FLYBY ANOMALY

According to ‘MATTER (Re-examined)’

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Abstract: ‘Flyby anomaly’ is a significant but unaccounted apparent increase or reduction in linear velocity of a spacecraft during Earth flybys. This phenomenon could not be explained by current physical laws. This article attempts to show that the noticed discrepancies are apparent and they are produced by faulty geometry used in contemporary laws of planetary motion. In reality, the spacecraft and external efforts on it behave normally. There are no causes or actions that vary the spacecraft’s linear velocity during Earth flybys. There is no basis for the assumption of strange ‘forces’ or mysterious effects on or about the spacecraft.

Keywords: Flyby anomaly, swing-by anomaly, planetary orbits.

Introduction:

Spacecrafts, whose velocities are boosted by gravitational assistance (the sling-shot effect) in conjunction with Earth, are sometimes noticed to have gained or lost a certain (very small) part of their calculated linear velocity. These inexplicable changes in the velocity of spacecraft (currently measured up to 13.5 mm/s), during Earth flybys, are called ‘flyby anomaly’ or ‘swing-by anomaly’. It seems to occur at varying magnitudes to arbitrary satellites during random flybys. This phenomenon gave rise to numerous speculations and exotic theories. However, none of them could, so far, logically explain the anomaly satisfactorily. As in the case of ‘pioneer anomaly’, ‘flyby anomaly’ is an apparent error introduced in calculations by the use of apparent orbital paths of spacecrafts around Earth and Earth’s apparent orbital path around the sun, instead of their real orbital paths in space.

Contemporary laws of planetary motions are derived from empirical data collected about the relative positions of a few planets in the solar system, with respect to an assumed static state of the Sun. Therefore, these laws can be true only for determining their relative positions in the planetary system with respect to the central body. Using these laws to determine other parameters of the macrobodies in the solar system or their orbital parameters is not right. Only the relative positions of a planetary body, moving in a stable (real) orbital path about a central body, can be predicted by contemporary laws of planetary motion.

All conclusions, expressed in this article, are from an alternative concept, presented in the book, ‘MATTER (Re-examined)’ [1]. For details, kindly refer to the same. Figures are not drawn to scale. They are depicted only to facilitate the illustration of phenomena described.

Planetary orbits:

All textbooks (and other literature) teach that the shape of a planetary orbital path is elliptical (or circular) around its central body. At the same time, simple mechanics tells us that no free macrobody can orbit around another moving macrobody in a closed geometrical path. An elliptical (or circular) orbital path, around a central body, is an apparent structure that suits the observation related to a static central body. This is not the real path of the planetary body in space. Unfeasibility to find a static macro body in space confirms the impracticality of a real circular/elliptical orbit around a central body. (Only stable galaxies remain stationary in space) [1]. With respect to absolute reference, the real orbital path of a planet is wave-like, about the central body’s path, with the planet periodically moving to the front and to the rear of the central body, as shown in Figure 1. In this article, we shall ignore the eccentricity of apparent planetary orbits and consider them as circular.

In Figure 1, the arrow in a black wavy line shows the planet’s real orbital path in space. The unevenness of curvatures and magnitudes of departure of the path on either side of the central body’s path (in the figure) are due to different scales used for linear and radial displacements. The path of the central body is shown by

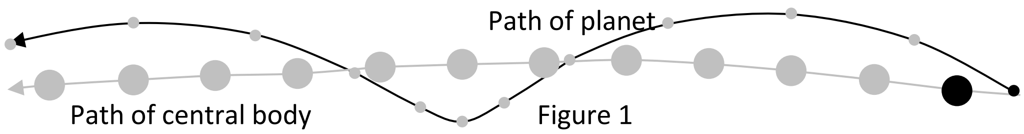

Figure 1

an arrow in a grey line. This curved path is also wavy to a smaller extent, curving in the same direction as the path of the planet. The path of a planet's satellite is a wavy line about the planet's path. The central body and planet are shown by black circles, and their future positions are shown by grey circles. In this sense, it can be seen that a planet (or a satellite) orbits around the centre of the central body's curved path, and the wave pattern in its path is caused by the presence of the central body. Such changes in the path of a free macro body may be attributed to perturbations caused by the presence of nearby macrobodies. These perturbations look like orbital motion around a central body, only when they are referred to an assumed static state of the central body in a relatively small system of macrobodies.

