SAMPLE

Cosmic Explorers: Space Tethers

Strings in the Sky

Aira Astralis

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Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

A space tether is a long cable deployed from a spacecraft that can be used for propulsion, power generation, and orbital maneuvers. The concept of space tethers, which has been studied since the 1960s, represents one of the most innovative technologies for space exploration. Space tethers work by exploiting the principles of physics, including gravity gradient forces, electromagnetic interactions, and momentum exchange. The history of space tethers began with the concept of the skyhook, proposed by the Russian space pioneer Konstantin Tsiolkovsky in 1895.

Tsiolkovsky, who imagined a tower reaching from the surface of Earth to geostationary orbit, laid the conceptual foundation for tether technology. The modern concept of space tethers, which involves cables deployed from orbiting spacecraft, was developed in the 1960s by Giuseppe Colombo and others. Space tethers come in several types, each with different principles and applications. Momentum exchange tethers transfer momentum between two objects, allowing a spacecraft to gain or lose velocity. Electrodynamic tethers interact with the Earth's magnetic field to generate thrust or power.

Gravity gradient tethers use the tidal forces of orbit to maintain stability. Each type of tether has unique advantages for different mission profiles. The first space tether experiments were conducted in the 1960s. The Gemini 11 mission in 1966 deployed a 30-meter tether between the Gemini spacecraft and the Agena target vehicle, demonstrating that a tethered system could be stabilized by gravity gradient forces. The Gemini 12 mission in the same year deployed a similar tether and observed the dynamics of the tethered system.

Space tethers offer several advantages over traditional propulsion. They do not require propellant, which reduces the mass and cost of spacecraft. They can provide continuous thrust or power, enabling long-duration missions. And they can enable new mission concepts, such as sample return from orbit, interplanetary transfer, and space elevator concepts that could revolutionize access to space. Space tethers work by exploiting gravity gradient forces electromagnetic interactions and momentum exchange.

The tether is also an old idea with a distinguished paper trail. Konstantin Tsiolkovsky imagined a tower tall enough that its upper reaches would be held up by the spin of the planet itself; Yuri Artsutanov, writing in 1960, turned the thought upside down and hung a cable from a geosynchronous satellite, down toward the ground and outward into balance. Jerome Pearson worked the orbital mechanics properly in the 1970s, Hans Moravec and Robert Forward simulated rotating versions that could trade momentum with the Moon and

Mars, and by 1979 NASA had begun funding the study of tethered satellites in earnest. The idea kept outrunning the materials, which is the honest reason the field spent a century as theory.

What the chapters ahead cover is the distance between that century of speculation and the hardware that has actually flown. The missions are real, the physics is settled, and the remaining arguments are about materials, control, and patience. A cable in the sky is no longer a fantasy; it is an engineering program with a schedule of unsolved problems, and this book walks through them one by one.

Chapter 01: The Physics of Space Tethers

Space tethers rest on three linked pieces of physics: gravity gradient forces, electromagnetic interactions, and momentum exchange. Understanding these principles is essential for designing and operating tether systems in space. The gravity gradient force is one of the most important principles for space tethers.

In orbit, the gravity of the Earth decreases with altitude, so the end of a tether that is closer to the Earth experiences a stronger gravitational pull than the end that is farther away. This difference in gravity, which is called the gravity gradient, creates a tension in the tether and tends to align it along the vertical direction. The gravity gradient force is proportional to the length of the tether and the mass at each end.

Electrodynamic tethers work by interacting with the Earth's magnetic field. When a conductive tether moves through the Earth's magnetic field at orbital velocity, which is about 7.8 kilometers per second in low Earth orbit, an electromotive force is induced along the tether. The electromotive force, which can be several hundred volts per kilometer, drives a current through the tether, which interacts with the magnetic field to produce a force called the Lorentz force. The Lorentz force can be used for propulsion or for power generation.

If the current is driven through the tether in the direction that produces a force in the direction of motion, the tether accelerates the spacecraft, providing thrust. If the current is driven in the opposite direction, the tether decelerates the spacecraft, providing drag. The direction of the current can be controlled by switching the current on and off, allowing the tether to be used for both propulsion and braking. Momentum exchange tethers transfer momentum between two objects.

A rotating tether can catch a payload at one end and release it at the other end, transferring momentum from the tether to the payload. If the tether is rotating in the direction of motion, the released payload gains velocity and is boosted to a higher orbit. If the tether is rotating in the opposite direction, the released payload loses velocity and is lowered to a lower orbit. Momentum exchange tethers can provide velocity changes of hundreds of meters per second without using propellant.

