

A New Method of Space Travel Optimized for Space Tourism and Colonization

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Abstract. High costs associated with expendable rockets are stifling the development of permanent space colonies. A new method of space travel is presented that enjoys significantly increased performance and reduced cost relative to competing concepts. Based on recycling the kinetic energy of an arriving spacecraft, up to 200 MW of average electrical power is generated and sustained for 2 minutes, and is immediately applied in launching a departing partner spacecraft. The resulting required delta vee for a round trip between low Earth orbit (LEO) and geosynchronous orbit (GEO) drops from 7.6 km/s to 0.54 km/s when 3 recycling stations with an 80 % energy coupling efficiency are used to exchange kinetic energy between 8 partner spacecraft transiting the same route. This method is well suited for round trip high volume space travel such as space tourism traffic to LEO, lunar orbit, and beyond. As the kinetic energy of an arriving spacecraft is the power source for launching departing spacecraft, nascent lunar colonies can electrically launch 26,000 kg payloads long before sustained 100 MW level power supplies become locally available. A pair of recycling stations at an orbiting space colony construction site provides a resource of net impulse, net torque, and electrical power to the colony irrespective of the contents of the arriving payloads. Kinetic energy recycling technology, configuration, operations, and near Earth applications are described.

Keywords: CataMitt Recycler, Space Transportation, Space Tourism, Space Colonization.

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INTRODUCTION

On July 4, 2005 NASA's Deep Impact spacecraft struck within 50 m of an aim point on a comet 130 million km from Earth (Dornheim, 2005). With a closing speed of 10.2 km/s it delivered 19 GJ of kinetic energy to the comet in the name of science (Fig. 1). This mirrors a similar capability demonstrated by the U.S. military two decades earlier. On June 10, 1984 the Homing Overlay Experiment interceptor struck a dummy InterContinental Ballistic Missile that had been launched from Vandenberg Air Force Base (Parsch, 2005). The closing speed was 6.1 km/s. Neither target provided guidance aides or course correction maneuvers to the approaching vehicle. The space transportation method presented here is a spin-off of this demonstrated technology, transforming hit-to-kill systems into a hit-to-deliver space transportation system. Hit-to-deliver guidance accuracies measured in meters at orbits eventually extending beyond the Moon is the first necessary condition for kinetic energy recycling to be viable, coupled with the reasoned courage to fly valuable spacecraft through the portals of a kinetic energy Recycler at relative engagement speeds from 100 m/s to 1.5 km/s.

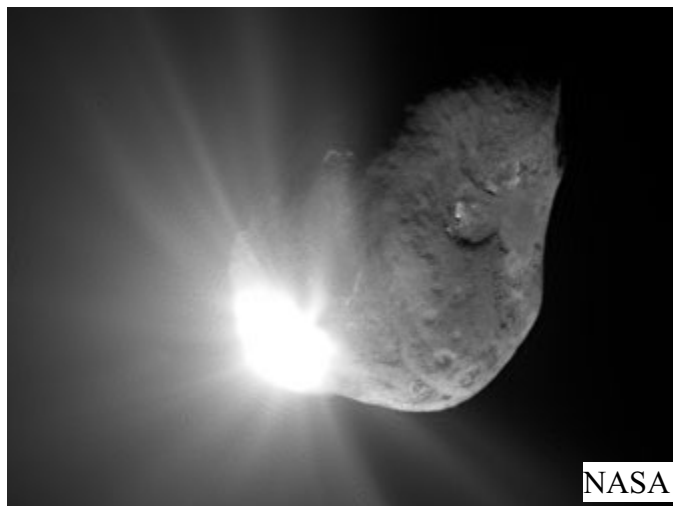


FIGURE 1. Hit-to-Kill Guidance Accuracy Typified by Deep Impact Lays the Technology Foundation for Hit-to-Deliver Space Travel.

