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The Launch Ring

Low Cost Launch for Space Exploitation

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Overview

Why is space launch so expensive? Most analyses blame expendable launchers, but this misses the mark. The space shuttle is reusable. Energy requirements are not the cause either — it takes about fifty cents worth of energy to orbit one kilogram. The true cause is the *rate* of energy expenditure during launch, i.e. power. Whether chemical, electrical, or nuclear, the tremendous power flows required by conventional launch systems are costly to produce and control. The obvious question: can space launch be accomplished in a practical manner without the use of extreme power?

Surprisingly, the answer is yes.

LaunchPoint Technologies began the development of an advanced magnetic levitation (maglev) freight transportation system in 2000, funded by venture capital. We devoted our first year of project work to an in-depth survey and analysis of maglev technologies, and discovered that most existing maglev systems were based on designs more than thirty years old. None of them had the performance or economics we required. By exploiting recent advancements in theory, materials, and electronics, we were able to develop a superior and far less expensive maglev system. A full-scale prototype vehicle (3000 kg gross weight) has been levitating for over three years in our lab.

In a totally unexpected result of this work, we learned that maglev technology has immense untapped potential. More specifically, it will allow the construction of a low power, low cost accelerator to launch orbital projectiles using electromagnetic propulsion rather than rockets. The accelerator design is radically different from the rail gun and coil gun projectile launchers investigated for the last four decades. We call our system the "Launch Ring". If successful, a single accelerator has the potential to launch multiple 1000 kg projectiles *per hour* into LEO at a cost of less than $100/kg.

Orbital Launch Technologies

The cost of sending a payload into orbit has been extremely high as long as the capability has existed. In the early 1960's, with development of the Saturn V in progress and the Space Shuttle planned, the cost of reaching orbit was forecast to decrease from $1400 per pound (in 1964 dollars) to $25 per pound by 1980. In fact, the cost remained virtually constant. Launch vehicles commercially available in 2001 had an average cost-per-pound to LEO of over $4000 [1]. Space Shuttle launch costs exceed $10,000 per pound of payload. Many organizations have tried, and are still trying, to reduce this expense and open space to more extensive commercial activities, but it is clear that traditional rocket-based approaches are highly unlikely to produce adequate cost reductions.

Non-traditional approaches have been considered and researched as well. The High Altitude Research Project (HARP) at McGill University in the 1960's used large-bore artillery in an attempt to reach the edge of space at low cost, and achieved limited success, but never came close to the velocities required for orbit. Light gas guns have had some success at achieving high velocities, culminating in the proposal for a "Jules Verne Gun" at the Lawrence Livermore National Laboratory [2]. This launcher would orbit 5 tons per shot, at a cost of $5 billion for construction and operation over ten years. This cost has been an insurmountable obstacle.

Rail guns such as the STAR concept out of the University of Texas at Austin [3] provide another potential solution. Still to be solved are the problems of creating and controlling electrical power flows of hundreds of gigawatts or more. Again, even if these daunting technical problems can be solved, a launcher of this type would cost well over a billion dollars and have limited longevity due to wear.

Other more extreme approaches have been proposed, all in an attempt solve a real and important problem. Low cost launch is the first step in opening up the entire universe beyond Earth to human exploitation. So far it has not been technically and economically achievable, but recent advances may offer an opportunity to achieve exactly this objective.

Particle Accelerators

The nuclear physics community encountered an analogous problem to EM launch when the proton was discovered in 1919. Within a few years various laboratories began constructing linear accelerators to experiment with charged particles, culminating many years later in the 2-mile Stanford Linear Accelerator (SLAC), used to collide electrons and positrons at 50 billion electron-volts. Soon after the first use of linear accelerators Dr. Ernest Lawrence realized that protons could be accelerated to much higher energies, at acceptable cost, if the accelerator was ***circular*** rather than straight. In 1929 he invented the cyclotron, for which he later received the Nobel Prize. Circular accelerators, in the form of the synchrotron, soon far outpaced linear accelerators. The most recent, the Large Hadron Collider under construction at the CERN laboratory in Switzerland, is nearly 27 kilometers in circumference and will provide a collision energy of 7 trillion electron volts when completed.

