Overview of Theories and Experiments on Electromagnetic Inertia Manipulation Propulsion

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Abstract. Experiments performed by independent research teams, suggesting that "propellantless" propulsion without external assistance is being achieved by means of electromagnetic inertia manipulation, are discussed here and compared within the framework of competing theoretical formulations. The authors' theory relies upon the fact that the electromagnetic (EM) field can exhibit a whole non-vanishing momentum in the "matter" frame, even for stationary regimes, provided Minkowski's energy-momentum tensor holds for EM fields in matter. In a closed system this EM momentum can be converted into mechanical momentum, so that electromagnetic inertia intervenes to modify the inertial properties of the generating device. Another theory, set forth by Corum and based on Slepian's works, states that the inertia manipulation effect stems from the Heaviside force density in vacuum, which is shown to lead to a zero instantaneous volume integrated force on a closed system. Although the system momentum is not conserved in the reported experiments, the propulsion effect is shown to be consistent with an alternative formulation of Minkowski's EM force density that correctly predicts former peer-reviewed experimental results. A fourth theory by J. Woodward, based on "Machian" mass/inertia fluctuations due to transient mass modifications, purportedly predicts the observed results but flaws are found in the predictions which, when corrected, considerably disagree with the experimental data. Finally, recent developments in vacuum physics allows building a conceptual framework with the potential of resolving the apparent violation of momentum conservation, closely connected to Minkowski's energy momentum tensor and its lack of symmetry.

INTRODUCTION

Either to go to the stars or, more pragmatically, to substantially cut down space transportation costs, new propulsion mechanisms must be found which get rid of propellants and/or conventional external assistance, i.e., the mythical "space drive" must still be invented. However, jetless-sailless-beamless-tetherless propulsion can theoretically be achieved by manipulating the spaceship inertia in a way analogous to a dancer who increases her angular velocity by manipulating her body's moment of inertia. The analogy goes this way: By considering space-time instead of 3-space, the spaceship 4-velocity (angular velocity analog) can be changed by manipulating its mass tensor components (moment of inertia tensor analog). To do that, an "extended" spaceship including the fields it eventually generates must be considered; a thrust then appears on the "material" spaceship by means of momentum exchange with its "field" counterpart. It follows from this picture that the 4-Momentum of the system should be conserved. The whole concept is embodied in the Covariant Propulsion Principle (CPP) which is derived from a relativistic covariant mass tensor description of the closed system consisting of the rocket driven spaceship and its propellant mass, provided the "solidification" point is other than the system center of mass (Brito, 1998).

When the EM field is chosen as the "field" counterpart, one may wonder if a static EM momentum can develop in the rest frame of the "material" spaceship. Different theoretical results are possible depending whether Planck's principle of inertia of the energy is satisfied or not between the Poynting vector (energy flow density) and the EM momentum density (Brevik, 1979). The results are basically Abraham's and Minkowski's forms of the EM

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momentum density, three dimensional expressions of the so called “Abraham-Minkowski controversy” about the correct Energy-Momentum tensor of EM fields in polarizable media. The controversy, lasting since 1909, remains as a yet unsolved issue of Physics (Obukhov and Hehl, 2003), with existing experimental evidence not allowing yet to draw definite conclusions (James, 1968; Walker, Lahoz and Walker, 1975; Walker and Walker, 1977; Lahoz and Graham, 1979). If Minkowski’s Energy-Momentum Tensor happens to be the right descriptor of the electromagnetic field-matter interaction in polarizable media, the inertial properties of the generating device can then be modified, allowing to obtain mechanical impulses on the device as part of a closed system, not undergoing any exchange of mass-energy with the surrounding medium (Brito, 1999).