Directly transferring kinetic energy from one spacecraft to another by purely mechanical means is impractical. Instead, the kinetic energy of an arriving spacecraft is converted into electrical energy using a highly efficient process common in the electric automobile industry named regenerative braking (Pirie, 2003). Electric motor/generator assemblies ring all Recycler portals. Generators mechanically couple to an arriving spacecraft as it passes through the portal(s). The inertia of the arriving spacecraft draws magnets through coils of wire, producing electricity at the expense of kinetic energy. High temperature superconducting electrical conduits transfer the generated electricity to the launch portal(s) of the Recycler, where motors immediately launch a departing partner spacecraft. The braking or launching distance for a given spacecraft can extend over 100 km, making it impractical to launch a partner spacecraft in line with an arriving spacecraft. To prevent a net torque from being applied to the Recycler, one of the two spacecraft arrives or is launched in a split configuration that later reconnect before arriving at the next Recycler. Figure 2 schematically illustrates the kinetic energy recycling process.

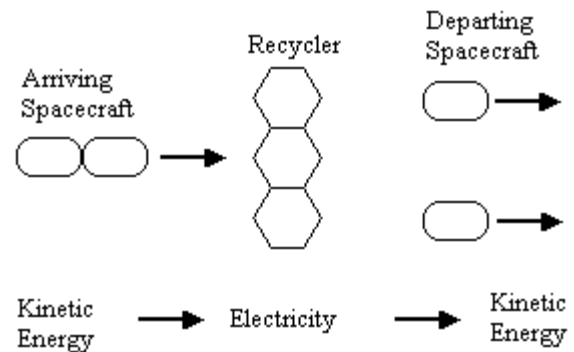


FIGURE 2. Spacecraft Energy Recycling Schematic Includes Two Highly Efficient Energy Conversions.

Nominally six tethers mechanically couple each of the two partner spacecraft to a Recycler over distances many times greater than the physical thickness of the Recycler. The choice of tether material limits the maximum delta vee rating of a Recycler. With a characteristic velocity of 1.6 km/s (Sorensen, 2001), Spectra 2000 fiber is suitable for engagement speeds to at least 0.4 km/s. At 0.6 km/s Recyclers should upgrade to carbon nanotube tethers to prevent the required tether mass from becoming impractically large. The maximum engagement speed used here is 1.5 km/s.

A Recycler has moving parts that participate in each engagement. An estimated total of up to 6,400 kg of mass must be put into motion at the center portal of a Recycler before an engagement occurs, corresponding to 7.2 GJ of kinetic energy. A Recycler normally pulls an interface plate up to the engagement speed of an arriving spacecraft. If an empty interface plate is pulled at 5 Gees to 1.5 km/s, the required power output level is 81 MW. These mechanical energy and power requirements constrain the choices for an electrical energy storage system for use onboard a Recycler. Superconducting Magnetic Energy Storage (SMES) rings form the primary energy storage system on a Recycler. Flywheels collocated with the tether spools are used as an independent backup energy storage system.

These disparate elements – hit-to-kill guidance accuracies, regenerative braking, high temperature superconductors, carbon nanotube tethers, low temperature SMES rings, and flywheels – form the basis of kinetic energy recycling technology. When blended together into a space transportation system, they provide a given spacecraft most of the benefits of employing an upper stage at a destination orbit without the mass penalty normally associated with bringing along fuel or engines to use that upper stage. As a result, the delta vee required for orbit transfers can drop by an order of magnitude, operations costs can drop by a factor of five, transit times can potentially beat Hohmann transfer times, all while enjoying accelerations no greater than one Earth gee. In this paper a baseline hardware configuration is put forth, orbits and operations are described, and sample performance calculations are modeled.

HARDWARE CONFIGURATION

Recycler portals are designed as six sided structures, with the length of each side set to 22.15 m. The clear radius of each portal is 17.6 m to permit positional errors up to +/- 9.5 m for External Tank (ET) sized spacecraft coasting through the portal. The distance from the center of one portal to the center of an adjacent portal is set to 136 m. Pairs of ETs docked at rotating subassemblies mounted about both the y and z axes of a Recycler compensate for torques induced by positional errors of arriving spacecraft. The ETs can be jettisoned as a means of shedding excess angular momentum from the Recycler. In general, minimizing positioning errors means minimizing wasted kinetic energy.

