A Brief Explanation of the Tethered Ring

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The Value Proposition

Achieving world-wide carbon neutrality by 2050 is the world's most urgent mission. At the same time human civilization must set up and maintain supply-lines to new space stations and colonies on the moon and Mars.

To achieve both objectives, a Tethered Ring must be built.

To decarbonize off-world supply lines, future space vehicles will be launched with an electrically powered mass driver that is supported in the stratosphere by the Tethered Ring. The mass driver is a 1000km long evacuated tube containing a magnetic levitation (maglev) track. A space vehicle enters at one end through an airlock, is accelerated down the track, and exits into the rarified atmosphere through a fast airlock at the other end. A space vehicle that is launched by a mass-driver can be small in proportion to its payload because it only needs to generate a small amount of additional delta-V to reach a stable orbit. In comparison, a traditional rocket that is launched from the surface of the Earth needs a lot more delta-V and thus must be very large in proportion to its payload, to reach the same stable orbit.

A Tethered Ring will decarbonize some high-speed international travel by supporting a suspended electrically powered evacuated tube transport system. This system will quickly ferry people and freight vast distances between cities and over land and ocean. This tube transit system allows us to retire many of the large kerosene-burning airliners that currently service long-haul routes.

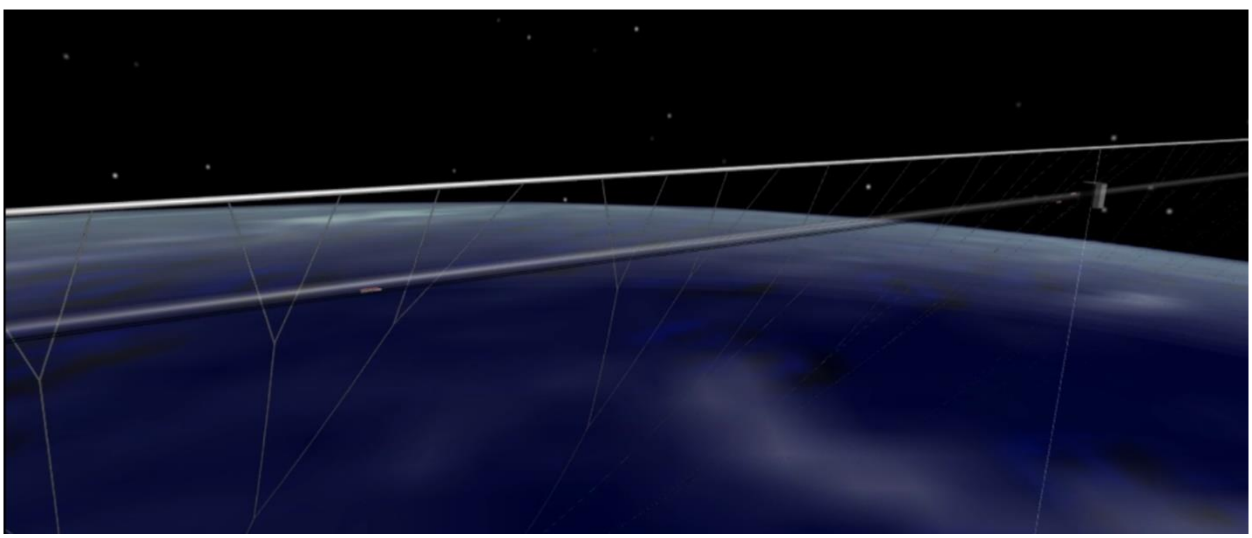

Figure 1: Elevator and an Evacuated Tube Transit System Suspended under the Tethered Ring

What is a Tethered Ring?

To help any reader, young or old, understand what a Tethered Ring is and how it stays aloft, let's start by imagining a simple globe of the Earth. Now imagine a ring made of thin stiff wire. Imagine that the diameter of this wire ring is 20% smaller than the diameter of the globe. Now place the ring on the globe.

Next imagine arranging a fleet of miniature tugboats on the globe. Arrange them so that they are all above the ring, all about 1cm away from the ring, and all pointing towards the top of the globe, up, and away from the ring. Imagine attaching a short filament of spider web between each tugboat and its nearest point on the ring. Then command all the tugboats to all pull on their filaments at the same time. This will cause the ring to be lifted a short distance off the surface of the globe.

Now let's consider this mental image from a high-school physics perspective.

First, there is the force of gravity pulling the ring down towards the ground. Each spider web is exerting a tensile force which pulls at an upwards angle. Because the ring is made of stiff wire, it is rigid and doesn't collapse. From a physics perspective, the ring transfers forces from one side to the other through compression.