Figure 2 compares real and apparent orbital paths of a planet. The blue arrow on the centre line shows the linear (curvature-ignored) path of the central body. The central body, in its present position, is depicted by a large black circle in the centre of the planet's apparent orbital path, shown by a red circle in a dotted line. Large grey circles indicate the future and past positions of the central body. The planet is shown in its present position by a small black circle, and small grey circles show the planet's future positions. The real orbital path of the planet is shown by a black curved line with an arrow in the direction of its motion.

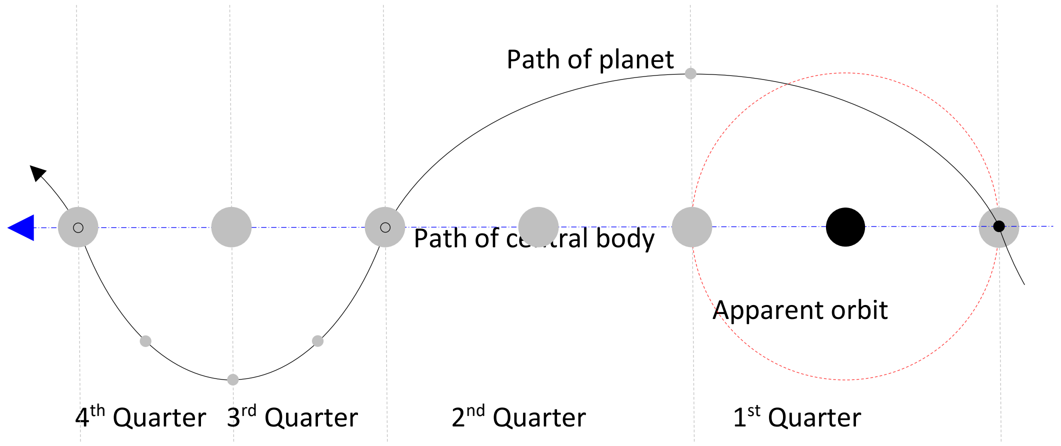

Figure 2

The real orbital path of the planet may be divided into four quarters as shown in the figure, separated by vertical dotted lines. Unevenness in the width of quarters is due to different scales used in the figure for vertical and horizontal measurements. The large circle in a dashed red line shows the apparent orbit of the planet around the central body in its present position. The apparent orbit travels along with the central body in its path. It is an imaginary path around the central body, on which every point is equidistant from the central body (for a circular apparent orbit). In order to obtain the apparent orbital path, we need to split the real orbital path into two curved paths, one on either side of the central body's path, and recombine them by changing the direction of the planet's motion in one curved path. The apparent orbital path gives accurate information on the relative positions of central and planetary bodies, but no other orbital parameters. According to the concept in reference [1];

Circular/elliptical orbital paths of planets are apparent orbits around another free macro body, which the observer assumes is static in space.

A planetary system can develop and sustain only (nearly) in the plane of the central body's curved path.

All planets enter into orbital paths from external space. Entry of a planet into its stable orbital path is a one-time process. There is no gradual development of a stable orbital path for a macro body or development of a macro body in its stable orbital path.

Every planet has an ideal ‘datum orbital path’ about its central body. Datum orbital path is a circular apparent orbit around the central body, assumed in a static state. Parameters of the datum orbital path depend on the 3D matter-contents of the central and planetary bodies, the angle of approach, and the linear speed of the planetary body.

A planetary body may enter into its stable orbital path only through two small conical windows in space, on the datum orbit, facing rearward on the outer or inner sides of the linear path of the central body.

Five-eighths of the ‘central force’ on a planet is utilised for its orbital motion, and the rest, three-eighths of ‘central force,’ is utilised for its spin motion.

