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THE ORBITAL SIPHON: A NEW SPACE ELEVATOR CONCEPT*

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A new concept for propellantless payload transfer from the surface of the Earth to Earth escape is presented. Firstly, a simple model of a payload ascending or descending a conventional space elevator is developed to explore the underlying dynamics of the problem. It shown that an unconstrained payload at rest on a space elevator at synchronous radius is in an unstable equilibrium, and that this instability can be used to motivate the development of a new concept for payload transfer. It will be shown that a chain of connected payloads stretching from the surface of the Earth to beyond synchronous radius can be assembled which will lift new payloads at the bottom of the chain, while releasing payloads from the top of the chain. The complete system therefore acts as an 'orbital siphon', transporting mass from the surface of the Earth to Earth escape without the need for external work to be done. Indeed the system performs net work by transferring energy from the Earth's rotation to the escaping mass. The dynamics of the siphon effect are explored and key engineering issues are identified.

Keywords: Orbital tower, payload transfer, orbital dynamics

1. INTRODUCTION

The concept of an orbital tower has been discussed in the literature by many authors over a number of years. While the concept is clearly futuristic, interest has recently been revived due to advances in materials science (see for example [1-4]). In this paper, a simple model of a payload freely ascending or descending a space elevator will be considered to explore the underlying dynamics of the problem. Firstly, it will be shown that an unconstrained payload at rest on a space elevator at synchronous radius is in an unstable equilibrium. This instability is due to the presence of a maximum in the effective potential of the problem, which represents the gravitational and centripetal forces acting on the payload. The existence of this maximum in the effective potential then leads to a barrier which must be crossed by payloads ascending or descending the elevator. Conditions can be found which allow, for example, a payload captured at the top of the elevator to freely descend through synchronous radius. Similar conditions can also be determined under which a payload ascending the elevator will coast through synchronous radius and ascend the elevator to escape [5].

A more complex problem will then be investigated with a chain of payloads attached together along their length. New conditions can then be found under which the uppermost payloads will pull the lower payloads across the potential barrier noted above, and along the elevator to escape. A continuous chain of such payloads can be envisaged with new masses being added to the bottom of the chain as masses are released from the top of the chain and escape. The assembly then provides a continuous stream of mass lifted from the surface of the Earth and delivered to Earth escape without the need for external work to be done. It can be shown that the system in fact performs net work by transferring energy from the Earth's rotation to the escaping mass stream. In this light the ascending chain can be seen as a machine which leverages (siphons) energy from the Earth's rotation to the escaping mass stream [6]. While there are significant engineering difficulties associated with this concept, the underlying dynamics demonstrates that such an 'orbital siphon' is in principle possible and offers the prospect of the continuous delivery of mass from the surface of the Earth without the input of external work.

The orbital siphon idea was first developed by Davis in 1991, as part of a concept for transferring material from the surface of a rapidly spinning asteroid. It was noted that it may be possible to draw up a continuous train of material from the asteroid surface to escape. In 1996, (with the assistance of Dr Andrew Gay), a numerical simulation was developed with a chain of masses attached to the Earth's equator. Using this model, the operation of a simple orbital siphon was demonstrated and published on the web in 1997 [7]. In 2005 McInnes conducted an analysis of the dynamics of the siphon and McInnes and Davis co-authored a paper that outlined the siphon principle at IAC 2005 [6]. In 2006, Davis developed an improved siphon simulation model, and made several further suggestions concerning siphon engineering issues [8]. A related concept was set out by Logsdon [9] the same year that the orbital siphon simulation was first published on the web. However Logsdon's SkyHook Pipeline requires pumps to raise water to geosynchronous orbit, after which the water 'falls' outward to drive turbines that generate more than sufficient power to drive the pumps, and could thus provide net electrical power generation. The siphon, by contrast, is simply a long chain of tethered masses, and requires no pumps or external work for its operation once the siphon in is operation.

* Aspects of this work were presented as paper IAC-05-D4.2.07 "Novel Payload Dynamics on Space Elevator Systems", 56th International Astronautical Congress, Fukuoka, October 2005.

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A Personal Postscript (C. Davis): Origins of the Siphon

The idea for the siphon first occurred to me in 1991, while I was conducting an unrelated thought experiment. I had imagined that an attempt was being made to mine a small asteroid for its carbon, by sending a single self-reproducing mechanical digger truck to the asteroid, with instructions to dig up carbon and transport it to a collection site on the asteroid equator. As the mechanical diggers multiplied exponentially in numbers, more and more carbon was delivered to the collection point, creating a steadily growing conical heap of carbon.

