RAPID SPACETIME TRANSPORT AND MACHIAN MASS FLUCTUATIONS: THEORY AND EXPERIMENT

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INTRODUCTION:

The equations of physics, generally, are invariant under the symmetry groups of infinitesimal space and time translations. This means that energy and momentum are conserved in "isolated" systems, that is, systems that do not couple physically to anything outside of themselves. Among the propellantless propulsion schemes of interest in the context of "breakthrough propulsion physics", however, are several apparatuses that purport to manipulate electromagnetic fields in ways intended to achieve propulsion by generating a force in one part of a system that is allegedly not cancelled by an equal and opposite force elsewhere in the system. (As one example of this sort of scheme, see Corum, *et al.*, 1999.) The unbalanced force, then, is the source of an acceleration of the system, achieved without acting on anything outside of the system. Setting aside schemes involving beamed electromagnetic radiation (so-called "photon rockets"), evidently conservation principles and their observationally corroborated underlying symmetries simply forbid such behavior. They dictate that the acceleration of a spacecraft can only be achieved if it couples somehow to the rest of the universe, with respect to which it moves. (In the case of normal rockets, this coupling to the rest of the universe is accomplished through the inertia of the propellant exhausted, for it is the gravitational action due to cosmic matter on the propellant that causes its inertial properties, making it possible to "push off" of it.)

Since direct electromagnetic coupling to exterior matter does not take place in these allegedly unbalanced force systems, if an accelerating force on the system is to be actually generated, it *must* involve the gravitational/inertial interaction – the only long-range force (other than electromagnetism) that couples local objects to distant matter. I say gravitational/*inertial* interaction here because in relativistically invariant, non-linear theories of gravity, in particular, in general relativity theory (GRT), inertial reaction forces are a consequence of the gravitational action of chiefly the most distant matter in the universe (Woodward and Mahood, 1999; Woodward, 2001). This fact, first argued with clarity and force by Sciama (1953 and 1964) as the essence of Mach's principle, has only lately been fully appreciated.

Allowing the foregoing, it appears that "breakthrough" propulsion can only be implemented in one of two ways. The first is to find a way to "convert" electromagnetic fields directly into gravitational/inertial fields; fields with the requisite strength – enormous by comparison with the gravitational fields normally associated with objects smaller than small planets – to accomplish some desired rate of acceleration. But there is no credible evidence that localized electromagnetic fields can be directly converted into *strong* gravitational fields that couple to distant matter. Electromagnetic fields couple to, and have as their sources, electric charge, not mass. Gravitational fields, on the other hand, have mass-energy as their source, not electric charge (and its currents) *per se*. The energy in electromagnetic fields is a source of gravity. But the energies needed to produce *strong* gravitational fields are gargantuan, and the fields produced by large concentrations of mass-energy are neither "beamed" nor directed, as one would want for propulsive purposes. The second way electromagnetic effects might be manipulated to achieve propellantless propulsion is to find a way to drive *large* changes in the instantaneous value of the local mass-energy content of spacetime. This does not directly produce beamed gravitational effects. But it does permit one to extract stationary forces that may be used for propulsion that involve gravitational/inertial energy and momentum fluxes coupling the local system with distant matter, as I sketch here now. As such, this seems to be the *only* way to achieve propellantless propulsion without *prima facie* violations of established conservation principles.

THEORY:

When inertial reaction forces are viewed as arising from the action of a locally Lorentz-invariant field, as they actually are, it turns out that objects subjected to accelerations by external forces undergo changes in their restmasses during the accelerations (Woodward, 1990, 1991, and 1995; Mahood, 1999). This is a consequence of the four-vector nature of the reaction forces (and the fields producing them) and the four-dimensionality of the divergence operator that is applied to the four-field strength to obtain an expression for the local charge density. In the simplest approximation, expressed as a function of the scalar gravitational potential ϕ, one obtains the relativistically invariant wave equation:

$$\nabla.\phi - (1/c^2)(\partial^2\phi/\partial t^2) = \ddot{y}\phi = 4\pi G\rho_o + (\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2) - (\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2 - c^{-4}(\partial\phi/\partial t)^2, \tag{1}$$

where G is Newton's constant of universal gravitation, ρ_o the restmass density, and c the vacuum speed of light. This field equation is obtained only if one assumes, as suggested by Mach's principle, that the local energy density of matter is equal to the matter density times ϕ. Since Mach's principle demands that $\phi = c^2$ when measured locally, this constraint merely amounts to asserting that $E = mc^2$. Additional terms would be present in this equation were it not for the fact that, as a consequence of Mach's principle in this approximation, $\phi = c^2$.

