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, spacecraft and external efforts on it behave normally. There are no causes or actions, which vary spacecraft's linear velocity during Earth-flybys. There is no basis for 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 (sling-shot effect) in conjunction with earth, are sometimes noticed to have gained or lost certain (very small) part of their calculated linear velocity. These unaccounted changes in 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 if '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 sun, instead of their real orbital paths in space.

Contemporary laws on planetary motions are derived from empirical data collected about relative positions of few planets in solar system, with respect to assumed static state of sun. Therefore, these laws can be true only to determine their relative positions in planetary system with respect to central body. Using these laws to determine other parameters of macro bodies in the solar system or their orbital characteristics is not right. Only relative positions of a planetary body, moving in 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 alternative concept, presented in book, 'MATTER (Re-examined)' [1]. For details, kindly refer to the same. Figures are not drawn to scale. They are depicted only to facilitate illustration of phenomena described.

Planetary orbits:

All text books (and other literature) teach that 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 macro body can orbit around another moving macro body in closed geometrical path. Elliptical (or circular) orbital path, around a central body, is an apparent structure that suits observation related to static central body. This is not real path of planetary body in space. Unfeasibility to find a static macro body in space confirms impracticality of real circular/elliptical orbit around a central body. (Only stable galaxies remain stationary in space) [1]. With respect to absolute reference, real orbital path of a planet is wave-like, about central body's path, with the planet periodically moving to front and to rear of central body, as shown in figure 1. In this article, we shall ignore eccentricity of apparent planetary orbits and consider them as circular.

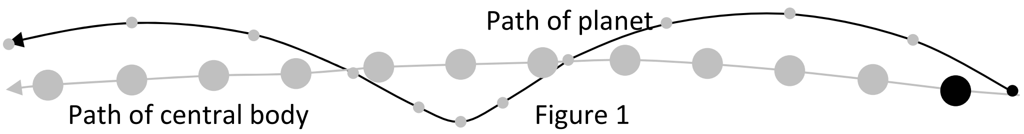

Figure 1

In figure 1, arrow in black wavy-line shows planet's real orbital path in space. Unevenness of curvatures and magnitudes of departure of path on either side of central body's path (in figure) are due to different scales used for linear and radial displacements. Path of central body is shown by arrow in grey line. This curved path, also, is wavy to a smaller extent, curving in same directions as path of planet. Path of planet's satellite is wavy-line about planet's path. 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 centre of central body's curved path and wave pattern in its path is caused by presence of central body. Such changes in path of a free macro body may be attributed to perturbations caused by presence of nearby macro bodies. These perturbations look like orbital motion around a central body, only when they are referred to assumed static state of central body in a relatively small system of macro bodies.

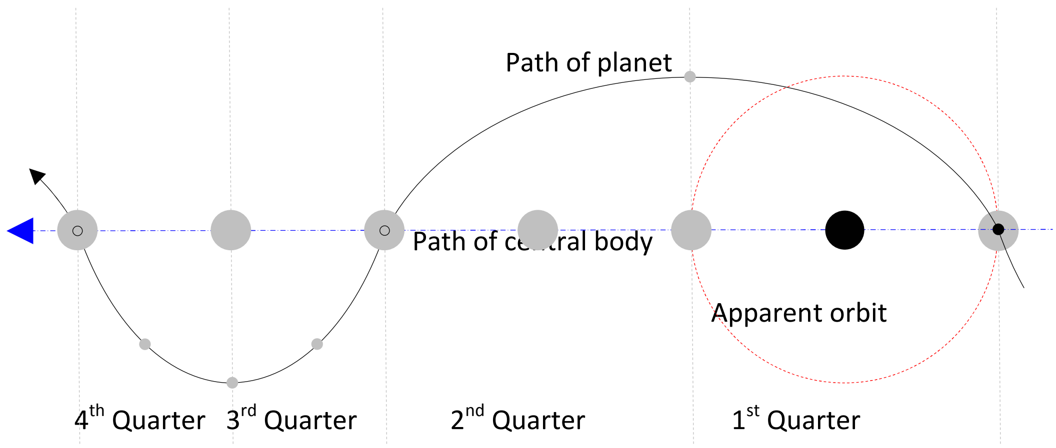

Figure 2

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

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

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

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

All planets enter into orbital path from external space. Entry of a planet into its stable orbital path is a one-time process. There is no gradual development of 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 central body, assumed in static state. Parameters of datum orbital path depend on matter-contents of central and planetary bodies, angle of approach and linear speed of planetary body.

