Are the Past and the Future Really Out There?

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1 Introduction

In the now six decades since Olivier Costa de Beauregard completed his doctoral dissertation with Prince Louis de Broglie the landscape of the field of physics has, in many respects, changed profoundly. High-energy particle physics was then only getting underway. Now we are approaching, indeed have perhaps reached, the limit that society is willing to support in the construction of massive accelerator complexes. Then quantum electrodynamics was in the process of being formalized. Now we have the standard model of quantum field theory; and it has been around for a couple of decades. Cosmology a half-century ago was the preserve of a small band of general relativists, and the fundamental equation of astrophysics was 1 = 10 =100. Now cosmology is practiced by many and is wedded to particle physics; and observations of the cosmic microwave background radiation (predicted, but unappreciated and unobserved, a half-century ago) has recently led to a claim of knowledge of the age of the universe with an error of only one percent. Strides of this sort are found in all areas of physics, indeed science generally. Advances in technology have made possible experiments that 50 and more years ago could only be done as thought experiments, if thought of at all.

For all of the strides taken, however, the underlying conundrums of the past bear a striking resemblance to those of today. At mid-century, only Einstein and a handful of others devoted their efforts to the creation of a "unified field theory" – a theory at once embracing both gravity and electromagnetism. At that time, this effort was widely regarded as a task unlikely to be successful and of dubious merit in any event. This view changed in the late '70s; but the focus changed from finding a unified theory of gravity and electromagnetism to seeking a quantum theory of gravity that would fit within the framework of relativistic quantum field theory. Though there are several contenders, a compelling version of the sought theory has not yet been found.

Another conundrum that came to the fore a half-century ago, chiefly through the work of Dennis Sciama, is the origin of inertia. The claim Sciama advanced was that inertial forces should arise as a consequence of their interaction with the material contents of the universe via the action of a field. This should not be confused with the claim that the fermions acquire their masses as a result of interactions with Higgs fields, for the field in question was taken to be the gravitational field. This claim – called Mach's principle – provoked a debate that continued into the '70s. And then, after a hiatus two decades, resurfaced in the '90s. The fundamental problem here is that inertial forces in accelerated objects appear at the instant applied "external" forces excite them, and, if these forces are caused chiefly by very distant matter, how can that be the consequence of a field interaction with a finite propagation velocity? This turns out to be related to the last major conundrum that I mention here.

At mid-century the Bohr-Einstein debate over the interpretation and completeness of quantum mechanics continued to simmer, notwithstanding that almost all had taken Bohr to be victorious and moved on to less "philosophical" matters. The Einstein-Podolski-Rosen (EPR) thought experiment, Schrödinger's cat, Wigner's friend, and David Bohm's "quantum potential" – all attempts to elucidate quantum "entanglement" – were all pretty much ignored. Until John Bell's critique of the "measurement problem" in the 1960s anyway. Since the '70s, experiments that only then became possible have convincingly confirmed the predictions of the formalism of quantum mechanics. But they have also called into question the appropriateness of the "Copenhagen Interpretation" of Bohr and his followers. A consensus on the fundamental problem, reconciling faster than light conveyance of information with relativity theory – first cast in stark relief by the EPR "experiment" – has not yet been reached however.

Unified field theory and the relativity of inertia have histories that antedate the 20th century by as much as a couple of centuries. Quantum entanglement, of course, does not have so long a history. But it is related to them since it shares with the relativity of inertia the seemingly instantaneous conveyance of information (indeed, forces) across arbitrarily large distances, that is, "action-at-a-distance", something that appears prohibited if all physical interactions are to be explained by field theories, for neither waves nor particles can traverse finite distances in zero time. It is to Olivier Costa de Beauregard's great credit that he saw, decades ago, how at least some of these conundrums can be accommodated without violating relativistic invariance (Costa de Beauregard, 1953). In particular, he saw that if one invokes advanced, as well as retarded, interactions – as in Wheeler and Feynman's action-at-a-distance "absorber" theory of classical electrodynamics (1945 and 1949) – all of the quantum mysteries involving "entanglement" dissolve into an atemporal, acausal, deterministic spacetime worldview where the future, as well as the past, plays a role in prefiguring the present. Eventually, he extended these ideas into the realm of psychokenesis (for example, Costa de Beauregard, 1976). This unorthodox extension of physical theory was not greeted positively by many in the physics community. Orthodoxy, however, is not the touchstone of truth. So, development of the application of absorber theory to quantum mechanics, without the extension into psychology, was also carried out by others, notably John Cramer in his "transactional" interpretation thereof (1986).

I must own that aside from casual, general interest, I didn't pay too much attention to many of the developments I've just sketched, at least as they occurred in "real" time. As an experimentalist chiefly interested in trying to figure out how to get things to go fast without obviously violating any of the serious laws of physics, quantum entanglement and absorber theory just didn't seem very relevant to me. Then, in the fall of 1989, after discovering a flaw in a calculation done a decade earlier, it became obvious that Mach's principle was absolutely central to what I was up to. From Sciama's explorations of Mach's principle, dating back to his earliest paper on the subject in (1953), it is clear that the gravitational action of the chiefly distant matter on local accelerated objects that causes inertial reaction forces is *radiative*. That is, it involves signals propagating at lightspeed. This presents us with a bit of a problem.