If we ignore $-c^{-4}(\partial\phi/\partial t)^2$ since it is always minuscule given its c^{-4} coefficient (not compensated for by any factor of ϕ in the numerator, as in the other terms), and extract a factor $4\pi G$, we may write the total, time-dependent matter density as:

$$\rho(t) \approx \rho_o + (1/4\pi G)[(\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2) - (\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2]. \tag{2}$$

The first time-dependent term – $(1/4\pi G)[(\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2)]$ – can be both positive and negative when ρ_o undergoes periodic fluctuations. When effects arising from this term are convolved with a second periodic force in an object, this restmass fluctuation can lead to the production of stationary forces (Woodward, 1992 and 1996; Mahood, 1999). One merely pushes on an object made more massive by this mass fluctuation, and then pulls it back when it is in a mass-reduced state to achieve a net accelerating force. For this reason I call this the "impulse engine" term in Equations (1) and (2). The second time-dependent term, unlike the first, is always negative, because the negative sign of the term is unaffected by the sign of ρ_o since it appears exclusively in quadratic factors: $-(1/4\pi G)[(\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2]$. This term holds out the possibility of the transient formation of "exotic" matter – matter with negative mass – the material needed to achieve the most extreme types of rapid spacetime transport by the warping of spacetime. Eschewing the temptation to assign this term a romantic label, I call it the "negative" term in Equations (1) and (2). As with the impulse engine term, when mass fluctuations driven by the negative mass term in some object are convolved with a second periodic force, stationary forces can be produced. So both the impulse engine and negative mass effect terms hold out the promise of realizable propellantless propulsion. *Note that the transient mass terms in Eq. (2) are enormous in comparison with, for example, the mass changes that occur from simply changing the energy content of some region in spacetime. This is a consequence of the transient terms being "magnified" by the factor* $(\phi/\rho_o c^2)$ *coefficients where, as a consequence of Mach's principle,* $\phi/c^2 \approx 1$, *rather than being a very small number as one might otherwise expect.*

The stationary forces that result from both of these terms depend on the relative phase of the driven mass fluctuation and the second applied force. Their periodicities, as a function of the relative phase, however, are not the same because for a driven periodic fluctuation in ρ_o, the resulting contributions from the impulse engine term have the same periodicity as the driving signal, but the negative mass term varies at twice the frequency of the driving signal because the time derivative of the driving signal is squared. Were the negative mass term much smaller than the impulse engine term, as simple calculations can lead one to believe, this would not be a matter of much moment. But, in fact, the negative mass term is comparable to the impulse engine term, as can be seen by inserting the *ansatz* $\rho_o = \rho cos(\omega t)$ into Equation (2) and computing the resulting expressions for the impulse engine and negative mass terms. This procedure does not yield an exact solution of this non-linear equation. But it does reveal that the amplitudes of the two factors in the square brackets are the same, to factors of order unity at any rate. Thus, should Machian mass fluctuations actually occur, one should be prepared to see evidence of the negative mass term, as well as the impulse engine term.

Before turning to a discussion of experiments designed to test for the presence of the mass fluctuations just described, I mention general considerations that should inform experiments. We ask first, where might one expect to see the sort of mass fluctuations predicted by Equation (2) above? Since this equation follows from the consideration of the action of an accelerating force on matter, plainly some material must be present that is accelerated. The fact that the transient terms in Equation (2) both involve derivatives of the local rest matter density, ρ_o, indicates that the local *rest* energy density, E_o [$=\rho_o/c^2$], must also be changing. Evidently, the largest Machian mass fluctuation effects are to be expected in materials where, viewed at the microscopic level, the application of external electromagnetic fields produce large accelerations accompanied by rapid changes in stored internal energy. Thus, for example, if mass fluctuations are to be driven in dielectric materials in capacitors, then one will want to use material with the highest possible dielectric constant, in particular, ferroelectric substances. It is worth noting, nonetheless, that if the vacuum can be truly regarded as a polarizable substance, then one may expect to drive mass fluctuations in the vacuum itself. And should such fluctuations be convolved with an appropriate periodic force, stationary forces like those expected in material media should be producible. Such forces, however, would be quite small in comparison with those produced in media with large dielectric constants. An experiment designed to test for mass fluctuations in the vacuum would make a good test of the reality of the "polarizable vacuum" model of GRT that has recently been elaborated by Puthoff (1999).