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

Five eighth part of 'central force' on a planet is utilised for its orbital motion and rest, three eighth part of 'central force' is utilised for its spin motion.

(Datum) point(s) at which a planet attains 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 sun, earth and a spacecraft orbiting about earth. Central line with arrow shows small part of sun's path around galactic centre. It is considered as a straight line. Sun moves in the direction of arrow. Galactic centre is towards lower side of figure 3. Sun's mother-galaxy is considered rotating in anti-clockwise direction, looking at the page.

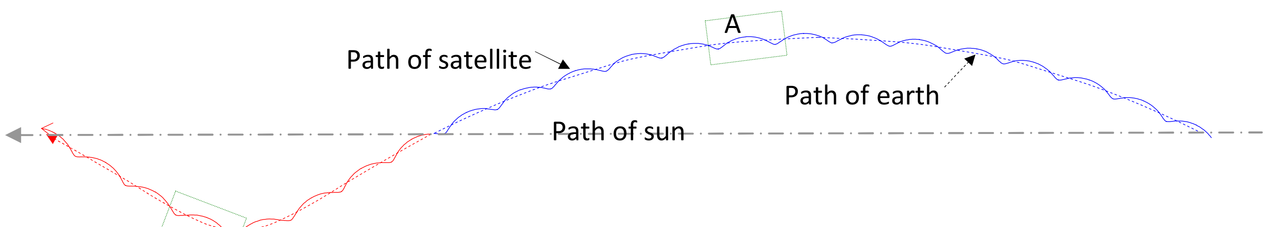

Figure 3

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

Bold wavy line (blue and red) about earth's real orbital path shows real orbital path of a spacecraft, orbiting about earth. Due to difference in lengths of curves representing earth's orbital path, as appearing in figure, numbers of spacecraft's apparent orbits during every half-apparent orbit of earth, shown in figure, are different (14 on outer side and 7½ on inner side). In reality numbers of apparent orbits of spacecraft during every half-apparent orbit of earth are same (in this case 14 each).

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

Parts of real orbital paths of earth and spacecraft, marked by rectangle A and B, in figure 3 are reproduced in figures 4 and 5 for comparison. Rectangle A (shown in figure 4) is on outer side of sun's circular path and rectangle B (shown in figure 5) is on inner side of sun's circular path around galactic centre.

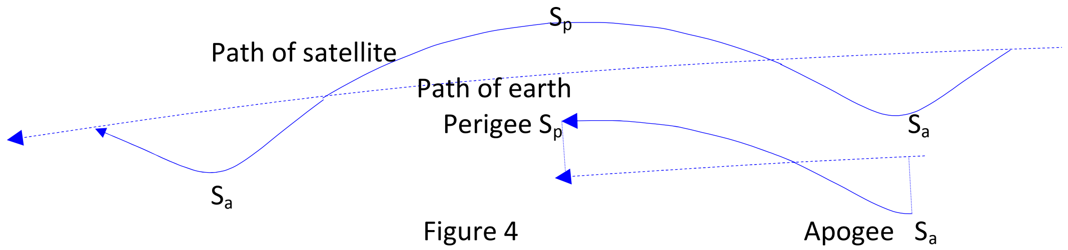

Figure 4

Figure 4 shows real orbital paths of earth and spacecraft on outer side of sun's real path in space. Dashed lines with arrow show parts of earth's real orbital path about sun. Bold lines (blue) with arrows show spacecraft's real orbital path about earth's real orbital path. On spacecraft's path, point S_p, shows 'outer datum point' and point S_a, shows 'inner datum point' on its datum orbit. ['Outer datum point' on real orbital path of a planetary body is where it has highest (absolute) linear velocity and 'inner datum point' is where it has 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 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 convergence of their curved paths and thus reduce distance between them. When earth is traveling on outer side of sun's circular path; gravitational attraction between spacecraft and earth, accelerates spacecraft during its travel from its 'inner datum point', S_a to 'outer datum point', S_p. Gravitational assisted boosting of spacecraft's velocity takes place during its travel from S_a to S_p.