Superconducting Levitation

Maglev transportation systems were first proposed nearly 100 years ago, and various large-scale systems have been constructed in the last three decades. The magnetic bearings used in these systems all produce levitation pressures on the order of 15 psi (~10 N/cm^2). But it is possible to create far higher levitation pressures with superconductors, which have been used extensively in particle accelerators for over twenty years. At cryogenic temperatures these materials are capable of handling extreme currents and producing extreme forces. For example, two superconducting cables, each 2.5 cm in diameter, with a current density of 100,000 amps per cm^2 or a total current of just over 500,000 amps per cable, when placed at a distance of 10 cm from each other will produce a force of more than 500,000 Newtons per meter of cable. While this current level may seem daunting, the current flow through a cross-section of the magnets already in use in accelerators such as the Tevatron exceeds 6 million amperes.

Superconducting magnetic bearings are not practical for conventional maglev systems due to high material costs and the requirement for cryogenic cooling on both sides of the bearing, so they have never been developed. But the technology required is well understood and its potential has stunning implications for electromagnetic launch.

The Launch Ring Design

By exploiting the capabilities of superconducting magnetic suspension, we created the conceptual design for a circular launch system – the Launch Ring – shown in Figure 1. This consists of a maglev sled accelerated by a linear motor around an enclosed, evacuated circular track of large ring diameter. A projectile is held in the sled until it reaches launch speed, whereupon the projectile is released into a tangential launch ramp, through an egress hatch and, potentially, into orbit.

