Engineering Dynamics of a Scalar Universe
Part II: Time-Varying Density Model & Propulsion

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Abstract. In this paper, the local fifth force model developed by the author (Robertson, 2009) for a static mass density is extended to time varying mass densities. The time varying mass density model allows for field-force effects due to the time variance of an object's mass density and uses a concept know to electrical engineers as "Time Dilation and Retardation." Time dilation and retardation (TDR) is used to describe the time delay effect on the ambient Chameleon field due to the changing of an object's mass density. From this, hot-gas rocket equations are developed from the integration of the local fifth force and the TDR equations.

The EM Field momentum model previous looked at by the author (Robertson, 2008) and the EMDrive (Shawyer, 2008) are discussed in light of the time-varying density model.

Keywords: Force Models, Propulsion, Time-varying Mass Densities, EM Field Momentum, EMDrive
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INTRODUCTION

The notion that our universe is composed of scalar fields is becoming more of a fact as we learn more about the nature of the universe. The most appealing fact toward this is the discovery that the cosmos is expanding due to vacuum or dark energy, which presents itself as a fifth force of nature. Khoury and Weltman (2004a and 2004b) presented this fifth force as a Chameleon scalar field hiding within known physics and tied to the density of matter threw a thin-shell concept or mechanism.

In a previous paper (Robertson, 2009), the author merged the fifth force search concept, where new forces are compared to gravitational forces, with the Chameleon scalar field model to produce local fifth force models for objects with a static mass density. Those local fifth force models presents an alternate means of acquiring the same force results as attainable from the standard Newtonian force models. [Readers should read the previous paper before reading this paper.]

In this paper, the local fifth force model is extended to time vary mass densities. To accomplish this, a concept known to electrical engineers as Time Dilation and Retardation is introduced. Time dilation and retardation (TDR) is used to describe the time delay effect on the ambient Chameleon field due to a changing mass density. By integrating the local fifth force model with TDR several time vary mass densities, to include hot-gas rocket and electromagnetic (EM) drive equations.

THE TIME VARYING DENSITY MODEL

Masses with varying density are investigated through the concept of time dilation and retardation. Time dilation and retardation is taken into consideration by electrical engineers when there are interfering sinusoidal electric and magnetic field; producing a small retardation of the electron motion. Retardation is a relativity slow phonon mediated process that occurs when electric and magnetic fields are sinusoidal (time-varying) and overlap in a material by an average separation distance s as described by the Lienard-Wiechert potentials. This induces a small reaction time or retardation time $\Delta t = s/c$ between earlier field interactions and corresponds to a phase shift $\omega\Delta t$ and infers a retardation time $t' = t - \Delta t$, which results in unidirectional forces "on the material" in the overlapping fields.

Time Dilation and Retardation Model

Under this model, time dilation and retardation is applied to the particulate matter in an object and specifically only to a small group much less than the total matter in the object and that matter which can be easily modulated without distortion to the peripheral boundary of the object. That is, no visible distortion of the object can be detected.

It is noted that this is different than oscillation of the object in its entirety, which would cause an oscillatory shifting of the thin-shell of the object in the direction of the oscillatory motion, where no net directional force would be achieved.

Under this criteria, retardation would exists between the mass to field coupling factor $\partial\beta_m$ (to be given later) and the object's changing density $\partial\rho_m$, which is given in like to equation (65) in Robertson (2008) as

$$\partial\rho_m \approx \rho_1 + \left|\vec{F}_m / \vec{F}_N\right| \rho_i = 3m/4\pi\partial\overline{R}_m^3 \, , \tag{1}$$

where ρ_i is the density of the particulate matter and $\partial\overline{R}_m$ implies a change to the mass's radial factor $\overline{R}_m$, given from equation (1) as

$$\partial\overline{R}_m = \left(\left(1 + \left|\vec{F}_m / \vec{F}_N\right|\left(m_i/m\right)\right)^{-1}\right)^{1/3} \overline{R}_m \, , \tag{2}$$

where m is the mass of the object and m_i is the total mass of the particulate matter in the mass m. Equation (2) then implies a change in the thin-shell given by

$$\partial\Delta R \approx \left(\overline{R}_m - \partial\overline{R}_m\right). \tag{3}$$

as shown in the time varying density model of Figure 1, which shows a thin slice of a mass with an internal density change $\partial\rho_m$ due to the movement of some of its particulate matter. It is assumed that this matter is oscillatory under an internal force in the direction of the wanted acceleration force $\vec{F}_m$ and an internal relaxation force opposite to the direction of the force $\vec{F}_m$. As shown, the internal oscillatory matter effectively reduces the objects radial factor, while increasing the object's thin-shell thickness by the equivalent amount.

