Beyond Chemical Rockets

John Kormylo

The amount of reaction mass needed to achieve a specific ΔV increases exponentially by the ratio of the ΔV to the rocket exhaust velocity. The exhaust velocities achieved by chemical rockets are considerably less than orbital velocity, which is why the fuel/payload ratio is so high for chemical rockets.

This also means that increasing the rocket exhaust velocity will exponentially reduce this figure. However, the energy needed to increase exhaust velocity also increases. Specifically, thrust is given by $F = mv$ for velocity v and mass flow m, and power is given by $P = \frac{1}{2}mv^2 = \frac{1}{2}Fv$. So for an exhaust velocity of 10 kps, 1 lb of thrust requires 2.27 kilowatts.

Nuclear and laser rockets are still thermal rockets, and are ultimately limited by the melting point of the engines. The main advantage of a nuclear rocket is that it uses hydrogen as its reaction mass. Because of its lower molecular weight, hydrogen will have a much higher exhaust velocity than any other gas starting from the same pressure and temperature (about 3 times higher than H_2O). Since nuclear rockets run cooler than chemical rockets, the actual advantage is much less.

The idea of firing a laser up the exhaust nozzle of a rocket engine is not well thought out, since it basically requires that the reaction mass be opaque inside the engine and transparent outside (not to mention the trajectory limitations). OTOH, attaching a laser target/heat exchanger to the side of a rocket would have all the advantages of a nuclear rocket with less weight.

For even more significant improvements, I prefer a microwave powered linear induction motor.

A very large phased array could more than equal the aiming and focusing power of a laser. The rocket would have a relatively large (compared to the shuttle) delta wing which doubles as the rectenna array. This means that bottom (or top) of the wing must consist of a nonconducting material (into which the rectenna array is embedded) in addition to the heat shields.

One approach would be to place a series of power stations in a remote arid environment (like Australia). A better solution would be to use a power satellite, since it is easier to beam microwaves down through the stratosphere then up through the troposphere. One satellite could replace many ground stations.

One could tile the entire rectenna area with bow-tie antennas. For each antenna one needs 4 diodes and a capacitor (or 2 of each). The main problem is that most of the energy will be absorbed by the diodes if the antenna voltage doesn't reach 0.7 V. It might be possible to use RF transformers to step up the voltage and/or combine the output of several antennas.

Mercury would be an ideal reaction mass if it were not expensive and toxic. About the only good conductors which are nontoxic are iron and carbon, but a mechanical loader is a disaster waiting to happen. On the other hand, water will conduct electricity at microwave frequencies. The current may consist of asymmetrical molecules spinning in place, but it still counts.

A frequency of 2.45 GHz (12.2 cm wavelength) with a coil spacing of 1 cm gives a phase velocity of 1.72×10^8 m/sec, which vastly exceeds any realistic exhaust velocity. If it works at all, it will work for any velocity, even with a constant coil spacing.

The force on a conductor in a moving magnetic field is proportional to the magnetic field strength and the relative velocity, and inversely proportional to the electrical resistance of the conductor. Increasing the numbers of turns in the coil/antenna will not increase the magnetic field strength for a given voltage, It will however reduce the amount of power wasted heating the coil.

The biggest problem will be keeping the reaction mass away from the walls at hypersonic speeds. Mostly this means putting a nozzle in the supersonic region and expanding the diameter faster than the shock wave.

A lunar lander is another good application for a linear induction motor (LIM). If the goal is to mine the moon for rocket fuel, one wouldn't want to waste it just getting it into orbit.

Lunar orbital velocity is about 1700 m/s. The ideal trajectory for landing follows three simple rules. The thrust vector should always point in the opposite direction from the velocity vector. The velocity and altitude should both reach zero at the same time. And since the control rule requires being able to throttle up, the nominal trajectory should be based on less then the maximum thrust.

A low thrust/weight ratio will require a higher starting altitude in order to provide enough time to slow down before reaching the surface. If the starting altitude is too low, one can thrust directly upward before starting the descent. You will have to thrust upward at some point, and the best time is while you are still in orbit. If the starting altitude is too high, one can reduce the orbital velocity horizontally until the altitude is low enough for a normal landing. If the horizontal velocity goes to zero first, one may have to coast for a while.

The ideal launch trajectory is basically a mirror image of the ideal landing trajectory.

The first step in using linear induction motors is to move a power satellite near the lunar L1 lagrange point. While L1 is an unstable equilibrium, there are stable orbits near it. Being directly in line between the moon and the earth, L1 would remain in sunlight except during lunar or solar eclipses. And while the best location for many lunar orbital maneuvers is on the far side, one should be able to achieve the same effect with two burns, one before and one after occultation. Ideally one would put at least 3 power satellites closer to the surface, but one near L1 will do.

Unfortunately, the exhaust from a linear induction motor would probably cause the regolith to explode, so the actual landing will require separate chemical rocket motors. One will also need smaller rockets on the corners for attitude control and orbital rendezvous and docking. With the rectenna array, one could use electrically powered turbo-pumps. The point where one switches to the chemical rockets depends on just how destructive the LIM exhaust is.

One would like to have the crew compartment and cargo as close to the ground as possible, although a low center of gravity makes a missile difficult to control by gimbaling the engine. To this end, I propose landing the vessel on its side relative to the linear induction motor. Placing the reaction mass tank at the center of gravity, one could put chemical rockets fore and aft of this tank and the fuel and oxidizer tanks nearby. The landing rockets would be gimbaled mostly to keep the thrust pointed down. The LIM should be far enough from the center of gravity to gimbal for control.

One option is to keep the LIM exhaust pointed away from the surface. Note that at 20 km altitude (for example) the edge of the moon is about 8.6 degrees below horizontal. As the landing proceeds, the velocity vector will start to point down and and the altitude will decrease until the exhaust points at the visible horizon. When this happens one can start the landing rockets, making sure they point directly downward. One can keep the thrust vector pointed correctly while decreasing the pitch angle by gradually increasing the thrust of the landing rockets, then decreasing the LIM thrust.

It should be mentioned that the crew compartment will be facing the wrong way during landing. One will need a downward facing camera for the navigation computer anyway. Besides, you really don't want human pilots trying to land the thing.

To handle a variety of possible landing locations, the rectenna arrays should be mounted on articulated arms. The orientation of the rectenna array should remain relatively constant, although it may be necessary to move the arms to keep the center of gravity aligned with changing thrust vector.

Lastly, I would land on wheels instead of pods. One will need a good suspension system either way, one **not** using crushable materials. Since landing and launching throws debris all over, a permanent installation would be located some distance from the landing area. Having the entire vessel move will greatly simplify the unloading and loading of crew and supplies. Besides, driving a vessel on the ground is something a human pilot can do better than a computer, making the crew feel less like cargo.