SECTION 8

The Flyby Anomaly

THE FLYBY ANOMALY

In March 2008 anomalous behavior in spacecraft flybys of Earth was reported in an article entitled "Anomalous Orbital-Energy Changes Observed during Spacecraft Flybys of Earth".

The data indicate unaccounted for changes in spacecraft speed, both increases and decreases, for six different spacecraft involved in Earth flybys from December 8, 1990 to August 2, 2005. These anomalous energy changes are a function of the incoming and outgoing geocentric latitudes of the asymptotic spacecraft velocity vectors and further indicate that a latitude symmetric flyby does not exhibit the anomalous speed change. The article states that, "All … potential sources of systematic error …. [have been] modeled. None can account for the observed anomalies…. "Like the Pioneer anomaly … the Earth flybys anomaly is a real effect …. Its source is unknown."

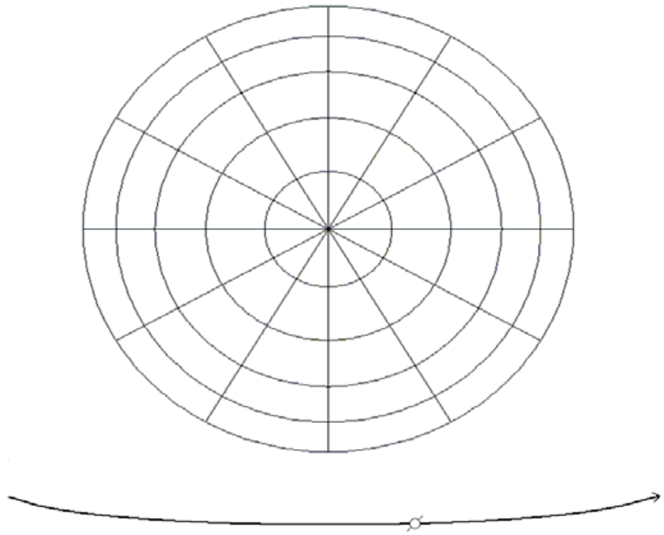
A phenomenon like that involved in galactic rotation curves and in the Pioneer Anomaly would account for the highly varied occurrences of the flyby anomaly: a small acceleration [in addition to that of natural gravitation], centrally directed and independent of distance; that is a modest and otherwise unknown acceleration directed toward the core center of the Earth, the principle body involved, the dominant factor in the mechanics of the flyby of Earth.

ANALYSIS OF THE FLYBY PARAMETERS

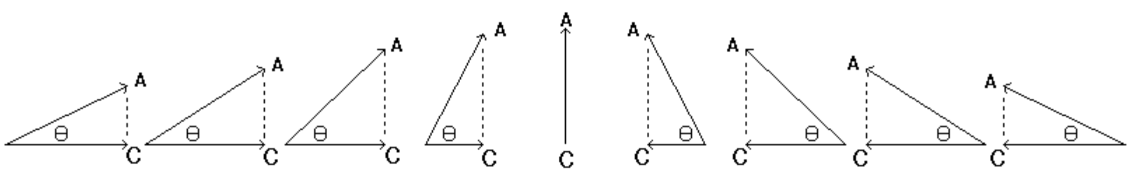
To observe the relation to the Flyby Anomaly of an otherwise unknown or un-detected anomalous, centrally directed, distance independent acceleration the first step is to consider a simple spacecraft pass of Earth where the pass is all at zero latitude as shown in Figure 8-1, on the following page. In the vectors analysis part of the figures A is the full anomalous acceleration, C is its component parallel to the direction of motion of the satellite, and θ is the angle between the direction of action of those two.