2 The Dynamical Nature of Inertial Reaction Forces

Putting it very crudely, when an external force causes an object to accelerate, the gravitational field coupling it to all the other matter in the universe is "kinked" by the acceleration. And the kink that carries the effect of the acceleration on the field propagates away from the accelerated object at the speed of light. This is shown for a transient "jolt" in Figure 1. From the inertial perspective, the creation of the kink in the field must be the cause of the inertial reaction force experienced by the external accelerating agent (through the accelerating object). This suggests that radiation reaction is the cause of inertial reaction forces. But the radiative reaction to the launching of a customary gravitational wave is utterly negligible, so how can that be?

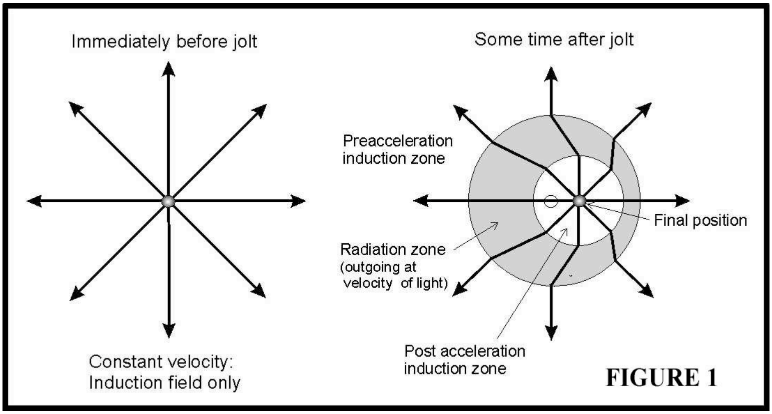


FIGURE 1

One way to deal with this problem is to simply deny that inertial reaction forces are effectively forces of radiation reaction. [Indeed, claims have been made that propagating solutions of the Maxwell-like gravitational field equations (in suitable approximation) do not even exist. Those claims, however, seem to arise from a misapplication of the harmonic gauge condition (Pasqual-Sanchez, 2000).] The denial approach has been followed quite aggressively by Ciufolinni and Wheeler in their recent book *Gravitation and Inertia* (1995), and also by Lynden-Bell, *et al.* (1995). The trick they employ to explain inertia is to use the elliptic – non-propagating – initial data constraint equations to fix the inertial structure of spacetime and, hence, the nature of inertial reaction forces. To be frank, I find this most unsatisfying. From the analogy with electrodynamics, it seems obvious that accelerating charges should radiate and experience radiation reaction forces. Since inertial reaction forces are *only* experienced when the charges of the gravitational field are accelerated relative to local inertial frames of reference (freely falling frames in the presence of matter), it would seem that those forces, by analogy with electrodynamics, must be forces of radiation reaction too.

The radiative nature of the interaction that causes inertial reaction forces was already evident to Sciama in 1953. His discussion of inertial forces was presented in terms of a simple vector representation for the gravitational field. [He took this to be different from general relativity theory (GRT), but, as later shown, the vector representation of the gravitational field is just an approximation to GRT (see: Nordtvedt, 1988).] In this representation, the "gravelectric" part of the field is given by:

$$\mathbf{E} = -\nabla\phi - \frac{1}{c}\frac{\partial \mathbf{A}}{\partial t}, \tag{1}$$

where **E** is the gravelectric field strength and ϕ and **A** are the scalar and three-vector potentials of the field which are computed for any point by integrating over the retarded contributions arising from all mass charges and currents in the causally connected part of the universe. $\nabla\phi$ turns out to be irrelevant to the generation of inertial reaction forces; but $\partial\mathbf{A}/\partial t$ does not. Indeed, $\partial\mathbf{A}/\partial t$ is responsible for them.

If, with Sciama, we assume a homogeneous and isotropic universe with a radius that corresponds to the particle horizon of relativistic cosmology, then the computation of **A** is straight-forward. It is obtained from:

$$\mathbf{A} = -\int_V \left(\frac{\mathbf{v}\rho}{cr}\right) dV, \tag{2}$$

Where **v** is the retarded velocity of the matter of density ρ in the volume element dV located at a distance r from the point where **A** is being computed. Sciama used a "trick" to avoid the full formal calculation of the retarded potential here. He noted that at any point where one might want to know **A** the entire universe appears to move rigidly past the point with velocity **v**, and any changes in **v** due to the acceleration of some object at the point where **A** is computed *appear* to take place instantaneously notwithstanding that the interaction is actually one that is retarded by finite propagation speed for the potential. This allows one to remove **v** (along with c) from the integral, leaving an integral which yields the scalar potential ϕ. The result of this is that:

$$\mathbf{E} = -\frac{\phi}{c^2}\frac{\partial \mathbf{v}}{\partial t}, \tag{3}$$

and if $\phi/c^2 = 1$, then **E**, the gravelectric force per unit mass, exactly produces inertial reaction forces whenever objects are accelerated by external forces.