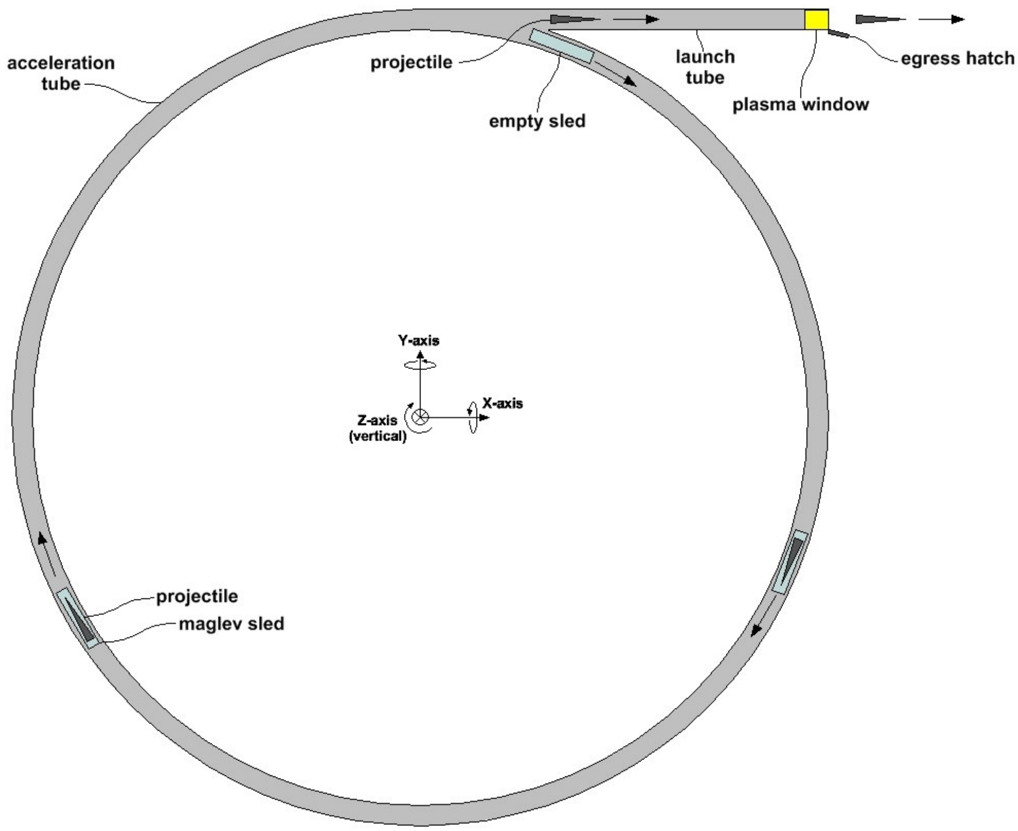

Figure 1 Launch Ring

In 2005 LaunchPoint began work, in conjunction with Argonne National Lab, on an Air Force study contract to determine the feasibility of using the Launch Ring design to place 10 kg micro-satellites into orbit. Our first task was to determine suspension force capabilities. The radial acceleration produced by the Launch Ring is equal to sled velocity squared divided by radius ($A = v^2/r$). Assuming a launch velocity of 10 km/sec (an orbital velocity of ~7.8 km/sec plus 2.2 km/sec to compensate for various launch losses), and an accelerated mass of 200 kg (100 kg projectile plus 100 kg sled), the required radial suspension forces for Launch Rings of a range of diameters are listed in Table 1. Are these force levels achievable?

Table 1. Required Radial Suspension Forces

Accelerated mass (kg)	**200**	**200**	**200**	**200**
Launch Ring Diameter (km)	**8**	**4**	**2**	**1**
Launch Velocity (km/s)	**10**	**10**	**10**	**10**
Radial suspension force (MN)	**5**	**10**	**20**	**40**

To find out we modeled a series of superconducting suspension designs, culminating in the general configuration shown in the cross-sections of Figure 2. This system forms an "acceleration compensator" consisting of six superconducting stator cables embedded in the accelerator structure and four sled coils, two in the top of the sled (one in front of the other)