The reference mass of an arriving spacecraft is set to 26,330 kg – the mass of an empty lightweight space transportation system ET. When split, each half of the reference mass nominally is 13,165 kg. Each half of the reference mass is adequate for a passenger canister accommodating 12 tourists plus a crew of two for up to four days. Generally the two halves of a given spacecraft share only a common destination and the capability to couple and decouple in transit. Figure 3 illustrates one spacecraft consisting of two passenger canisters coupled together.

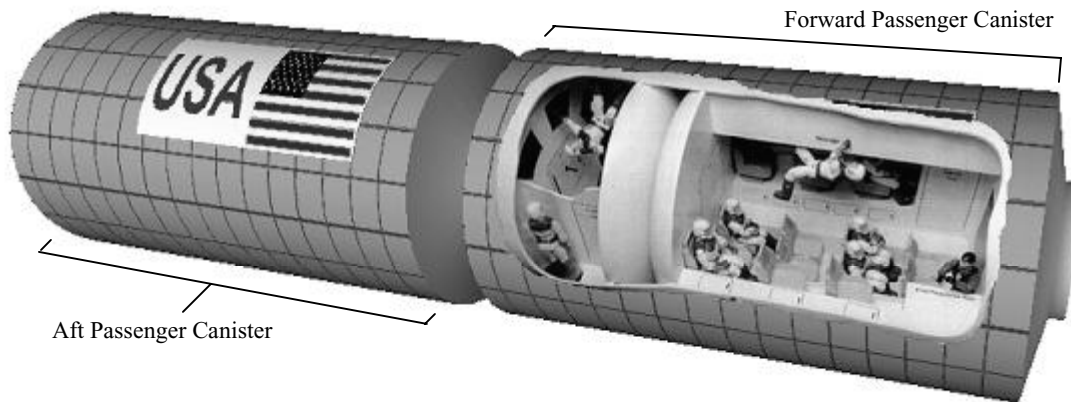


FIGURE 3. A Single Spacecraft Generally Consists of Two Separable Components Such as These Two Passenger Canisters. Canister Interior Image Courtesy Claremont McKenna College.

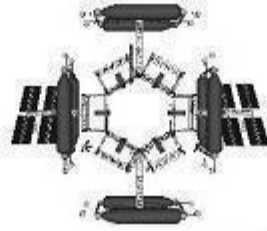
With the reference mass of a spacecraft set to 26,330 kg, and an engagement speed of up to 1.5 km/sec, the amount of kinetic energy delivered to a Recycler can be as high as 30 GJ. The amount of braking force applied is a design variable; a baseline value is to accelerate the participating spacecraft at one Earth Gee (9.81 m/s^2). The amount of time required to brake to rest an object with an initial velocity of 1.5 km/sec with an acceleration of negative one Gee is 153 sec. The corresponding average output power level over this time span is 190 MW. In comparison, the solar arrays aboard a completed International Space Station will generate a total of 74 kW of usable electrical power.

An arriving or departing spacecraft might be equipped with the six eyelets required to connect with the grappling hooks located at the ends of the tethers deployed from the Recycler. For all other spacecraft, an interface plate is required. A center portal interface plate sized for the reference mass has an estimated mass of 1,500 kg (Turek, 2004). Outer portal interface plates carry only half the load of a center portal interface plate. The corresponding estimated mass of each outer portal interface plate is 830 kg. Either the center portal interface plate or both of the outer portal interface plates must be brought up to the engagement speed of the arriving spacecraft before it arrives. In addition, the tethers deployed from the Recycler will necessarily also be spun up to the arriving spacecraft's engagement speed. The spools that hold the tethers also are required to spin at the engagement speed of the arriving spacecraft before it arrives. Moving parts associated with the departing spacecraft must also be managed.

The material choices of the tether spools ringing each portal drive the minimum diameter of the tether spools. For an engagement speed of 0.4 km/s and a tether spool material that includes steel (allowing the tether ends to electromagnetically clamp to the tether spool), the minimum radius of a tether spool is just under 4 m. Adding a flywheel to the tether spool assemblies allows several functional components to be physically collocated in the same housing. Thus, the spool structures ringing Recycler portals each contain an acceleration tether and a regenerative braking tether, tether spools, a flywheel, a motor/generator assembly for converting between kinetic energy and electricity, and the terminals of electrical conduits for transferring electricity between portals. A 4 m spool structure radius matches the radius of an ET, implying the spool structure could be launched into space as a complete unit. The minimum spool structure radius for an engagement speed of 0.6 km/s is 10 m and requires the advancement of space based assembly capabilities. The spool structure radius for an engagement speed of 1.5 km/s is 50 m.