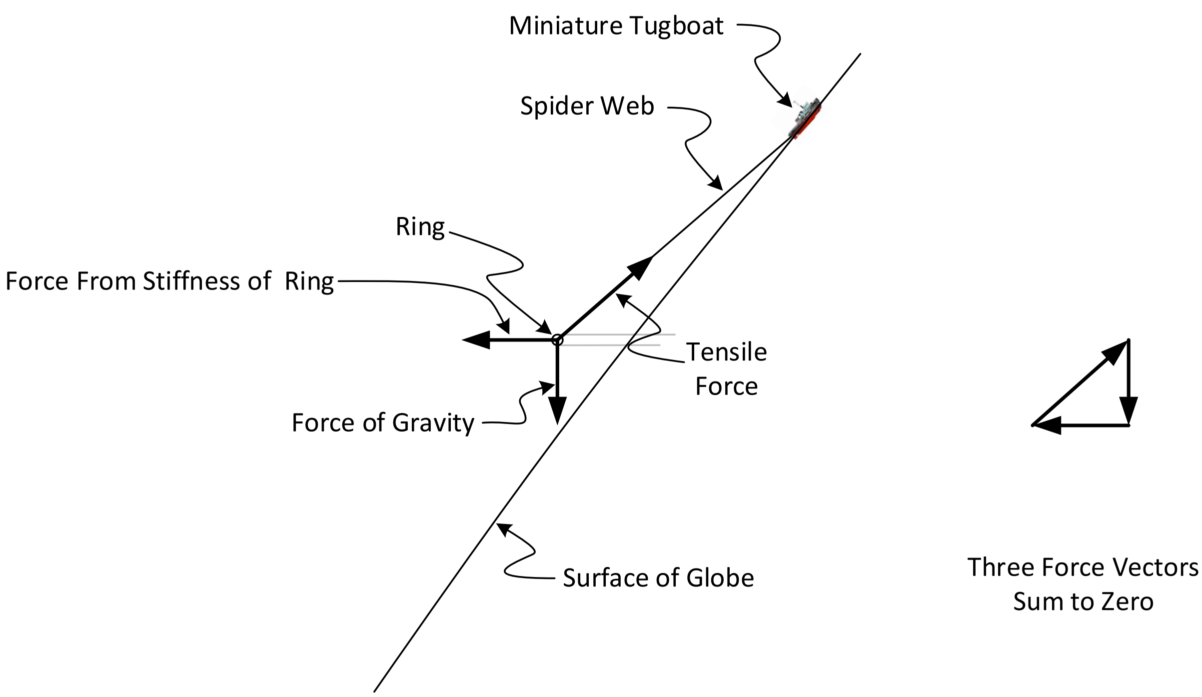

Figure 2: A "Mental Image" of a ring made of wire being lifted off the surface of a globe.

What we have is a situation where the tensile forces and the forces transferred through the stiffness of the wire ring combine to counter the force of gravity that is pulling the ring down. This is a bit like a bicycle wheel lying on its side. The spokes of the bicycle wheel generate tensile forces which, combined with forces transferred through the stiffness of the wheel's rim, offset the force of gravity pulling down on the rim.

Next, let us scale this mental image up the dimensions of the real planet Earth. To do this we must make a few changes:

1) On the real Earth the force of gravity will point towards the center of the Earth as opposed to "straight down".

2) Replace the miniature tugboats with real tugboats – and large ones.
3) Replace the spider webs with engineered cables called “tethers” that are made of a strong material, such as carbon fiber, that we can mass-produce in factories.
4) At the scale of the Earth, the tethers will droop under their own weight, so we will need to change their shape in our diagram to be curved. We will also need to adjust the direction of the tensile force vector to account for the droop.
5) At the scale of the Earth, a ring made of wire will not be stiff enough to generate (or transfer) the forces needed to counter the combined force of gravity and tensile force from the tether. Therefore, we need to come up with a different way to generate this force. We will use “inertia” to do this, so for now let’s relabel this new force as the “Inertial Force”.