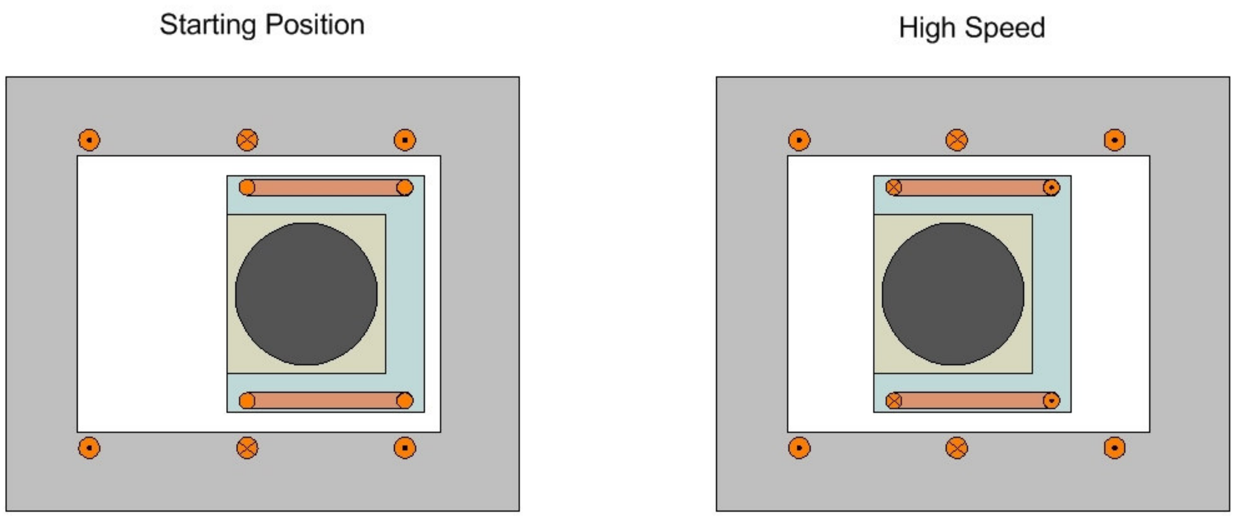

Figure 2 Suspension Configuration

and two in the bottom of the sled. As the sled circles the track at gradually increasing speed (moving into the page in Figure 2), centrifugal force pushes the sled radially outward (to the left) while magnetic shear forces pushes it radially inward (to the right) with an exactly equivalent force. Unlike conventional electromagnetic levitation, the unique traits of superconductors make this acceleration compensation dynamically stable. The superconductors also provide vertical suspension and passive stabilization in roll, pitch and yaw. Compensation forces in excess of 30 million Newtons can be produced using conventional industrial superconductors.

Acceleration Motor

With the acceleration sled isolated from contact with anything and friction-free, the period of acceleration can be arbitrarily long. This eliminates the requirement for extremely high power that has stymied rail guns and coil guns and makes rockets so expensive. A 20 megawatt linear synchronous motor, roughly the power level used in high speed electric locomotives, will accelerate a mass of 2000 kg (projectile and sled) to 9 km/second in just over an hour. Segmented motor control would allow multiple sleds to be accelerated simultaneously, providing a convenient upgrade path. For example, a launch ring 8 kilometers in diameter with motor segments 250 meters long and sufficient power could accelerate up to 100 sleds simultaneously and could place in excess of 50 metric tons per hour into orbit. Note that the addition of energy storage units would allow the kinetic energy of empty sleds (after the projectile is released) to be harvested as the sleds are decelerated, and re-used to accelerate succeeding projectiles.

Launch Ramp

The projectile is enclosed in a sabot, as shown in **Figure 3**. When the sled attains the desired speed the projectile and sabot are released into a tangential branch off the ring. The sabot protects the projectile from contact with the tube wall as it travels out the launch ramp, and uses Lexan ablation to create a gas bearing, minimizing friction and preventing significant loss of speed. The launch ramp would typically be constructed up the side of a hill or mountain to achieve the optimal launch angle (~15-20 degrees [4]).

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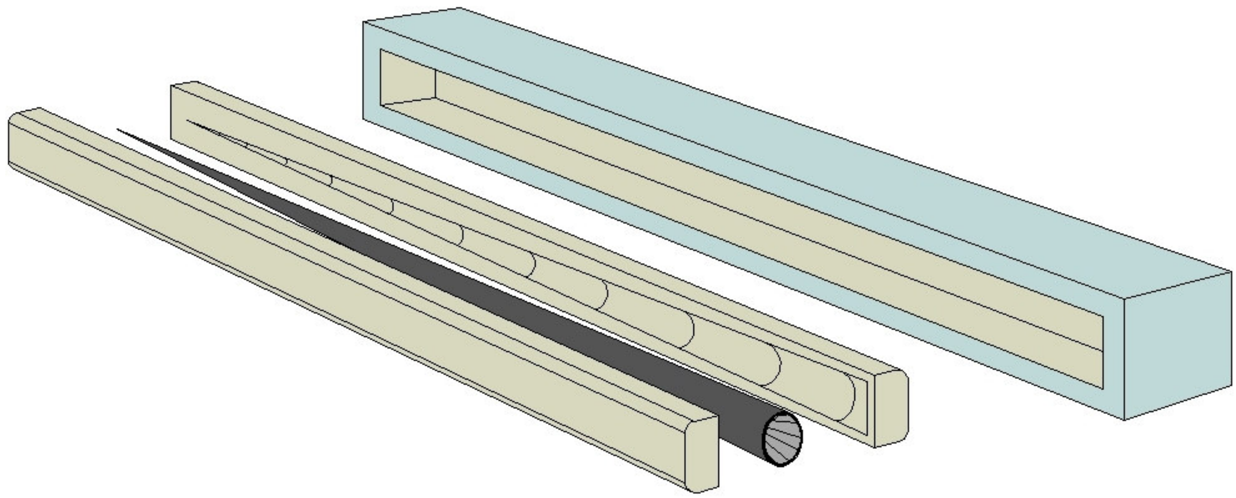

