Spaceships kinetic energy recovery and reutilization

An initial concept

Alvaro Antolinez Abellan
Palma de Mallorca, Spain
regenorbitals@gmail.com

Abstract—**Proposal for a system that recovers and stores the excess kinetic energy of a spaceship arriving from another planet. It's composed by an orbital station that capture the spaceship by electromagnetic means and stores it in batteries. The stored energy in form of electricity and a higher station orbit can be reused to provide impulse for departing spacecraft.**

Index Terms—**Spaceship momentum, regenerative braking, orbit station, tether cable.**

I. INTRODUCTION

Current space exploration programs, consider the kinetic energy of a spaceships as expendable. Liquid fuel rockets are the main propulsion system, for both acceleration and deceleration. Atmospheric drag it's also used when possible to lose a big part of the energy of the vehicle arriving to a planet.

Due to the tyranny of the rocket equation, all the extra weight that spacecraft carry in form of fuel, heat shields, and of course bigger rockets, implies more fuel and still bigger rockets.

For interplanetary propulsion there are options that allow lighter and more efficient (and/or cheap) spacecraft propulsion, like ionic engines, nuclear engines, planetary gravitational sling, interplanetary transport network and solar sails.

But still all of them address the spacecraft energy as a problem to be solved if you need to modify the arriving trajectory in to an orbit. That means that you need to carry extra propulsive capacity in form of fuel to reduce the speed to the desired levels.

There is no need at the moment (nor in the near future) to try to recover any part of the energy of a spacecraft, but eventually a more mature and massive interplanetary space travel network will be built for passenger and cargo transportation. This network will need to pay attention to the reduction in costs and resources consumption (like all current transportation infrastructures in earth do) at all the phases of the space flight. This will make the study and investment in such recovery systems a vital necessity.

A system able to recovery at least part of the orbital energy of a spacecraft, will lead to a cascade of fuel, structural and economical savings.

The system described in this document makes use of current known physics and techniques (not space-time warping needed) but unfortunately it needs unobtanium materials. Due to the materials and control systems needed, it´s probably similar to a space elevator (in how possible it is to build it).

Even if the system described in this paper is theoretically possible, it´s not technologically or economically viable to build it at the moment, nor it´ll be in a foreseeable future. If the materials and technology existed right now, still it would require a huge investment and a number of interorbital flights similar to a modern airport, in order to build, deploy and operate the station network and obtain some kind of saving.

II. SYSTEM DESCRIPTION

In space there are no rails or roads nor any other fixed surface that can be used to transfer the energy of a spacecraft. To be able to reuse the kinetic energy of a space ship, we need a mass in orbit to transfer such energy, and engineering, navigation and control systems able to handle the ultra accurate navigation and the structures needed to transfer huge quantities of energy of a spacecraft traveling at speeds of tens of km/sec .

The system requires a station in orbit much more massive (relatively speaking) than the spacecraft that it´ll brake. This will help to keep the station´s orbit and energy levels within tolerable ranges.

Due to the extremely high speeds differentials between a station at a fixed orbit and an arriving spacecraft (some km/s), and the energy involved it is impossible to use any mechanical method that involves physical contact between the station and the spacecraft. The only way that seems plausible at this moment is using induction motors to apply the braking force via electromagnetic fields over a (very) long braking distance.

The spacecraft´s kinetic energy will be transferred to the station or transformed as follows:

- Transferred to the station as kinetic energy, that alters the station´s orbit to a higher, more eccentric one.
- Electricity generated by the induction linear motors as they interact with the spacecraft. These motors will be the ones that effectively perform the spacecraft "grabbing", braking and transferring the KE to the station. The electricity produced can be stored in batteries for further use.
- Heat and other system inefficiencies.

The point where the spacecraft´s kinetic energy is higher is at its periapsis (the point of lower). At this point is where potentially more energy can be transferred from the spacecraft to the station.

As the spacecraft meets the station and transfers its energy, the spacecraft speed will be decreased, the station speed will be increased and the trajectory of both objects modified. The spacecraft will ideally get a new lower orbit.

The energies and speeds involved are so high that it´s probable that a single station will not be able to handle the spacecraft speed reduction needed in just one pass. A series of stations at different altitudes, could be used to brake the spacecraft in a cascade sequence, till the speed has been reduced enough to perform a reentry or keep a desired orbit.

III. SYSTEM ELEMENTS

The system behavior below is just a concept and does not try to be an accurate description of the orbital maneuvers performed.

Initially the station is placed at a "track 0", on an initial circular orbit at a given altitude. Once the arriving spacecraft meets the station, it starts decelerating. The station´s orbit is altered as if it were performing a common motor acceleration; the new orbit will be more elliptic and of a higher energy than before, a higher "track".