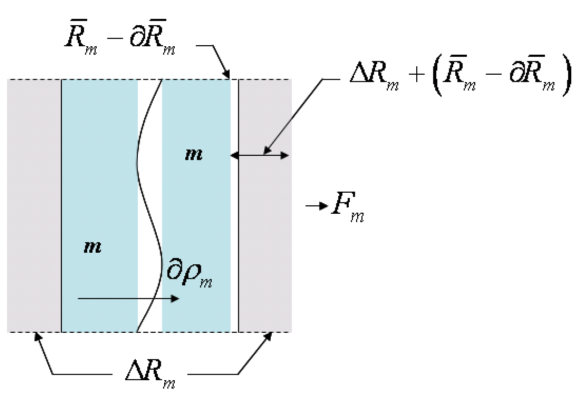

FIGURE 1. Time Varying Density Model

Example 1 – Given a small mass $m \approx 0.020\ kg$ of density $\rho_m \approx 5850\ kg/m^2$, gives a radial factor $\overline{R}_m = 9345.33 \times 10^{-6}\ m$, where the object's weight $\vec{F}_N = mg_N$ is $\approx 0.196\ N$. With a downward field force $\vec{F}_m$ of $\approx 0.035\ N$, the downward acceleratory force $\vec{F} \approx \vec{F}_N + \vec{F}_m$ is $\approx 0.231\ N$ and the object's acceleration $a_m \approx 11.57\ m/s^2$. Now letting the oscillatory particulate matter mass $m_i = 2.75\times10^{-6}\ kg$, where the particulate matter mass density $\rho_i \approx 0.8032\ kg/m^2$, yielding a density change $\partial\rho_m \approx 5850.16\ kg/m^2$ from equation (1) and radial change $\partial\bar{R}_m = 9345.26\times10^{-6}\ m$ from equation (2), which then gives the change in the thin-shell $\partial\Delta R_m \approx 7.62\times10^{-8}\ m$ from equation (3).

Time Dilation

To begin and given an object of mass m , the factor $\partial\Delta R_m/\bar{R}_m$ in the typical field force equation

$$\vec{F}_m \approx \theta_m \vec{F}_N = 6\partial\beta_m \left(\partial\Delta R_m/\bar{R}_m\right)\vec{F}_N \tag{4}$$

is taken to be a function of the number N of perturbations in the distribution of an object with a changing density $\partial\rho_m$ over an effective time t with each perturbation occurring over the object's relaxation time $\tau \approx t/N$ corrected by a "time dilation" $\tau + \Delta\tau$ corresponding to a volume expansion $V_r + \Delta V_r$, which results in a dimensional translation or change $\partial\Delta R_m$ in the object's thin-shell in the direction of any resulting motion. Such that, the field force can be given in terms of a time dilation or perturbation factor by

$$\vec{F}_m \approx \theta_m \vec{F}_N = 6\partial\beta_m \left(\tau/\left(\tau+\Delta\tau\right)\right)\vec{F}_N , \tag{5}$$

where the perturbation factor

$$\tau/\left(\tau+\Delta\tau\right) \approx \partial\Delta R_m/\bar{R}_m << 1 \tag{6}$$

and the sum of the local fifth force coefficients as

$$\theta_m = 6\partial\beta_m \left(\tau/\left(\tau+\Delta\tau\right)\right). \tag{7}$$

Now since the relaxation time $\tau \approx t/N$, the perturbation factor

$$\tau/\left(\tau+\Delta\tau\right) \approx t/\left(t+N\Delta\tau\right) \equiv t/t+\Delta t , \tag{8}$$

where the retardation time $\Delta t \equiv N\Delta\tau$ reflects an interaction with an earlier event and corresponds to a phase shift

$$\Delta\varphi_m \approx \omega\Delta t \tag{9}$$

Example 2 – The electron relaxation time τ can be as fast as $10^{-14}\ s$ in some materials. However, in many conductive metals, the electron relaxation time only ranges in the $10^{-9}\ s$. Then by letting the relaxation time $\tau \approx 0.956\times10^{-9}\ s$, noting that equation (6) can be rewritten as $\Delta\tau \approx \left(\left(\bar{R}_m/\partial\Delta R_m\right)-1\right)\tau$ and using the values for $\bar{R}_m$ and $\partial\Delta R_m$ from **Example 10,** the perturbation time $\Delta\tau$ required to achieve the $\vec{F}_m \approx 35\ mN$ force on the $20\ gram$ object is $\approx 1.17\times10^{-4}\ s$, which implies an angular frequency $\omega = 2\pi/\Delta\tau \approx 53.6\ kHz$ for $N = 1$.