Figure 5 shows real orbital paths of earth and spacecraft on inner side of sun's real path in space. Dashed lines with arrow show parts of earth's real orbital path about sun. Bold lines with arrows show spacecraft's real orbital path about earth's real orbital path. On spacecraft's path, point S_p, shows 'outer datum point' and point S_a, shows 'inner datum point' on its datum orbit.

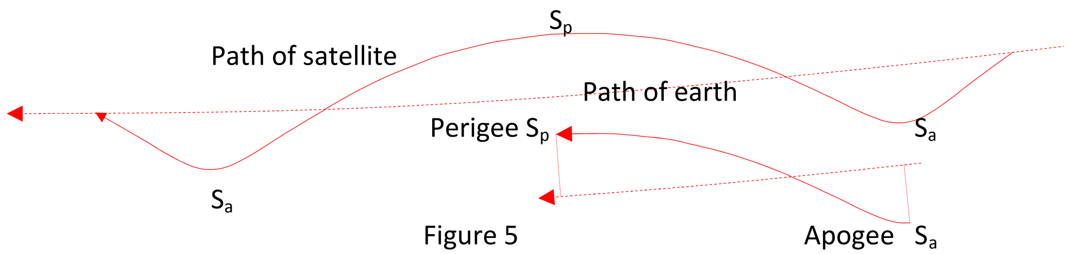

Figure 5

Curvatures of real orbital paths of earth and spacecraft are in opposite sense (earth's path is concave and space craft's path is convex), as shown in 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 divergence of their curved paths and thus increase distance between them. When earth is traveling on inner side of sun's circular path; gravitational attraction between spacecraft and earth, decelerates the spacecraft during its travel from its 'inner datum point' S_a, to 'outer datum point' S_p. Gravitational assisted reduction of spacecraft's velocity takes place during its travel from S_a to S_p.

For comparison, real orbital paths of earth and spacecraft, for duration of spacecraft's displacement in apparent orbit from figures 4 and 5 are super-positioned in figure 6. Parts of spacecraft's real orbital path, on either side of earth's real orbital path are shown in equal sale. Hence, magnitudes of their departure from earth's real orbital paths, in figure 6, appear almost similar. Curvatures of parts of earth's real orbital path, shown in dashed (blue and red) lines, are highly exaggerated. Figure 6 shows real orbital path of a spacecraft about earth, equivalent to one apparent circular orbital path around earth. Blue curved lines show real paths of earth and spacecraft, during earth's motion on outer side of sun's path. Red curved lines show real paths of earth and spacecraft, during earth's motion on inner side of sun's path.

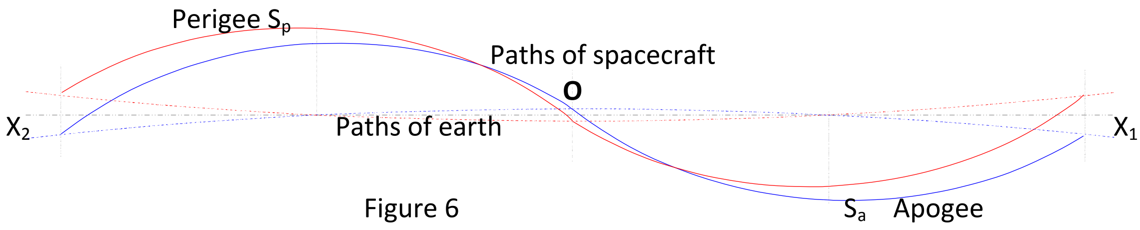

Figure 6

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, apparent path of earth, with respect to 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 earth and keeps a constant distance between the two. Apparent orbit of spacecraft is circular around earth. Distances between earth and spacecraft at its perigee, S_p, and at its apogee, S_a, are equal. Spacecraft accelerates, due to gravitational attraction, during its travel from apogee to perigee. Spacecraft decelerates, due to gravitational attraction, during its travel from perigee to apogee. (Part of) 'central force', simultaneously, provides spacecraft with constant radial acceleration and constant radial velocity towards earth. Inward radial velocity of spacecraft is nullified by outward component of spacecraft's present (absolute) linear speed. Spacecraft has no linear acceleration or deceleration in its apparent orbital path. Its linear speed, along 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 opposite direction.