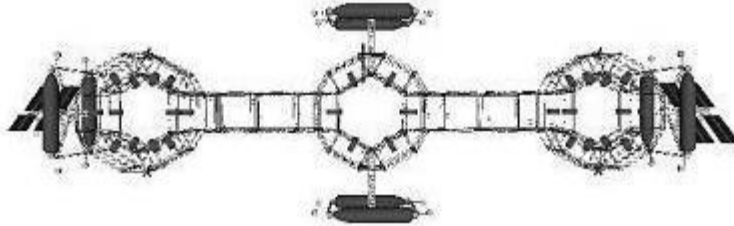
The mass of a CMR315 Recycler (rated to 1.5 km/s) is estimated to be 360,000 kg, excluding the ETs docked to it for torque management. A rough-order-of-magnitude development and production cost estimate for six CMR315s spanning from LEO to Lagrange point 5 (L5) orbit is \$64 billion in FY 2004 dollars. It may be possible to hinge and fold a portal structure (excluding spool structures) into a single heavy lift payload that springs open when deployed.

The Recyclers featured in this paper contain features suggestive of catapults of Roman military fame (with respect to departing spacecraft) as well as a Catcher's Mitt in baseball (with respect to an arriving spacecraft). Hence, these Recyclers are referred to as CataMitt Recyclers (CMR). Three dimensional models of CataMitt Recyclers have been generated using Satellite ToolKit (STK) software provided by Analytical Graphics, Inc, and are shown as Figure 4.

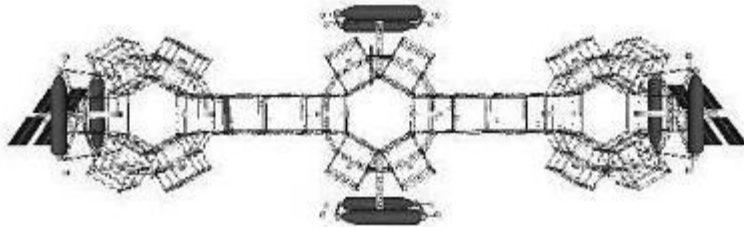


(a) CMR104 with One Portal and 0.4 km/s Maximum Engagement Speed.

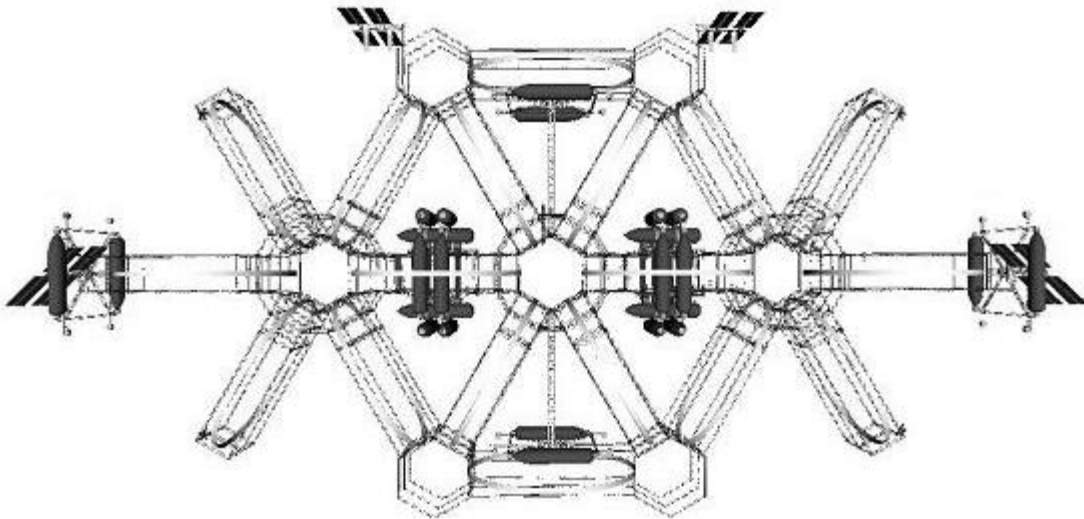
136 m



(b) CMR304 with Three Portals and 0.4 km/s Maximum Engagement Speed.