(Datum) points at which a planet attains its highest/lowest linear speed need not coincide with perigee/apogee of its (elliptical) apparent orbital path.

Spacecraft’s orbital path about earth:

Figure 3 shows representations of paths of the sun, Earth, and a spacecraft orbiting about the Earth. The central line with an arrow shows a small part of the Sun’s path around the galactic centre. It is considered a straight line. The sun moves in the direction of the arrow. The Galactic centre is towards the lower side of Figure 3. The Sun’s mother-galaxy is considered rotating in an anti-clockwise direction, looking at the page.

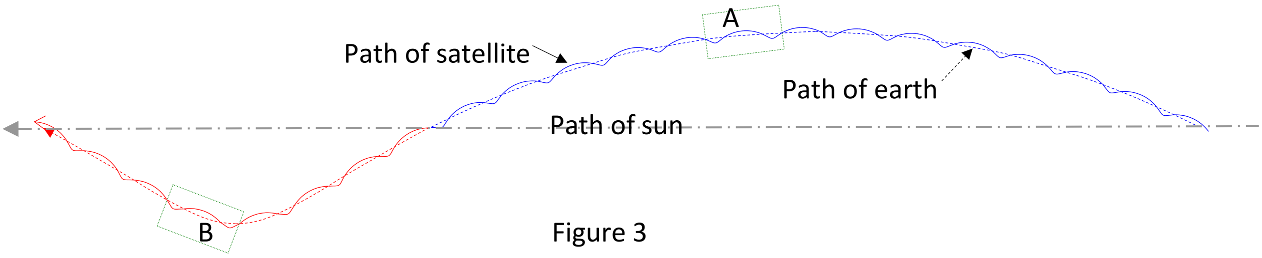

Figure 3

Dashed curves (blue and red) on both sides of the sun’s path show Earth’s real orbital path about the sun, which is equivalent to Earth’s one apparent orbital path around the sun. Earth’s apparent orbit is considered circular, with the Sun at its centre. The large difference in curvatures of these curved paths, on either side of the sun’s path, in Figure 3, is due to the very small horizontal scale used, compared to the vertical scale. In reality, they are almost the same size and curvature.

A bold wavy line (blue and red) about the Earth’s real orbital path shows the real orbital path of a spacecraft orbiting about the earth. Due to differences in lengths of curves representing Earth’s orbital path, as appearing in the figure, the number of spacecraft’s apparent orbits during every half-apparent orbit of Earth, shown in the figure, is different (14 on the outer side and 7½ on the inner side). In reality, the number of apparent orbits of spacecraft during every half-apparent orbit of Earth is the same (in this case, 14 each).

The spacecraft moves along with Earth, which moves along with the sun. In effect, the sun, Earth, and spacecraft move together around the galactic centre. Stable galaxies have a special mechanism to keep them in space without translational motion with respect to neighboring galaxies [1].

Parts of the real orbital paths of Earth and spacecraft, marked by the rectangles A and B, in Figure 3 are reproduced in Figures 4 and 5 for comparison. Rectangle A (shown in Figure 4) is on the outer side of the sun’s circular path, and rectangle B (shown in Figure 5) is on the inner side of the sun’s circular path around the galactic centre.

Figure 4 shows the real orbital paths of Earth and spacecraft on the outer side of the Sun’s real path in space. Dashed lines with an arrow show parts of Earth’s real orbital path about the sun. Bold lines (blue) with