Figure 7 shows part of earth's real orbital path, when earth is moving on outer side of sun's path (in blue dashed curve) and on inner side of sun's path (in red dashed curve). Corresponding part of spacecraft's real orbital path, during accelerating stage is shown in blue (when earth is moving on outer side of sun's path) and red (when earth is moving on inner side of sun's path) by cured bold lines. Set of corresponding paths are super-positioned to highlight their relative differences.

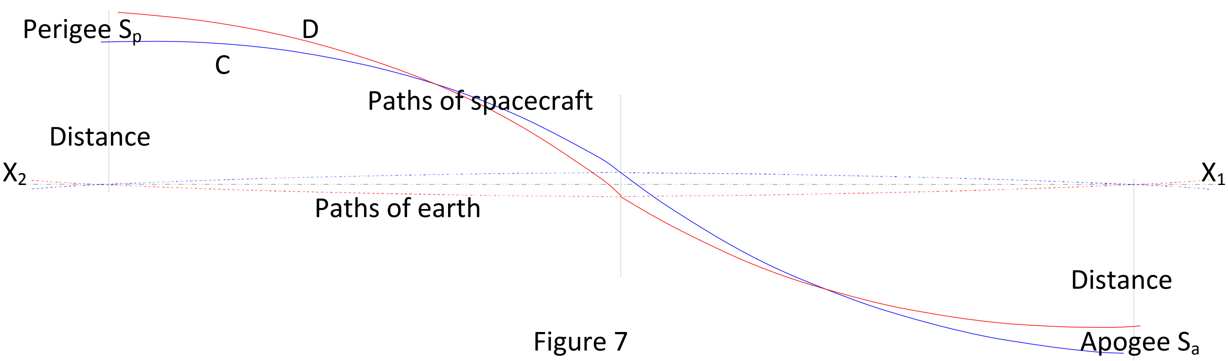

Figure 7

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

When earth is in its real orbital path, outside sun's path (blue dashed curve), distance between earth and spacecraft (which has circular apparent orbital path) at S_p (at perigee) is less than distance at S_a (at apogee). Similarly, when earth is in its real orbital path, inside sun's path (red dashed curve), distance between earth and spacecraft at S_p (at perigee) is more than distance at S_a (at apogee). Magnitudes of differences depend on curvatures of earth's real orbital path, at any given point. If shape of apparent orbital path differs from being circular (elliptical), differences in distances between 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 earth and orbiting (in circular apparent orbit) spacecraft, explained above, are due to curvature of earth's real orbital path, produced by perturbations mainly due to gravitational attraction between earth and sun. Since, perturbations of spacecraft's real orbital path, due to gravitational attraction between spacecraft and sun (although very small) are of same sense; they augment variations in distances between earth and spacecraft. Similar perturbations due to presence of other celestial bodies (especially 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 circular apparent orbital path are fulfilled [1]. At these points, condition $\left[W = 2\,\mathrm{Sin}^{-1}(u \div 2V)\right]$ is satisfied. (Where, W is deflection rate of angle between present absolute linear speed and future absolute linear speed of planetary body, u is magnitude of radial velocity of planetary body towards central body and V is magnitude of present absolute velocity of planetary body). At these points, 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 stable apparent orbit) can breakdown. Depending on magnitude of 'central force', spacecraft may choose to maintain its orbital motion, fly away from central body or fall into central body [1]. To form stable real orbital motion about a central body, 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 magnitude of 'central force' within certain limits, spacecraft is able to maintain its orbital motion. Excess linear speed (caused by higher magnitude of radial acceleration) moves spacecraft, away from central body, as it may happen during earth-flybys. Reduction in linear speed (caused by higher magnitude of radial deceleration) moves spacecraft towards central body to fall into it.