EXPERIMENTS:

I have already reported results of experiments designed to detect Machian mass fluctuations (Woodward, 1990, 1991, 1996, 2000), as has Thomas Mahood (1999). I report here the preliminary results of the ongoing experimental program underway in my laboratory. For the past several years that program was focused on the detection of stationary forces in stacks of lead-zirconium-titanate [PZT] crystals driven with voltage signals of several hundred volts at several tens of kHz using sensitive torsion pendula, started with Mahood in the course of his graduate work. (See Mahood, 1999; Woodward, 2000; and especially Woodward and Mahood, 2000 for the details of this work.) Since fall 2000 the focus of work in my lab has changed to an updated version of my early experimental tests of mass fluctuations by looking for the effect as a weight fluctuation with force transducers. *Approaching experimental detection of any mass fluctuation effect in this way has the great merit that only the mass fluctuation* per se *is detected (as a weight fluctuation), so all issues relating to the production of stationary forces by signals of several frequencies and phases are set aside (unless such forces are produced by convolution of harmonics of the fundamental signal with mass fluctuations driven thereby).* This is being done, in collaboration with Kirk Goodall, using PZT stacks like that shown in Figure 1, employing both the load cell used in earlier work, and utilizing optical detection of displacements driven in cantilever beams to detect any weight fluctuations. (The PZT stack shown in Figure 1 consists of four crystal disks, 1.91 cm in diameter by 0.16 cm thick, made of EDO Ceramics EC-65 material epoxied together with suitable electrodes. It is clamped by an aluminum collar and six machine screws to a 0.64 cm thick brass disk.) The optical/cantilever beam technique was suggested by John Cramer. The cantilever beam method of weight detection, even with mechanical resonance amplification, is not sufficiently sensitive to see the sort of effects expected , especially should the small effects seen in the torsion pendulum results be indicative of very small mass fluctuations. This state of affairs is a consequence of the fact that the magnitude of the expected mass fluctuation scales with the square of the operating frequency, and operation at the mechanical resonance frequency of the weigh system constrains one to rather low frequencies (on the order of less than 100 Hz).

In earlier work of this sort (Woodward, 1990 and 1991) arrays of capacitors, rather than stacks of PZTs, were driven by a voltage signal at nearly half the mechanical resonance frequency of the load cell so that the mass fluctuation excited at the power frequency of the applied voltage would produce a periodic weight fluctuation that would be resonance amplified by the load cell. Since the resonance frequency of the load cell is typically about 100 Hz, only minuscule weight fluctuations could be driven, and mechanical resonance amplification and signal averaging were essential to see any effect at all. Since that early work was done, the importance of the negative mass term in Equations (1) and (2) has come to light. Because the effect of this term is always to reduce the mass of the object in which it is excited (being negative definite), a stationary time-averaged mass shift arising from this effect can be produced by a voltage signal of much higher frequency than the mechanical resonance frequency of the load cell. Indeed, this effect can be optimized by driving the PZT stack at one of *its* mechanical resonance frequencies (typically about 50 to 100 kHz in devices like that in Figure 1). *Since the time-average of this effect during an applied power pulse will lead to a weight reduction, one may simply observe any weight change directly should it be large enough.* (Note that impulse engine term effects, by themselves, do *not* lead to such stationary weight shifts since they time-average to zero.)

