In a November 2001 publication by the Power Electronics and Electric Machinery division of Oak Ridge National Laboratory (ORNL) titled "Transportation for the 21st Century", sub-titled a "Success Story", un-named Oak Ridge Scientists (ORS) reported that work done by J.F. Woodward in the field of propulsion physics contained fundamental errors. Notwithstanding that Woodward's work had been published in refereed literature, the ORS claimed that they had shown it worthless and wrong. The claims made in the ORNL document by the ORS, however, were based on bad physics and faulty analysis. Since it is always important to keep bad physics from spreading, the central claim of the ORS is explained here, and then that claim is demonstrated *as a matter of observed fact* to be wrong.

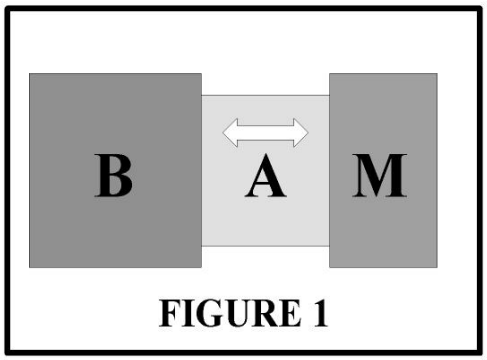

FIGURE 1

Consider a simple system composed of a massive block B and another mass M connected by an actuator A that causes the distance between B and M to vary when a varying voltage is applied to it, as in Figure 1. In the BAM system, B is taken to be sufficiently large that it can be regarded as at rest in an inertial frame of reference as A is activated to produce a sinusoidal excursion of M. If the mass of M can be made to vary synchronously with the excursion induced by A, then a net, time-averaged force can be brought to bear on B. For, if the mass of M is less than its mean value as A draws it toward B, and greater than its mean value as A drives it away from B, then the inertial reaction forces arising from the acceleration of M communicated through A to B in these two situations are not equal and opposite.

Woodward has proposed that the mass fluctuations needed to make a scheme of this sort work might arise from an effect based on Mach's principle that is surprisingly large. However, it is important to note that a scheme of this sort, in principle, will work even should that Machian effect prove to be non-existent – a matter still under active study. For example, mass fluctuations of the sort needed might be induced simply by charging and discharging a capacitor (since $m = E/c^2$), albeit that any propulsion produced in this way would likely turn out to be utterly minuscule. Moreover, momentum conservation dictates that an isolated system containing a thrust-generating device of the $m = E/c^2$ sort would not, as a whole, accelerate. The Machian effect being explored differs from such conventional systems in that it makes the distant matter in the universe part of any "isolated" system via direct coupling through the gravitational/inertial field, so local accelerations of devices based on the effect relative thereto are not precluded in principle. (No extraction of momentum "from the vacuum from an alleged application of Mach's principle" as claimed by the ORS is involved here.)

The ORS' argument is that proper account of Newton's second law of motion was not taken in the above analysis of the motion of M and the reaction forces on B in the BAM system. As is universally known, that law says:

$$\boldsymbol{F} = \mathrm{d}\boldsymbol{p}/\mathrm{d}t = m\mathrm{d}\boldsymbol{v}/\mathrm{d}t + \boldsymbol{v}\mathrm{d}m/\mathrm{d}t = m\boldsymbol{a} + \boldsymbol{v}\mathrm{d}m/\mathrm{d}t,$$

where the symbols have their customary meanings. The ORS claim that by ignoring the $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ term in the foregoing equation when assessing the reaction force that acts on B, physics that leads to the cancellation of the time-averaged force on B has been omitted. That is, as put in the ORNL "success story", "ORNL found that Woodward's theory . . . produced a non-zero force only because variation of the mass was not considered in the averaging process." Were the ORS correct in insisting that the $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ term, where $\boldsymbol{v}$ is the velocity of M relative to B, must be included in the equation of motion for M when assessing the reaction force on B, then the cancellation they assert occurs would indeed take place and there would be no net, time-averaged force on B.

But the ORS are wrong. Inclusion of the $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ term in the equation of motion of M in the rest frame of B when calculating the force on B communicated through A is simply incorrect. This is not to say that including a $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ term in the equation of motion for M is inappropriate in all circumstances. For example, if the mass fluctuation in M is achieved by the expulsion and recovery of some mass, that acts as a propellant, in the direction of the motion produced by A, then a force arising from $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ would be communicated from M to B through A. *But* $\boldsymbol{v}$ *in this case would be the invariant velocity of the propellant plume with respect to* M*, not the velocity of* M *relative to* B.