Nevertheless, studies about inertia manipulation by means of electromagnetic fields for propulsion purposes are not new, an earlier precursor can be found back in the forties with Slepian’s “electromagnetic space drive” (Slepian, 1949), then in the sixties when inertia changes based on the relativistic mechanics of extended bodies under electrostatic pressures were under investigation (Marchal, 1969), until recently with electromagnetically induced mass/inertia reductions based on unbalanced self-interaction having been proposed (Petkov, 1999), together with thrusting by manipulating the electromagnetic component of a system inertia (Brito, 1999, 2001; Corum *et al.*, 2001; Woodward and Mahood, 1999). On this last regard, experimental results have been reported by independent research teams, suggesting that “propellantless” propulsion without external assistance – i.e. solar radiation, beamed power, gravity field – is being achieved. The objectives of the paper are to review these apparently diverse theories and experiments and to show that they share a common theoretical background when analysed from the CPP viewpoint, combined with the EM whole momentum concept, while the reported experimental data will be discussed and compared with predictions from the competing theoretical interpretations.

ELECTROMAGNETIC INERTIA MANIPULATION CONCEPTS

A non-exhaustive review of several electromagnetic devices was pursued that can be viewed as producing inertia modifications of the related material system. Within the scope of this work, the list is restricted to those concepts having been proposed and described in peer-reviewed literature, being functionally able to generate “force-producing” effects, as required for propulsion purposes. They are: Brito’s EMIM Thruster, Corum-Slepian’s EM Drive, and Woodward’s Mach-Slepian Device.

Brito’s Thruster

By Minkowski’s formalism (Brevik, 1979), a non-vanishing momentum of electromagnetic origin is shown to arise for the particular device depicted in Fig. 1. It is always possible to represent the Electromagnetic Momentum Generator (EMMG) as a single particle located at the “matter” system center of mass (or any “structural” point). When the ON condition is set, the whole system must include the EM fields being created under such a condition, so that a mass tensor is readily found as related to the whole system (Brito, 1998), given by

$$\mathbf{M} = \left(\mathrm{m}_0 + \mathrm{m}^*_{\mathrm{EM}}\right)\mathbf{I} + \left(\mathbf{p}_{\mathrm{EM}} \wedge \mathbf{v}\right) / \mathrm{c}_0^2 \; . \tag{1}$$

Since, by assuming a closed system, the 4-momentum must be conserved, the thrust in 3-space becomes

$$\boldsymbol{T} = -\frac{d\,\boldsymbol{p}_{\mathrm{EM}}}{d\,t} \; . \tag{2}$$

The change of the mechanical momentum exactly balances the change of the EM field momentum; momentum is then being exchanged within the whole closed system. The device works as an EM field momentum “accumulator” whereas the mechanical momentum that can be drawn from is, for a closed system, limited to the EM field momentum amount. It follows that the EM field can modify the inertial properties of the generating device, their variation producing forces on the device without any exchange of mass-energy with the surrounding medium.

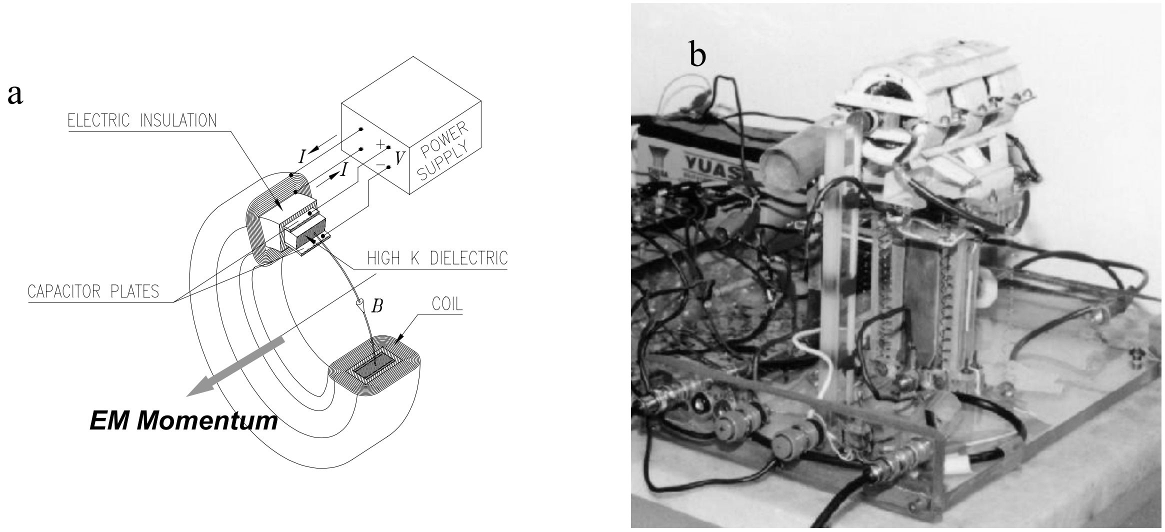

FIGURE 1. (a**)** Electromagnetic Momentum Generator Scheme. (b) Electromagnetic Inertia Manipulation Thruster.