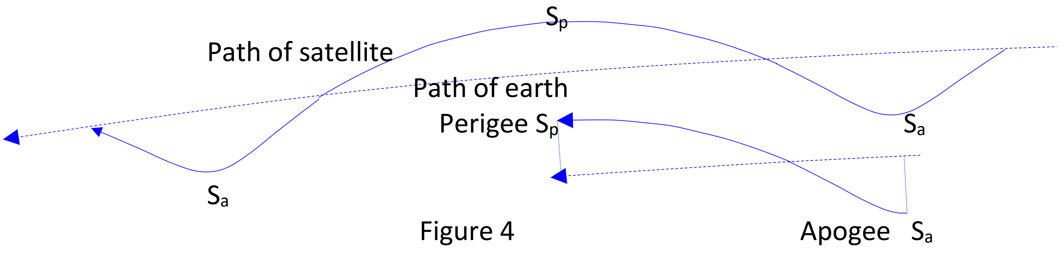

Figure 4

arrows show the spacecraft's real orbital path compared to Earth's real orbital path. On the spacecraft's path, point Sp shows the 'outer datum point,' and point Sa shows the 'inner datum point' on its datum orbit. ['Outer datum point' on real orbital path of a planetary body is where it has the highest (absolute) linear velocity, and 'inner datum point' is where it has the lowest (absolute) linear velocity. These points need not coincide with perigee or apogee of its apparent (elliptical) orbit around the central body].

Curvatures of real orbital paths of Earth and spacecraft are in the same sense (convex), as shown in the smaller figure. Earth's real orbital path has a small convex (pointing upwards in the figure) curvature. Earth and spacecraft tend to come closer due to the convergence of their curved paths, and thus reduce the distance between them. When the Earth is traveling on the outer side of the Sun's circular path, gravitational attraction between the spacecraft and Earth accelerates the spacecraft during its travel from its 'inner datum point', Sa, to 'outer datum point', Sp. Gravitational-assisted boosting of the spacecraft's velocity takes place during its travel from Sa to Sp.

Figure 5 shows real orbital paths of Earth and spacecraft on the inner side of the Sun's real path in space. Dashed lines with an arrow show parts of Earth's real orbital path about the sun. Bold lines with arrows show the spacecraft's real orbital path compared to Earth's real orbital path. On the spacecraft's path, point Sp shows the 'outer datum point,' and point Sa shows the 'inner datum point' on its datum orbit.

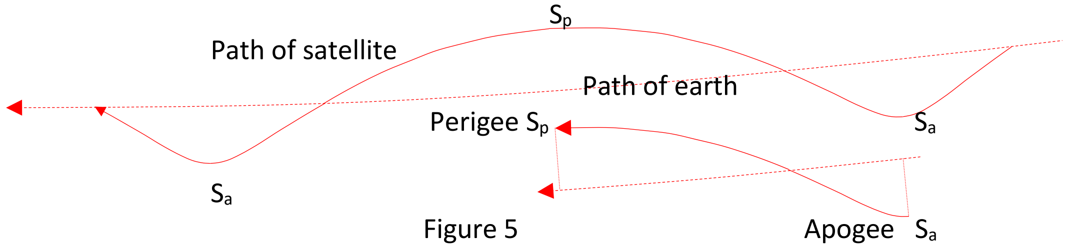

Figure 5

Curvatures of real orbital paths of Earth and spacecraft are in opposite sense (Earth's path is concave and spacecraft's path is convex), as shown in the smaller figure. Earth's real orbital path has a small concave (pointing downwards in the figure) curvature. Earth and spacecraft tend to move away from each other due to the divergence of their curved paths, and thus increase the distance between them. When the Earth is traveling on the inner side of the Sun's circular path, gravitational attraction between the spacecraft and Earth decelerates the spacecraft during its travel from its 'inner datum point' Sa, to 'outer datum point' Sp. Gravitational-assisted reduction of the spacecraft's velocity takes place during its travel from Sa to Sp.