Retardation

Retardation implies that the motion coupling factors are not identical as has been assumed. This is easily seen from equation (5), which yields

$$\partial\beta_m \approx 1/6\left(\left(\tau+\Delta\tau\right)/\tau\right)\left|\vec{F}_m/\vec{F}_N\right| \tag{10}$$

and the equations (51) from Robertson (2009) and (6), which yields

$$\partial\beta_N \approx \left(\left(\tau/\left(\tau+\Delta\tau\right)\right)\sqrt{\bar{R}_m/l_p}\right)^{1/2} \tag{11}$$

and combining them with the form of mass to field coupling factors given by equations (56) and (57) from Robertson (2009), respectfully to yields the motion coupling factors as

$$\partial\hat{\beta}_{C_m} \approx 1/3\left(\partial\beta_m\right)^{-2}\left(M_E^2/\partial\rho_m\partial\bar{R}_m\sqrt{l_p\partial\bar{R}_m}\right)\left(2M_{PL}^4/\rho_0\right)^{1/3}\left(1-\left(\rho_0/\rho_m\right)^{1/3}\right) \tag{12}$$

and

$$\partial\hat{\beta}_{C_N} \approx 1/3\left(\partial\beta_N\right)^{-2}\left(M_E^2 \big/ \rho_N \bar{R}_N \sqrt{l_p \bar{R}_N}\right)\left(2M_{PL}^4/\rho_0\right)^{1/3}\left(1-\left(\rho_0/\rho_N\right)^{1/3}\right) \tag{13}$$

Differences in the motion factors implies that there exists both a retarded mass to field coupling factor $(\beta_m)_R$ and a retarded Newtonian mass to field coupling factor $(\beta_N)_R$, relating a retarded or past density change $(\partial\rho_m)_R$, given by

$$\left(\beta_m\right)_R \approx \partial\beta_m \sin\left(\omega t + \varphi - \Delta\varphi_m\right), \tag{14}$$

$$\left(\beta_N\right)_R \approx \partial\beta_N \sin\left(\omega t - \Delta\varphi_m\right), \tag{15}$$

where ωt is the phase between events and φ is the phase between the changing coupling factor $\partial\beta_m$ and the changing Newtonian mass to field coupling factor $\partial\beta_N$ relating to the non-retarded or current density change $\partial\rho_m$ of the object, given by

$$\left(\beta_m\right)_{NR} \approx \partial\beta_m \sin\left(\omega t + \varphi\right), \tag{16}$$

$$\left(\beta_N\right)_{NR} \approx \partial\beta_N \sin\left(\omega t\right), \tag{17}$$

where the subscript $(_R)$ implies retarded and the subscript $(_{NR})$ implies non-retarded.

Equations (14-17) provide a phasing of the sum of the local fifth force coefficients given with respect to equation (7) as

$$\left(\sum\theta_L\right)_{NR} \approx 6\partial\beta_m\left(t/(t+\Delta t)\right)\sin\left(\omega t+\varphi\right)\sin\left(\omega t\right) \tag{18}$$

and

$$\left(-\sum\theta_L\right)_R \approx -6\partial\beta_m\left(t/(t+\Delta t)\right)\sin\left(\omega t+\varphi-\Delta\varphi_m\right)\sin\left(\omega t-\Delta\varphi_m\right), \tag{19}$$

where the minus sign implies a past event .

Now in order to achieve the correct sum of the local differential fifth force coefficients, equations (18) and (19) must be added and time averaged, such that, the time averaged sum of the local fifth force coefficients is given as

$$\theta_m = \partial\left(\left(\sum\theta_{L_m}\right)_{NR} + \left(-\sum\theta_{L_m}\right)_R\right)\Big/\omega\partial t \approx 6\left(\partial\beta_m/\omega\right)\cdot\partial\left(\left(\frac{t}{t+\Delta t}\right)\begin{pmatrix}\sin\left(\omega t+\varphi-\Delta\varphi_r\right)\sin\left(\omega t\right)\\ -\sin\left(\omega t+\varphi\right)\sin\left(\omega t-\Delta\varphi_r\right)\end{pmatrix}\right)\Big/\partial t, \tag{20}$$

where ω is the frequency between events.