When the spacecraft is at a great distance out from Earth the spacecraft's motion is close to being directed toward the center of the Earth but not exactly so. A centrally directed acceleration there analyzed into components parallel and perpendicular to the spacecraft's motion would show most of the centrally directed anomalous acceleration acting to increase the spacecraft's speed.

a. <u>Polar View - Flyby</u>



b. <u>Polar View - Anomalous Acceleration Vectors</u>



Here the acceleration phase and the deceleration phase are of equal magnitude and offset each other.

c. <u>Equatorial View</u>

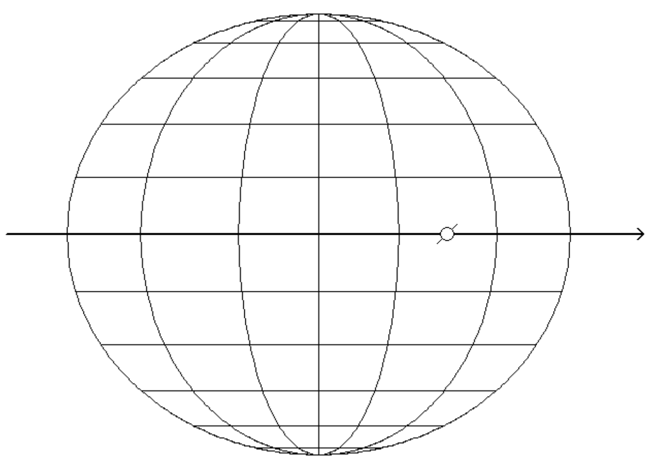


Figure 8-1
A Zero Latitude Pass

As the spacecraft travels nearer to Earth that component parallel to its motion decreases, becoming zero at the closest approach to Earth. From that point on the parallel component acts in the opposite direction on the spacecraft, that is its effect is to decelerate the spacecraft not accelerate it. Ultimately, in this example, the anomalous acceleration and anomalous deceleration experienced by the spacecraft become equal and cancel each other out leaving as the only flyby effect the gravitational boost, due to another effect, that is the overall purpose of the flyby.

Of the full centrally directed acceleration, A, the component, C, parallel to the path of the flyby in this case is

$$(8\text{-}1) \quad C = A\cdot \mathrm{Cos}[\theta]$$

which is apparent if the flyby path is a straight line. However, the actual flyby path is somewhat curved by the Earth's gravitation. But, the anomalous acceleration is always centrally directed toward the core of the Earth so that C is nevertheless as stated.

Equation *(8-1)* is valid when the flyby pass is solely at zero latitude. However, if other than zero the latitude of the flyby pass has a significant effect on the magnitude of C, the component of the overall centrally directed acceleration parallel to the spacecraft flight path. As latitude increases the magnitude of C, decreases. That is most easily visualized by imagining the flyby over the geographic north pole at $90°$ north latitude. There the centrally directed acceleration toward the center of the Earth has no component parallel to the flight path.

Therefore, for flyby paths at other than zero latitude the effective value of A is $A(\lambda)$ a function of latitude, λ, as equation *(8-2)*

$$(8\text{-}2) \quad A = A(\lambda) = A\cdot \mathrm{Cos}[\lambda]$$

so that equation *(8-1)* then becomes equation *(8-3)* the full expression for the extent to which the centrally directed anomalous acceleration actually accelerates or decelerates the spacecraft.

$$(8\text{-}3) \quad C = A\cdot \mathrm{Cos}[\lambda]\cdot \mathrm{Cos}[\theta]$$

The gross effect of latitude can be evaluated by examining three cases:

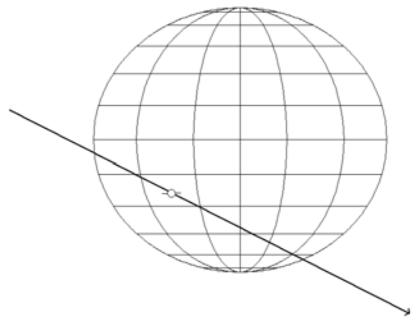
A - The flyby path is symmetrical relative to the equator so that the latitude effect in the first half of the flyby, $\theta = 0°$ to $90°$, is exactly offset or balanced by the second half of the flyby, $\theta = 90°$ to $180°$. This case is essentially the same as presented in Figure 8-1, above.