(c) CMR306 with Three Portals and 0.6 km/s Maximum Engagement Speed.



(d) CMR315 with Three Portals and 1.5 km/s Maximum Engagement Speed.

FIGURE 4. CataMitt Recycler Models CMR104, CMR304, CMR306, and CMR315.

OPERATIONS

Favorable results are predicated on a judicious choice of Recycler orbits and matching transfer orbits. Table 1 lists a set of orbits that work well with a CMR315. MEO refers to Middle Earth Orbit, TLI is Trans Lunar Injection, T5I is Trans L5 Injection. Elliptical transfer orbits intersect a circular Recycler orbit at perigee. The transfer orbits overshoot the next higher orbiting Recycler, intersecting the higher Recycler orbit twice. All orbits are synchronized to allow multiple opportunities for an engagement at both ends of each transfer orbit. The five orbits spanning from LEO to GEO repeat on a six day period. The values listed are based on an Earth point mass, ignoring perturbations.

TABLE 1. A Set of Circular Recycler Orbits and Elliptical Spacecraft Transfer Orbits from LEO to L5 Orbit.

Orbit Label	Orbit Type	Orbital Period (hours)	Engagement Delta Vee at Higher Intersection (km/s)	Flight Path Angle at Intersection (degrees)
LEO	Circular	1.6	1.293	0.
LM_Trans	Elliptical	3.2	1.356	+/- 12.24
MEO	Circular	4.8	1.223	0.
MG_Trans	Elliptical	14.4	1.201	+/- 20.8
GEO	Circular	24.0	1.061 (TLI) 1.154 (T5I)	0.
GL_Trans	Elliptical	288 (12 days)	0.9 (enter/exit lunar orbit)	variable
G5_Trans	Elliptical	28 days	1.068	+/- 63
L5	Circular	28 days		

Arriving spacecraft travel along the elliptical transfer orbits, delivering kinetic energy to a Recycler when they engage it. Partner spacecraft passively wait in the circular orbit of the Recycler until an arriving spacecraft empowers the Recycler to launch the partner spacecraft onto the transfer orbit. The departing partner spacecraft is directed onto the same transfer orbit previously occupied by the arriving spacecraft. As long as each pair of spacecraft match in mass and velocity, almost no net force acts on the Recycler, and no net torque acts on the Recycler. Note the arriving spacecraft powers its partner's launch, ending the partnership. New partnerships between spacecraft form with each new engagement at each Recycler, strongly favoring standardized spacecraft masses.

Conventional space travel is governed by the rocket equation. A classical rocket trip from LEO to GEO would use a Hohmann transfer orbit. The required delta vee for such a round trip between LEO and GEO is 7.59 km/s.

Recycler travel is governed by the kinetic energy formula. Kinetic energy varies as the square of velocity, rendering it irrelevant which object is going faster when two objects meet. Either way, a positive amount of kinetic energy will be released. Equally noteworthy, the velocity of an object varies as the square root of its kinetic energy. Thus, an object that retains only 25 % of its original kinetic energy still has 50 % of its original velocity. The relevant parameter of interest is energy coupling efficiency – the ratio of the kinetic energy of a partner spacecraft just after it departs a Recycler to the kinetic energy of an arriving spacecraft just before it engages the Recycler. A pertinent question is, what is a reasonable energy coupling efficiency value to use in assessing the usefulness of a Recycler?

The position taken here is that the mechanical to electrical conversions on board a Recycler could potentially be as efficient as the conversions between mechanical energy and electrical energy that have been achieved with flywheels. NASA Glenn boasts round trip efficiencies of 85 % for their flywheel systems (Reehorst, 2004). A value of 80 % shall be used for the results listed below; it can readily be parameterized as part of a sensitivity analysis.

