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Apex Anchor: A Multi-Mission Developmental Program

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Abstract

With the development of space elevators as a transportation system, it is crucial to integrate the concept of 'just-in-time' delivery. The Apex Anchor which will be situated at 100,000 km can further develop this concept by inculcating a multitude of activities to be carried out. It will act as a multi-functional space station supporting technologies for exploration, planetary science, and space situational awareness. This study explains the development stages of Apex Anchor from the perspective of using it as a Transportation system. The objective of this study is two-fold. Firstly, the concept of operations for the transition between phases is laid out. The three phases are Assembly, Robotics, and Humans. The second objective is to discuss the Robotics phase development in detail. This consists of different hubs dealing with logistics and management activities. The six functions of the robotics phase consist of operations, storage, maintenance, refueling, planetary defense, and interplanetary spacecraft hub.

Introduction

Apex Anchor is defined as the complex located at the end of the Space Elevator providing counterweight stability for the space elevator as a large end mass. Attached at the end of the tether will be a complex of Apex Anchor elements such as; reel-in/out capability, thrusters to maintain stability, command and control elements, etc. When full stability is achieved, the Apex Anchor can be further developed to host multiple commercial activities. Due to its unique positioning and large platform availability, it can be used for several activities such as conducting experiments, launching spacecraft, utilizing space resources, and collision avoidance. This is referred to as Assembly at the top of the Gravity Well. This report explores a conceptual idea outlining various ways in which the Apex Anchor can be a multifunctional hub of activities.

Apex Region

The region around the Apex Anchor is defined by the amount of motion expected at the full extension of the tether. The region is the volume swept out by the end of the tether during normal operations. When two or more space elevators are operating together, the region spreads to the volume between.

Based on the location and definition of the apex region, the following assumptions are made for the multi-mission development concept:

- Full volume exists in a hard vacuum
- Rare transits of space rocks or human spacecraft during the assembly phase
- A significant amount of fuel is available for thrust to keep objects within the region without attachment to the Apex Anchor

Benefits of a Multifunctional Hub

The use of the apex anchor of a space elevator as a multifunctional hub would offer many potential benefits, including increased efficiency, improved safety, reduced cost, and increased functionality.

- Increased efficiency: By combining multiple functions at the apex anchor, such as a launchpad, docking hub, maintenance unit, communication systems, and experiment facilities, the space elevator would become more efficient, as resources and infrastructure could be shared and optimized.
- Improved safety: It will provide a central location for the safe and efficient operation of the space elevator and other space-based infrastructure, helping to minimize the risk of accidents and malfunctions.
- Reduced cost: By combining multiple functions at the apex anchor, the cost of operating and maintaining the space elevator would be reduced, as resources and infrastructure could be shared and optimized.
- Increased functionality: The use of the apex anchor as a multifunctional hub would increase the functionality of the space elevator allowing for a wide range of activities to be conducted, such as research, manufacturing, and assembly of new space-based infrastructure.

Phases of Development

➢ Phase I - Assembly
The Assembly of Apex Anchor begins with assembling the Tether Deployment Satellite in Low Earth Orbit. After moving to Geostationary Earth Orbit, it will act as the upper terminus of the space elevator tether establishing essential stability for the entire system.

➢ Phase II - Robotics
With the completion of the Assembly phase, the Apex Anchor is fully capable of providing infrastructure for the development of technologies. In this Robotics phase, the possibilities of a multifunctional infrastructure for commercial and research activities are explored.

- Phase III - Humans
  At the end of the Robotics phase, the Apex Anchor has a well-established network of robotic & autonomous systems, communications & power, and emergency protocols. The final phase will support commercial activities such as the establishment of a lab for conducting experiments & research with the involvement of humans onboard.

Phase I

The primary function of the Apex Anchor is the deployment and continued stability of the tether.

The Apex Anchor begins as the tether deployment vehicle, assembled in LEO Raised to GEO to initiate tether deployment. As the tether descends, the vehicle ascends to its final position – gravity gradient forces are dominant so no large energies are required. As tether buildup vehicles reinforce the tether, additional mass is added to the Apex Anchor to maintain tether balance and tension. The four stages of the Assembly phase are as follows:

1. Initial Deployment of Satellite in Low Earth Orbit
2. Apex Anchor Buildup to Match Tether Mass Buildup
3. Initial Operations Capability to stabilize the entire tether
4. Customer Support toward Full Operations Capability

Phase II

With the use of robotics and autonomous systems, the development of the multifunctional space-based infrastructure happens in this phase. It equips the apex anchor with facilities to manage tether dynamics, telecommunication, attitude control, debris detection, space-based solar power, and lab experiments. To deal with the logistics, operations, and management of these activities, six hubs have been conceptualized. Each of these hubs has particular functions, they are as follows:

1. Operations Hub: Communication, Power and Monitoring systems
2. Storage Hub: Docking and Refueling
3. Service Hub: Maintenance
4. Innovation Hub: Research lab and experiments
5. Interplanetary Spacecraft Hub: Launchpad and assistance
6. Planetary Defense Hub: Space Traffic Management

Understanding the Hubs

Operations Hub: The Operations Hub consists of communication, power distribution, and autonomous monitoring systems. Autonomous systems could be used to monitor and maintain the equipment and infrastructure at the apex anchor, and to perform repairs as needed without the need for human intervention. Communication systems at the apex anchor would allow for the rapid and efficient exchange of data and information between different elements of

the space-based infrastructure, potentially improving the efficiency of operations. They could offer reliable communication, increased efficiency, improved safety, and support for a wide range of space-based activities. Space-based solar power would be a promising solution for providing sustainable and reliable power to the apex anchor. It could offer renewable energy, reliable power, increased efficiency, and reduced cost, making it an attractive solution for powering space-based infrastructure.

