Acta Astronautica 99 (2014) 99–110

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Gravity-assist engine for space propulsion

Arne Bergstrom *

B&E Scientific Ltd, Seaford, BN25 4PA, United Kingdom

ARTICLE INFO

Article history:
Received 5 December 2013
Received in revised form
10 February 2014
Accepted 15 February 2014
Available online 28 February 2014

Keywords:
Spacecraft propulsion
Angular momentum conservation
Tidal locking
Three-body interactions
Numerical simulation

ABSTRACT

As a possible alternative to rockets, the present article describes a new type of engine for space travel, based on the gravity-assist concept for space propulsion. The new engine is to a great extent inspired by the conversion of rotational angular momentum to orbital angular momentum occurring in tidal locking between astronomical bodies. It is also greatly influenced by Minovitch's gravity-assist concept, which has revolutionized modern space technology, and without which the deep-space probes to the outer planets and beyond would not have been possible. Two of the three gravitating bodies in Minovitch's concept are in the gravity-assist engine discussed in this article replaced by an extremely massive 'springbell' (in principle a spinning dumbbell with a powerful spring) incorporated into the spacecraft itself, and creating a three-body interaction when orbiting around a gravitating body. This makes gravity-assist propulsion possible without having to find suitably aligned astronomical bodies. Detailed numerical simulations are presented, showing how an actual spacecraft can use a *ca* 10-m diameter springbell engine in order to leave the earth's gravitational field and enter an escape trajectory towards interplanetary destinations.

© 2014 IAA. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Rocket propulsion of spacecraft is technically extremely advanced from the engineering point of view. However, rocket propulsion is actually at the same time a very crude and primitive method for space propagation, requiring as it does huge amounts of propellant to transport the huge amounts of propellant necessary to produce the massive amounts of exhaust gases required to propel the rocket in the opposite direction.

First after several years of space flight in this way, a method for gravitational propulsion, now called gravity-assist, was proposed by Minovitch [1,2] at Jet Propulsion Laboratory (JPL) in USA. This method uses (minute) parts of the orbital energy and momentum of a planet or moon for the further propulsion of a space probe. The three-body problem involved, which Minovitch thus managed to treat in a special case, made interplanetary travel a realistic prospect. Without this method, the exploration of the outer planets (and now interstellar space) by the space probes Voyager I and II (and subsequent missions like the Cassini mission) would not have been feasible with present technology.

Inspired by the gravity-assist method for space propulsion described above, the present study considers an alternative method for space propagation without rockets. The proposed new method also finds its inspiration in the tidal damping of orbital motion. This indicates that there are ways in which rotational motion of a planetary body may be converted into orbital motion (and conversely orbital motion be converted into rotational motion), which can be exemplified as follows (*cf* Fig. 1, from http://en.wikipedia.org/wiki/Tidal_locking, reprinted here in accordance with Creative Commons Universal Public Domain Dedication).

Tidal bulges may occur on a body B that rotates around and close to a more massive body A. If these tidal bulges happen to be misaligned with the major axis, the tidal

* Tel./fax: +44 1323 491310.
E-mail address: arne.bergstrom@physics.org

http://dx.doi.org/10.1016/j.actaastro.2014.02.017
0094-5765 © 2014 IAA. Published by Elsevier Ltd. All rights reserved.

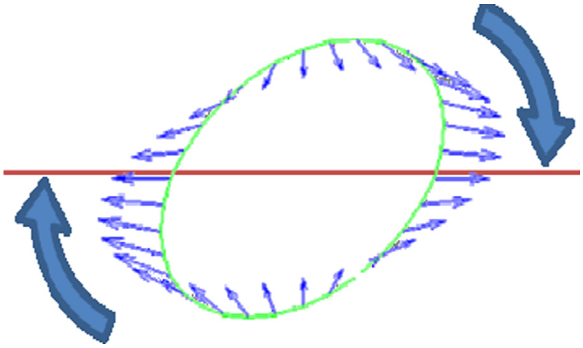

Fig. 1. A spinning, deformable body exposed to the gravitational field from a parent body (to the right), around which it rotates in a close orbit. If the tidal bulges in the body are misaligned with the major axis (red), then the tidal forces exert a net torque that twists the body towards the direction of realignment and acts to change its orbital angular momentum. The spinning springbell shown in Fig. 2 attempts to artificially recreate this effect in a controllable manner. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