The first step in completing a round trip between LEO and GEO using Recyclers is to depart LEO and enter onto a transfer orbit linking LEO to MEO. By table 1, the required delta vee is 1.293 km/s. Presume a spacecraft arriving at LEO from MEO transfers 80 % of its kinetic energy to the spacecraft waiting to depart LEO. For such a coupling efficiency the departing spacecraft enters onto the transfer orbit with a velocity of 1.156 km/s, catapulting from the LEO Recycler with a deficit of 0.137 km/s in its target velocity. This is the departing spacecraft's required delta vee.

When this spacecraft completes its transfer from LEO to MEO it expends no fuel to arrive in MEO. Both the regenerative braking mechanisms aboard the MEO Recycler and friction do all the work of braking the arriving spacecraft to rest with respect to the Recycler. An external observer would view this engagement as a faster moving Recycler overrunning the slower moving arriving spacecraft. The arriving spacecraft pulls on the Recycler toward the transfer orbit. The kinetic energy liberated in this engagement is immediately applied in launching a new partner

spacecraft onto the MEO to LEO transfer orbit, preventing the Recycler from leaving its circular orbit. Energy and momentum transfer between partner spacecraft. Thus, a given spacecraft expends a delta vee of 0.137 km/s to travel from a circular LEO to a circular MEO – provided there exists partners at each Recycler heading the other way.

The end result is a spacecraft completing a round trip between LEO and GEO using Recyclers requires a total delta vee of 0.54 km/s compared with 7.59 km/s for a conventional rocket using a Hohmann transfer orbit. The one way travel time from LEO to GEO using Recyclers is estimated to be 12.7 hours. In comparison, the one way travel time from LEO to GEO along a Hohmann orbit is 5.3 hours. Even if 75 % of the kinetic energy were wasted at each engagement the total required delta vee would still be only 2.54 km/s for the spacecraft using Recyclers.

It is preferable to assign to the Recycler's interface plates the task of compensating for energy coupling losses. For example, during launch a restartable Boeing Delta 2 2nd stage mounted on the aft end of each launch interface plate could push the departing spacecraft enough to correct for energy coupling losses at that Recycler. This allows spacecraft masses to be standardized, and eliminates significant rocket engines or fuel tanks on board spacecraft.

Sebens et al. (2003) develop a formula useful for estimating the operating cost of a Recycler. The authors determined operating cost for an aerospace vehicle is most strongly correlated with thrust power. They produced an empirical formula valid over six orders of magnitude. A Recycler has relatively low thrust levels, imparting accelerations no greater than one Earth Gee to spacecraft engaging it. With a maximum thrust level of 407 MW, the estimated operating cost for a Recycler is \$3.6 million in FY 2000 dollars. Presuming the operating cost applies to each engagement of a Recycler, the estimated cost of sending an empty ET on a round trip between LEO and GEO using Recyclers is \$29 million. The round trip cost for a Hughes HS-702 (with a mass of 3,832 kg) is \$3.5 million.

Additional operational characteristics of Recyclers are briefly mentioned here. Recyclers can be upgraded incrementally, following the model order displayed in figure 4. Models CMR104 and CMR304 can be built today using existing technology, as they do not employ carbon nanotube tethers nor do they require high energy coupling efficiencies to service the needs of de-orbiting LEO spacecraft. Spacecraft arriving at Recyclers are braked into circular orbits, leaving them readily available for resupply, refurbishment, and reuse. Although designed to efficiently recycle kinetic energy, Recyclers can be employed in recovering space debris both to mitigate the orbital debris hazard as well as for training and educational purposes. Small spacecraft can engage Recyclers to both land and launch without involving partner spacecraft – at the expense of the Recycler's momentum and onboard energy.

Recyclers can deploy themselves to operational orbits as they are assembled; they do not require rocket propulsion for moving into new orbits. A Recycler launching a partner spacecraft in the opposite direction from normal operations results in the Recycler undergoing two impulses of momentum, one caused by the arriving spacecraft plus one caused by launching the partner spacecraft. A Recycler can be deployed on the lunar surface or any other airless body, providing the advantage of using the Moon as a stabilizing anchor for the system – an infinite source or sink of momentum, much as the Earth is used as an infinite source or sink of charge (ground) for electrical systems.

