transfers via centrifugal launch. For an arbitrary departure date, a transfer from the near side of the moon will require approximately 2500–2700 m/sec and about 3.7–5.7 days to deliver cargo to an arbitrary location on Earth. For different departure epochs and locations, and Earth landing locations, the departure vector (DV) numbers are all pretty much the same.

The major difference is in time of flight (TOF), which ranges from 3.7 days to 5.7 days, depending on launch site, epoch, and landing location. The higher latitudes require slightly higher DV than the equatorial landing sites, but the differences are relatively small (less than about 100 m/sec).Targeting different longitudes requires more or less only a shift in the TOF (there is also a small change in the DV).

These observations, combined with a preliminary investigation of other latitudes, gives confidence that these results will hold for "arbitrary" landing locations on Earth**.** Launches from the far side fall in line with these results. The TOFs tend to fall toward the higher end of the TOF range, but still in family with the near-side results.

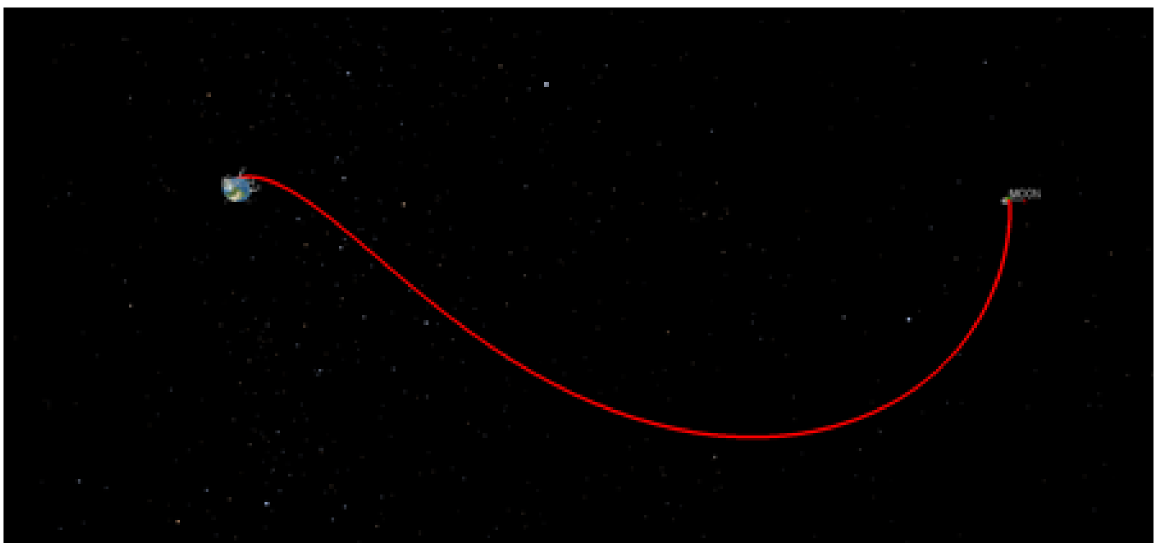


Figure 7. Moon to Earth trajectories.

It should be noted that these notional trajectories, such as illustrated in Figure 7, do not account for any trajectory correction maneuvers, or powered flight to ensure safe entry, descent, and landing at the desired location on Earth. Such maneuvers are likely to be required and cannot be directly supplied by the centrifugal launch system, and thus the cargo modules will likely need some form of onboard propulsion system.

Getting There

The first step in implementing the concept would be the landing and installation of the rotating propulsion system and power supply at a lunar site. The power system must energize the batteries that will power the centrifugal system.

It may be possible to take advantage of the lunar landing projects of NASA and commercial enterprises to conduct a “ride share” proof-of-concept flight test. We would land a prototype spinner power supply and launch test objects in multiple directions over distances of approximately 100–500 km (requiring less than 1 km/sec). This would allow measurement of the system characteristics, validation of technical maturity, and calibration of landing point predictability. Success would lead to deployment of larger devices capable of reaching lunar escape speed of 2.5 km/sec, as well as deployment of such devices at remote sites.

Courtesy of SpinLaunch

Figure 8. The SpinLaunch Inc. prototype.

Lunar escape velocity has already been achieved by the ground-based prototype (Figure 8) built by SpinLaunch Inc. as a proof of concept for launching payloads from Earth into low Earth orbit. The Earth-based mechanism must operate within a strong structure to spin the heavy rotor and its balancing counterweight within a vacuum chamber—this complexity and expense would not be needed on the moon.

Further simplifications come from the elimination of the mass and complexity of the aerothermal protection of the payload needed during Earth operations. The payload shape can therefore be optimized for all-vacuum operations. For Earth-based operations, a projectile mass of several thousand kilograms is needed to launch an approximately 200 kg satellite into low Earth orbit. By comparison, to launch a 10 kg payload from the moon corresponds to a weight ratio of 10**e**-3. This weight ratio makes the mechanical system small enough to build on the moon and reduces the needed power per launch by the same factor.

Conclusion

The use of rotational kinetics to create a network of cargo distribution stations across the moon, without dependence on water, is an intriguing concept. We offer these ideas for further consideration, to develop modeling and concept designs, and to speed the pace and reach of the ARTEMIS program in exploration of the entire moon. We are grateful to SpinLaunch Inc. for their innovative work and contributions to this paper.