Estimations of orbital parameters are always approximate and vary continuously. Orbital parameters may best be estimated to 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, helps 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 spacecrafts are considered. Discrepancies develop into prominence only when spacecrafts are diverted away from their (regular) orbital path about earth.

Real orbital path of spacecraft about earth depends on its orbital parameters. Real orbital parameters of 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 more valid. Correct estimations depend of real orbital parameters of spacecraft at the instant of instability. Result may be (slightly) different from average parameters estimated for continuous orbital motion. It is this type of difference in estimation of orbital parameters that causes 'flyby anomaly'.

Flyby anomaly:

Usually, orbital parameters of a planetary body (or a spacecraft), except angular orbital speed with respect to earth, are estimated from mathematical relations based on various assumptions used in physics, like; central body is static in space, planetary body orbits around its central body (in closed geometrical path), planetary body has highest linear and angular speeds at perigee, planetary body has lowest linear and angular speeds at apogee, matter-content of a macro body is concentrated at a point (centre of gravity), distance between two macro bodies is between their centres of gravity, etc. Angular orbital speed with respect to earth can be easily measured by instruments on surface of earth and corrected for various motions of earth. Another exemption is that of distance between earth and moon, which we are able to measure accurately with the help of 'laser rays' and reflectors placed on moon's surface, recently. Even in this case, due to various continuous motions of earth and moon, measured distance is valid for only for the instant of measurement. Apparent orbital path of a spacecraft, which is capable to supply only its relative position, is used to estimate all its other orbital parameters.

Estimates of orbital parameters of spacecraft are based on (Newton's) 'laws of motion' and 'laws of universal gravitation'. Linear velocity of 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 matter-content), etc. Changes or discrepancy in any one of these factors is bound to introduce errors in estimation of all other parameters.

In the case of spacecraft, its instantaneous linear speed is determined from its observed angular orbital speed (usually, at perigee or at apogee) and distance between earth and spacecraft. In circular apparent orbit, distance between spacecraft and earth is assumed constant. Hence, variation in spacecraft's observed angular orbital speed is attributed to change in its linear orbital speed. Logically, in order to change linear orbital speed of a spacecraft, it has to be decelerated or accelerated. If no external effort is known to decelerate or accelerate spacecraft, this anomalous phenomenon becomes a mystery. It then becomes fertile ground for speculations and exotic theories. If only we would consider accuracy of assumption of constancy of distance between spacecraft (moving in circular apparent orbit) and earth, this mystery could be avoided.

For the same magnitude of linear orbital speed, greater distance produces lower angular orbital speed and smaller distance produces 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 previous section shows that if real orbital path of planetary body is considered, distance between centre and planetary bodies (even for circular apparent orbital motions) vary 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 make divergences from average values.

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

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

Let us take two other instances, where distances between earth and spacecraft are Or_1 and Or_2. Let

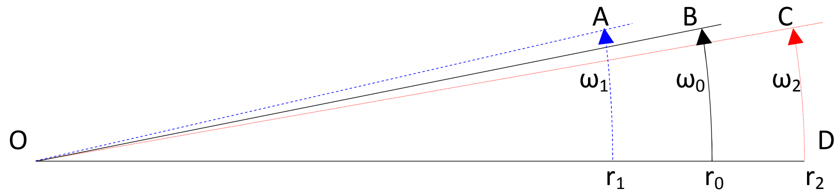

Figure 8

the spacecraft move at constant linear orbital speed, $Ar_1 = Br_0 = Cr_2$. When spacecraft is at distance Or_1, 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 spacecraft's linear speed, without logical causes. When spacecraft is at distance Or_2, angular orbital speed, observed from earth, is ω_2. This is lesser than ω_0. If increase in distance is not taken into consideration, smaller angular speed would indicate apparent reduction in spacecraft's linear speed, without logical causes.

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

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

Conclusion:

Depending on 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 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 spacecraft. Although, apparent acceleration/deceleration is indicated by 'flyby anomaly', spacecraft's linear speed (in space) hardly varies. Therefore, 'flyby anomaly' is a phantom phenomenon, caused by incorrect use of orbital geometry of spacecraft's apparent orbital path around earth instead of geometry of its real orbital path (in space) about earth.

References:

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

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

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