

Essentially Free: Shipping from Asteroids, Moons and Planets to Earth

Darrin Taylor
Outer Space Colonization
outerspacecolonization@gmail.com
ISSC 2018



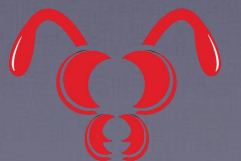
Thank you

- Thanks to Dr. Alessandra Babuscia
- Thanks to the acceptance committee
- Thanks to listeners for your patience



The Problem Statement

- Can vast wealth be created from space? (YES!)
- Current Shipping prices are too high.
- Essentially free Shipping would revolutionize space transit.
- Although technically difficult, the physics does not prohibit extremely low cost shipping in space.



Fuel is the enemy

- In space velocity is used to overcome the acceleration of the sun's gravity and $Acc=V^2/R$ gives us the amount of velocity in m/s we need to overcome the sun's gravity between two points.
- As such delta-V tells us how "far" we can go against the sun's gravity.
- For a given delta-V that requires 50% fuel we can say that traveling n * delta-V will require $(2^n) * 50% * \text{ship mass}$
- $n=1$: 1 kg fuel per 1 kg ship; $n=100$: $10E29$ kg fuel per 1 kg ship.

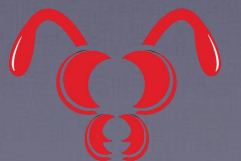


Reusable Reaction Mass



Background Talks

- ISSC 2016 Proposed Transferred Momentum Technique using Solar Sail Spacecraft as “fuel” for 2nd Space craft so Fuel is reusable and never consumed.
- ISSC 2017 Using transferred momentum it is possible to transit to Mars outside the Hohman Transit window on any arbitrary day at similar “fuel consumption” although with massive start up mass requirements. ~E15 less fuel.
- Mars Society 2017 Free Shipping with your order. Exploring free and low cost shipping from Mars surface to Earth using Transferred Momentum and coilguns.



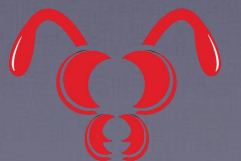
How to get out of a gravity well without using fuel

- Mass Drivers
- Lasso
- Space Elevator
- Tether
- Nuclear explosion



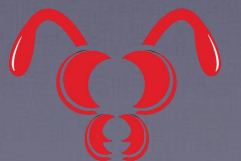
Mass Drivers and Coilguns

- This is essentially a solved problem
- NASA proposed a large expensive Mass Driver on the Moon capable of launching tons of mining material
- Consider a coilgun with multiple stages for Mars to fire <1 kg pellets to space at $>5\text{km/s}$. This is also a solved problem for pellets of $\sim 2\text{g}$ using less than 5 cm track. Mars would need larger pellets or higher velocity.



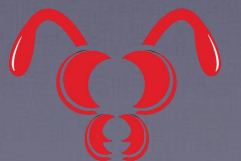
Overcoming Escape Velocity

- Martian escape velocity outside orbit is 5.03km/s
- Current railgun technology can fire a Military multi kg projectile at ~2km/s
- 0.1g projectiles have been fired to 16 km/s by (Sandia NRL) and 1.6 kg has been fired to 3.3 km/s (Maxwell Laboratories) [source powerlabs.org]
- “In 1978, Bondaletov in the USSR achieved record acceleration with a single stage by sending a 2-gram ring to 5000 m/s in 1 cm of length” (Coilgun in Wikipedia.com)



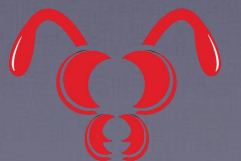
Rough Estimate of Energy

- A Coilgun or Railgun type massdriver can be built on Mars using today's technology that could Send a 1 kg metallic mass to escape velocity would require on the order of 100 MegaJoules per kg to escape velocity
- Using Martian sourced materials such as Mechanical flywheels and inductors instead of capacitors this could grow to 360 MJ per kg.
- A 1 MegaWatt solar array could launch 1 Kg every 6 minutes of sunlight.
- Inductor array of 1.5 Farad with 10,000 Amp pulses could provide 150 MegaJoules sufficient for 66% energy transfer to mass driver.
- Mechanical Flywheel system that is ~50% efficient could store 360 MJ over 6 minutes and deliver to inductor array



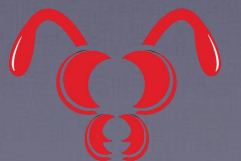
Lasso the moon

- A Motor with 4 arms each 10-100 meters in length may be able to cast objects into space using a Lasso type motion to escape Lunar 3 km/s escape velocity
- 10 km long Lasso would have 91 Gs and 17-18 m droop
- 50 km long Lasso would have 18 Gs and 436 m droop
- 100 km long Lasso would have 9 Gs and 1742 m droop
- 1000 km long Lasso would have 1 Gs and 174 km droop. The curvature of the moon with radius 1737 km means the moon falls away at distance and this is possible in theory.
- This is roughly 1/3 to 1/2 the stress load of the Earth space elevator concept



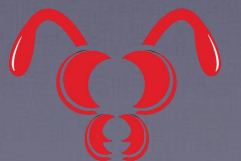
It gets better...

