IJHSR
ijhighschoolresearch.org
REVIEW ARTICLE

How A Rotating Orbital Tether Advances Space Travel

Ufuk Çetiner
American Robert College of İstanbul Arnavutköy, Kuruçeşme Cd. No:87, 34345 Beşiktaş/İstanbul; cetinerufuk1@gmail.com

ABSTRACT: The idea of an orbital tether was first proposed by the Russian scientist Konstantin Tsiolokovski. This study optimizes and develops on the idea of the Russian scientist. By combining different methods, this study shows how a momentum exchanging rotating orbital tether can be built for space travel and it compares this method of space travel to the conventional methods of space travel.
KEYWORDS: Momentum exchange; rotating; Skyhook; space travel; tether.

Introduction

As technology advances, traveling to other planets and colonizing them seem inevitable. Although there are companies that try to commercialize a space experience, what they offer is no more than five minutes of zero G. The main reason why space travel hasn't been commercialized yet is because of the lack of access to the Earth's orbit. It takes giant rockets filled with expensive chemical propellants to get into the Earth's orbit and then launch to outer space. This makes a rocket launch very expensive and dangerous which makes space travel unaffordable.

The Earth Orbiting Tether or the structure called Skyhook aims to reduce the cost of putting a satellite or a payload into low earth orbit. It allows payloads or satellites to be raised to a higher orbit in which then they can use a meager amount of propellant to accelerate to escape velocity. The structure is built with a strong fiber that makes up the tether which orbits around the Earth.

This study aims to optimize, improve, and build on the idea while also comparing it to the conventional ways of space travel. The technologies that are discussed in this study are based on existing technologies.

Importance of The Subject:

If this project were to be built, its impact on space exploration would be significant. It would significantly reduce the propellant needs in space missions, which would make these missions much cheaper compared to their predecessors. Since the tether can accelerate objects into space, it can do the opposite: decelerating incoming objects. This allows landing on places where it is hard to decelerate, for example, asteroids. Since there is no atmosphere to slow the objects down; the orbiting tether can do that job. This would allow asteroid mining which would advance humanity in resource gathering.

Discussion

Background Research:

The concept of a skyhook was first proposed by a Russian scientist named Konstantin Tsiolokovski. He wrote about the possibility of an object's withdrawing from the earth with the aid of a rigid structure (tower) that would extend upward at right angles to the earth's surface.[1] Artsutanov then developed his idea with a 36,000 kilometer stationary satellite.[1] Extending straight up and down from the satellite are the lengths of the cable.[1] The lower end of the cable is secured to the earth's surface and the upper end does not need to be anchored as if it were on a "skyhook."[1]

There hasn't been a skyhook sent into the atmosphere, but there have been a number of flight experiments exploring various aspects of the space tether concept in general. One of these being a draft proposal for a skyhook system for NASA under the name of HASTOL (Hypersonic Airplane Space Tether Orbital Launch).[2]

Proposed Orbital Tether Structure Operational Methodology:

In a momentum exchanging orbital tether, a long thin cable is placed in orbit and set to rotate around a center of mass. In one end of the tether a docking structure is present for an incoming payload to connect to the tether at a lower orbit. If the rotation of the tether is timed correctly with the payload's position, a specialized quadtrap can dock the payload to the tether (See Figure 1). The details of this structure will be discussed throughout this section. After the payload has successfully docked to the tether, the rotation of the structure will accelerate it to a higher orbit. The structure then releases the payload at a high orbit setting it on course. After the release of the payload the tether is off its operational orbit. In order to readjust its orbit to the operational one, the tether can catch an incoming payload to regain momentum. If there are no arriving payloads at that time the tether uses the ion boosters to readjust its course. The operational summary can be seen in Figure 2.

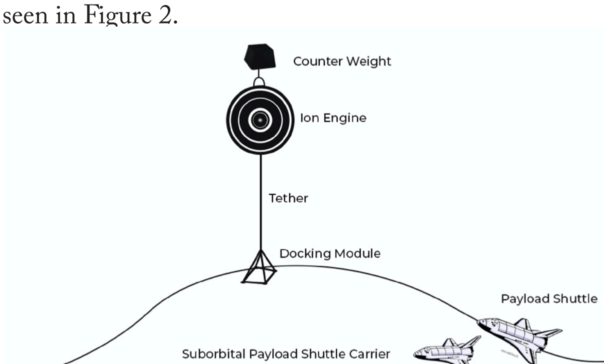

Figure 1: Momentum exchanging rotating orbital tether structure operation overview.