Sciama's use of the trick of apparently rigid motion of the accelerating (relative to some object at the point where **A** is computed) universe to simplify the above calculation can leave the false impression that he thought the potentials and their associated forces propagate instantaneously. But there can be no mistake that he did not think so, for in his discussion he remarks that, “We see from the argument leading to [an equation that follows from those here above] that “inertia-induction” arises from the term $\partial\mathbf{A}/\partial t$, that is, from the ‘radiation-field’ of the universe. . . .” The problem here is simple: each of the mass elements throughout the universe must have accelerated with the counterpart of the “jolt” in Figure 1 to launch its contribution to the disturbance in the gravitational field that arrives precisely at the instant required to produce the inertial reaction force on the jolted object.

Quite apart from the difficulty of accounting for how the phasing of all of the jolts throughout the universe is accomplished to produce the field disturbance that shows up at just the right time to produce the required inertial reaction force on the accelerated object, one is faced with the further problem of *when* all of those jolts take place out there. Given the propagating nature of the disturbances involved in this radiative interaction, and assuming that the proximate cause of the interaction is the external force applied to the local object, it would seem that the utterly minuscule gravitational disturbance launched by its acceleration must be the cause of the jolts throughout the universe that produce the gravitational disturbance that causes the inertial reaction force the external agent feels. The alternative is to believe that all of the matter throughout the universe anticipates – by some unspecified means – the fact that the accelerating force will be applied to the object at some particular time and spontaneously jolts itself so as to launch the required gravitational disturbance at just the right time. To causally connect such behavior of distant matter in the past to the action of the external force on the local object in the present would demand that we posit that the gravitational disturbance created by the acceleration of the local object propagate along the *past* lightcone of the object as an *advanced* wave. While there is no *a priori* reason why this must not be the case, it seems a fairly dubious proposition at best.

If we assume instead that the gravitational disturbance created as the local object is accelerated propagates along the *future* lightcone of the acceleration event, then the waves produced by the jolting of the matter throughout the universe out there in the future must propagate along the *past* lightcones of all of those events as *advanced* waves in order to arrive in our present from the future in phase and at the right time to cause the inertial reaction force experienced by the accelerating agent. So, either way, if we demand that the gravitational disturbances caused by the acceleration of matter *radiate* with finite propagation speed, then Mach’s principle *requires* that we admit both retarded and advanced interactions – Wheeler-Feynman absorber theory that is. That’s almost enough to make one want to take seriously the utterly obscurantist proposition that inertial forces are communicated via the action of non-proagating, elliptic constraint conditions. Almost. But not quite. *Occult* forces today are just as occult as they were in yesteryear.

Was Sciama aware of this problem? Of course. As he remarked in a 1964 paper (Sciama, 1964) where he laid out his ideas in tensor form, ". . . inertial forces have a dynamical rather than a kinematic origin, and so must be derived from a *field theory*,[4] . . . 4 – or possibly an action at a distance theory in the sense of J.A. Wheeler and R.P. Feynman . . ." This is the price exacted by demanding relativistic invariance for inertial forces. And the price is even higher than it may at this point appear. Wheeler-Feynman absorber theory only "works" if the amplitude of the outgoing retarded [advanced] field disturbance is equal to the amplitude of the incoming advanced [retarded] disturbance. If this is not so, then the unwanted advanced [retarded] disturbance caused by the acceleration of the source charge would not be fully cancelled by the advanced [retarded] disturbance returning from the absorber (distant matter in our case) out there. That means that either the gravitational disturbances involved in the generation of inertial reaction effects must be many orders of magnitude larger than those of customary calculations, or we must (consistently) redefine the notion of gravitational charge so that the amplitudes of the retarded and advanced field disturbances are of equal amplitude, making inertial reaction forces ones of gravitational radiation reaction.

3 Invariants and Gauges

In electrodynamics and quantum theory the action-at-a-distance, absorber interpretation is just that: an interpretation. One can always simply choose to ignore Wheeler-Feynman electrodynamics and the "transactional" interpretation of quantum mechanics of Cramer (anticipated by Costa de Beauregard by several decades). Those theories have gauge properties that make this possible. For example, in electrodynamics one can either assume the Lorentz gauge condition with fully retarded interactions (that can be modeled as absorber interactions), or one can choose the "radiation" gauge where the Coulomb part of the electromagnetic interaction seemingly propagates instantaneously. Gravity, however, is not like that, for insisting that inertial reaction forces have a dynamical origin does more than just require that we take absorber theory seriously. It imposes on us the further condition that the total gravitational potential □ of Sciama's vector approximation theory must, like the locally measured vacuum speed of light *c*, be a *locally measured* invariant.