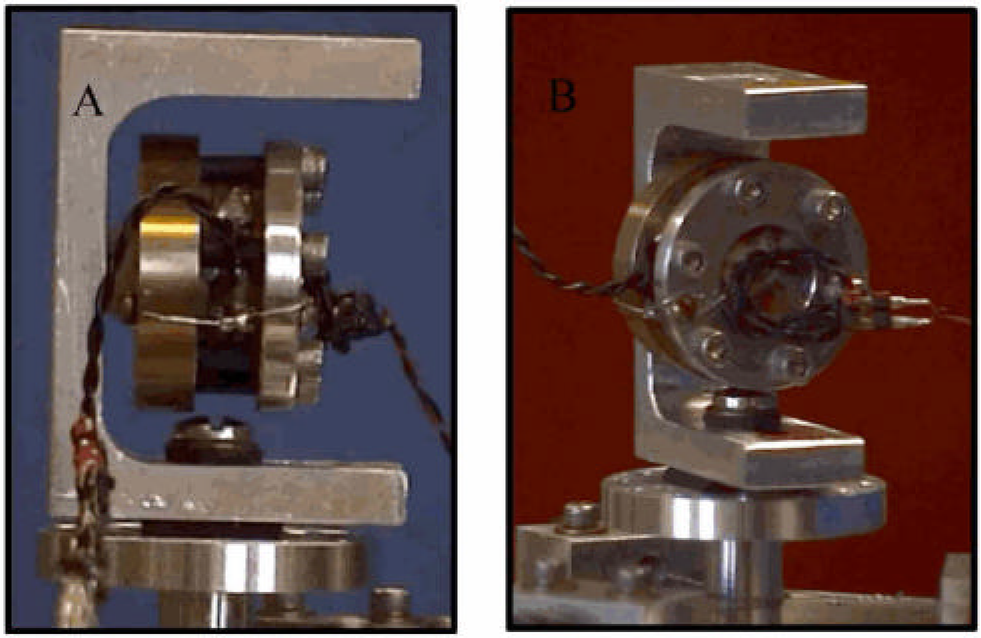

FIGURE 1: Pictures of the PZT stack used to obtain the results reported below, mounted on the load cell stage, from the side (A) and obliquely from the front (B). The crystals are clamped between a brass disk and an aluminum collar with six 4-40 stainless steel cap screws, and the brass disk is affixed to the mounting block with a threaded stud. A nylon nut on the stud suppresses vibration in the mounting block, and further vibration suppression is achieved by the rubber pads on the screw that secures the mounting block to the stage.

Mass fluctuations arising from the negative mass term, in real circumstances, if present at all, may be much smaller than ideal considerations might suggest. So, should one want to excite a mechanical oscillation of the weigh system near its resonant frequency to bring out a small effect, one need only pulse the high frequency voltage signal to the PZT stack at some suitable low frequency. This is easily done by amplitude modulating the high frequency voltage signal. Moreover, the modulating voltage signal can be used as a synchronizing signal for a lockin amplifier to extract the resulting mechanical excursion of the weigh system from the DC weigh signal and extraneous noise. Using both AC and DC detection of the expected effects of a pulsed negative mass term weight reduction lends confidence to any conclusion that one or the other of the effects is real.

Load Cell Weight Determination:

The apparatus in use in the load cell version of this experiment is shown in Figure 2. Here a stack of PZTs is mounted on a Unimeasure U-80 Hall effect position sensor fitted with a diaphragm spring to make it a force transducer. The transducer is located in the 1 cm thick steel shielding case visible in the figure. The associated circuitry and instrumentation is displayed schematically in Figure 3. (Not shown in Figure 2 is additional instrumentation that allows measurement of acceleration of the PZT stack by an accelerometer and recording the temperature of the device with a thermistor.) Other parts of the apparatus for this experiment shown in Figure 3 are: a power amplifier (150 Watt linear amplifier), a 5 to 1 toroidal stepup and isolation transformer (TRANS), voltage and current sense resistors in the high voltage circuit so that the voltage and current signals could be multiplied (4 QUAD MULT.) to get the instantaneous power delivered to the PZT stack, and a rectification and filtering circuit (POWER METER) so that the power could be read digitally in real time.

The load cell is normally operated in a vacuum chamber – a small box about 22 cm on a side made of 3 cm thick acrylic plastic – routinely pumped out to a few tens of microns or less with a rotary vane vacuum pump. Operation of the system and data acquisition and processing is computer controlled. Post acquisition data processing is done with software written specifically for that task (adapted from software used in earlier experiments). As in earlier realizations of experiments using the U-80 load cell, with

FIGURE 2: The PZT stack mounted on the U-80 load cell.

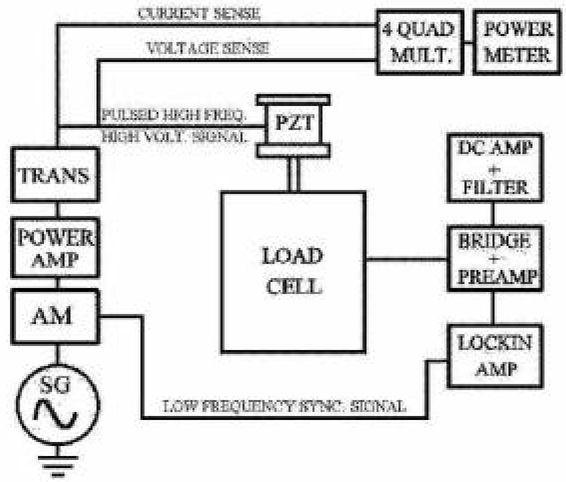

FIGURE 3: A schematic diagram of the chief components of the load cell system.

sufficient averaging of data, a mass (or weight) shift of a few tenths of a milligram could be resolved – assuming that the static calibration of the load cell with a one gram mass is applicable to signals registered in conditions of small, high frequency vibration. This last assumption is open to question, for the manufacturer of the U-80 stipulates that the sensitivity of the Hall probe changes unpredictably in the presence of vibration with frequencies above 1 kHz. Nonetheless, although one would not want to rely only on the U-80 load cell, it is useful as a check on some other method of mass fluctuation detection.