Pedagogically, the fact that the $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ term in Newton's second law must be treated with some care is often made in simple problem situations. For example, one such problem asks: Does a flatcar rolling down a smooth level track at constant velocity accelerate if a pile of sand it carries is allowed to fall through a hole in the floor of the car onto the track? The obvious answer, of course, is no. The present case, where an external force acts on an object with a changing mass, in the context of this example, leads to the question: If an external force is applied to the flatcar as the sand falls through the hole, aside from the fact that m in $m\boldsymbol{a}$ must be treated as a function of time, does the falling sand affect the acceleration of the car produced by external force? Woodward says no. The ORS, to be consistent with their $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ based cancellation claim, must say yes.

Simple, compelling arguments for the absence of $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ effects in the circumstances under consideration can easily be made. For instance, should one use the (inertial) instantaneous rest frame of M as that in which the force on B is computed, the $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ term vanishes. Plainly, if the $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ "force" vanishes in this inertial frame, it cannot act on B in any other inertial frame, for real forces that produce accelerations are invariant under the Galilean transformation group. That is, they cannot be made to vanish by simple choice of inertial frame of reference. Several years ago Woodward advanced such arguments to the ORS (and others). Those arguments, obviously, at least at ORNL, fell on deaf ears. Nowadays, difficult arguments usually involve subtle interpretations of theory that involve very small effects. The ORS' claim, however, is so egregiously wrong that it can be demonstrated factually false by a simple experiment employing slightly modified Physics 100 level laboratory apparatus. The proposition to be tested is: If a Pasco dynamics demonstration cart, fitted with a one liter water bottle that discharges its contents through two opposed nozzles (in a little more than two seconds), is accelerated by an external force, does the equation of motion (in the lab frame) of the cart include the $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ term that arises from its velocity and changing mass? That is, is the correct equation of motion of the cart $\boldsymbol{F} = m(t)\mathrm{d}\boldsymbol{v}/\mathrm{d}t + \boldsymbol{v}\mathrm{d}m/\mathrm{d}t$? Or is it $\boldsymbol{F} = m(t)\mathrm{d}\boldsymbol{v}/\mathrm{d}t$? The ORS, to be consistent with their cancellation claim, must say the former. Woodward says the latter.

FIGURE 2

The modified cart used in this test is shown in Figure 2. Its mass is 2.1 kg. loaded, and 1.1 kg with the bottle empty. A guillotine valve at the base of the one liter bottle is opened at the instant that the cart is released on the 2.2 meter long Pasco test track, whereon it is accelerated by a falling mass of 0.16 kg. attached to the cart with string via pulleys. Those party to earlier discussions of this issue will likely recognize the test cart in Figure 2, shown in operation in Figure 3, as the "southern California booster" invoked in a then thought experiment where Woodward tried to convince the ORS that their argument was specious.

One might think that definitive results might be unobtainable with such elementary, not to say crude, apparatus. That turns out not to be the case. For example, the mass flow from the nozzles as a function of time can be determined by videotaping several "static firings" of the "booster". That tape can then be digitally captured (at 15 fps in fact) and analyzed frame-by-frame to get $m(t)$ and thus $\mathrm{d}m/\mathrm{d}t$. Dissipative forces in the system, lack of perfect level of the test track, and other things that might affect the motion of the cart that are independent of any $\boldsymbol{v}\mathrm{d}m/\mathrm{d}t$ behavior can be modeled by doing cart accelerations with fixed masses of several values (that is, various fill levels of the "propellant" bottle). These can be used to compute "effective" values for $\boldsymbol{g}$ (in $\boldsymbol{F} = M\boldsymbol{g}$ for the external force, where M is the 0.16 kg. mass of the counter-weight) as a function of the mass and velocity of the cart. The resulting equation of motion,

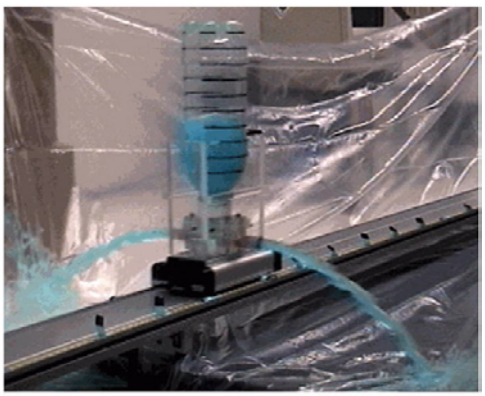

FIGURE 3

$$\boldsymbol{F} = M\boldsymbol{g} = m(t)\mathrm{d}\boldsymbol{v}/\mathrm{d}t + \boldsymbol{v}\mathrm{d}m/\mathrm{d}t,$$

where $\boldsymbol{g}(m, \boldsymbol{v})$, $m(t)$, and $\mathrm{d}m/\mathrm{d}t$ are obtained from observations in the absence of any disputed effect, can be numerically integrated by solving for $\mathrm{d}\boldsymbol{v}$ and then computing $\mathrm{d}\boldsymbol{v}$ for each successive time step

d*t*, updating the position and velocity for the change in ***v*** in each step.