Figure 3 Sled, Sabot & Projectile

An egress hatch at the end of the launch ramp is opened just before the projectile arrives. This hatch could be augmented by a "plasma window"[5] or a frangible diaphragm to prevent external air from entering the evacuated launch tube while letting the sabot and projectile freely pass into the open atmosphere where the sabot falls away and the projectile climbs into the sky. The sled continues around the ring where it is decelerated for loading with the next projectile. Because the branch leading to a launch ramp has no moving parts and has no effect on a maglev sled passing by, a single Launch Ring could have several launch ramps to release projectiles in different directions for various trajectories or orbital inclinations.

Projectile Design

The projectile must be designed to withstand high lateral force during acceleration and will be highly streamlined. Similar projectiles have been described in numerous prior studies, including [3][4][6]. Hypersonic projectiles of this type, such as the one shown in Figure 4 (provided by Dr. Miles Palmer of SAIC) have been tested at up to 6500 meters per second in the lower atmosphere.

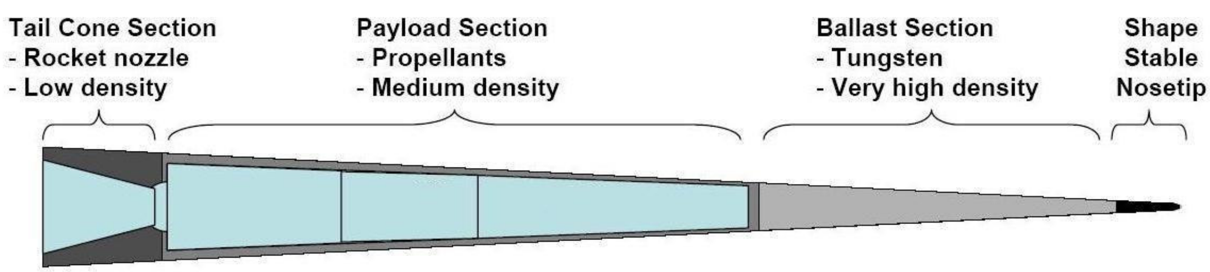

Figure 4 Hypersonic Projectile

The projectile skin will be constructed of high-strength, high-temperature materials to withstand passage through the first 100 km of altitude. Projectile designs may use transpiration cooling or other related techniques to decrease frictional heating [3][4][6][7], although for large (1000kg) projectiles an ablative carbon-carbon nosetip may prove the most cost effective. The projectile will be equipped with maneuvering thrusters and a small rocket engine for trajectory changes and orbital insertion, and could also be equipped with an aerodynamic maneuvering capability similar to the Advanced Maneuvering Reentry Vehicle successfully tested in 1981 [8]. This would allow trajectory changes, as the projectile transits the atmosphere during launch, to minimize the propellant mass needed later for orbital insertion.

Cryogenics and Vacuum System

Cryogenic cooling equipment and the vacuum system for the accelerator ring will be similar to systems used in synchrotron particle accelerators such as the Tevatron and the LHC. No new developments are needed here. Design and installation would be a straightforward engineering exercise.

Environmental and Safety Issues

As the projectile exits the launch ramp at 8+ km/second, it will create what could be a substantial shockwave zone, depending upon the size of the projectile and the launch angle. This, along with range safety, will require that the Launch Ring be constructed in a remote location. Conventional missile-launch safety protocols will be required, including the capability to destroy projectiles that malfunction and threaten to deviate from acceptable launch trajectories.

A further safety issue involves the Launch Ring itself. The ring, the projectile, and the maglev sled must all be designed such that a malfunction during acceleration cannot result in severe damage to the ring. This can be accomplished through the use of back-up ablative bearings, emergency braking, and “dump tubes” – tangential branches off the ring where the projectile and sled can be redirected if necessary. The projectile and sled would be destroyed, but the ring would remain intact.