The station´s modified orbit could be considered the first stage of a Hohmann transfer maneuver.

If the next arriving spacecraft to the station it´s synchronized properly at the highest point of the new elliptic orbit of the station (apoapsis), the rendezvous can be used to provide the Delta V of the second stage of the Hohmann maneuver (one of the most common maneuver to change the orbital altitude), giving the station the needed speed for circularizing the orbit again (but at a higher orbit)

This operation can be performed several times, creating several potential energy levels of "charge" or "tracks". This potential and electrical energy can be transformed back to kinetic energy when accelerating a departing spacecraft.

Once a station has absorbed the energy of one or several spacecraft, in form of a higher orbit and charged batteries, it will be possible to use this energy again for accelerating departing spacecraft. This will be done reversing the previous procedure, a departing spacecraft reaches LEO or a given altitude (with just a parabolic trajectory) with conventional rocket engines, then rendezvouses with the Station, which then proceeds to accelerate it.

The main advantages of a recovery system like this are:

- Less fuel needed for accelerating to scape speed or decelerating a spacecraft so it can establish an orbit.
- If a spacecraft needs to carry less fuel, the tank and overall spacecraft size is smaller.
- With lower reentry speeds, the heat shields needed could be thinner and lighter. This means once again weight savings on fuel and structure.
- Less fuel needed to reduce the arriving speed for atmospheric reentries.
- Less fuel needed to slow down in planets and moons where the stations are installed and that have no atmosphere or a very thin one (which make aero braking impossible).
- Possibility to recharge the station´s batteries via solar panels in order to use this energy for further acceleration of departing spacecraft.
- Possibility of using the stations to make orbit inclination changes of a spacecraft without needing huge amounts of fuel.

A. Braking system

How to build a system able to perform such maneuvers with a realistic infrastructure?

The (extremely) hard part is designing and building a system that exerts the electromagnetic force between the stations to the spacecraft, over very long distances and keeping a reasonable station size.

It´s impossible to build a station with a physical "rail" long enough, the linear motors present at the station must be relatively short (some dozens or hundreds of meters) not hundreds of kilometers.

The solution proposed is to use a cable attached to the spacecraft. This cable is deployed behind the spacecraft. It works as a long linear stator, like a "tail" that the station is able to "grab" electromagnetically, effectively transferring the kinetic energy of the spacecraft to the station.

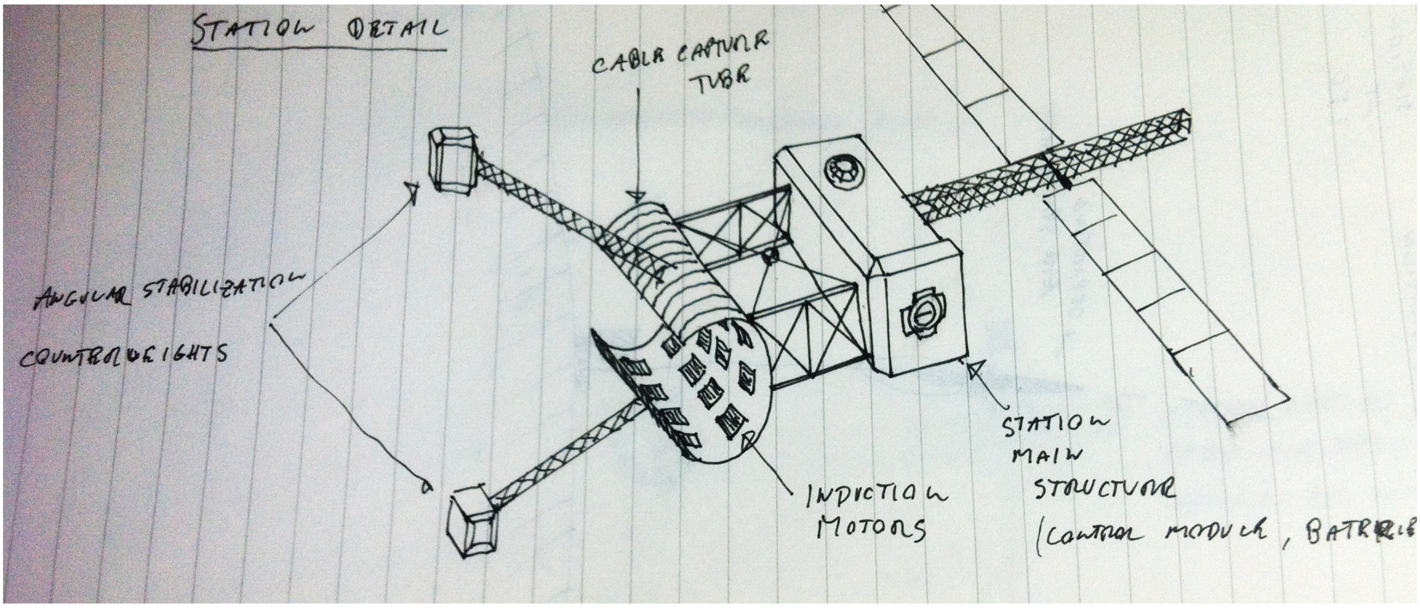
To better visualize it, imagine a cyclist that doesn´t have brakes, but it drags a long rope behind it. In order to reduce speed he asks a friend to grab the rope and start applying friction with his hands. While grabbing the rope, the friend is going to receive part of the kinetic energy of the bike, he is going to start moving in the same direction of his friend while the bike reduces its speed (he probably will probably burn his hands too).