□ must be a locally measured invariant (which is not the same thing as a constant by the way) in order for inertial reaction forces to be gravitational in origin. ϕ/c^2 in Equation (3) must always be exactly equal to one. Since c is a locally measured invariant (but not the "constant" of popular lore), so too must be ϕ. If this assumption is not made, then Newton's third law of motion is not valid. For example, in an expanding universe, ϕ might be epoch dependent. And one might naively believe that the value of ϕ should vary in the neighborhood of massive objects (as is routinely assumed in elementary physics situations when Newtonian gravity is derived from a scalar potential). Einstein thought that this was also true for Machian situations in GRT (see: *The Meaning of Relativity*, 1956, pp. 99 - 108) where, in a vector approximation formalism, he thought that the piling up of "spectator" matter in the vicinity of an object would lead to the increase of its mass owing to an increase in its gravitational potential energy. Only in 1962 did Carl Brans show this to be mistaken. In GRT the masses of objects do not change due to the gravitational potential energy one might naively think conferred on them by the presence of local "spectator" masses. It is forbidden by the Equivalence Principle, which makes the localization of gravitational energy in this way impossible.

Ironically, though, if one insists on the strongest possible statement of "Mach's principle" – that the observed masses of things arise from their gravitational interaction with the rest of the matter in the universe (so that in the absence of that other matter their masses would vanish) – then one finds that the natural way to achieve this is to posit that observed mass arises from the total gravitational potential energy of an object via the special relativistic relationship $E = mc^2$. Note that the mass in this equation is the *inertial* mass. E, however, according to the strong form of Mach's principle is:

$$E = m\phi, \tag{4}$$

where m is now the *passive gravitational* mass – which need not necessarily be the same as the *inertial* mass unless the Equivalence Principle (from which GRT follows) is true. [Note, by the way, that passive gravitational mass, strictly speaking, is not a source charge of the gravitational field. So placing m in Equation (4) does not constitute a tautological definition of mass.] If we take the total relativistic energy to be the total gravitational potential energy and allow the validity of the Equivalence Principle, then we find that $\phi = c^2$, precisely the condition for inertial reaction forces to be gravitational in origin.

The fact that gravity that includes Mach's principle has a second locally measured invariant, in addition to c of special relativity – albeit that that second invariant is just the square of the first – and the fact that that second invariant fixes total energies and masses of material things has suggested to some that similar behavior might be expected, say, in electrodynamics. Reasoning in this way, one might be tempted to think that electromagnetic potential energy should contribute to the masses of charged objects. For example, one might conjecture that the masses of electrons and protons in the dome of a van de Graaf generator charged to high potential might be perceptibly changed from their normal values. Such changes in the masses of elementary particles might be detectable through shifts in the spectral lines emitted by atoms located in regions of high electrical potential. In other words, we might expect to see an "electrostatic redshift". GRT does in fact predict a minuscule effect of this sort (see: Woodward and Crowley, 1973), but nothing on the order of the sort of effect one would expect to see if the electron rest mass could be nulled by putting it in the dome of a van de Graaf charged to a half a megavolt potential. The experimental upper limit to the electrostatic redshift was set back in the 1930s. To the level of detection, no effect was found, as should be expected if GRT is correct (Kennedy and Thorndike, 1931, and Drill, 1939).

The reason why the naïve extension of the Machian notion that the masses of things arise from their total gravitational potential energies to electrostatics doesn't work is that electrodynamics has the gauge property, mentioned at the outset of this section, that is not shared by GRT, despite their formal similarities. In particular, the electrostatic potential in electrodynamics can be scaled by the (global) addition of an arbitrary potential. Since forces originate only from non-vanishing gradients of potentials, such scaling is without physical consequences. Thus the particular numerical value of the electric potential assigned to any point in space is not, in itself, significant. The total gravitational potential, in contradistinction, as we have just seen, is a locally measured invariant. Accordingly, it cannot be scaled in the same way. Indeed, it cannot be scaled at all.

4 Mach's Principle and Experiment

While it is tempting to pursue the issue of gauges and invariants in gravity and electrodynamics farther, instead I want to address the issue of experimental support for Mach's principle. After all, the final arbiter for all theoretical speculation is experiment. In the case of Mach's principle we are faced with a rather unusual problem. If we accept the arguments of Sciama and others that inertial reaction forces *are* the gravitational action of chiefly distant matter on local objects when they are accelerated, then every detected inertial reaction force that is equal and opposite to the external accelerating force that excites it is experimental evidence for the theoretical conjecture. If, however, we insist that Mach's principle lead to the prediction of hitherto unanticipated effects that can be experimentally detected, then all of that evidence goes by the boards and we must find such novel predictions. For some time now I have argued that Mach's principle does in fact lead to testable predictions of this sort. In particular, one may reasonably expect fluctuations in the masses of accelerated objects that may be large enough to be detectable.