Our new figure depicting the forces looks like this…

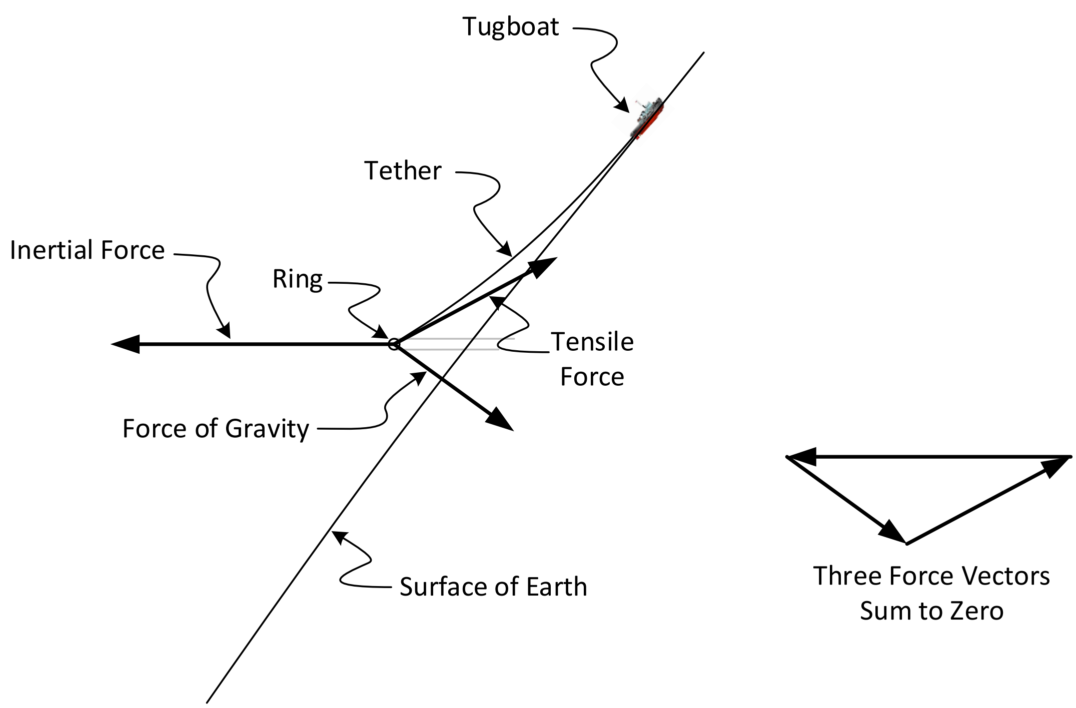

Figure 3: The forces in play after Earth-sizing the mental image depicted in Figure 2.

To generate the inertial force, we must make the ring hollow - like a pipe. We must create another ring inside it which is called the “moving ring”. The moving ring is supported by a maglev track, like a maglev train. It spins to generate a centrifugal force. That force pushes on the maglev track to generate the force we are calling the “inertial force”. To produce sufficient inertial force, the moving ring must make one complete revolution roughly every 30 minutes.

Once again, we have three forces in balance. The sum of the inertial force vector and the tensile force vector is a vector that is equal and opposite to the gravity force vector. In other words, the combined inertial and tensile forces prevent the ring from falling due to the force of gravity.

A 4K video of the ring being raised can be found here.

Additional Forces

A value proposition analysis must consider costs as well as benefits. Costs are made up of capital costs and operating costs. To understand some of the operating costs, it helps to understand some of the other forces at work within a Tethered Ring.

The inertial force is adjusted (by spinning the moving ring faster) to be slightly greater that the Tensile force plus the force of gravity. This creates some “hoop stress” within the moving ring which serves to stiffen it.

Tensile forces are distributed evenly around the ring to avoid large “point loads”. Thin tethers are attached to the ring every few meters. Closer to the ground it is better to have thick tethers spaced kilometers apart rather than thin tethers spaced meters apart. Thick tethers have a lower cross-section to the wind, and it is easier for ships and airplanes to travel between tethers that are spaced far apart. To accomplish this, the tethers are designed with numerous branches.