Projectile Cost Estimates

Projectile costs may be derived using standard flight vehicle cost estimation techniques. Based on a long history of air vehicle development, a projectile of the type needed by the Launch Ring is expected to cost approximately $300 per pound of vehicle dry weight for the first production prototype [9]. For a gross launch weight of 1000 kilograms the projectile will have an empty weight of about 300 kilograms, giving an initial cost of $198,414. As production quantities increase this cost will drop according to established learning curves. Table 2 shows the result of applying an 85% learning curve to the projectile cost for quantity production. Larger production volumes will decrease cost further. Costs may also decrease if, in some applications, we are able to re-use projectile components such as avionics.

Table 2 1000-kg Projectile Production Cost

N (Number of units built)	1	10	100	1,000	10,000
Projectile dry weight (kg)	300				
Payload (kg)	600				
Cost of Nth unit	$198,414	$140,466	$99,443	$70,400	$49,839
Cost/lb of payload	$150	$106	$75	$53	$38

Operating Cost Estimates

The accelerator has a small cross section and will be fabricated of fiberglass reinforced concrete recessed into the surface of a flat area such as a dry lake. These factors can be expected to produce low construction costs. Using projectile cost estimates and very preliminary estimates of construction cost, we can roughly estimate the most important number of all – the cost to launch a payload to LEO. Table 3 factors in the primary contributors to calculate projectile launch costs for 300 to 30,000 shots per year, assuming a projectile gross weight of 1000 kg and a payload of 600 kg.

Table 3. 1000-Kg Projectile Estimated Launch Costs			
Shots/year	**300**	**3,000**	**30,000**
Launch Ring capital cost ($M)	**$500**	**$500**	**$500**
Projectile mass (kg)	**1,000**	**1,000**	**1,000**
Payload mass (kg)	**600**	**600**	**600**
Energy usage (kWh/kg)	**12.5**	**12.5**	**12.5**
Energy cost ($/kWh)	**$0.05**	**$0.05**	**$0.05**
Cost of projectile ($k)	**$100**	**$70**	**$50**
O&M costs (% of cap cost)	**10**	**15**	**20**
Energy cost/shot ($)	**$625**	**$625**	**$625**
Projectile costs/year ($M)	**$30**	**$210**	**$1,500**
Amortization cost/yr ($M)	**$21.5**	**$21.5**	**$21.5**
Energy costs/year ($M)	**$0.2**	**$1.9**	**$18.8**
O&M costs/year ($M)	**$50**	**$75**	**$100**
Total costs/year ($M)	**$102**	**$308**	**$1,640**
Total costs/shot ($)	**$338,958**	**$102,792**	**$54,675**
Projectile fraction of cost	**0.30**	**0.68**	**0.91**
Cost/kg of payload ($)	**$565**	**$171**	**$91**
Cost/lb of payload ($)	**$256**	**$78**	**$41**

This example assumes construction is commercially capitalized, with amortization (at 7% simple interest per year) included in the launch costs. At a launch rate of 3000 shots per year, the resulting cost of $78 per pound is far lower than any other known or expected launch technology. At higher rates the cost drops even more. Note that the cost of the projectile makes up more than 90% of total launch costs (Projectile fraction of cost) at high launch rates. This tells us two important things: 1) any unexpected projectile cost reductions resulting from as-yet undiscovered technologies, improved manufacturing techniques, or component re-use will quickly bring launch costs even lower; and 2) at high launch rates the launch cost is relatively insensitive to the construction cost of the accelerator ring.