A thruster was engineered up to the "proof of concept" level and experiments were performed yielding by spectral analysis techniques, in an exploratory phase, indirect evidence of Minkowski's approach being valid (Brito, 1999). Slightly modified experiments yielded direct evidence of sustained thrust being produced, as observed in frequency domain plots (Brito, 2001, 2004), and recently in time domain plots (Brito and Elaskar, 2003). These experiments addressed the "rectified" or "sustained" thrust issue, which according to the "closed system" assumption should have been exactly zero. Nevertheless, a conjectural approach based on the mass tensor concept suggests that the "accumulator" limitation can be circumvented by assuming that translational motion in gravity-free regions is not affected by tensor mass rotations. Therefore Eq. (2) is no longer valid when the EM momentum changes derive from rotations in 3-space of the EM momentum carriers. The equation of motion is modified as follows

$$\mathrm{d}\left(\mathbf{M}\cdot\mathbf{v}\right)=\mathrm{d}^{\mathrm{R}}\mathbf{M}\cdot\mathbf{v} \quad , \tag{3}$$

where $\mathrm{d}^{\mathrm{R}}\mathbf{M}$ represents the tensor mass variation due to rotations in 3-space of the EM momentum carriers. The thrust definition in 3-space is accordingly modified as

$$\boldsymbol{T} \;=\; -\;\frac{d^{**}\boldsymbol{p}_{\mathrm{EM}}}{d\,t} \quad . \tag{4}$$

Thrust is, according to the conjecture, related to the variation of the EM momentum, as measured in the generating device comoving frame. By Eqs. (3) the system 4-momentum is no longer conserved and to preserve the law of 4-momentum conservation, one must admit that the system cannot be considered a closed one, in which case it can bear a non-symmetric energy-momentum tensor, as when Minkowski's represent the field contribution. Feigel (2004) provides some hint of where to look for the extended system from which 4-momentum could be drawn. Crossed EM fields are predicted to create vacuum fluctuations anisotropies that translates into a non-zero vacuum field momentum, closely matching Minkowski's. Interestingly, the thrust calculated using Eq. (4) as applied to the EM momentum carriers in polar dielectrics coincides with that obtained by using a modified EM force density formalism (Brito, 2004). The latter was found to be equivalent either to Minkowski's plus the forces on Roentgen currents, or Abraham's minus the Kelvin forces contribution. The time-averaged thrust is accordingly given by

$$\left\langle T\right\rangle=\frac{\varepsilon_r\omega\;\,nIV\,d}{2c_0^2}\;\sin\varphi\;\cdot \tag{5}$$

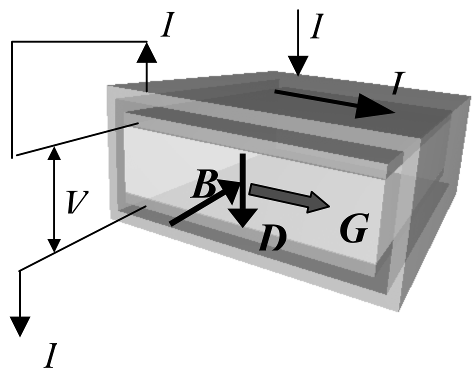

FIGURE 2. Slepian Concept Schematics.