Cantilever Beam Weight Determination:

All of the supporting apparatus used with the U-80 load cell is also used with the cantilever beam system. Indeed, one merely substitutes the beam assembly, shown in Figure 4, for the load cell. A laser beam is directed to a small front surface mirror located near the PZT stack on the beam from above. Its reflection is then directed by another small mirror (near the laser) to a position detector located on a steel cabinet some three meters distant. The position detector (comprised of a gradient density photographic filter and a solar cell with amplification) can resolve beam location changes of 0.01 mm (with sufficient data averaging). Since the addition of a 1 gm mass to the PZT stack produces, typically, a deflection of the laser beam of about 5 mm at the position detector, in principle a mass fluctuation of a few milligrams can be discerned. Several different cantilever beams were tried. Eventually, beams made of 0.08 mm thick stainless steel roughly 12 mm wide were adopted. They are simple, easily fabricated, and quite resilient. To affix the PZT stacks to the end of a beam, an acrylic block roughly 12 mm square by 2 to 3 cm length was machined to clamp onto the beam. The block was machined with several threaded holes so that the PZT stack could be screwed into the block (with a stud in the brass disk used in the stack to clamp the crystals). This acrylic block was also fitted with a thermistor so that the operating temperature of the stack could be monitored. This is important for two reasons. First,

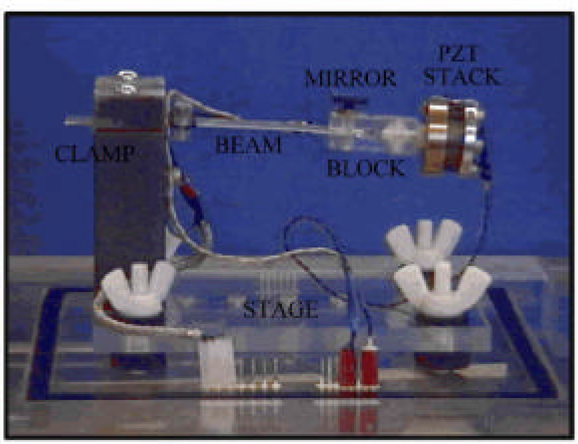

FIGURE 4: A picture of the cantilever beam weight detection apparatus. The laser used in the optical lever is mounted above the part of the assembly shown here.

if the operating temperature exceeds the Curie point of the crystals, the PZT stack is depoled and ceases to function correctly. Second, because the thermal expansion properties of the different substances in the system are not the same, differential expansion of the parts takes place as they are heated. This causes the mechanical resonance characteristics of the stack to change, possibly altering any effect sought. The temperature sensor permits operation of the system in repeatable thermal conditions.

RESULTS:

As of this writing – mid-December, 2000 -- preliminary results have been obtained with both the load cell and cantilever beam systems. Neither system, however, has been fully characterized and optimized. And full check protocols, summarized in the next section, have not been applied to any of the results so far obtained. The type of results sought, however, are displayed in Figures 5 through 7 for illustrative purposes. They were obtained using a 20 second data acquisition interval, power to the PZT stack being switched on 5 seconds into the cycle and switched off after 4 seconds. The results in Figures 5 and 6 were obtained with the cantilever beam arrangement shown in Figure 4. In the case of Figure 5, the PZT stack was driven with a sinusoidal signal at a frequency of 88.7 kHz. But the actual signal in the stack

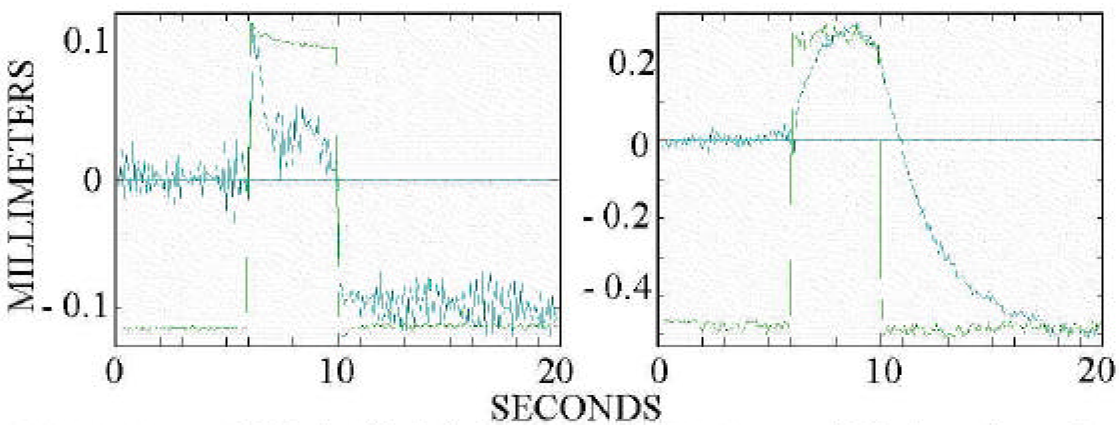

FIGURE 5: Averaged deflection (blue) obtained at 88.7 kHz and an applied power (green) of 34 Watts. Note the prompt deflections when the power is switched.