G-Hardened Payload Design

High-g tolerant structures and electronics have been in use for at least three decades. The Copperhead 155mm laser-guided artillery round has been in Army service since 1980. Precision guided munitions of this kind typically experience gun shocks of 10,000 to 20,000 g's. Future gun-launched applications will encounter in excess of 20,000 g's [14]. Improving materials and fabrication techniques now permit more intricate systems, including small drone recon aircraft [13], to be developed for gun launch. High-g spacecraft designs for gun or electromagnetic launch have also been proposed [6][16][17]. Some of these designs will be applicable to Launch Ring payloads, with one significant change — the g-loading is much lower. Instead of 10-20 thousand g's or more the forces could be two to five thousand g's or less, depending upon ring diameter. Furthermore, the g-loading is transverse (across the short dimension) rather than axial (along the long dimension) as in gun launch, easing design constraints. Elements such as folding antennae, mirrors, airfoils, or inflatable structures [15] will be much less difficult to implement.

Some of the economic issues involved in the comparison between a few large, low-g payloads and many small, high-g payloads are examined in [12]. Greatly reduced launch costs for the small, high-g payloads can give them a major advantage in some applications, even when the increased cost of g-hardening is considered. This is particularly the case when an application can utilize many identical copies of a single payload design, as with constellation satellites.

Non-superconducting Ring Design

Our initial work focused on analysis of launch accelerators using superconductors on both sides – stationary and moving – of the magnetic suspension. We are now extending this analysis into designs employing superconductors in the maglev sled but not in the stationary ring. Such a design approach does have disadvantages:

1. It decreases suspension force capability compared with a purely superconducting approach, and thus requires a larger ring diameter to compensate.
2. It increases electro-dynamic drag at high speeds, necessitating a higher power acceleration motor.

These disadvantages may be more than offset by the potential advantages, however:

1. With no superconductors in the ring no cryoplant is required, saving $30 million or more, the cryogenic cool-down period (days to weeks) is eliminated, and so is the need to provide constant electrical power (>10 MW) to the cryoplant.
2. The cost of the track superconductors ($50 million or more) is eliminated.
3. With no need for thermal isolation and super-insulation, the ring is greatly simplified.
4. The more powerful motor required to overcome drag at high speed provides much faster acceleration at low speeds, when drag is low, decreasing overall acceleration time and increasing the maximum launch rate.

Preliminary results indicate that this approach is likely to provide adequate suspension force, and could reduce system costs by as much as fifty percent.

Implications for Human Activities In Space

For every person launched into orbit – or beyond – many tons of oxygen, fuel, food, water, components, construction materials and radiation shielding will be needed. Nearly all of this materiel could be shipped via Launch Rings, resulting in major reductions in the cost of manned space activities. This is only the beginning.

In his presentation at DARPATech 2004, Dr. Leo Christodoulou described the concept of large-structure assembly in orbit. He characterized it as “out there on the far side” — but with huge reductions in the cost of orbital transport perhaps it wouldn’t be so “far out” anymore. Launch Rings could be used to ship components and materials to space facilities where remotely operated robots, with their operators located in safe, comfortable, and convenient offices on the planet surface below, could assemble and test equipment and facilities for use in space. Not just large structures — anything that can be assembled from G-tolerant subassemblies, components and materials. Additional assembly robots, test equipment, and facility space along with communication, imaging, and radar satellites of unprecedented capability, vehicles for transport to higher orbit, solar energy collectors, space and planetary exploration vehicles, and many other products are candidates for assembly. Remotely operated robots are already being used in the medical field for remote surgery. Remote assembly is arguably an easier task. Using this approach, the cost to establish and maintain a major support infrastructure in space could be radically reduced relative to the currently expected cost.

Project Status

LaunchPoint Technologies complete a Phase I STTR study contract for the Air Force Research Lab in April of 2006, with no insurmountable technical obstacles to prevent construction of an operational Launch Ring discovered so far. A Phase II contract is pending and, if awarded, will commence in the second half of 2006. If no show-stoppers are encountered as work progresses deeper into the many design issues, and if adequate funding is available, a series of intermediate development steps could lead to an operational industrial-scale Launch Ring in less than ten years. This would clearly be a landmark facility — a gateway to unlimited opportunities in space.

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