Propellantless gravity assisted acceleration in two-body systems

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Abstract

Propellantless gravity assisted acceleration is a well known phenomena and has been practically used in spaceflight (e.g. Luna-3 and Voyager probes). However conventional propellantless acceleration in gravity field requires a three-body system. The fact that propellantless acceleration is possible also in two-body systems doesn't appear to be widely known.

1 Introduction

Modern spacecraft engines work by ejecting mass (also known as propellant) in the opposite direction of intended acceleration. There is also a category of propellantless propulsion methods - solar sails, magnetic sails and gravity assist. These methods do not violate the law of conservation of momentum as they interact with external fields and so are not reactionless. Propellantless gravity assisted acceleration has successfully been used in Luna-3 (Earth-Moon-spacecraft system) and Voyager probes (multiple gravity assists at planets).

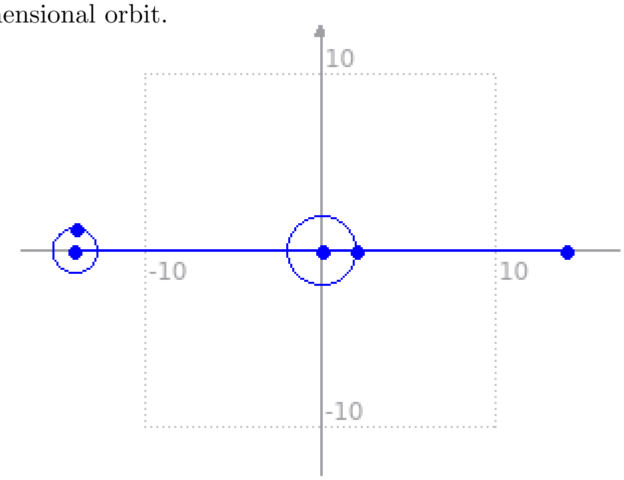
2 Gravity assist

Gravity assist is an mechanism of altering the path and speed of a spacecraft. Conventional gravity assist can be considered a form of restricted three body problem where two bodies are massive (e.g. Sun and a planet) and one has negligible mass (spacecraft). This approach has already been successfully applied in multiple space missions - Luna-3 and Voyager space probes. It is important to note that gravity assist preserves both total energy and momentum of the system - acceleration is done by transferring energy and momentum between bodies.

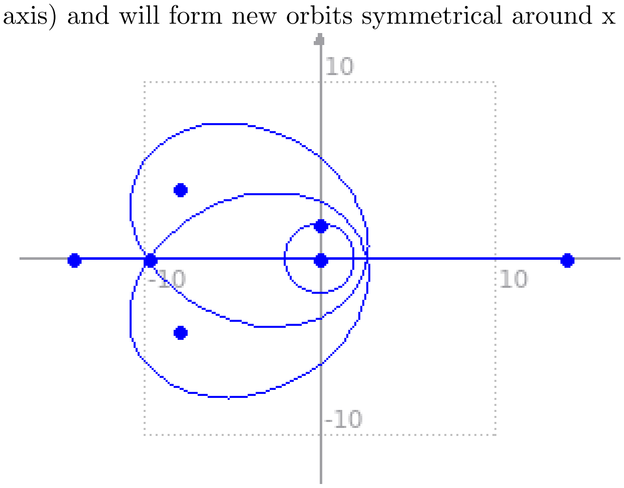
3 Two-body gravity assist

It is possible to construct a mechanism where gravity assist works in restricted two body problem (e.g. a spacecraft of minuscule mass and a massive planet).

Just as in in conventional three-body gravity assist total system energy and momentum would be preserved. For the sake of simplicity let us look at two dimensional system with a planet and spacecraft orbiting planet in a one dimensional orbit.



Spacecraft is also carrying reaction mass (it will be recovered later so can be usable cargo and shouldn't be considered a propellant) with the same mass as the rest of the spacecraft. Lets say that this reaction mass is accelerated and ejected from the spacecraft at some place in the orbit in direction perpendicular to the orbit. Both spacecraft and reaction mass will start orbiting the planet in new elliptic orbits. Because masses of spacecraft and reaction mass are equal, they will be accelerated to same speed V_{sep} (speed component perpendicular to x axis) and will form new orbits symmetrical around x axis.



At some point both orbits of spacecraft and reaction mass will intersect on the x axis due to symmetry. The speed of each part at this point can be expressed as two components - one perpendicular to the x axis and on parallel to it. Lets call the perpendicular component V_{ren}. If spacecraft catches the reaction mass at this point and absorbs the kinetic energy from V_{ren} a new linear orbit will be formed again. If $V_{ren} < V_{sep}$ it means that some energy was left and the newly formed linear orbit is of higher energy than the initial linear one. Analogous reasoning can be applied to the case $V_{ren} > V_{sep}$. If $V_{ren} = V_{sep}$no changes in orbit energy happened.

The most efficient case when V_{ren} approaches 0 would be when spacecraft and reaction mass reach escape speeds, form hyperbolic trajectory and rendezvous point is at infinity. In this case all kinetic energy that was put into spacecraft at separation point perpendicular to x axis would be translated into speed parallel to x axis.

This mechanism can also be extended to 3 dimensional space (actually the already demonstrated linear orbit is valid also in 3D space). Also more elaborate orbits can be created where separation point is at elliptic orbit in 3D space and reaction mass is ejected perpendicular to orbital plane.

4 Conclusion

Here we have demonstrated gravity assisted acceleration in two-body systems. Further work is required to apply this mechanism to realistic assumptions of planet radius, size of atmosphere, availability of acceleration mechanisms at separation point and breaking mechanisms at rendezvous point. This mechanism can also be used to improve the the conventional three-body gravity assist.