FIGURE 6: Averaged deflection and power for frequencies in the 61 to 63 kHz range with typical powers of 80 to 120 Watts.

contained several harmonics of the driving signal owing to the non-linear nature of ferroelectric materials. The amplitude of the power in the stack was about 33 Watts. The 4 second power pulse is accompanied by a prompt deflection of 0.1 mm, which corresponds to a stationary weight decrease of roughly 20 milligrams. This result was obtained in a vacuum of 35 microns. The results displayed in Figure 6 were obtained by driving the stack at about 62 kHz with a power level of about 100 Watts in air after several modifications to the beam/block assembly had been made. (The vacuum system was undergoing repairs and upgrades.) The deflection, averaged for frequencies between 61 and 63 kHz, is now 0.3 mm, and the peak individual cycles very close to the resonance reached 0.7 mm, corresponding to a weight decrease approaching a tenth of a gram. But the response is sloppier, and clear evidence of thermal effects is present both during and after the power pulse. Evidently, not all of the modifications were entirely auspicious.

The results displayed in Figure 7, obtained with the load cell under the same operating conditions as those that attend the results in Figure 6, are nearly ideal. (They are the average of 16 individual cycles.) There is essentially no evidence of thermal drift at any time during the cycle notwithstanding that the results were obtained in air. They show a prompt weight decrease of a bit more than a tenth of a gram for an applied power of 75 Watts, that is, almost exactly the same weight shift as that obtained with the cantilever beam system in the same circumstances. The absence of drift is particularly important, for it signals the successful suppression of high frequency vibration by the rubber pads visible in Figures 1 and 2 that isolate the mounting block from the stage/shaft assembly that carries the Hall probe in the U-80. When those pads are removed, results like those in Figure 8 are obtained. They are clearly contaminated by pronounced drift, and the recorded signal is somewhat larger, seemingly confirming the manufacturer's claim that the sensitivity of the U-80 is affected by the presence of high frequency vibration.

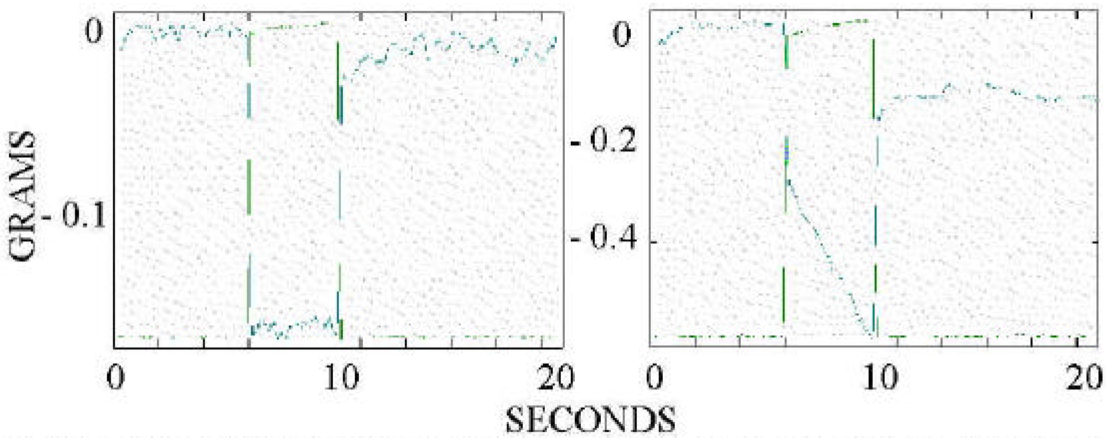

FIGURE 7: Weight shift registered by the U-80 load cell when a 62.3 kHz signal with 74 Watts is switched on.

FIGURE 8: The weight shift recorded when the vibration isolation pads visible in Figure 1 were removed.

Taken together, Figures 5 through 8 suggest that the sought Machian mass fluctuations expected on the basis of the negative mass term in Equations (1) and (2) may well be present. Moreover, since the mass shifts lie in the range of several hundredths to several tenths of a gram for applied powers of tens of Watts in the tens of kHz frequency range, they approach the level of mass shifts expected on the basis of naïve calculations for ideal circumstances. But let me reiterate, these results are *very preliminary*. They have *not* been subjected to the full range of check protocols, described below, that must be satisfied before any observed effect can seriously be claimed to be truly genuine.