B - The flyby path starts at low latitude and finishes at high latitude, Figure 8-2 on the following page.

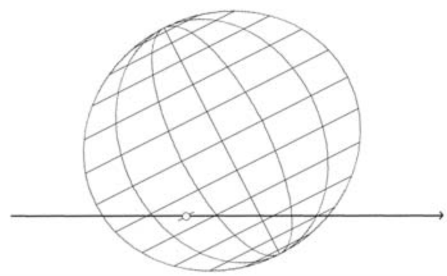
C - The flyby path starts at high latitude and finishes at low latitude, Figure 8-3 on the second following page.

Per the equations and Figure 8-1 in the first half of the flight path the effect of the anomalous, centrally directed acceleration is to increase the speed of the spacecraft whereas the effect in the second half of the flight path is to decrease the spacecraft's speed. By its definition Case A produces no net anomalous acceleration or deceleration of the spacecraft because the first and second halves of the flight path balance and offset each other.

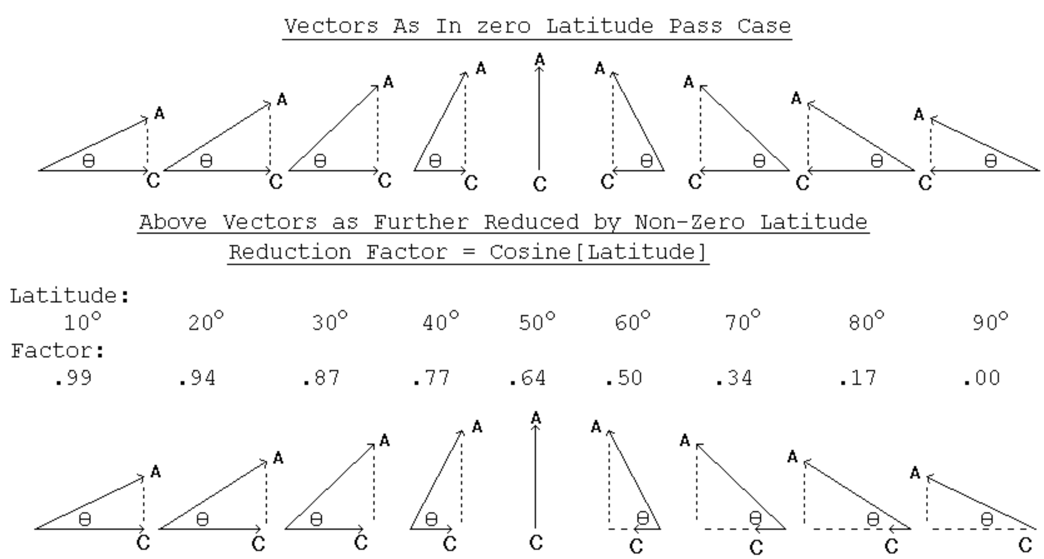
a. Equatorial View - Flyby



b. Equatorial View - Flyby, Rotated



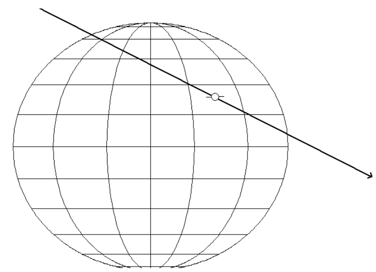
c. Anomalous Acceleration Vectors



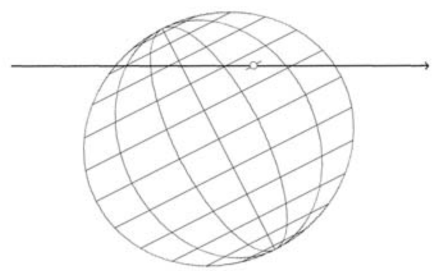
The result n this case is a net acceleration
[to the right in the diagrams].