Corum – Slepian's EM Drive

Corum's works are based on Slepian's EM space-drive which consists of a solenoid and a parallel-plate capacitor electrically wired in series and driven by an RF source, as shown in Figure 2 (Slepian, 1949). According to Corum, in this arrangement Heaviside force densities acting even on empty space will develop on the space between the plates as given by the following equation .

$$\boldsymbol{f}^{H} = \frac{\partial}{\partial t}\left(\boldsymbol{D}\times\boldsymbol{B}\right) \quad . \tag{6}$$

Slepian concludes that since the momentum density $\boldsymbol{D}\times\boldsymbol{B}$ in the space between the plates is caused to vary at a rapid rate, by the law of conservation of momentum there will be an equally large but opposite rate of change in the momentum of the material system. This will correspond to an unbalanced instant-by-instant force on the material system whose magnitude will equal $-\boldsymbol{f}^{H}$ of Eq. (6), which is conceptually and formally identical to what is expressed in Eq. (2). This comes indeed from the same form of the EM momentum density, which happens to be Minkowski's. However, in this configuration of charges and currents, the force is sinusoidal with zero time average value, being a different wording for what is considered the "accumulator" problem in the preceding section.

Corum's contributions deal with both, the possibility of achieving instant-by-instant thrust even when the space between the capacitor plates is matter-free (vacuum) and the possibility of circumventing the resulting zero time average by proposing a force "rectification" procedure. He assumes that by means of a temporally discontinuous (nonstationary) physical action such as modulating the boundary conditions, then the average of the integrated force will no longer vanish, and the "desired" Space-Drive can upgrade to "possible".

The first possibility is completely ruled out for closed systems since it has been shown that the volume integrated effect is identically equal to zero (Furry, 1969). Therefore, the second possibility becomes meaningless, unless polarized matter is present, in which case modulating the boundary conditions of the dielectric domain does not help too much since other momentum distributions must be taken into account (Misner, Thorne and Wheeler, 1973).

Woodward's Mach - Slepian Device

Rapid fluctuations of the electrostatic energy stored in capacitors as excited by an alternating voltage, produce, according to Woodward, periodic proper mass fluctuations δm_o that can be used to generate "rectified" thrusts (Woodward, 1999). In Woodward's words "To generate such forces one acts on the capacitors with a second periodic force that pushes on the capacitors in one direction when δm_o is large, and the opposite direction when δm_o is small or negative.

a b

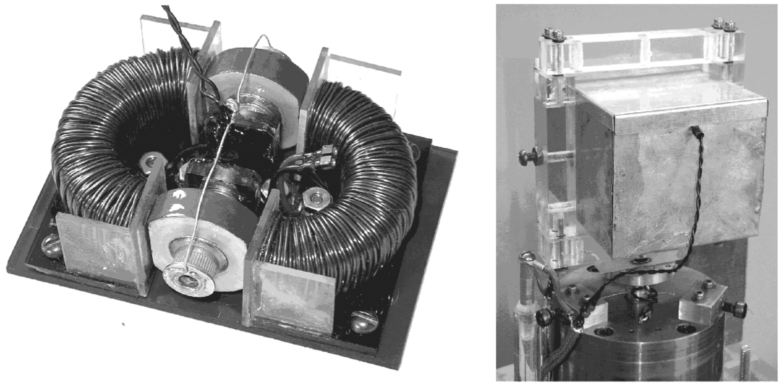

FIGURE 3. (a) Woodward's "Mach 3" Mach-Slepian Device. (b) Mach 3 Mounted in a Faraday Cage [Steel Box], Itself Mounted in a Plastic Frame on the Thrust Sensor. (Courtesy of J. Woodward).

Since the reaction forces during the two phases are not equal, a time-averaged net force on the object results." Formally, the time-averaged force may be stated as:

$$\langle T \rangle \approx -\frac{\omega^3 \delta l_0}{2\pi G \rho_0 c_0^2} P_0 \cos\psi \cdot \qquad (7)$$