B. The station

The main station elements are (see Fig 1):

- Induction motor. Performs the braking and acceleration of the spacecraft.
- Control module. Contains the main systems and batteries to store the recovered electrical energy.
- Solar panels.
- Angular stabilization structures and systems. Due to the violent nature of the braking action, stabilization structures and systems will be very important. The induction motor will need to be located at the center of mass of the station to reduce the angular momentum created during the rendezvous.

Due to the high mass of a station compared to the regular spacecraft, it´s possible that the stations will need to be built in orbit, using materials mined at asteroids, to save in launch costs.



C. The Spacecraft

The most delicate parts of this system it is probably the cable deployed by the spacecraft. To deploy and control it's necessary to use a small pod with conventional rockets, must be used.

If the cable-stator is thin and light (and at the same time strong enough) a very long one could be carried stored at the spacecraft, giving enough braking length to obtain a milder deceleration and/or a higher speed reduction.

Due to the high accelerations needed to perform a useful deceleration or acceleration and the limits imposed by the cable physical size, weight and length, it´s possible that the spacecraft´s only payload will be raw materials or cargo able to sustain high G´s. If a cable long enough could be deployed, humans and delicate manufactured goods could be carried with this system.

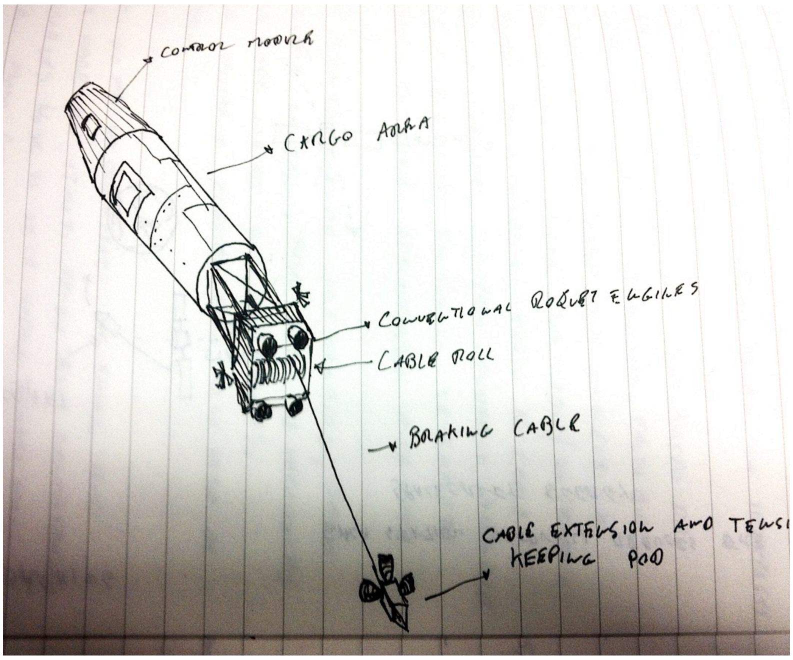
The use of a cable-stator and induction motor combinations means that the rendezvous between the spacecraft and the station structure needs to be very close to be effective. At the speeds involved this means an extremely dangerous maneuver that will need ultra precise navigation, control and maneuver systems.

The pod has also the mission of keeping the cable´s relative position and tension not only during the deployment but specially through the braking procedure. It's very important that through the braking procedure the cable is kept with enough tension to keep it from collapsing towards the station. Once the spacecraft has started decreasing it´s speed, the cable portion that has not passed through the station yet, will keep it´s initial (higher) speed and will try to overtake the spacecraft. Due to this, the pod will need to be firing it's rockets, to keep the whole cable and the pod itself at the same speed reduction rate than the spacecraft and the cable water down the station.