To evaluate equation (20), it is first noted that

$$\left(\sin\left(\omega t+\varphi-\Delta\varphi_r\right)\sin\left(\omega t\right)-\sin\left(\omega t+\varphi\right)\sin\left(\omega t-\Delta\varphi_r\right)\right)=\sin\left(\varphi\right)\sin\left(\Delta\varphi_r\right), \tag{21}$$

which by letting $\Delta\varphi_r << 1$ to give $\sin(\Delta\varphi_r) \approx \Delta\varphi_r$, reduces equation (20) to

$$\theta_m \approx \left(6\partial\beta_m\left(\Delta\varphi_r/\omega\right)\sin\left(\varphi\right)\right)\times\partial\left(t/(t+\Delta t)\right)\big/\partial t. \tag{22}$$

Then noting that

$$\partial\left(t/(t+\Delta t)\right)\big/\partial t = \Delta t\big/\left(t+\Delta t\right)^2 \approx \Delta t^{-1} \tag{23}$$

and that time averaging allows $t \approx 0$, which further reduces equation (22) to

$$\theta_m \approx 6\partial\beta_m\left(\Delta\varphi_r/\omega\Delta t\right)\sin\left(\varphi\right). \tag{24}$$

Now noting equation (9),

$$\theta_m \approx 6\partial\beta_m \sin\left(\varphi\right). \tag{25}$$

Then by equating equation (25) to equation (7) gives the phase φ from

$$\sin\left(\varphi\right) \approx \varphi = \tau/\left(\tau+\Delta\tau\right) << 1; \tag{26}$$

indicating that the phase φ between the changing coupling coefficient $\partial\beta_m$ and the sum of the fifth force coefficients $\theta_m = \sum\theta_{L_m}$ is simply the time-dilution or perturbation factor of equation (6), as one should expect.

Example 3 – It is noted that **Example 2** gives a phase $\varphi \approx 8.16\times10^{-6}$, which satisfies the requirement that the phase $\varphi \ll 1$. And applying this value to equations (10) and (11) yields the mass to field coupling factors

$\partial\beta_m \approx 3.64\times10^3$ and $\partial\beta_N \approx 4.43\times10^5$. Then using the values from **Example 1 & 2** with $\rho_{0_{atm}} = 1.2\ kg/m^3$, and $\rho_{N_{earth}} = 5520\ kg/m^3$, the motion factors are given as $\partial\hat{\beta}_{C_m} \approx 1.21\times10^6$ from equation (11) and $\partial\hat{\beta}_{C_N} \approx 4.89\times10^{-12}$ from equation (11), which differ by approximately a factor of 10^{18}.

THE SOLID ROCKET MOTOR

The time varying mass model can be best illustrated by a solid rocket motor (SRM), where the density varies as the propellant mass is exhausted as hot-gas to produce thrust. Using the concepts derived in the previous paper (Robertson, 2009), a model of the solid rocket motor was developed and a cross section of the solid rocket motor is shown in Figure 2. In this model there are two masses, 1) the changing rocket mass ∂m_r with changing density $\partial\rho_r$ and radial factor $\bar{R}_r$ and 2) the exhaust hot gas mass m_{gas} with density ρ_{gas} - generally in the nozzle - with radial factor $\bar{R}_{gas}$.

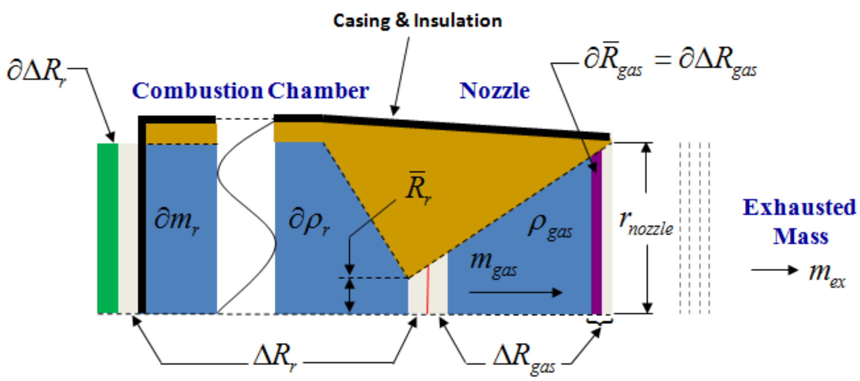

Figure 2. Solid Rocket – Local Fifth Force Model

The dash lines outward from the nozzle indicate a small perturbation in the ambient field density caused by the exhausted mass m_{ex}, which is assumed small and is neglected in this analysis. Further, the changes to the thin-shells of the two masses are only shown in Figure 2 in the plane of motion as the radial changes counter one another and therefore do not add to the propulsive forces. As will be discussed, the SRM model of Figure 2 shares properties of both the mass collision model, where the change in the gas radial factor $\partial\bar{R}_{gas} = \partial\Delta R_{gas}$, and the time vary density model, which involves a phase φ between the coupling factors. However since, the phase φ was shown to be equivalent to the ratio of the thin-shell thickness change $\partial\Delta R_m$ to the object's radial factor $\bar{R}_m$, no sin-functions are required in the determination of the SRM's fifth force coefficients.