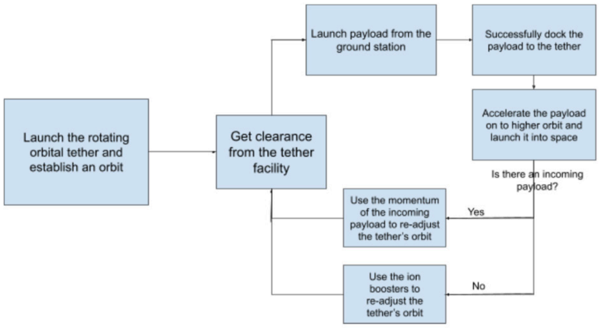

Figure 2: Operational summary of momentum exchanging orbital tether structure.

Ion Boosters:

After launching each payload into outer space, the structure loses momentum. The structure may slow down other incoming payloads to regain its momentum. However, if there are no incoming payloads at that time or if an emergency takes place the structure will need an auxiliary system to correct its orbital course. Ion boosters placed in the center of mass of the structure will help with the re-adjustment of the orbit at will. Ion booster's efficient use of fuel and electricity make modern spacecrafts travel farther, faster, and cheaper.[3] This structure will have seldom refueling since the engines on board need a small amount of fuel to continue the operation for long periods of time. In summary, the high fuel efficiency of ion boosters makes them a great choice for the proposed structure. For instance, the ion boosters in the Deep Space 1 mission used less than 159 pounds of fuel in over 16,000 hours of thrusting.[3]

Tether:

A tether, also known as a space tether in the context of space traveling, is a long cable which can be used for propulsion, momentum exchange, stabilization and altitude control, or maintaining the relative positions of the components of a large, dispersed satellite spacecraft sensor system.[4] The proposed structure will employ a rotating tether for momentum exchange, which essentially works by creating a controlled force on the end-masses of the system.

The tether in this structure will be exposed to intense amounts of tension so the fiber should be strong. A synthetic fiber called zylon is designed to withstand tensions like this. The fiber is like Kevlar that is used in bullet proof vests and will be used in this structure as the tether's main component.

Docking Station:

Docking to the momentum exchanging rotating orbital tether structure is a challenging task. Since the docking tip of the structure is traveling at high speeds, timing the docking sequence is paramount to the mission's success. However conventional docking procedures that are used in current space missions take up minutes.[5] To dock to this structure the aircraft will have no longer than seconds, so a new method of docking must be used. A method proposed by Soresen Kirk and his colleagues in a recent study will be taken in consideration for this research paper. At the tip of the tether a mechanism named "quadtrap" will be attached. Quadtrap is a rectangular mechanism that has two configurations: and open (See Figure 3). The mechanism quadtrap acts as a trap to guide the payload to a center point. In an open or deployed position, the capture mechanism has all four spreader bars translated at a maximum displacement from each other (See figure 3).[6] In a fully closed position the four corner nodes come together to close around a point.[6] In the middle position the payload has been securely captured and the docking window is met.[6]

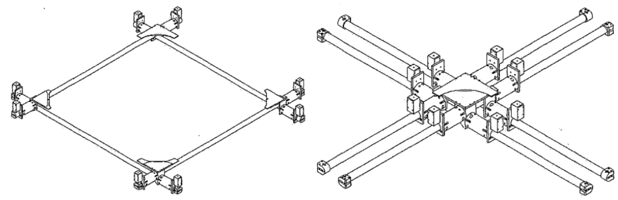

Figure 3: Quadtrap design open and closed configurations.[6]

Suborbital payload shuttle:

The docking tip of the momentum exchanging orbital tether dips down to earth around 80 to 100 kilometers above the sea level. This means that the payload cannot be delivered via jet engines since they can't reach such extreme heights. The proposed solution for this is a combination of both jet engines and rocket propulsion. The payload will be delivered via a suborbital space shuttle similar to the spacecraft "SpaceShipOne."[7] A payload shuttle will be specifically designed to help with the docking of the payload. The designed payload shuttle will be attached to a normal jet engine powered aircraft that will carry it to the maximum cruising altitude. From there the rocket-powered payload shuttle will launch itself in the air reaching the desired height and then glide back to safety with its wings; similar to the mission "Tier One" which involved the spacecraft "SpacesShipOne" and the carrier "White Knight"(See Figure 4). This design is very effective in reducing costs since the spacecraft is reusable and if the payload fails to dock the payload won't go to waste.