For comparison, real orbital paths of Earth and the spacecraft, for the duration of the spacecraft's displacement in apparent orbit from figures 4 and 5, are superpositioned in figure 6. Parts of the spacecraft's real orbital path, on either side of Earth's real orbital path, are shown in equal scale. Hence, the magnitudes of their departure from Earth's real orbital paths, in Figure 6, appear almost similar. Curvatures of parts of Earth's

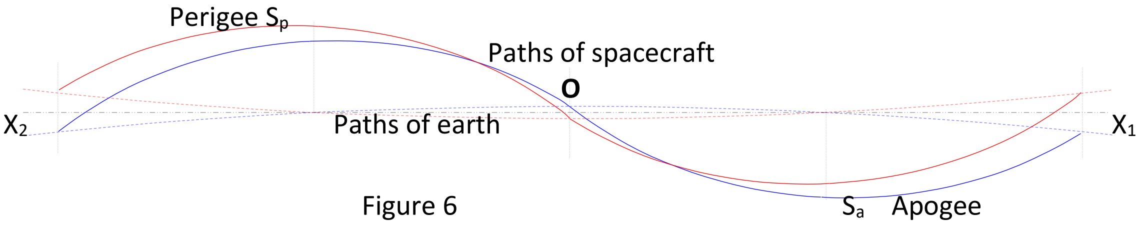

Figure 6

real orbital path, shown in dashed (blue and red) lines, are highly exaggerated. Figure 6 shows the real orbital path of a spacecraft about Earth, equivalent to one apparent circular orbital path around Earth. Blue curved lines show the real paths of Earth and spacecraft during Earth's motion on the outer side of the Sun's path. Red curved lines show the real paths of Earth and spacecraft, during Earth's motion on the inner side of sun's path.

We consider apparent orbital paths of celestial bodies for all practical purposes. Since apparent orbital paths are from observed relative positions of various celestial bodies in space, they can only give their relative positions at any time. In this case, the apparent path of the Earth, with respect to the spacecraft's path, is generally considered as (an average) straight-line path, shown by central line X_1X_2.

We shall consider real orbital paths of a spacecraft that is orbiting about the Earth and keeps a constant distance between the two. The apparent orbit of the spacecraft is circular around Earth. Distances between the Earth and the spacecraft at its perigee, Sp, and at its apogee, Sa, are equal. The spacecraft accelerates, due to gravitational attraction, during its travel from apogee to perigee. The spacecraft decelerates, due to gravitational attraction, during its travel from perigee to apogee. (Part of) 'central force', simultaneously, provides the spacecraft with constant radial acceleration and constant radial velocity towards Earth. Inward radial velocity of the spacecraft is nullified by the outward component of the spacecraft's present (absolute) linear speed. The spacecraft has no linear acceleration or deceleration in its apparent orbital path. Its linear speed, along the apparent orbital path, is of constant magnitude. 'Central force' is assumed to provide only radial acceleration, which is nullified by an illusory acceleration provided by imaginary 'centrifugal force' in the opposite direction.

Figure 7 shows part of Earth's real orbital path, when Earth is moving on the outer side of the Sun's path (in blue dashed curve) and on the inner side of the Sun's path (in red dashed curve). Corresponding part of the spacecraft's real orbital path, during the accelerating stage, is shown in blue (when Earth is moving on the outer side of the Sun's path) and red (when Earth is moving on the inner side of the Sun's path) by curved bold lines. A set of corresponding paths is superpositioned to highlight their relative differences.