- Most objects in the solar system that lack atmosphere are smaller than the moon
- Shorter lasso could be used and because a smaller delta-V is needed to escape velocity the Acceleration could be much less
- Any Solar Sail Spacecraft that could be manufactured on a moon or asteroid could potentially be launched for very reasonable price



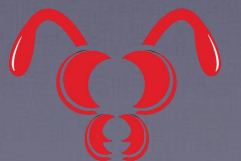
Catching the cargo

- Ideally the cargo would be fully functional solar sail spacecraft capable of self auto-navigating and docking in space as needed for Transferred momentum.
- It is much more difficult to create all the systems to catch projectiles in space than it is to make spacecraft



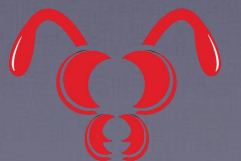
Technology to catch space projectiles

- Spacecraft(s) of similar orbit would be needed to shadow the launched piece of metal and apply ping radar or ping lidar to the cargo and locate its true orbit
- The spacecraft would then need to match this orbit and interact magnetically or electro-dynamically with the cargo so that they are following very similar orbits
- A magnetic harpoon with friction on the out cast may allow for reasonably simple non fuel docking



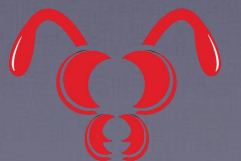
Lower mass limits

- The initial mass to set up a mass driver for solid pure metallic objects is on the order of 100 Metric Tons
- This system could be able to deliver >5 metric tons per year to escape velocity
- Locally sourced solar energy collection, flywheels, inductors and even explosive switches are possible for future iterations.



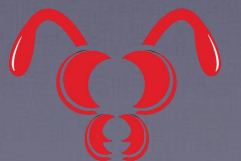
Cheap Transits

- (Slow) Solar Sail Transportation doesn't consume any reaction mass and will allow "Free" transits because nothing is consumed. Presently 2 Thrust Errors
- Single Use is obvious. Jet fuel is ejected as gas never to be reusable by humans. But reuse reaction mass 10 times and the average cost is 10 times less.
- Un-Carried is more powerful but less obvious. The tyranny of the rocket equation is a byproduct of carrying reaction mass.
- If one delta V costs \$100/kg a delta V 10 times greater isn't \$1000/kg but rather \$100¹⁰/kg
- That's \$100,000,000,000,000,000,000 / kg! Carrying Reaction (Mass) Costs \$
- Finally Aero braking and parachute entering Earth's atmosphere can eliminate the need for a costly rocket on the LEO to Earth surface portion of the journey



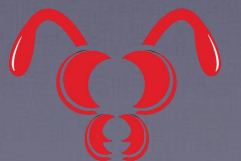
Free Solar Momentum

- Between Venus and Mercury a solar sail can amass 500km/s of delta V in 30 year life. This is equivalent to $>70,000$ s Isp if you consider half mass as cargo and half as sail.
- Transferred momentum uses solar sail powered “baseballs” as reaction mass for a “Pitcher” as a way to transfer the delta V earned by solar sails to a spacecraft with higher acceleration.
- The “Pitcher” ejects “baseballs” at 900 to 2700 km/hr for delta V (25.5s Isp to 76.5s Isp)
- The “Pitcher” picks up different “baseballs” every 100 m/s of delta V. The pickup is just docking in space like the ISS has done many times. Both the “Pitcher” and the “baseballs” are spacecraft. Matching up orbits is technically challenging but possible.
- After being pitched the “baseballs” extend their solar sails and use the sun’s photons to navigate to the correct position and velocity for a different “Pitcher#2” to pick them up for transit. Because they are spacecraft they can achieve essentially any orbit.
- Two 80 km/s one way Earth to Mars or Mars to Earth transits each taking 9.39 Months could be achieved for total of 800 kg of Baseballs per kg of dry mass.



Lunar or Martian PV

- The initial cost and mass requirements to set up a mass driver or Lasso are affordable
- Mars/Moon will be able to transport that Mass to Earth surface with minimal losses of reaction mass. 2-3 kg consumed for 1 kg delivered to Earth
- Once that mass is in Low Earth Orbit it will compete with SpaceX for a market that is currently >\$2,000 per kg at 5 metric tons/year per 100 metric ton system
- Early digital and LEO supply revenue of \$1B Earth dollars/yr should increase Mars PV \$50B
- Correct estimates of the PV of Moon/Mars should fall between \$65B-\$700B @ 2-3% ROR
- Colonies below this PV will be profitable



Questions

- Contact info for Outer Space Colonization
- outerspacecoloniztion@gmail.com
- outerspacecoloniztion.com
- Twitter [@spacecolonize](https://twitter.com/spacecolonize)

