Analysis of the Around-the-World Atomic Clocks Experiment

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Abstract-The description of the experiment, published in 1972 in Science by J.C. Hafele and R.E. Keating, shows in the first part, called: Predicted Relativistic Time Gains, the theoretical background for the calculated time gains. In the second part: Observed Relativistic Time Gains, the results of the measurements are shown. This analysis shows several theoretical errors and a tendentious presentation of the measurements, so clear that the reader cannot avoid a feeling of being deceived in order to get convinced of the correctness of the Special Theory of Relativity.

Analysis

The basic idea is to differentiate the time transformation formula with respect to t, leading to:

$d\tau/dt = d\{\beta(t - (v/c^2)x)\}/dt$, with: $\beta = 1/\sqrt{(1-v^2/c^2)}$ See [1].

It turns out that the authors didn't realize that the variable x, in the theory as described by Einstein, is defined as a constant in the system K in rest. (x is projected in the system k, moving with constant velocity v in the direction of the x-axis w.r.t. K, so only this projection is a function of time.)
In the differentiation process they have written dx/dt as v, while it is zero.

Doing so, the result is the formula applied by them: $d\tau/dt = (1-v^2/c^2)^{+½} \sim 1 - v^2/2c^2$.
However applying dx/dt=0 would have resulted in: $d\tau/dt = (1-v^2/c^2)^{-½} \sim 1+ v^2/2c^2$.

This change of sign plays an essential role in the predicted time-gain / time-loss between the stationary and flying clocks.

The table below shows the predicted time-gain / time-loss between the stationary and flying clocks, presented as nsec per day, for $d\tau/dt = 1 - v^2/2c^2$ ("published"), respectively for $d\tau/dt = 1+ v^2/2c^2$ ("correct $d\tau/dt$").

	published			**correct dτ/dt**	
effect	eastward	westward	*effect*	eastward	westward
gravitational	144	179	gravitational	144	179
kinematic	-184	96	kinematic	184	-96
net	-40	275	net	328	83

Remarks:

1. The measurements have been carried out with a 707 and a Concorde.
2. The gravitational time difference, predicted by the GTR as the authors claim, is calculated as gh/c^2, with $g=9,8m/s^2$ and h the height of the airplane.
3. The value 179 follows from an height of 19000 m, clearly the height of the Concorde.
4. The normal flight height of a 707 is 10000 m, but that height would lead to the value 94.
5. The value 144 is found when the height would be 15300 m, clearly the mean value of the heights of the Concorde and the 707.
6. That means that it may be expected that the kinematic contribution is also a mean value of both airplanes

The following questions can now be asked:

1. Why have these values been mixed? Nothing has been explained about this approach. The reader has to find out this by himself, by checking the presented numbers.
2. There has been a Concorde flying westward, of which the results are presented separately. There must also have been a Concorde flying eastward. Why are the results of this flight not presented separately?
3. The same question can be asked for the 707, flying eastward.
4. Might it be that only the mixed value showed enough similarity?
5. Was the so-called predicted value of these mixed flights really predicted, or calculated after the experiment had been carried out and evaluated?
6. Regarding the accuracy of the observations: isn't it accidentally that they observed the (wrong) predicted time gains with a claimed accuracy of not more than 10 nsec per day, while, as they wrote:

> "However, no two "real" cesium beam clocks keep precisely the same time, even when located together in the laboratory, but generally show systematic rate (or frequency) differences which in extreme cases may amount to time differences as large as 1000 nsec per day."

and:

> "A much more serious complication is caused by the fact that the relative rates for cesium beam clocks do not remain precisely constant. In addition to short term fluctuations in rate caused mainly by shot noise…………"

and:

> "These unpredictable changes in rate produce the major uncertainty in our results."

Besides the error in the expression for $d\tau/dt$ the authors overlooked another fundamental phenomenon. They wrote:

> "Because the earth rotates, standard clocks distributed at rest on the surface are not suitable in this case as candidates clocks of an inertial space. Nevertheless, the relative timekeeping behaviour of terrestrial clocks can be evaluated by reference to hypothetical coordinate clocks of an underlying nonrotating (inertial) space (6).
>
> For this purpose, consider a view of the (rotating) earth as it would be perceived by an inertial observer looking down on the North Pole from a great distance. A clock that is stationary on the surface at the equator has a speed $R\Omega$ relative to nonrotating space, and hence runs slow relative to hypothetical coordinate clocks of this space in the ratio $1-R^2\Omega^2/2c^2$, where R is the earth's radius and Ω its angular speed. On the other hand, a flying clock circumnavigating the earth near the surface in the equatorial plane with a ground speed v has a coordinate speed $R\Omega+v$, and hence runs slow with a corresponding time ratio $1-(R\Omega+v)^2/2c^2$. Therefore, if τ and τ_0 are the respective times recorded by the flying and ground reference clocks during a complete circumnavigation, their time difference, to a first approximation, is given by $\tau - \tau_0 = -(2R\Omega v + v^2)\, \tau_0\, /2c^2$."

Why did the authors choose for this position of the "inertial observer", in stead of an observer at such a great distance with respect to earth that 'it' would have observed not only the velocities as described, but also the velocity, let say w, of the earth due to its rotation around the sun? This velocity not only is much larger than $R\Omega$ and v (~100000 km/hour), it would also have led to a completely different theoretical consideration, not only due to the fact that the influence of w is very large on the result, but also due to the fact that $R\Omega$ and v are continuously differently oriented with respect to w.

Incorporating the influence of w would lead to the velocity for the ground reference clock: $v_r = w + R\Omega\cos\Omega t$, respectively for the airplane: $v_a = w + (R\Omega + v_r)\cos(\Omega t + \varphi(t))$, with $\varphi(t)$ representing the position of the airplane w.r.t. the position of the ground reference clock.

Due to the square of the velocities v_r and v_a in the expression for $\tau - \tau_0$ the influence of w on the this time difference is very large.

Maybe our earth does have yet another velocity, together with our solar system, maybe even much larger than w! However (the position in universe of) the reference of this velocity is unknown, so the "hypothetical inertial observer" cannot be placed.

Conclusion

Due to the most fundamental theoretical errors and the clear tendentious and biased presentation of their measurements, J.C. Hafele and R.E. Keating have been compelled, or by themselves or by the scientific establishment, to "prove" the correctness of the Special Theory of Relativity, whatever they might have measured.

It is therefore, from a scientific point of view, all the more poignant to have to read in their article their next statement.

> "In science, relevant experimental facts supersede theoretical arguments."

Reference

[1] http://siba.unipv.it/fisica/articoli/S/Science1972_%20177_4044_%20166.pdf