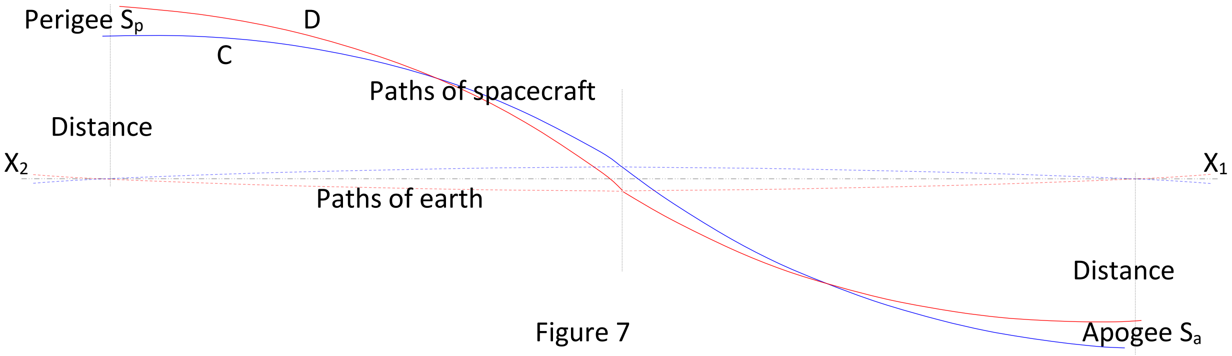

Figure 7

When the apparent orbit of the spacecraft is considered circular, the distance between the spacecraft and Earth is assumed constant. However, considering the real orbital path of the spacecraft (corresponding to circular apparent orbit) about the Earth, distances between Earth and the spacecraft do not remain constant. They differ as shown in Figure 7. The average distances between spacecraft and Earth, at different points on the spacecraft's apparent orbital path, are the average distances at corresponding points on its real orbital paths with respect to various locations of Earth on its real orbital path.

When the Earth is in its real orbital path, outside the Sun's path (blue dashed curve), the distance between Earth and spacecraft (which has a circular apparent orbital path) at Sp (at perigee) is less than the distance at Sa (at apogee). Similarly, when the Earth is in its real orbital path, inside the Sun's path (red dashed curve), the distance between Earth and spacecraft at Sp (at perigee) is more than the distance at Sa (at apogee). Magnitudes of differences depend on the curvatures of Earth's real orbital path at any given point. If the shape of the apparent orbital path differs from being circular (elliptical), differences in distances between the spacecraft and Earth change correspondingly. Since we consider apparent orbits of spacecraft around Earth, for all practical purposes, these differences do not appear in our assessment.

Regular and cyclic variations in distances between the Earth and orbiting (in circular apparent orbit) spacecraft, explained above, are due to the curvature of Earth's real orbital path, produced by perturbations mainly due to gravitational attraction between Earth and the Sun. Since perturbations of the spacecraft's real orbital path, due to gravitational attraction between the spacecraft and the sun (although very small), are of the same sense, they augment variations in distances between Earth and the spacecraft. Similar perturbations due to the presence of other celestial bodies (especially the moon) may also contribute towards variations in instantaneous distances between spacecraft and Earth.

In apparent orbit, perigee and apogee are the only two points at which conditions for a circular apparent orbital path are fulfilled [1]. At these points, the condition $\left[W = 2\,\mathrm{Sin}^{-1}\left(u \div 2V\right)\right]$ is satisfied. (Where, W is the deflection rate of the angle between present absolute linear speed and future absolute linear speed of planetary body, u is the magnitude of radial velocity of planetary body towards central body, and V is the magnitude of present absolute velocity of planetary body). At these points, the magnitude of ‘drifting rate’ (rate of change of angle between direction of present absolute linear speed and tangent to apparent orbit) is half of ‘deflection rate’, W. For details, please refer to reference [1], equation (16/8).

Hence, it is at either of these points, orbital motion of a spacecraft (in a stable apparent orbit) can breakdown. Depending on the magnitude of ‘central force’, a spacecraft may choose to maintain its orbital motion, fly away from the central body, or fall into the central body [1]. To form stable real orbital motion about a central body, the spacecraft has to have its ‘drifting rate’, between $\left[\mathrm{Sin}^{-1}(u \div 2V)\right]$ and $\left[-\mathrm{Sin}^{-1}(u \div 2V)\right]$, at perigee or apogee of its apparent orbit. For variations in the magnitude of ‘central force’ within certain limits, the spacecraft is able to maintain its orbital motion. Excess linear speed (caused by a higher magnitude of radial acceleration) moves the spacecraft away from the central body, as it may happen during earth-flybys. Reduction in linear speed (caused by a higher magnitude of radial deceleration) moves the spacecraft towards the central body to fall into it.