The mass fluctuations (that may, or may not, really exist) appear in a "wave equation", that is, a field equation of standard form for, as I shall call it, the *gravinertial* field that can be recovered if the "strong form" of Mach's principle is employed to separate variables in the derivation of the field equation. The field equation in question, obtained by considering the behavior of a test particle subjected to an acceleration by an "external" force, is:

$$\nabla^2\phi - \frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} = 4\pi G\rho_0 + \frac{\phi}{\rho_0 c^2}\frac{\partial^2\rho_0}{\partial t^2} - \left(\frac{\phi}{\rho_0 c^2}\right)^2\left(\frac{\partial\rho_0}{\partial t}\right)^2 - \frac{1}{c^4}\left(\frac{\partial\phi}{\partial t}\right)^2 \tag{5}$$

On the left hand side (LHS) of this equation we have the d'Alembertian of the scalar gravitational potential ϕ (making it a classical hyperbolic wave equation for ϕ) and on the right hand side (RHS) we have the *local* sources of the field. G and c are Newton's constant of gravitation and the vacuum speed of light respectively. It is the transient terms on the RHS involving the time-derivatives of the *local proper matter density*, ρ_0, that are of interest. (We ignore the last term on the RHS, as it is negligibly small owing to its c^{-4} coefficient.) Equation (5), of course, is an approximate field equation. The correct, exact equations for the gravitational field are the Einstein equations of general relativity theory (GRT). But for our purpose, this simple approximation is sufficient.

The way in which this approximate field equation is obtained is straightforward. (The derivation sketched here of Equation (5) above was first obtained in complete form in Woodward (1995) and can also be found in Woodward (1997).) The action of the gravitational field of all of the matter in the universe (taken, for simplicity, to be homogeneous and isotropic) on a local test particle subjected to an "external" accelerating force is considered. Mach's principle in its weak form stipulates that the gravitational action of "cosmic" matter in this case is precisely the inertial reaction force that the test particle exerts on the accelerating agent. The inertial reaction force is taken to be caused by the gravitational field, and the strength of the field is written in terms of the inertial reaction force it produces. Since it is the action of the field in these circumstances on the local source strength – the mass of the test particle that is – that is of interest, the four-divergence of the field strength that causes the inertial reaction force is calculated. The space-like three-vector part of this calculation leads immediately to the Laplacian of the scalar gravitational potential in Equation (5) because the field is irrotational. Since the time-like part of a four-force (and thus four-field strength) is *power* – the rate at which the force does work on the source – and the time-like part of the four-divergence is partial derivative with respect to time, taking the four-divergence of the gravitational field strength [that produces the inertial reaction force on the test particle] yields terms involving the power (per unit mass) and its time-derivative. (An apposite discussion of four-forces is to be found in section 35 of W. Rindler's outstanding *Introduction to Special Relativity* [Rindler, 1991].) Formally,

$$\nabla^2 \phi - \frac{1}{\rho_0 c^2}\frac{\partial^2 E_0}{\partial t^2} + \left(\frac{1}{\rho_0 c^2}\right)^2 \left(\frac{\partial E_0}{\partial t}\right)^2 = 4\pi G \rho_0 . \qquad (6)$$

E_o is the proper energy density of the test particle.

In order to put the four-divergence of the "gravinertial" field strength into a form from which Equation (5) can be recovered, the "strong form" of Mach's principle must be invoked. This version, as defined above, says that the *inertial* mass of any object originates in its gravitational potential energy arising from the action of the *active* gravitational mass of cosmic matter on its *passive* gravitational mass. That is, we can rewrite Equation (4) above (if we divide both sides of the equation by a unit volume) as:

$$E_o = \rho_o \phi . \qquad (7)$$

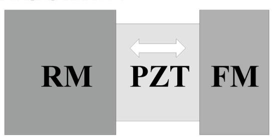
Substituting $\rho_o \phi$ for E_o in Equation (6) makes it possible to, in effect, separate the variables ρ_o and ϕ to the extent at least that the d'Alembertian of ϕ can be isolated. The remaining terms that follow from the time-derivatives of E_o in Equation (6) then become transient sources of ϕ when its d'Alembertian is made the LHS of a standard classical wave equation. Equation (5) can then be recovered if we keep in mind that $\phi/c^2 = 1$. *It is important to note that if we were doing this for any other field, the procedure would not work* for mass-energy and its time derivatives are not sources of, say, the electromagnetic field. But they are sources of the gravinertial field.

5 Forces in Systems With Mass Fluctuations

Simple calculations reveal that in order to make the mass fluctuations predicted by Equation (5) large enough to be detectable, transient or periodic accelerations involving moderately high frequencies – on the order of tens of kilohertz – are required. And to be detected the mass fluctuation must be rendered as a force, either as a weight fluctuation, or by other means. Force detection systems of the requisite sensitivity do not have fast enough response times to measure such fluctuations directly in real time. As a result, an experimental apparatus designed to detect mass fluctuations must either do so “ballistically” by creating a short impulse that is deposited in a system that reacts with a much longer response time, or a way to “rectify” the force into a stationary, unidirectional force must be found.