In previous works Woodward used as a shuttling method the application of direct mechanical excursions induced by some suitable exterior electromechanical device. In Woodward (2004) he proposed to produce the desired shuttling by the application of a suitable magnetic flux **B** generated by an inductor located close to the capacitor, as in Figure 3. If the capacitor has a simple parallel plate configuration, the induced **B** flux is perpendicular to the **E** field between the plates and the fields have the same frequency and a convenient relative phase, then the magnetic part of the Lorentz force, due to the polarisation current induced by the variation of the **E** field, will generate a stationary force like that described by Eq. (7). According to Woodward, such a stationary force, however, can only arise in this sort of systems without violating 4-momentum conservation if Mach effect mass fluctuations actually take place, physically coupling the system with the chiefly distant matter in the universe. To test the concept, Woodward assembled the device shown in Fig. 3, basically a Corum-Slepian device he renamed Mach-Slepian. Although geometrically different from the Electromagnetic Momentum Generator (Fig. 1), the Mach-Slepian device shares a common concept for the creation of "crossed" electric and magnetic fields domains.

DISCUSSION OF EXPERIMENTAL vs. PREDICTED RESULTS

Experimental results have been reported in peer-reviewed literature for Brito's and Woodward's devices. The authors are not aware of publications regarding Corum's experimental data.

Brito's EMIM Thruster

The experimental setup basically consists of mounting the device as a seismic mass atop a thin vertical cantilever beam (a resonant blade), sitting on a vibration-free platform. Piezoceramic strain transducers are used to detect the seismic mass displacements through output voltages proportional to the strain level in a broad dynamic range, achieving very high sensitivities. A common supply of 200 V - AC @ 39 kHz, to three 900 turns parallel mounted toroidal coils in series with three parallel mounted 10 nF - 8 mm wide annular capacitors, allows for a total Minkowski's EM momentum around 10^{-10} Ns (peak), by using $BaTiO_3$ ceramic dielectrics ($\varepsilon_r \approx 4400$).

An average thrust of 13 μN should be obtained according to Eq. (5). Using sine modulation of the supply ("carrier") voltage yields, when Eq. (5) is applied, a modulated average thrust, at the modulation and twice the modulation frequencies, with amplitudes 1/2 and 1/8, respectively, of the non-modulated average thrust. The hardware was configured for full "closed system" mode of operation. Both the EMMG and its Power Processing Unit (PPU) were located and rigidly assembled atop the resonant blade of the sensing fixture which presented a fondamental vibration mode @ 1Hz. A modulation frequency of 1 Hz was then selected to take advantage of the mechanical amplification factor at resonance.

Tests were performed with the setup at various azimuth angles, so that the influence of the geomagnetic field be complete and quantitatively assessed. In order to investigate other spurious influences, these tests were repeated with the PPU operating at nominal conditions, by powering an EMMG electrical emulator instead of the thruster itself, and reverting the PPU orientation with respect to the EMMG. Following test data processing, a 0.39 ±0.02 V residual value was found, depending only on the power delivered by the PPU, which was kept fixed at 200 V on the EMMG's capacitors and coils. The claim is that this result corresponds to a genuine electromagnetic inertia manipulation propulsive effect. Thrust stand simulations according to a model presented elsewhere (Brito *et al.*, 2000) yield a sensing device mean response amplitude of 0.38 V, including micro-seismic excitation accounting for ±0.01 V peak values within 1σ dispersion.

Woodward's Mach - Slepian Device

The device is made with two modified 5.5 nF high voltage capacitors mounted between two halves of a powdered iron toroidal inductor core each wound with several hundred turns of bifilar copper magnet wire. All parts are firmly affixed to a plastic plate and the device is mounted in a Faraday cage with bolts that screw into the outer lugs on the capacitors. The predicted thrust is a maximum when δm_o is in phase with δl, thus in opposition of the shuttling force phase which depends upon the **B** flux in both the inductor and capacitor cores, and the polarisation current in the capacitors. Since δm_o is also in phase with the absolute value of the voltage, in order that the acceleration peaks when the voltage peaks, the **B** flux must peak when the polarisation current in the dielectric peaks. This means that the voltage in the capacitor circuit and the current in the inductor circuit, when stabilized, must have a relative phase of either 90 or 270 degrees for a maximum thrust to be obtained. At 0 and 180 degrees of relative phase, no effect is expected for the mass fluctuations to occur when the B field does not act on the ions in the dielectric.