While this seemed a neat way of extracting carbon, I hadn't thought how to collect and transport the carbon back to Earth. While I was trying to think of some cheap transportation method, the carbon heap grew higher and higher, with the digger trucks struggling up to the top to deposit their loads. It was while I was considering this scene that I found myself imagining carbon flying off the top of the the conical heap, dragging trucks with it, one after another.

This was a distinctly odd notion, but I soon realised that it wasn't entirely implausible. If the carbon heap had grown so high that it rose above the synchronous orbit of the rapidly rotating asteroid, material would indeed fly off the top, because centrifugal or inertial forces would exceed gravitational forces. However what wasn't clear was whether such a mountain would allow a continuous stream of material to flow into space in a siphon effect.

The matter then rested there for several years, while the mechanical diggers went on to form the foundation of the Idle Theory of evolution. Then, in 1996, with the advice and assistance of a physicist friend, Dr Andrew Gay, I put together a 2D simulation model of orbiting satellites - something I had wanted to do for a long time. Once I had this model, it almost immediately occurred to me that I could maybe use it to explore the siphon idea. I began connecting satellites into chains with elastic cables, and connected one end of the chain to the equator of the Earth, to create an orbital tower along the lines of Pearson's 1975 tower - only higher.

The first attempt to simulate the siphon simply entailed releasing this tower at its base, and feeding in new satellites as it rose. But, after lifting a few satellites up from the Earth, the tower simply slowed, became misshapen, and finally collapsed. At first I thought that I had simply shown that the siphon idea was unworkable. But then I remembered that the conical pile of carbon on the asteroid was an inflexible and rigid mountain. So I took my simulation model, and made the tower rigid by simply removing all tangential forces acting on it, so as to constrain it to radial motion. With this fix in place, the siphon effect began to work. In fact, it began to work rather too well, with satellites accelerating up the tower faster and faster.

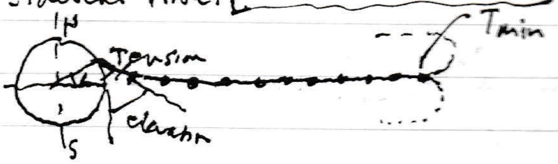
After a little more development, and having convinced myself (if nobody else) that the siphon was a plausible idea, I re-wrote the model as a Java applet that showed the various stages from the orbital model through to the final working orbital siphon, and put it up on the internet in 1997. There it remained, almost entirely unremarked - until, in early 2005, Colin McInnes emailed me with a question about it.

Non Equatorial Tower

Siphon, Towers, and Strings of Beads

4 Jun 05

sidereal tower?



1) For any latitude set up some length tower, using small masses + short ties

2) Cruise along tower for Tmin (if any)

3) Decrease tension at base + see if Tmin increases or decreases

If decreases, decrease further, else increase

4) Once no further ~~increase~~ Tmin decrease is found, decrease angle of elevation.

If Tmin decreases, decrease angle further, else increase angle.

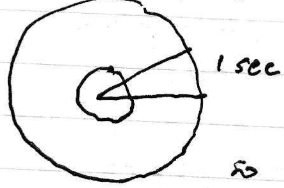
5) If no further decrease in Tmin go back to 3), using a 10th of previous values

If Tmin = 0, stop.

The ~~ea~~ non-equatorial tower from base to Tmin should be in stable equilibrium.

Try modelling with Siphon Simul? Can there be siphons?

Siphon-within-siphon



$$\frac{1}{S.D} \cdot \pi r^2$$

$$= \frac{1}{2} \omega r^2$$

so

: fuel siphon consists of a train of rocket fuel containers. If Hydrazine, then 8 oxygen containers per 1 hydrogen.

: This fuel siphon wouldn't actually launch anything into space, but would be consumed within the main train of payloads.

: The fuel siphon would have a diminishing mass from bottom to top. The siphon can raise increasing masses (from '97 studies), but can it handle this converse case?

: The fuel siphon would ~~have~~ a higher radial velocity than the main tower, and would increase coriolis forces.

: Solid or binary fuel? Why not deliver whole solid fuel thrusters? What is the advantage of solid over binary fuel.

: How about having the fuel siphon act as the thrusters?