We can extract a stationary force from a system in which rapid mass fluctuations take place in some device by adding two components to a device in which a mass fluctuation takes place, as shown in Figure 2. Those additional components are an electromechanical actuator (customarily made of lead-zirconium-titanate, so-called PZT) and a “reaction mass” (RM) located at the end of the actuator opposite the fluctuating mass (FM) element. The principle of operation is simple. A voltage signal is applied to the FM element so that it periodically gains and looses mass (at the power frequency of the voltage signal – twice the frequency of the voltage signal). A second voltage signal is applied to the PZT actuator at the power frequency of the voltage signal delivered to the FM element. The relative phase is then adjusted so that, say, the PZT actuator is expanding when the FM element is more massive, and contracting when it is less massive. The inertial reaction force that the FM element exerts on the PZT actuator is communicated through the actuator to the RM. Evidently, the reaction force on the RM during the expansion part of the PZT actuator cycle will be greater than the reaction force during the contraction part of the cycle. So, the time-averaged force on the RM will not be zero. Indeed, one finds that:

FIGURE 2



$$<F> = -2\omega^2 \delta l_o \delta m \cos \phi, \tag{8}$$

where δl_o is the amplitude of the excursion of the FM induced by the PZT actuator, δm the amplitude of the mass fluctuation, ϕ the relative phase of the excursion and the mass fluctuation, and ω the angular frequency of the power signal driving the FM. It would appear that stationary forces might be obtained from mass fluctuations in this way.

For completeness, I should mention here that if one includes the "**v***dm*/*dt*" part of Newton's second law in the calculation of <*F*> taking the rest frame to be one fixed in the reaction mass, then one obtains zero for <*F*>. In general, however, this way of calculating <*F*> is incorrect, as can be seen by carrying out the calculation in the instantaneous rest frame of the fluctuating mass where, instant-by-instant, **v** vanishes making the contribution of the "**v***dm*/*dt*" term exactly zero. This term actually relates to the momentum flux to/from the fluctuating mass in the gravinertial field. It only produces a force on the system if it directed along the longitudinal axis of the mechanical system in Figure 2.

6 An Experiment in Progress

Unambiguous detection and practical application of Machian effects turn out to be a good deal more daunting than one might like. The difficulties stand out when one examines the equation for mass fluctuations [obtained from the RHS of Equation (5)]:

$$\delta\rho_0(t) \approx \frac{1}{4\pi G}\left[\frac{\phi}{\rho_0 c^4}\frac{\partial^2 E_0}{\partial t^2} - \left(\frac{\phi}{\rho_0 c^4}\right)^2\left(\frac{\partial E_0}{\partial t}\right)^2\right], \tag{9}$$

or, taking account of the fact that $\phi/c^2 = 1$,

$$\delta\rho_0(t) \approx \frac{1}{4\pi G}\left[\frac{1}{\rho_0 c^2}\frac{\partial^2 E_0}{\partial t^2} - \left(\frac{1}{\rho_0 c^2}\right)^2\left(\frac{\partial E_0}{\partial t}\right)^2\right]. \tag{10}$$

It might seem that inclusion of the second term on the RHS of Equations (9) and (10) is not germane to any reasonable discussion of testable effects since its coefficient is smaller than that for the first term by a factor of $1/c^2$.

But this assumption ignores the fact that ρ_0 in the denominators of the coefficients of both terms can be driven, at least in principle, to zero (since it is not a constant). Should this happen, then the second term, otherwise negligibly small, dominates these equations. *Note that this term is always negative.* (For that reason it is the term that holds out the greatest promise for practical applications, notwithstanding that it is so very small in almost all circumstances.)

As indicated by Equations (9) and (10), to produce mass fluctuations we must cause large, rapid changes in the proper [internal] energy of an accelerating system. The obvious way to do this is to is to rapidly charge (and discharge) capacitors made with insulating material with a very high dielectric constant. If we assume that all of the power P fed to capacitors being tested for mass fluctuations goes into changes in the rest energy density E_0, then when an integration over the volume of the dielectric in the capacitors is done we find a mass fluctuation δm_0:

$$\delta m_0 = \frac{1}{4\pi G}\left[\frac{1}{\rho_0 c^2}\frac{\partial P}{\partial t} - \left(\frac{1}{\rho_0 c^2}\right)^2 P^2\right]. \qquad (11)$$

Note that the assumption that all of the power delivered to the capacitors ending up as a proper *energy density fluctuation is an optimistic, indeed, perhaps wildly optimistic, assumption.*