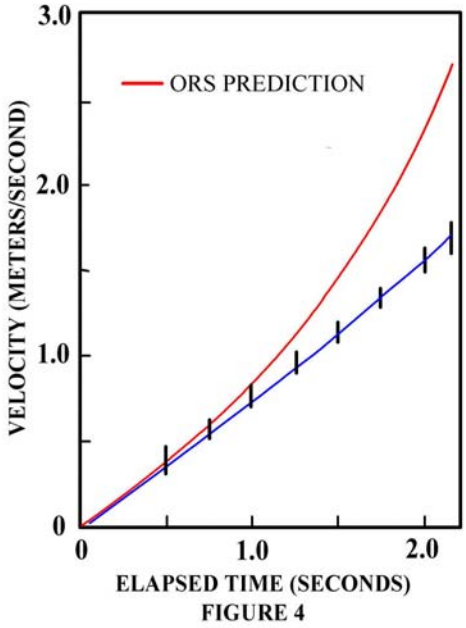

FIGURE 4

The results of the tests of this system for twenty runs of the cart are shown in Figure 4, where the ORS' prediction for the velocity of the cart as a function of time is shown in red, and the prediction for ***v***d*m*/d*t* not contributing to the equation of motion of the cart is shown in blue. *Reality is represented by the black data error bars. The obvious need not be belabored. The ORS' claim is wrong.*

The other ORS' claims mentioned in the ORNL document of a year ago, for similarly elementary reasons, are also false. For the most part, those claims arise from the mistaken belief on the part of the ORS that the static force of local gravity is 27 orders of magnitude larger than the forces involved in the Machian effect sought in the laboratory. This led the ORS to introduce a term into the field equation derived by Woodward to account for the effect of gravity that Woodward had allegedly ignored. When the new term was introduced into the field equation, the ORS found that it led to the cancellation of the time-dependent Machian effects derived by Woodward. The astute reader, reflecting on this supposed fortuitous cancellation, may already detect the pungent odor of fish. That an added term for a *static* effect 27 orders of magnitude larger should *exactly* cancel the allegedly minuscule *time-dependent* Machian terms sounds, on its face, pretty ludicrous. In fact, when all transient effects are set equal to zero, Woodward's field equation gives Newton's law of gravitation (in the form of a Poisson equation), so local gravity is already accounted for in that field equation. Therefore, the ORS' modification of Woodward's equation, together with an elementary sign error, which has the effect of subtracting gravity from gravity, thus leading to the cancellation of the Machian terms, is unwarranted in the first place. Accordingly, the ORS' claims in this connection are seen to be patently erroneous. More important, though, is the fact that observable Machian effects only occur when transient (or periodic) forces of several hundred ***g***s or more are applied to test materials, circumstances in which ignoring static local gravity is obviously reasonable in any event.

Finally, the ORS could not resist asserting that they had found a simple conventional explanation for the experimental results obtained by Woodward and his then graduate student Thomas Mahood in 1999 and early 2000. Allegedly, a simple thermal effect (identified in the ORNL piece as "an alternate interpretation involving only classical mechanics") could account for them. This claim is factually wrong. No thermal effects large enough to account for the observations in question were observed to be present. And thermal observations were actually carried out. That this claim is repeated in the ORNL "Success Story" is especially troubling, for Mahood explained to the ORS in detail that this claim was factually wrong in the spring of 2000. Indeed, the only counter-argument mentioned here unknown to the ORS by the spring of 2000 is the results of the Physics 100 level experiment reported above. That experiment was only carried out recently, and its results give the lie to the ORS claims. Those interested in "revolutionary" propulsion physics would be ill advised to give any credence whatsoever to the ORS claims related thereto. As shown here, they rest on bad physics and faulty analysis.

Jeffrey Cady helped with the execution of the experiment described herein. April Bullock and Craig McConnell helped gather some of the data; and Paul March, Thomas Mahood and Harold White, Jr. read earlier drafts of this piece and made helpful suggestions for its improvement.