Storage Hub: The Storage Hub mainly acts as a docking hub on could serve as a platform for attaching and servicing spacecraft, including satellites, space probes, and other spacecraft. Equipped with autonomous systems, such as robots and other computer-controlled systems, which could perform docking and transfer operations without the need for human intervention. It would also allow for the transfer of personnel, cargo, and other resources in a stable and predictable environment, potentially increasing the efficiency and reliability of these operations. Refueling spacecraft at this hub would increase the functionality of the elevator and other space-based infrastructure, as it would enable extended missions, such as missions to other planets, asteroids, or the Moon, which would otherwise be limited by the fuel capacity of the spacecraft.

Service Hub: A servicing unit would be an important component in ensuring the continued operation and maintenance of the apex anchor. It would allow for regular maintenance and repair of the space elevator's cable, equipment, and infrastructure, helping to ensure its continued safe and reliable operation. A swarm of small in-orbit servicing modules can be developed for launching out of the infrastructure for servicing.

Innovation Hub: Autonomous systems could be used to assemble and construct new equipment and infrastructure at the apex anchor, including satellites, space stations, and other space-based infrastructure. This hub can also as a microgravity lab for conducting research. It can provide a location for long-term exposure of experiments to the space environment, including radiation, vacuum, and other conditions. It would provide a convenient and accessible location for experiments, allowing for easy access and retrieval of experiment results.

Interplanetary Spacecraft Hub: With the unique positioning of the Apex Anchors, it can quickly deploy spacecraft and satellites with an initial velocity of 7.76 km/sec. A launchpad on the apex anchor of a space elevator could be used as a platform for launching satellites, space probes, and other spacecraft into orbit. a launchpad on the apex anchor of a space elevator could offer several potential benefits over ground-based launches, including increased efficiency, reduced cost, increased payload capacity, and improved safety. It would eliminate the need for ground-based launches, which can be subject to weather

and other conditions that can affect the success of a launch. Launches from the apex anchor would be conducted in a stable and predictable environment, potentially increasing the efficiency and reliability of launches. Launches from the apex anchor would have access to the full length of the space elevator cable, which would provide a longer, more stable launch trajectory. This could potentially increase the payload capacity of launches, allowing for the launch of larger and heavier spacecraft.

Planetary Defense Hub: Sensors and other monitoring equipment could be placed at the top of the Apex Anchor to provide a constant view of the surrounding space, allowing early detection and tracking of potential threats. This information could then be used to direct defensive measures. Autonomous systems could be used to identify and remove space debris in orbit, helping to reduce the risk of collisions and other hazards in space.

Phase III

The two main areas of development for the final phase are as follows:

1. Development of Life Support Systems
2. Rescue Missions

Life Support Systems

Life support systems are critical for maintaining a safe and livable environment for people and other organisms in space. If the apex anchor of a space elevator were to be used as a multifunctional hub, it may require life support systems to sustain humans and other life forms.

Essential components of a life support system for the apex anchor:

- Atmosphere control: Maintain a suitable environment for life, the apex anchor would need to control its atmosphere, providing sufficient oxygen and removing carbon dioxide and other waste gases.
- Climate control: Maintain a stable temperature and protect against extreme conditions, such as temperature swings, radiation, and micrometeoroids.
- Waste management: Ensure a safe and sanitary environment, the apex anchor would need to manage its waste, including human waste, food waste, and other forms of waste.
- Water management: Provide a reliable source of water, including potable water for drinking, washing, and other uses, as well as water for cooling, growing food, and other purposes.
- Food production: Provide food for its inhabitants, either through growing food on-site or by importing food from Earth or other locations.

Rescue Missions

Space is vast and dangerous to human life so a large benefit from Space Elevators is the Apex Anchors located in space near the end of the tether which can release rescue vehicles to astronauts in need of assistance. The space elevator offers a solution by

being able to send help directly from the Apex Anchor. Starting up a rescue vehicle loaded with aid and supplies for stranded or endangered astronauts would be as simple as charting the course and powering up the rescue vehicle a bit. Aid and supplies will include basic necessities such as oxygen, water, electricity, habitat replacement, food, scientific instruments, fuel, and anything that requires emergency help.

Conclusion

The use of the apex anchor of a space elevator as a multifunctional hub would offer many potential benefits, including increased efficiency, improved safety, reduced cost, and increased functionality. However, much more research and development would be needed to demonstrate the feasibility and viability of the use of the apex anchor as a multifunctional hub and to develop the necessary infrastructure and support systems to support this concept.

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