Spacecraft traveling via Recyclers can choose to turn around and reverse their direction of travel at any Recycler station just as Earth passengers can choose to reverse their direction of travel at a subway or train station. A given spacecraft can remain in any of the orbits listed in table 1 indefinitely within limits imposed by orbital decay. For example, a payload consisting of sacks of Moon dust (no propellant loss) can be sent onto a transfer orbit and left there until another spacecraft desires to enter onto that orbit. Conversely, spacecraft are stranded in Recycler orbits until an arriving spacecraft delivers the kinetic energy required to launch them on their way. Finally, solar arrays can trickle charge and recharge a Recycler's onboard energy storage system increasing overall system effectiveness.

SIGNIFICANCE

Space travel based on recycling kinetic energy is a fundamental paradigm shift, offering a dramatic increase in performance and a dramatic decrease in cost compared with conventional rocket travel. It also has significant advantages over popular tether proposals.

Cate (2003) proposes using a momentum exchange tether for assisting bringing 4,000 kg payloads from Earth into orbit. An arriving suborbital spacecraft must match the tip speed of the rotating tether at the right time and place to connect with it. A CataMitt Recycler, in comparison, is a three axis stabilized station. Interface plates on it are not

accelerated to the engagement speed of an arriving spacecraft until typically 30 s before the spacecraft arrives. This operational flexibility, coupled with the Recycler's ability to slew in pitch and yaw in preparation for engagements occurring off the velocity vector, opens a Recycler engagement window from Earth to 20+ seconds, not milliseconds.

Hoyt (2004) is pursuing a Momentum Exchange/Electrodynamic Reboost (MXER) tether system relying on an external magnetic field to replenish lost orbital momentum. The only locations away from the Sun with significant external magnetic fields are in LEO and around the outer planets. The forces applied by Earth's magnetic field in LEO are not that significant, taking an estimated 45 days to restore the momentum lost during a single 2,000 kg payload engagement. In comparison, a Recycler has almost no change of momentum during normal operations, and the reset time for it to prepare to engage the next spacecraft is designed to be 12 hours for most Recyclers and as little as one hour for the Recycler deployed to MEO. Recyclers do not require external magnetic fields to operate.

Wilson (2000) advocates a space hotel attached to a hanging beanstalk, estimating the concept requires 1,400 km of tether with a mass of 15,000,000 kg. In comparison, the estimated mass of all the tethers used on board a CMR315 is 4,300 kg. They are deployed to a maximum operating length of 115 km.

The holy grail of tether systems is the space elevator, spanning from Earth's surface to GEO. Presume such a space elevator exists and pose the question, what delta vee would be required to place a spacecraft in LEO? The space elevator orbits the Earth in 24 hours. At an orbital height of 554 km a point on the elevator is moving at 0.50 km/s. Orbital velocity at this height is 7.58 km/s. A spacecraft stepping off the space elevator would therefore require a delta vee of 7.08 km/s to enter into LEO. Alternatively, stepping off the space elevator in GEO and using a Hohmann transfer orbit to LEO would require a delta vee of 3.80 km/s. In comparison, the delta vee to transfer from GEO to LEO using 3 Recyclers as listed in table 1 is 0.270 km/s. Even if a space elevator existed Recyclers would be built and used to travel to destinations below and above GEO, and be used to change inclinations at GEO.

APPLICATIONS

A CMR304 co-orbital with the ISS permits the exchange of unmodified Progress supply vehicles in less than four hours from launch pad on Earth to docking port at the ISS with an increase in mass delivered to orbit estimated to be 520 kg as 2nd stage propellants plus 97 kg as Progress payload. Using a LEO CMR315 for exchanging spacecraft launched from Earth results in a 68 % increase in payload mass delivered to orbit for a typical rocket launcher.

A CMR315 662 km above the Moon permits unmodified Apollo program Lunar Modules (LM) to be completely reused in a robust manned exploration of the Moon. By launching a descending LM off a Recycler at a speed of 1.43 km/s the LM becomes momentarily stationary in space. Calculations show both the LM descent stage and the LM ascent stage are independently capable of returning to the height of the orbiting Recycler after the LM completes a vertical descent. Launching them from the Moon with a separation of 2.5 minutes enables them to simultaneously arrive at the Recycler's outer portals, delivering kinetic energy usable for launching a second LM down to the Moon. Both components of the proposed Lunar Surface Access Module (LSAM) could probably also be recovered.