If for whatever reasons the cable control pod doesn´t work, the braking procedure will have to be aborted, to avoid the cable collision with the station.

The spacecraft will need also a go-around capability (fuel and systems wise) that allows a rejected rendezvous in case the systems are not nominal. After a rejected rendezvous, a new alternate maneuver should be available with another station. If it´s not possible, at least a safe spacecraft rejection trajectory must be planed that sends the spacecraft in a safe trajectory (even if that means loosing it).

Fig. 2



The main parts of the spacecraft are (see Fig. 2):

- Cargo area.
- Control & nav. systems.
- Stator-cable (Tail). It goes behind the spacecraft and works as a tail that the station "grabs" electromagnetically while the spacecraft and the cable keep moving pass the station. The cable needs to be kept tense and in the spacecraft travelling direction. The cable needs to be thin and very strong and at the same time have electromagnetic capabilities to allow the linear motor at the station to "grab it".
- Cable deployment and control pod. Deploys the cable and keeps it with enough tension and adequate position during the braking and acceleration maneuver. The pod needs to be able to keep the cable speed consistent with

the one of the spacecraft. It´ll need a conventional rocket engine able to be throttled.

- Spacecraft conventional propulsion. Necessary to maneuver and modify the trajectory and at least perform a rejected rendezvous.

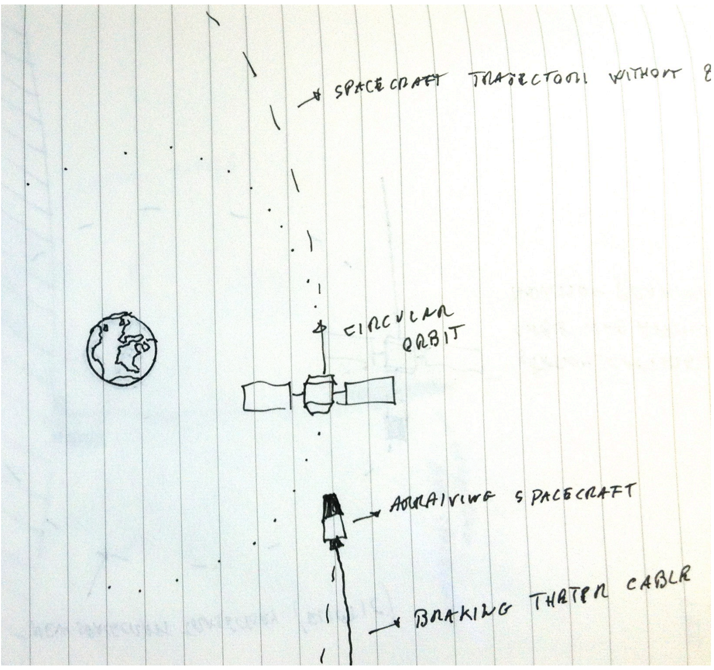
IV. RENDEZVOUS PROCESS

This is how a braking rendezvous takes place:

- A spacecraft returning from an interplanetary or a solar orbit trajectory (for example from an asteroid mining station) to the Earth, was initially launched with a rendezvous slot assigned to a given station (see Fig. 3). The optimal rendezvous point could to be the spacecraft´s periapsis, as it´s where the kinetic energy is higher.

  Before the rendezvous, the spacecraft deploys the cable using the pod.