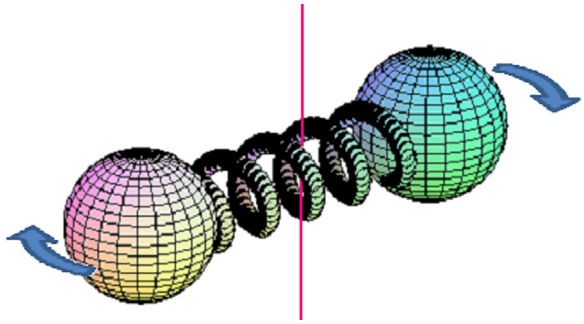

Fig. 2. Schematic springbell engine consisting of two massive weights coupled by a strong spring and in orbit around the earth (to the right). The spring expands or contracts in response to the gravitational force from the earth and to the centrifugal forces from the weights when the springbell spins around its axis (red), creating a three-body problem analogous to Minovich's gravity assist [1]. The springbell can be used for converting rotational energy into orbital angular momentum as illustrated in Figs. 5 through 9. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

forces will exert a net torque on body B that twists the body towards the direction of realignment. The angular momentum of the whole A–B system must be conserved, so when B slows down and loses rotational angular momentum in this way, its orbital angular momentum is boosted by a similar amount (there are consequently also some smaller effects on A's rotation). As a result, B's orbit around A is raised in tandem with its rotational slowdown. For the other case when B starts off rotating too slowly, tidal locking both speeds up its rotation and lowers its orbit.

In order to exploit this effect for space propagation, I will here consider a disk-shaped design containing a spinning dumbbell. Etymologically, the word 'dumbbell' originates in Stuart-era England from training for ringing church-bells by practising with dummies. To describe a spinning dumbbell consisting of two masses connected to each other by a spring as discussed in the following (see Fig. 2), I will here use the term 'springbell'.

Instead of the spacecraft interacting gravitationally with two external celestial bodies as in the three-body interaction in conventional gravity-assist, the onboard gravity-assist proposed here uses weights and spring forces between two of the three bodies involved in the three-body interaction, and where these two bodies and the spring replacing the gravitational interaction between them are situated onboard the vehicle itself. The onboard gravity-assist presented in the following thus uses only the gravitational field of just one celestial body. Since the method presented here thus can be described as involving artificially manipulated tidal forces, it could perhaps also be called tidal drive or tidal warp.

By skilful use of special trajectories, conventional gravity-assist can have many uses in interplanetary travel, but onboard gravity-assist always permits much faster and more direct trajectories. The advantage with conventional gravity-assist is that it uses only existing gravitational fields, whereas onboard gravity-assist requires an energy source for its trajectories. In this way, onboard gravity-assist as presented here could be said to compare to conventional gravity-assist in the same way as engine-powered ships compare to sailing ships.

2. The spinning springbell

What is interesting with a spinning springbell in a gravitational field, *e.g.* from the earth, is that it is actually a three-body problem, just as the gravity-assist case discussed above. Although simple, it retains the basic characteristics of a three-body problem in that it cannot be simplified by replacing the two masses in the springbell by a mass at its centre of gravity. Instead it can for example, as will be discussed further below, be arranged to display an analogue to the tidal damping discussed above.

The advantage of replacing two of the three gravitationally interacting bodies in the classical three-body, gravity-assist case by a springbell is that the problem suddenly in this way may become much more practically useful. Now just a springbell is involved instead of having to find planetary bodies in suitable positions. The chance alignments of the outer planets, making possible the gravity-assisted 'grand tour' mentioned above of Voyagers I and II, will for instance not happen again for more than a hundred years.

The springbell concept is also easier to implement since a (normal) spring force between the masses in the springbell causes their mutual attraction to increase with separation, not as in the gravitational case to decrease with separation.

I will in the following thus consider a system consisting of a rotating springbell combined with a counter-rotating circular flywheel. Without changing the total angular momentum of the whole system, we can then in an orchestrated manner adjust the angular velocity of the springbell (and correspondingly of the flywheel), and thus change the angular momentum of the springbell by feeding energy into the system, or conversely removing energy from it.

Download English Version:

https://daneshyari.com/en/article/8056918

Download Persian Version:

https://daneshyari.com/article/8056918

Daneshyari.com