Estimates of orbital parameters are always approximate and vary continuously. Orbital parameters may best be estimated to the nearest average magnitudes. Variations or discrepancies of orbital parameters, thus determined, are usually attributed to assumed properties, like tidal effects, inconsistency of earth’s matter-content, frame dragging, rotary motions of macro bodies, effects of other celestial bodies, anomalous Doppler effects, effects of dark matter, etc. These, in turn, help to produce exotic theories about physical phenomena. However, real orbital paths of corresponding macro bodies are never considered. As we require average values of parameters for all practical purposes, changes in real orbital paths or cyclic changes in distance between Earth and spacecraft do not make much difference when continuous orbital motions of the spacecraft are considered. Discrepancies develop into prominence only when the spacecraft is diverted away from its (regular) orbital path about Earth.

The real orbital path of the spacecraft about Earth depends on its orbital parameters. Real orbital parameters of the spacecraft may be manipulated to move it in any desirable apparent orbital path by external influences. Should magnitudes of variations in real orbital parameters exceed values required for their desirable apparent orbital motion, real orbits may become unstable and cause spacecraft to fly away from Earth or fall into Earth. From the instant of instability that terminates a spacecraft’s orbital motion, average orbital parameters, estimated for apparent orbital motion, are no longer valid. Correct estimations depend on the real orbital parameters of the spacecraft at the instant of instability. The result may be (slightly) different from the average parameters estimated for continuous orbital motion. It is this type of difference in the estimation of orbital parameters that causes the ‘flyby anomaly’.

Flyby anomaly:

Usually, orbital parameters of a planetary body (or a spacecraft), except the angular orbital speed with respect to Earth, are estimated from mathematical relations based on various assumptions used in physics, like; the central body is static in space, a planetary body orbits around its central body (in a geometrically closed path), a planetary body has highest linear and angular speeds at perigee, a planetary body has the lowest linear and angular speeds at apogee, 3D matter-content of a macrobody is concentrated at a point (centre of gravity), the distance between two macrobodies is between their centres of gravity, etc. Angular orbital speed with respect to the Earth can be easily measured by instruments on the surface of the Earth and corrected for various motions of the Earth. Another exemption is that of the distance between the Earth and the moon, which we are able to measure accurately with the help of ‘laser rays’ and reflectors placed on the moon’s surface, recently. Even in this case, due to various continuous motions of the Earth and the moon, the measured distance is valid only for the instant of measurement. The apparent orbital path of a spacecraft, which is capable of supplying only its relative position, is used to estimate all its other orbital parameters. Estimates of orbital parameters of a spacecraft are based on (Newton’s) laws of motion and the laws of universal gravitation. Linear velocity of a spacecraft is estimated from mathematical equations constituted by its orbital angular speed about Earth, gravitational attraction towards Earth, radii of Earth and spacecraft, distance between Earth and spacecraft, ‘mass’ of Earth (representing its 3D matter-content), etc. Changes or discrepancies in any one of these factors are bound to introduce errors in the estimation of all other parameters. In the case of a spacecraft, its instantaneous linear speed is determined from its observed angular orbital speed (usually, at perigee or at apogee) and the distance between Earth and the spacecraft. In a circular apparent orbit, the distance between the spacecraft and Earth is assumed constant. Hence, variation in the spacecraft's observed angular orbital speed is attributed to a change in its linear orbital speed. Logically, to change the linear orbital speed of a spacecraft, it has to be decelerated or accelerated. If no external effort is known to decelerate or accelerate the spacecraft, this anomalous phenomenon becomes a mystery. It then becomes fertile ground for speculations and exotic theories. If only we would consider the accuracy of the assumption of the constancy of the distance between the spacecraft (moving in circular apparent orbit) and the Earth, this mystery could be avoided. For the same magnitude of linear orbital speed, a greater distance produces a lower angular orbital speed, and a smaller distance produces a higher angular orbital speed. If variations in distances are not acknowledged, changes in angular orbital speeds are obviously attributed to changes in linear orbital speeds. This would certainly require linear acceleration/deceleration of the spacecraft and corresponding external influence on it. Explanations in the previous section show that if the real orbital path of a planetary body is considered, the distance between its centre and planetary bodies (even for circular apparent orbital motions) varies continuously, within certain limits. Since these changes are cyclic, they do not appear distinctly during average considerations. However, when instantaneous parameters are determined, they do diverge from average values.