Figure 4: SpaceShipOne suborbital spacecraft attached to the carrier White Knight.[7]

Comparison to conventional methods of space travel:

All conventional space missions have large amounts of rocket fuel to get the payload to escape velocity. If you want to add more payload you need more rocket fuel. More rocket fuel means a heavier rocket, and heavier the rocket means

DOI: 10.36838/v4i4.20

more rocket fuel. So, in all space missions, mass is arguably the biggest constraint. For each kilogram of payload mass, a significant amount of propellant is needed for altitude control, orbit transfers, momentum dumping, station-keeping, and a variety of other applications during the lifetime of the mission. Currently, the average cost to launch a kilogram of payload mass into Low-Earth Orbit (LEO) is $10,000.[8]

With the use of the momentum exchanging orbital tether that is being mentioned in this research heavier payloads can be launched into space with ease. Since large amounts of rocket fuel is not required to accelerate the payload to the escape velocity, larger amounts of the total mass can be dedicated to actual payload and not to rocket fuel. To make a comparison the previous Mars mission "Perseverance" will be examined.

Table 1: From Budget of Mars mission "Perseverance".[9]

Service	Cost
Spacecraft Development	2.2 billion dollars
Launch Services	243 million dollars
Operations and Scientific Analysis	300 million dollars
Ingenuity Mars Helicopter	80 million dollars
Total Cost of the Mission	2.7 billion dollars

As listed in Table 1, the launch services of the latest Mars mission took up about 9% of the whole budget. The latest Mars mission was expensive because it included state of the art equipment that's why the launch services seem like a small fee. However if a mission required just to send building materials to Mars the cost of sending something would be much more than the payload sent.

On the other hand for the momentum exchanging orbital tether the launch services solely depend on the reusable spacecraft (after the structure has established an orbit). Since the suborbital payload shuttle discussed in this paper was similar to the spacecraft used in the "Tier One" mission we can compare the costs of development, construction and operation. Although the costs of development, construction and operation for mission "Tier One" were not publicly shared it was estimated to be around 20 to 30 million dollars.[10] This means that this method of space travel can operate continuously with just 1% of money spent on one-time conventional launch service.

Conclusion

Space travel, while being a topic of high interest, is usually very difficult and expensive. This study has demonstrated that the solution to make space travel cheap and easy has already been found. With the correct combinations of currently existing technology a fully functioning momentum exchanging orbital tether can be built. Not only has this study shown that this design can work it also makes current methods of space travel irrelevant. This is because this method is highly reusable and a lot cheaper. Future research on this topic should include precise and accurate calculations of the instruments mentioned in this research.

Acknowledgements

I would like to thank my friends for their valuable opinions throughout this research.

References

1. Lvov, V. Sky-Hook: Old Idea. https://www.google.com/url?q=https://www.science.org/doi/pdf/10.1126/science.158.3803.946&sa=D&source=docs&ust=1643547005798064&usg=AOvVaw26BuNBwg_bMULespUmq9ba (accessed Jan 30, 2022).
2. Boeing. Hypersonic airplane space tether orbital launch (HASTOL). http://www.niac.usra.edu/files/studies/final_report/391Grant.pdf (accessed Jan 30, 2022).
3. Dunbar, B. Ion Propulsion: Farther, faster, cheaper. https://www.nasa.gov/centers/glenn/technology/Ion_Propulsion1.html (accessed Jan 30, 2022).
4. Cosmo, M. L. Tethers In Space Handbook. https://web.archive.org/web/20111027063548/http://www.nasa.gov/centers/marshall/pdf/337451main_Tethers_In_Space_Handbook_Section_1_2.pdf (accessed Jan 30, 2022).
5. Wertz, J. R.; Bell, R. Autonomous Rendezvous and Docking Technologies Status and Prospects. https://web.archive.org/web/20120425122952/http://microcosminc.com/analysis/spie03.pdf (accessed Jan 30, 2022).
6. Kirk, S. F. Design rules and analysis of a capture mechanism for rendezvous between a space tether and payload - NASA technical reports server (NTRS). https://ntrs.nasa.gov/citations/20070001536 (accessed Jan 30, 2022).
7. Wikipedia. SpaceShipOne. https://en.wikipedia.org/wiki/SpaceShipOne (accessed Jan 30, 2022).
8. Jones, H. W. The Recent Large Reduction in Space Launch Cost. https://ttu-ir.tdl.org/bitstream/handle/2346/74082/ICES_2018_81.pdf (accessed Jan 30, 2022).
9. Planetary Society. Cost of perseverance. https://www.planetary.org/space-policy/cost-of-perseverance (accessed Jan 30, 2022).
10. Wikipedia. Scaled composites tier one. https://en.wikipedia.org/wiki/Scaled_Composites_Tier_One#Funding (accessed Jan 30, 2022).

Author

Ufuk Çetiner is a sophomore student as of 2022 studying at the American Robert College of İstanbul. He runs the underwater robotics team in his school and plans to pursue a career in engineering.

DOI: 10.36838/v4i4.20