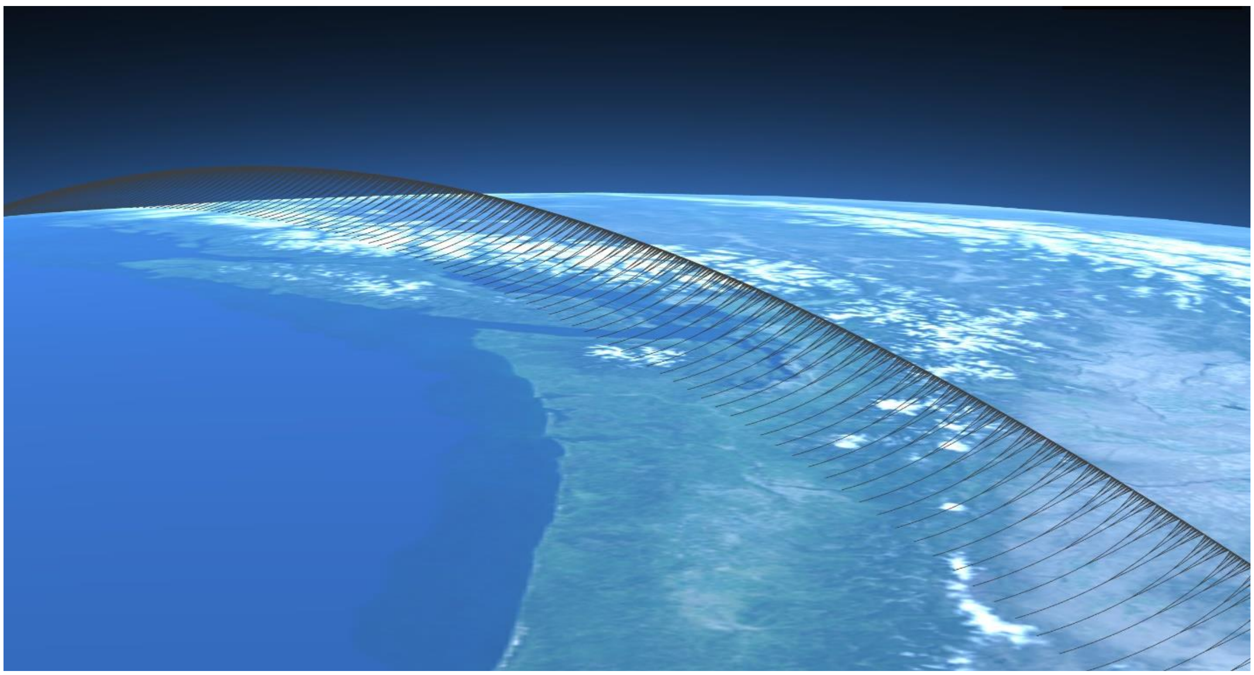

Figure 4: Tethers with Branches

To prevent the ring and its tethers from being blown out of position by the wind, station-keeping thruster nacelles (that is, ducted electric fans) are installed on the ring and on the tethers.

To keep the cost of operating the ring low, the moving ring travels within a vacuum to reduce air friction.

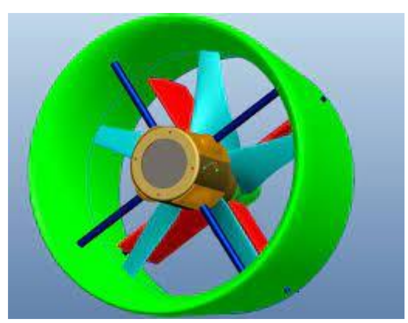

Figure 5: Figure 5: A Ducted Fan

There is another kind of friction called “magnetic friction” that can occur – typically when changing magnetic fields induce eddy currents in nearby conductive materials. The Tethered Ring is different from other proposed dynamic structures, such as the space fountain (Figure 6) and the Lofstrom Loop (Figure 7), because its architecture permits it to have minimal magnetic friction during steady state operation. The moving ring of a Tethered Ring travels through a magnetic field of constant strength. Because the moving ring does not experience significant changes in magnetic field strength, significant eddy currents are not induced in the metal components of the moving ring. Likewise, from the point of view of the magnetic levitation track, the moving ring is a constant influence. Therefore, the moving ring does not induce significant fluctuations in the magnetic field that it travels through. From the point of view of the magnetic levitation track, there are no significant changing magnetic fields and thus no significant eddy current losses.

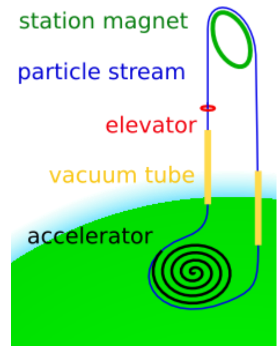

Figure 6: Space Fountain

In contrast, a space fountain employs a mass stream comprised of discrete pellets or bolts. The architecture of a space fountain requires that these discrete components travel slower and closer together at the top of the structure, and faster and further apart at the base of the structure. These discrete components will induce significant fluctuations, and thus eddy current losses, in the magnetic fields that they travel through. Similarly, a Lofstrom Loop employs a ribbon with expansion joints for the same reason - the ribbon must travel slower at the top of the structure, and faster at the base of the structure. The expansion joints will induce significant fluctuations in the magnetic field that the ribbon travels through.