In Figure 8, let the central body (Earth) be at O. Let Or_0 be the average distance between Earth and a spacecraft, moving in circular apparent orbit about Earth. ω_0 is the angular orbital speed of the spacecraft, observed from Earth. ($Br_0 = \omega_0 r_0$) is the estimated linear orbital speed of the spacecraft.

If instantaneous conditions are considered, in terms of the real orbital path of the spacecraft about Earth, the distance between Earth and the spacecraft (even for circular apparent orbital motions) varies continuously. When the Earth is on the outer side of the Sun's path, and a spacecraft is on the outer side of Earth's path, the distance between the spacecraft and Earth is less than when Earth is on the outer side of the Sun's path, and the spacecraft is on the inner side of Earth's path. Similarly, when the Earth is on the inner side of the Sun's path, and the spacecraft is on the outer side of Earth's path, the distance between the spacecraft and Earth is less than when Earth is on the inner side of the Sun's path, and the spacecraft is on the inner side of Earth's path.

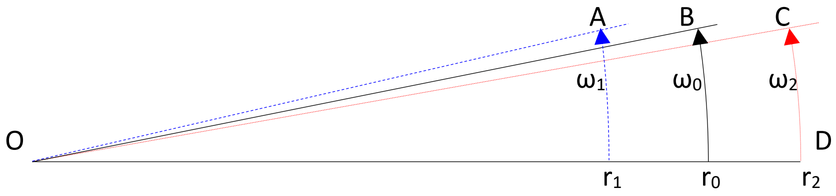

Figure 8

Let us consider two other instances, where the distances between the Earth and spacecraft are Or_1 and Or_2. Let the spacecraft move at constant linear orbital speed, $Ar_1 = Br_0 = Cr_2$. When the spacecraft is at distance Or_1, the angular orbital speed observed from Earth is ω_1. This is greater than ω_0. If reduction in distance is not taken into consideration, greater angular speed would indicate an apparent increase in the spacecraft's linear speed, without logical causes. When the spacecraft is at distance Or_2, the angular orbital speed, observed from Earth, is ω_2. This is less than ω_0. If an increase in distance is not taken into consideration, a lower angular speed would indicate an apparent reduction in the spacecraft's linear speed, without logical causes.

Variations in the distances between the Earth and spacecraft, at different locations in its real orbital path, are reflected in its angular orbital speed, observed from the Earth. The magnitude and sense of apparent change in the spacecraft's linear speed, on its release from orbital bond with Earth, depend on the locations of the spacecraft and Earth in their respective real orbital paths. Hence, depending on the locations of the Earth and spacecraft in their real orbital paths, apparent variations in the spacecraft's linear speed may vary in magnitude and sense.

Explanations in this article are with respect to a spacecraft destined to move in a circular apparent orbit, where the distance between the Earth and the spacecraft is assumed constant. If the apparent orbit of the spacecraft is elliptical, the eccentricity of the apparent orbit is bound to make additional variations in its orbital parameters.

Conclusion:

Depending on the locations of spacecraft and Earth, in their respective real orbital path, at the instant of its release from orbital bond, a spacecraft's linear speed could show an apparent increase or reduction, without external causes. This phenomenon is quite logical, and there is no mystery about it. There are no puzzling actions or anomalous effects. There is no increase or reduction in (kinetic) energy associated with the spacecraft. Although apparent acceleration/deceleration is indicated by 'flyby anomaly', the spacecraft's linear speed (in space) hardly varies. Therefore, 'flyby anomaly' is a phantom phenomenon, caused by incorrect use of the orbital geometry of a spacecraft's apparent orbital path around Earth instead of the geometry of its real orbital path (in space) about Earth.

References:

[1] Nainan K. Varghese, *MATTER (Re-examined)*, https://www.matterdoc.in .

[2] http://en.wikipedia.org/wiki/Flyby_anomaly

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