A CMR215 on the lunar surface connects a lunar surface colony to the rest of the Recycler transportation network. The delta vee to land on the Moon from lunar orbit is 1.9 km/s using a Hohmann route. As this is above the limit of a CMR315, auxiliary rockets would be required to slow down each descending spacecraft by 0.5 km/s just before they engage the lunar surface Recycler at a tangent to the surface. With the Moon as a firm base the Recycler does not require a third portal and is therefore designated a CMR215. The two portals can be separated by a considerable distance. The total delta vee to complete a round trip between LEO and the lunar surface using 5 Recyclers is 1.9 km/s. In comparison, the total delta vee to complete the same round trip using conventional rockets is 11.8 km/s.

Another significant distinction between Recycler travel and conventional rocket travel lies in the accelerations associated with a return from the Moon. An Apollo style travel direct reentry into Earth's atmosphere entails 6 Earths Gees of acceleration. In comparison, Recycler travel from the lunar surface to LEO entails a maximum acceleration of one Earth Gee, allowing a greater fraction of the general population to engage in travel to the Moon.

Commuting by conventional rocket from LEO to L5 requires 5 days and a delta vee of 3.9 km/s on a Hohmann transfer orbit. Separate ascending and descending Recycler routes link GEO to L5. Commuters ascend from GEO to

L5 in three days, launching ballast onto a 25 day transfer down to GEO. Commuting from LEO to L5 by CMR315s takes 4 days and a required delta vee of 0.39 km/s, beating the Hohmann time at one tenth the required delta vee.

The establishment and growth of orbiting space colonies can be facilitated using Recyclers. A pair of CMR315s can be deployed toward a future colony construction site and then physically linked to each other through a mechanical boom. Two slip joints on the boom akin to alpha joints on the ISS allow the growing colony to spin between the Recyclers. By symmetry, the center of mass of the two Recycler system lies along the boom. Construction materials, crews, and supplies shipped to the construction site are assigned to arrive at the Recyclers in a split configuration. As the mass of the colony accretes it is distributed to maintain the center of mass between the Recyclers. The choice of arrival and departure portals determines the effect of each engagement on the colony. Consider an upper Recycler with portals labeled 1, 2, 3 and a lower Recycler with portals labeled 4, 5, 6 as shown in Figure 5. Spacecraft arriving in portals 3 and 6 would apply positive torque to the colony. Spacecraft arriving in portals 1 and 4 would apply negative torque to the colony. Spacecraft arriving in portals 1 and 6, or 2 and 5, or 3 and 4 would apply zero net torque to the colony. Launching less mass than arrives results in a net gain of electrical energy at the colony while simultaneously imparting a net impulse (orbit adjusting maneuver) to the colony. All of these benefits accrue to the colony regardless of the contents of the arriving payloads and without expending rocket fuel.

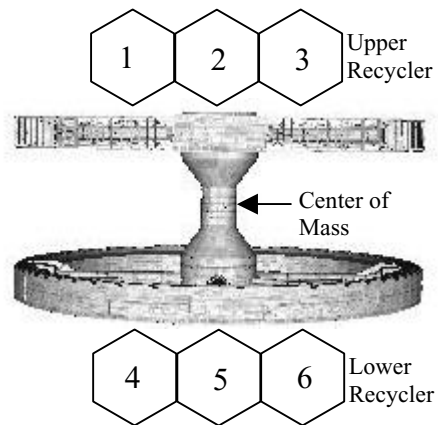


FIGURE 5. A Pair of Recyclers Straddling a Space Colony Construction Site Brings Numerous Benefits to the Endeavor.

CONCLUSION

Space travel based on recycling kinetic energy is demonstrably superior to conventional rocket propulsion for round trip high volume traffic – a hallmark characteristic of space tourism. Recyclers are versatile devices that are well suited for connecting nascent space settlements to a major transportation network. Those who come to see the light regarding this new method of space travel will likely look back upon the adherents to conventional rocket travel (with its penchant for strewing rocket parts throughout near Earth space) as suffering from temporary insanity.

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