Capacitors and inductors were independently AC driven @ 50 kHz, yielding about 1 kV peak on each of the capacitors and four amperes peak in the inductor windings. Processed experimental data show that there is little or no thrust present in either the 0 or 180 degree phase settings – as expected. This is not true for the 90 and 270 degree data. A thrust of 200 to 300 μN is present in both cases, and the direction of the thrust changes between 90 and 270 degrees of phase – exactly as one would expect of a Mach effect thrust, although Eq.(5) predicts the same effect, too. Woodward predicts an average thrust of 200 μN, using a dubious mass ratio ($\delta m_o/m_o$) approach instead of Eq. (7). Moreover, miscalculations were found that, when corrected, yield an average thrust of 50 μN. Precautions were taken to avoid spurious signals**,** as consequence of switching on the capacitors or due to leakage fields not fully trapped by the Faraday cage. The fact that practically no thrust is present at 0 and 180 degrees speaks against the first possibility while the absence of any effects when only one of the two power circuits is activated rules out the second one.

Experimental and Predicted Results

By applying Eqs. (5) and (7) to the available configurational and operating data, theoretical estimations of the thrust, according to the two competing formulations presented in this work can be achieved. The latter requires δl_0 to be estimated; "static" excursions of the the dielectric mass due to the shuttling magnetic forces were calculated by means of COSMOS®, a structural mechanics finite elements code. When compared with the corresponding "free-body" excursions at the reported driving frequencies, they were found to be considerably higher, so the vibration was assumed inertia dominated. The obtained results are shown in Table 1 together with the experimental values.

TABLE 1. Comparison Between Theoretical Estimations and Experimental Thrust Values.

DEVICE	THRUST [μN]		
	MINKOWSKI "MODIFIED"	TRANSIENT MASS FLUCTUATION	EXPERIMENTAL
EMIM THRUSTER	13	0.072	13
MACH-SLEPIAN	240	65.6	200 - 300

CONCLUSION

Electromagnetic inertia manipulation mechanisms have already been tested by independent research teams with evidence of sustained thrust being produced, although for a closed system the ultimate achievable mechanical momentum in a given reference frame cannot be higher than the maximum EM field momentum in the same frame. This is interpreted in terms of diverse theoretical supports having reasonable good predictive capabilities. Both of them rely on the physical reality of an extended system from which momentum can be drawn: the vacuum field as the former, the distant matter in the universe as the latter. A comparative analysis of the competing theories seems to favor the electromagnetic momentum based formulation *vis a vis* the Machian one, although more experimental data is indeed needed to conclusively settle the question.

NOMENCLATURE

ε_r = relative permittivity of the medium
δl_0 = amplitude of excursion (m)
φ = relative phase angle of current and voltage (radian)
ψ = relative phase angle of δl_0 and δm_0 (radian)
ω = angular frequency (radian/s)
$\boldsymbol{B}$ = Magnetic induction vector (T)
c_0 = velocity of light in vacuum (m/s)
$\boldsymbol{D}$ = Electric displacement vector (C/m^2)
d = width of the annular capacitor (m)
$\boldsymbol{E}$ = electric field (N/C)
$\boldsymbol{f}^H$ = Heaviside electromagnetic force density (N/m^3)
G = gravitational constant (N m^2/kg^2)
$\boldsymbol{G}$ = electromagnetic momentum density (N s/ m^3)
I = electric current (A)
$\mathbf{I}$ = 4-space metric tensor
$\mathbf{M}$ = 4-space mass tensor, kg
m^*_{EM} = mass of the electromagnetic field in the "matter" rest frame (kg)
m_0 = spaceship rest mass (kg)
N = number of turns of the toroidal coil
$\mathbf{p}_{EM}$ = 4-momentum of the electromagnetic field (kg · m/s)
P_0 = amplitude of capacitor proper power (w)
t = time (s)
$\boldsymbol{T}$ = Thrust (N)
$\mathbf{v}$ = 4-velocity (m/s)
V = voltage (V)
d^{**}/dt = derivation w.r.t. time in the instantaneous rotating frame of the system
$\wedge$ = symbol of wedge product between two 4-vectors

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