Nonetheless, this is arguably a reasonable place to start. How are we to test for the presence of such mass fluctuations? Since the second term on the RHS of Equation (11) is hopelessly small in all but very special "just so" conditions, it seems that it can be ignored. In order to make the first term on the RHS as large as possible, we need to maximize $\partial P/\partial t$. In a "one shot", or pulsed "one shot" system this can be done by making the switching on, or off, of the voltage to the capacitors being tested as quick as possible. The mass fluctuation, of course, will only persist during the very brief switching process, so any weighing system designed to detect the transient mass fluctuation will have to be exceedingly fast. The same requirement for the weigh system obtains if we use an AC voltage signal to drive the mass fluctuations sought, for to produce a mass fluctuation of detectable magnitude, the frequency of the applied voltage signal will have to be as high as possible. And while P, being the product of the voltage and the current delivered to the capacitors, is positive definite, $\partial P/\partial t$ is not. For a simple sinusoidal voltage signal, it is positive half of the time, and negative the other half of the time – so it time-averages to zero. Nonetheless, since PZT material responds non-linearly to high electric field strengths, if the second harmonic of the exciting voltage is part of the response it may combine with the mass fluctuation driven at the power frequency of applied voltage signal – which is the same as the frequency of the second harmonic – and a stationary force of the sort mentioned in the previous section above may result (if the phase relationship of the mass fluctuation and second harmonic acceleration is auspicious).

Instead of building real devices that mimic the features of the schematic diagram in Figure 2 we can instead build devices where the PZT actuator and the capacitative element with the fluctuating mass are integrated into a single PZT stack, as shown schematically in Figure3. The brass disk in this configuration acts as the reaction mass; and the PZT stack includes a thin pair of crystals that can be used to monitor the acceleration of the end of the stack where the largest mass fluctuations are driven (because of its location and the thickness of the crystals in that part of the stack).

FIGURE 3

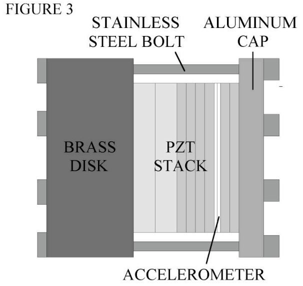
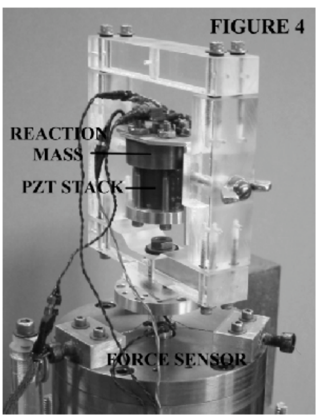


FIGURE 4

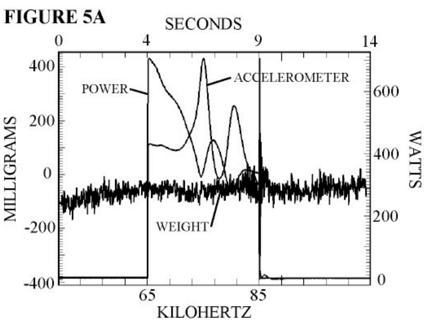


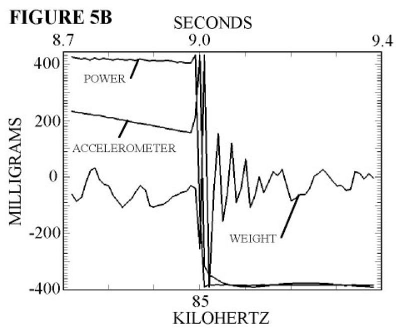
A device of the sort shown in Figure 3 can be mounted on a force sensor in a variety of ways. That I have chosen is shown in Figure 4. The force sensor is a high sensitivity magnetoresistive position sensor fitted with a stiff spring (encased in a thick steel shield as shown here). A clear Plexiglass frame is affixed to the mounting stage of the sensor; and the device is mounted on a bracket within the Plexiglass frame. This mounting scheme was adopted to facilitate the most important test for spurious signals in the system: rotating the device in the frame into the horizontal position and repeating the data protocol. While weight fluctuations will not change with device rotation, real thrusts should disappear in the horizontal position of the device. Other tests for spurious signals can also be carried through. For example, data can be taken at atmospheric pressure and at a moderate vacuum to insure that "sonic wind", corona, and the like are not the source of any signals seen. The device can be enclosed in a small metal box (a Faraday cage) to check for any electromagnetic coupling between the device and objects in its immediate environment and so on.

I will not belabor here the technical details of the construction and execution of this particular experiment, for it is still an experiment in progress. Let me just present some interim results of recent vintage to give a flavor of what can be found with a system of this sort. Excitation of the device was accomplished by applying a simple sinusoidal signal that was swept from 65 kHz to 85 kHz during a five second interval to a power amplifier. The voltage output of the power amplifier was stepped up with a toroidal transformer so that the voltage swing at the device was a few hundred volts (that is, a peak applied power of several hundred Watts). Quiescent data were taken for several seconds before and after the powered frequency sweep in each data cycle; and signal averaging was performed by combining the results of typically one to three dozen data cycles. The swept frequency range was chosen because it spanned the frequencies of mechanical resonance of the device where one might expect to see effects if correctly phased second harmonic oscillations were present.