SPURIOUS SIGNALS AND CHECK PROTOCOLS:

As in any experiment where relatively small effects are sought, experiments designed to detect mass fluctuations are attended by several sources of potential spurious signals. Before any claimed result can command serious attention, these sources of spurious signals must be identified, carefully investigated, and shown convincingly not to be the source of any signals reported. The potential sources of error in both versions of the experiment reported here are, in general, the same, though the details of their actions may differ from one version to the other. I list them here:

1. **Sonic wind** – PZT stacks, set into rapid vibration, can produce acoustic effects that lead to forces on the stacks that might be mistaken for a mass fluctuation in some circumstances. They are easily dealt with by running the system in a vacuum and by changing the orientation of the components in such a way as to discriminate forces from weight fluctuations.
2. **Coronal discharge –** The amplitude of the voltages in the PZT stacks are several hundred volts during operation, enough to produce coronal discharge effects, especially when the system is run at a case pressure of more than 50 microns. Careful sealing of all high voltage surfaces must be observed to eliminate these effects; and operation of the system in vacua of less than 50 microns is also preferred.
3. **Electromagnetic coupling** – This may either take place between the devices and fixed objects in their environment, leading to spurious forces, or, in the case of the load cell, may directly affect the sensor circuit used in the weight determination. In the former case, care must be taken to minimize fields generated by the power circuit, especially the leads to the PZT stacks. And in the latter case, the sensor and its circuitry must be very carefully shielded from stray electromagnetic fields that might contaminate the signals observed. The cantilever beam/optical detection system is, of course, immune to this problem.

4. **Mechanical vibration** – As already noted, the manufacturer of the U-80 stipulates that the sensitivity of the instrument is susceptible to change in the presence of high frequency vibration. Although it may be unlikely that the U-80 responds to vibrations in the 50 to 100 kHz range, when the system is run in air it is obvious that, at high frequency resonances, power switching transients can excite vibrations of lower frequency (in the high audible range) in the system that might affect the U-80. In the case of the cantilever beam system, high frequency vibration can cause prompt cavitation heating especially of the mounting block and beam, leading to thermal deformation and distension of these parts. While such effects can be discriminated in principle from the effect sought, since they are cumulative as the power is applied and the sought effect is prompt, they can become so large that isolation of any small real effect is seriously complicated.
5. **Thermal effects –** In addition to the thermal problems that result from mechanical vibrations just mentioned, heating of the PZT stack leads to other difficulties. Run in air, thermal expansion of the stack can produce buoyancy shifts in the measured weight of the stack. Moreover, thermal expansion also changes the center of mass of the stacks (and other heated parts), producing apparent weight shifts with the cantilever beam because the torque around the clamp point of the beam changes as the beam/block/stack lengthens. All of these thermal effects display cumulative behavior as heat is evolved during the application of power to the stacks, rather than the prompt weight shift expected with a mass fluctuation when the power is switched on. Nonetheless, together with mechanical vibrations, they are the chief source of spurious signals in these experiments.

Testing for spurious effects can be as simple as applying a little heat to a component with a hair dryer to gauge its effect, or as complicated as major redesign and reconstruction of significant components of the systems. These sorts of tests are a natural part of the evolution of any system of research apparatus. For these experiments, after the systems have evolved to the point of serious, extensive, systematic data acquisition, several standard check protocols can be invoked to insure that any signals seen arise from the effect sought. They are:

1. **Operation in air and in vacuum** – Changing the ambient surroundings allows one to identify sonic wind, corona, and some thermal effects, should they be present. The presence, or absence, of coronal discharges can also be detected by observing the devices with a “night vision” image intensifier while operating the system in total darkness.
2. **Proximity of materials –** In the same vein as 1, by placing slabs of metals and insulators in proximity to the apparatus as it is operated, electromagnetic, and in the case of air operation acoustic, coupling to local objects can be detected.
3. **Dummy loads –** Electromagnetic coupling to local objects can further be explored by replacing the PZT stacks with circuit elements that mimic the electromagnetic behavior of the stacks without driving the electromechanical effects that generate the negative mass effect.
4. **Static fields –** Electromagnetic coupling can be further explored by applying static electric and magnetic fields to the systems to gauge their effects.
5. **Variation of physical parameters –** In addition to tests 1, 2, 3, and 4, the design of the weigh systems and PZT stacks can be varied. Should any effect be found to occur only in one special set of circumstances, at the very least, a compelling explanation for its absence in other circumstances would have to be adduced.
6. **PZT stack orientation –** a particularly important test is varying the physical orientation of the PZT stack on its mounting block. If any effect seen is actually a simple response to vibration, the effect seen should change significantly when the orientation of the stack is altered
7. **Multiple weigh systems –** if an effect is recovered with two (or more) fundamentally different force transducers, one can be reasonably sure that the effect is not some spurious quirk of a particular type of transducer.