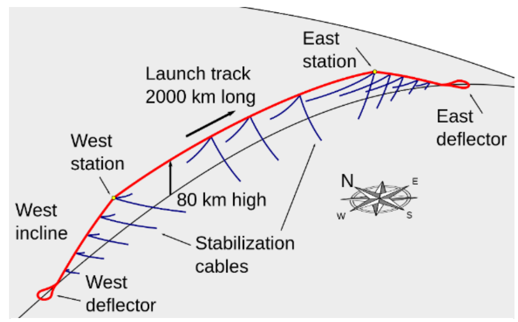

Figure 7: Launch Loop or Lofstrom Loop

As a point on the mass stream of a space fountain or Lofstrom Loop travels its circuit, it experiences rapidly varying degrees of lateral and longitudinal acceleration. A point on the mass stream of a Tethered Ring experiences a relatively unvarying amount of acceleration, which makes it easier to engineer the mass stream's containment system for high reliability and low power consumption.

An expert in the field of magnetic bearings might note that the magnetically levitated moving ring resembles a large diameter homopolar Active Magnetic Bearing (AMB), which is a bearing type that uses sensors and control circuits to actively adjust the magnetic fields that levitate the rotating part of the bearing. Energy is used by these circuits as they make fine positional adjustments in response to external perturbations and these adjustments will create changing magnetic fields; however, these control-related actions result in minor energy losses. To help put them in perspective, in some industrial applications, such as flywheel energy storage systems, a well-designed AMB is favored over a traditional mechanical bearing because the higher capital cost of an AMB is more than offset by its lower energy losses and thus lower operating costs.

Economic Feasibility

A project's economic viability is not defined by its absolute cost, but rather by its cost relative to the value that it generates. In other words, to be economically viable, the project must have a credible plan to service the debt incurred during its research, development, design, and construction phases.

Broadly speaking, a Tethered Ring creates value by supporting, at a high altitude, both terrestrial and space facing communication and imaging services, carbon-neutral high-speed transit, high-altitude leasable floor space, and at least one electromagnetic mass driver for low-cost launch of satellites and spacecraft.

Terrestrial facing communications gear on the ring has the advantage of being 10X to 20X closer to customer equipment than low-earth orbit satellite constellations. This translates to 100X to 400X better beam density (that is, the number of simultaneous individual radio beams that can service an area) and a corresponding increase in the number of customers served. This communication gear can connect to internet points-of-presence with fiber, rather than by using radio down-links. At the same time, customer equipment becomes smaller, cheaper, and less complex which improves the profitability of the communications service. Unlike satellite mega-constellations, ring-mounted communications systems can scale without increasing the risk of run-a-way space debris, also known as “Kessler Syndrome”.

Space facing communications have the advantage of being able to connect directly to terrestrial datacenters by fiber-optic cable and, because the ring is above the clouds, to orbiting satellites with communication lasers.

Earth sensing and imaging equipment on the ring will be in a fixed position and closer to the ground, so it will have both higher resolution and higher update rates.

Telescopes mounted on the ring will have the low cost and simplified repair and maintenance associated of mountain-top observatories, while also being situated above the clouds and most of the atmosphere like space telescopes such as the Hubble or the James Webb Space Telescope.

The suspended evacuated tube transport system provides the terrestrial transportation services. When compared to long-haul airliners, it is 4X faster, has 4X lower operating costs, is 10X more energy efficient, 20dBA quieter, provides 30X more frequent departures. Because the vehicles by the system are small and cannot be commandeered, it is not necessary to delay passengers with security screening procedures. While rail or track based transit systems are often expensive due to the high cost of securing land rights or tunnelling underground, the Tethered Ring’s tube transit system avoids these costs by suspending the transit tube at a high altitude. Passengers travel to and from the tube transport system by using elevators. While airports require a lot of land for runways, the footprint of each elevator’s ground terminus is small which allows many terminuses to be placed conveniently close to a variety of popular travel destinations. The transportation system consumes no fossil fuels, emits no greenhouse gasses and is thus sustainable.

High altitude leasable floorspace is valuable because it will provide millions of people with a safe, convenient, and afford way to experience the Overview Effect. This may have the added benefit of compelling many visitors to influence their elected officials to enact legislation that is better for the environment.

Electromagnetically assisted launch has significant cost and environmental benefits over pure rocket launch. An electromagnetic mass driver mounted on the ring can accelerate space vehicles up to orbital and even interplanetary velocities without using rockets. A fully fueled space vehicle that is launched by a mass driver will be on the order of 1X the mass of its payload, whereas a fully fueled multi-stage rocket that launches from a launch pad will be anywhere from 20X to 100X the mass of its payload.

The Tethered Ring is infrastructure that generates value by serving multiple use-cases. It will economically disrupt and revitalize several industry sectors including satellite broadband communications, earth imaging, astronomy, long-haul air transportation, high-rise real-estate, and space launch services. Its strong value proposition and ability to generate a substantial return on investment in a reasonable amount of time make it attractive as an investment.