Figure 8-2
A Pass at Increasing Latitude

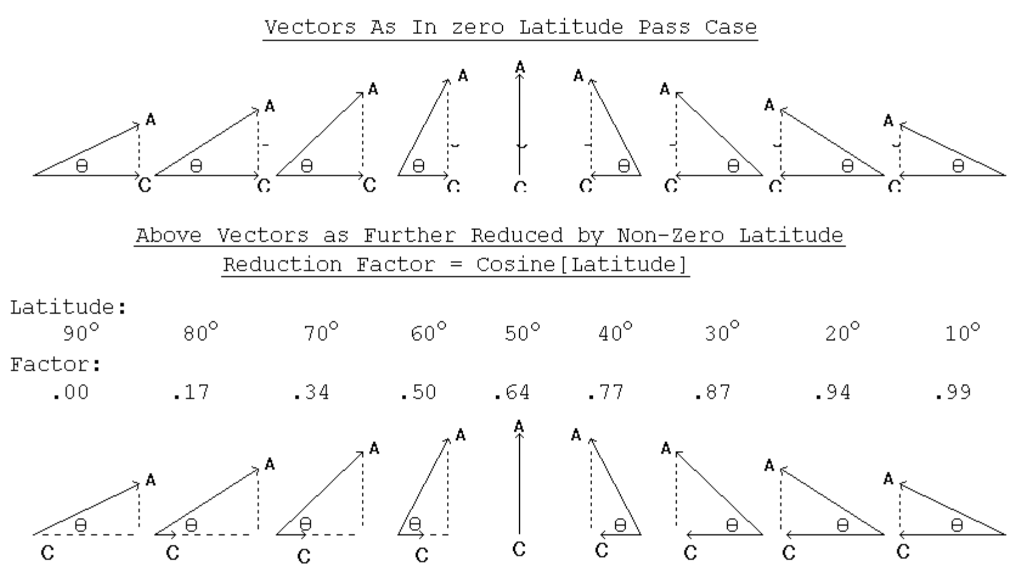
a. <u>Equatorial View - Flyby</u>



b. <u>Equatorial View - Flyby, Rotated</u>



c. <u>Anomalous Acceleration Vectors</u>



The result in this case is a net deceleration, that is an acceleration to the left in the diagrams, against the direction of the flyby.

Figure 8-3
A Pass at Decreasing Latitude

In Case B, the first half, i.e. the acceleration half, of the flight path is at low latitude where the latitude effect only modestly reduces the anomalous acceleration magnitude. But for that case and path the second half, i.e. the deceleration half, of the flight path is at a high latitude where the latitude effect greatly reduces the anomalous acceleration magnitude. The net effect is a relatively large acceleration followed by a lesser deceleration for a net increase in the spacecraft's speed.

In Case C, the effect is just the reverse of that in Case B; the first, i.e. the acceleration, half of the flight path is at high latitude where the effect of the latitude greatly reduces the anomalous acceleration magnitude. But for that case and path the second, i.e. the deceleration, half of the flight path is at a low latitude where the effect of the latitude only modestly reduces the anomalous acceleration magnitude. The net effect is a relatively small acceleration followed by a greater deceleration for a net decrease in the spacecraft's speed.

Therefore, depending on the specific flight path of the spacecraft's flyby pass of Earth the spacecraft may experience an overall net anomalous acceleration or a net anomalous deceleration, those in various amounts depending on the specific encounter and the latitudes involved, and zero net modification if the path is perfectly latitude symmetrical.

Thus there is a small acceleration [in addition to that of natural gravitation], centrally directed and independent of distance producing the flyby anomaly; that is, a modest and otherwise unknown acceleration directed toward the core center of the Earth, the principle body involved, the dominant factor in the mechanics of the flyby.

And, that is another appearance of the same common small acceleration (in addition to that of natural gravitation), centrally directed and independent of distance appearing [here planet-wise in the Flyby Anomaly] and previously [solar system sun-wise in the Pioneer Anomaly] and again [galaxy-wise in the rotation curves anomaly].

Next: The Dark Flow Anomaly