Other tests may come to light as this work progresses. Any reasonable (and affordable) test will be done.

CONCLUSION:

Where, beyond further straight-forward confirmation and exploration of the effects reported here, does one go from here? Well, from the point of view of rapid spacetime transport two issues seem to be the most important. First, can the effects reported here be scaled to useful levels? A mass fluctuation of a tenth of a gram or so is only of laboratory interest. It is worth noting that the negative mass term effect, everything else held constant, scales with the square of the frequency and with the square of the power. So, in principle, very large mass fluctuation effects should be producible with only modest power levels. I hasten to add that there are subtleties to the production of this effect that are not yet fully explored. For example, generation of the effect seems to depend quite critically on the production of higher harmonics in the PZT stacks, for sinking a lot of power into a stack at a mechanical resonance of the stack is not, itself, sufficient to yield an effect. The details of the processes that lead to large mass fluctuations need to be studied and *understood* in some detail before serious engineering is undertaken.

Second, from the point of view of propellantless propulsion, the creation of impulse engines requires that objects with induced mass fluctuations be acted upon by another periodic force to extract a stationary force. In the torsion pendulum experiments that preceded those sketched here, Mahood and I were only able to produce minuscule forces many orders of magnitude smaller than those expected on the basis of naï ve calculations. Likely this can in part be attributed to subtleties involving the yet to be explored details of the production of mass fluctuations in real non-linear systems. These details will have to be sorted out before the dream of propellantless propulsion can be fully realized. In this regard I note that it may be worth exploring systems other than simple stacks of PZT crystals driven with complex voltage waveforms (like those already investigated by Mahood and me). For instance, one might expect to see impulse engine effects in the systems used by Corum, *et al*. (1999) where a sinusoidal voltage is applied to a circuit with an inductor and capacitor in series. The inductor is arranged so that the periodic magnetic field it generates permeates the dielectric between the plates of the capacitor, orthogonal to the electric field therein. Taken as a strictly electromagnetic system, the conservation principles mentioned at the outset require that any forces produced in the dielectric be balanced by equal and opposite forces elsewhere in the circuit. So there is no reason to expect to see propulsive forces in this type of system.

But note that if Machian mass fluctuations actually occur, then the acceleration of the charge carriers that comprise the displacement current in the dielectric in the capacitor, driven by the periodic electric field, will induce a mass fluctuation at the power frequency of the voltage frequency – that is, at twice the frequency of the applied voltage signal. Now consider the action of the magnetic field. The motion of the displacement current charge carriers will interact with the period magnetic field to yield a force on the charge carriers via the magnetic part of the Lorentz force: $(q/c)(\boldsymbol{v} \text{ X } \boldsymbol{B})$. Since the velocity of the charge carriers, $\boldsymbol{v}$, and the magnetic field, $\boldsymbol{B}$, are both periodic with a frequency equal to the applied voltage frequency, their cross product will yield a force with twice this frequency -- that is, the frequency of the mass fluctuation putatively being driven by the action of the electric field in the dielectric. Should the relative phase of the mass fluctuation and the magnetic part of the Lorentz force be auspicious, a stationary force should result. But such a force, if present, is a result of the mass fluctuation that arises from the inertial coupling of the constituents of the dielectric to the rest of the universe. It is not due to a local violation of the conservation of momentum in a purely electrodynamical system. It is worth remarking that a stationary force in a system of this sort may be expected even if the “substance” between the plates of the capacitor is the vacuum. If the charged particle pair production in the vacuum of quantum lore actually takes place, the pairs should experience the same effects as material dielectric media. So exploration of this sort of arrangement of circuit elements has scientific value (as a test of the “polarizable vacuum” conjecture), as well as potential technological implications.

Finally, I note that the 0.1 gm mass shift that seems to have taken place in the PZT stack approaches a percent of the total mass of the PZT material, and this with an applied power on the order of 75 Watts. If this effect is real, and should no physical mechanism operate that enjoins true negative total mass states, then it seems that we may be able to actually generate, however fleetingly, truly exotic matter. Should this prove possible, the most extreme sorts of rapid spacetime transport may be feasible. Experiments designed to probe these possibilities, however, should be undertaken with some care.

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