Fig. 3

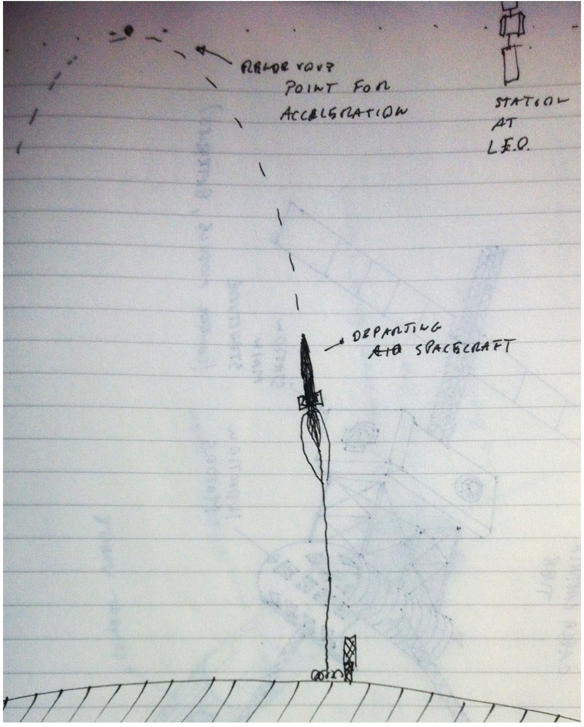


- Deceleration rendezvous: First the spacecraft passes very close to the station, once the spacecraft has cleared the station, the linear motor starts applying force to the cable. The cable´s pod starts pulling from the cable to keep it with enough tension and with the correct trajectory. A part of the spacecraft´s kinetic energy will be stored as electricity at the station thanks to the induction linear motors, another part will be lost as heat, and a third part will be transferred as kinetic energy to the station itself.
- Resulting orbits: The rendezvous will modify the orbits of the two objects. Depending on the efficiency and system capability, there can be 4 resulting orbits for the spacecraft:

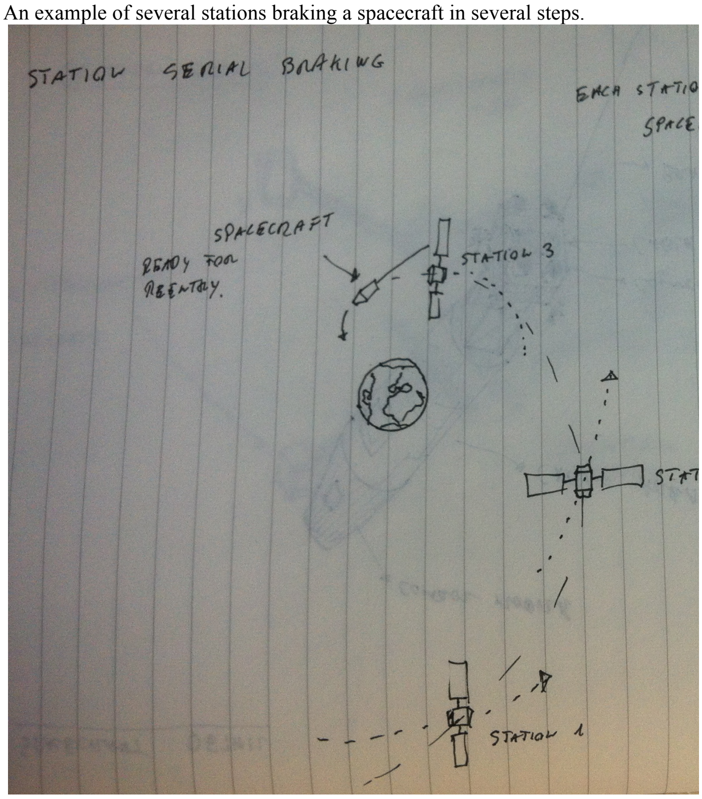
  a. Optimal: Result of a high deceleration, the capsule falls into a elliptical orbit where the periapsis is closer to the earth than the original station´s orbit. The station´s orbit changes from a circular to elliptical.
  b. Neutral: There is a lower energy interchange and the spacecraft is decelerated to a speed that converts it´s trajectory into a circular orbit similar to the one that the station had. The station changes it´s orbit to an elliptical one.
  c. High: There is still less energy interchange and the spacecraft is braked to a speed that allows to keep elliptical orbit around the destination planet, but with an apoapsis that´s higher than the station´s original orbit. The station also sees it´s orbit changed to an elliptical one.
  d. Insufficient: The energy absorbed by the station is not enough to slow down the spacecraft below a scape speed, so it keeps it´s hyperbolic trajectory out of the destination´s planet orbit. The station still sees it´s orbit altered to a higher one.

How a departing rendezvous takes place:

- The spacecraft is launched with a conventional rocket. It can be launched in to LEO or just with a parabolic trajectory that intersects the station´s orbit. Once outside of the atmosphere it deploys the cable and gets ready for the rendezvous. But for the acceleration the cable must be deployed IN FRONT of the spacecraft, just the opposite than the breaking. This way the station captures the cable close to the spacecraft and then as it goes faster than the spacecraft, it starts pulling from the cable while moving along it´s length, till the station arrives to the pod and releases the cable.



An example of several stations braking a spacecraft in several steps.



V. FINAL THOUGHTS

No previous literature has been found on a system like this, the only orbital tether that has been studied and tested uses the Earth electromagnetic field to slowly reduce the speed of a satellite. Also, no first principles calculations have been performed yet.

Even if it´s unrealistic or possible but impractical, to build it from the point of view of physics, engineering or economy, still it can be an interesting exercise in orbital mechanics, and hopefully could start a debate on energy recovery in space.

VI. COLLABORATIONS

Those interested in developing or studying the idea, please contact regenorbitals@gmail.com