In the 1970s, Jerome Pearson independently conceived the idea of a space elevator, sometimes referred to as a synchronous tether, and, in particular, analyzed a lunar elevator that can go through the L1 and L2 points, and this was found to be possible with materials then existing. In 1977, Hans Moravec and later Robert L.

Forward investigated the physics of non-synchronous skyhooks, also known as rotating skyhooks, and performed detailed simulations of tapered rotating tethers that could pick objects off, and place objects onto, the Moon, Mars and other planets, with little loss, or even a net gain of energy. In 1979, NASA examined the feasibility of the idea and gave direction to the study of tethered systems, especially tethered satellites.

In 1990, Eagle Sarmont proposed a non-rotating Orbiting Skyhook for an Earth-to-orbit / orbit-to-escape-velocity Space Transportation System in a paper titled "An Orbiting Skyhook: Affordable Access to Space". In this concept a suborbital launch vehicle would fly to the bottom end of a Skyhook, while spacecraft bound for higher orbit, or returning from higher orbit, would use the upper end.

In 2000, NASA and Boeing considered a HASTOL concept, where a rotating tether would take payloads from a hypersonic aircraft (at half of orbital velocity) to orbit. A tether satellite is a satellite connected to another by a space tether. A number of satellites have been launched to test tether technologies, with varying degrees of success. There are many different (and overlapping) types of tether. Momentum exchange tethers are one of many applications for space tethers.

Momentum exchange tethers come in two types; rotating and non-rotating. A rotating tether will create a controlled force on the end-masses of the system due to centrifugal acceleration. While the tether system rotates, the objects on either end of the tether will experience continuous acceleration; the magnitude of the acceleration depends on the length of the tether and the rotation rate. Momentum exchange occurs when an end body is released during the rotation.

Deployment is the tether's first exam, and most of the failures in the field's history happened in the first minute of the first flight. A coiled line leaving a reel does not simply fall out of the spacecraft; it responds to the same gravity gradient that will later steady it, to friction in the dispenser, to the spring or motor that gave it its initial push, and to its own growing inertia. Pay out too slowly and the line goes slack and whips; too fast and it oscillates; unevenly and the system librates, swinging in a slow pendulum about the vertical that can take hours to calm. The successful flights treated deployment as a measured experiment of its own: the SEDS missions counted turns of a simple friction brake, while the Tethered Satellite System used a motorized reel with instruments watching every meter of a deployment that stuck twice at awkward moments and taught the engineers more about tether mechanics than any simulation had.

The tethered system is also, strictly, a piece of orbital mechanics with a personality. A compact satellite can be treated as a point mass; a cable of kilometers cannot, because different points along it, at different altitudes, want to travel at different speeds. The result is a family of motions unique to tethers: librations like a slow pendulum swing, transverse vibrations that travel along the line like a plucked string, and the skipping-rope mode in which the whole cable rotates in a lazy cone. Every mission plan includes control authority over these motions, whether by thrusters, by reeling the line in and out a few meters at a time, or by varying the current in an electrodynamic tether so that the magnetic field itself becomes both brake and rudder. The surprise of the field is not that a cable is hard to manage but that it is manageable at all, and with such small nudges.

There is a neat physical rhyme running through all of this: a hanging tether swings like a pendulum whose period is set by the same clock as the orbit itself. A satellite circles the planet in about ninety minutes at typical low altitudes, and a gravity-gradient tether's slow libration wants to keep a fixed relationship with that period, which is why controllers time their nudges to the orbital clock rather than fighting the swing head on. Get the timing wrong and a small push at the wrong phase grows the swing; get it right and the same push calms it, a lesson in resonance that every tether flight has relearned, usually within the first week of operations.

Units in this field reward a little intuition. Orbital speeds near Earth run near eight kilometers every second; tether lengths in the flight record run from tens of meters to tens of kilometers; and the useful forces, a few millinewtons per kilometer of conducting line, sound negligible until they are multiplied by the months a mission spends in orbit. Tether engineering is therefore the discipline of small forces applied for a very long time, which is also a fair description of patience, and the numbers that follow in later chapters keep that character: nothing here is violent, but everything adds up.

The chapters that follow keep the physics in plain words, but three pictures are worth carrying the whole way. First, a tethered system is one machine, not two: everything on the line shares a fate and an orbit. Second, tension is not a design choice but a fact of the environment, present the moment the line goes taut, and every piece of hardware that touches the cable meets it. Third, nothing in the system is static; the line, the ends, and the forces all breathe on orbital timescales, and the difference between a stable flight and a tangled one is usually the difference between a control system that respected the rhythm and one that fought it.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.