Unfortunately, auspiciously phased second harmonic signals didn't show themselves at the mechanical resonances of the device. (Recall, this is a work

in progress.) But other interesting behavior did. It is shown in Figure 5A, a





spectacular transient effect when power to the device is shut off. The transient is displayed in detail in Figure 5B. Is it a real thrust? Or is it just spurious junk? Well, it is present at the same amplitude in air and in vacuum. And more importantly, it goes away when the device is run in horizontal mode, as shown in Figure 6. If a switching transient effect is present at shut-off, one might expect to see similar behavior at switch-on. And when timing slop in the (now antique) ADC board is compensated for, such behavior appears in Figure 7.

Analysis of the accelerometer waveform showed that the second harmonic needed to account for the behavior in Figures 5 and 7 as Machian effects was actually present. Nevertheless, the question to be answered remains: Are the switching transients actually evidence for Mach effects? The correct way to answer this question is to show that no other known effect can account for the signals seen. The obvious candidate of this sort is the jolt delivered to the

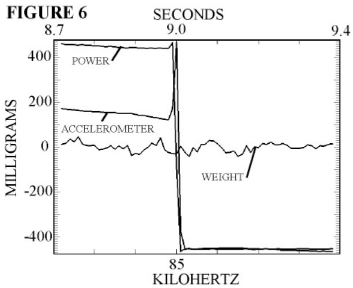


FIGURE 6

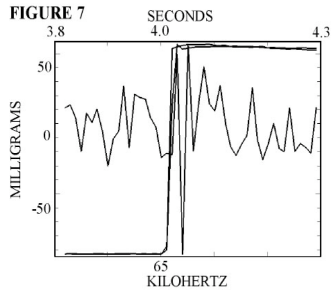


FIGURE 7

device when it is switched on or off by the linear electromechanical response of the material in the PZT stack to the applied voltage. Signal averaging, however, eliminates this possibility because the switching time was uncorrelated to the applied voltage waveform. (That is, the switching was not phase-locked to the signal waveform.) As a result, switching the voltage was as likely to produce a jolt in either direction. Random jolts average to zero over any reasonable number of data cycles.

As the linear response jolt considerations show, signal averaging restricts candidate explanations of the switching thrust transient effects to those that are effectively quadratic in the applied voltage. There are only two such effects that I have been able to think of: thermal effects and electrostriction. In the case of thermal effects, as the stack begins to expand at switch-on the acceleration of the free end of the stack will push off of the RM and bracket until the rate of expansion of the stack stabilizes. This should lead to an observed thrust that mimics a transient weight *decrease* at switch-on. At switch-off, an inverse effect of this sort (that is, transient weight *increase*) should occur. Inspection of the transients in the figures here reveals that the transients have the opposite sense of that predicted for thermal jolts. Moreover, quantitative calculation of the magnitude of thermal effects shows them to be too small to account for the observations.

Analysis of electrostrictive effects requires another piece of information not yet mentioned: the duration of the transient switching events. In fact, their duration is much shorter than the time-resultion of the data presented in the figures here (which was taken at a rate of 100 Hz – remember, it's an antique ADC board [soon to be replaced]). Using a Picoscope ADC-212 virtual oscilloscope, the duration of the transients was found to be between 500 microseconds and 2 milliseconds, far shorter than the 10 milliseconds between data registry by the main data acquisition system. For thermal effects, this makes no difference. Thermal jolts are unidirectional at either switching event because the rate of thermal expansion after the switching event is essentially constant. So, notwithstanding that they are very brief, thermal jolts get registered ballistically by the force sensor and main data acquisition system. In the case of electrostriction, each switching event has both acceleration and deceleration of the stack for, unlike the thermal case, the electrostrictive extension of the stack stops after the transient event. This is all accomplished in 2 milliseconds or less. Consequently, the force sensor, which has a frequency response of about 35 Hz, simply does not see any electrostrictive effects that might be present. And, as in the case of thermal effects, quantitative calculation shows electrostrictive effects to be smaller than those displayed in the figures here.

7 Conclusion

Do the experimental results reported here constitute conclusive corroboration of Mach's principle? Frankly, no. They are part of a work in progress and, although they suggest that Mach's principle may well be correct, they are not yet completely conclusive corroboration thereof. What, you may be wondering, do they have to do with Costa de Beauregard's action-at-a-distance interpretation of quantum mechanics? Well, note that the predicted transient effects arise in a hyperbolic relativistic wave equation for the gravinertial potential. As such they are the bell-weathers of a dynamical, radiative inertial interaction. And that type of interaction, given the instantaneity of inertial reaction forces, can only be squared with relativity in a Wheeler-Feynman action-at-a-distance context. The alternative interpretations available in the cases of electrodynamics and quantum theory seem unavailable in the case of inertia. Accordingly, the past and the future may really be out there. And Costa de Beauregard's insight of a half-century ago may well prove to be correct.

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