Therefore for the SRM model of Figure 2, the fifth force coefficients in the plane of motion are given by

$$\partial\theta_r \approx 6\partial\beta_r\left(\partial\Delta R_r/\bar{R}_r\right) \approx 6\partial\beta_r\left(\partial\beta_{gas} - \partial\beta_{N_r}\right)^2\sqrt{l_p/\bar{R}_r} \quad (27)$$

forward of the changing rocket mass ∂m_r and

$$\partial\theta_{gas} \approx -6\partial\beta_{gas}\left(\partial\Delta R_{gas}/\bar{R}_{gas}\right) \approx -6\partial\beta_{gas}\left(\partial\beta_r - \partial\beta_{N_{gas}}\right)^2\sqrt{l_p/\bar{R}_{gas}} \quad (28)$$

aft of the hot gas mass m_{gas} associated with the nozzle.

The sum of the fifth force coefficients can now be given as

$$\sum\theta_L = \partial\theta_r + \partial\theta_{gas} = 6\partial\beta_r\left(\partial\Delta R_r/\bar{R}_r\right) - 6\partial\beta_{gas}\left(\partial\Delta R_{gas}/\bar{R}_{gas}\right)$$

or

$$\sum \theta_L \approx 6\partial\beta_r \left(\partial\beta_{gas} - \partial\beta_{N_r}\right)^2 \sqrt{l_p / \bar{R}_r} - 6\partial\beta_{gas} \left(\partial\beta_r - \partial\beta_{N_{gas}}\right)^2 \sqrt{l_p / \bar{R}_{gas}} \tag{29}$$

The Newtonian coupling factor for the SRM is given as

$$\partial\beta_{N_r} \approx \left(1/3 \left(M_E^2 \big/ \partial\hat{\beta}_{C_r} \rho_N \bar{R}_N \sqrt{l_p \bar{R}_N}\right) \left(2M_{PL}^4 / \rho_0\right)^{1/3} \left(1 - \left(\rho_0 / \rho_N\right)^{1/3}\right)\right)^{1/2} \tag{30}$$

and by placing the effects of the exhausted mass on the hot gas motion factor $\partial\beta_{C_{gas}}$, the Newtonian coupling factor for the hot gas is given by

$$\partial\beta_{N_{gas}} \approx \left(1/3 \left(M_E^2 \big/ \partial\hat{\beta}_{C_{gas}} \rho_N \bar{R}_N \sqrt{l_p \bar{R}_N}\right) \left(2M_{PL}^4 / \rho_0\right)^{1/3} \left(1 - \left(\rho_0 / \rho_N\right)^{1/3}\right)\right)^{1/2}, \tag{31}$$

which only differ by the motion coupling factors $\partial\hat{\beta}_{C_r}$ and $\partial\hat{\beta}_{C_{gas}}$.

Time Dilation and Retardation

The hot gas mass m_{gas} and its density ρ_{gas} are taken to be constant. Whereby, the rocket-hot gas system can be viewed as a single body system with phased fifth force coefficients about the rocket due to time dilation and retardation. This implies a phase factor φ; the changing rocket mass and hot gas motion factors $\partial\beta_{C_r}$ and $\partial\beta_{C_{gas}}$; and the changing rocket mass and hot gas radial factors $\partial\bar{R}_r$ and $\partial\bar{R}_{gas}$ as ascribed in time varying density model. This allows the mass to field coupling factors

$$\partial\beta_r \approx \partial\beta_{gas} \approx \left(\vec{F}_r / \vec{F}_{N_r}\right) \big/ 6\varphi, \tag{32}$$

where $\vec{F}_r$ is the thrust and $\vec{F}_{N_r}$ is the Newtonian force at burn out. Combining equation (32) with the sum of the fifth force coefficients given by equation (29) gives

$$\sum \theta_L \approx \left(\vec{F}_r / \vec{F}_{N_r}\right) \big/ \varphi \cdot \left(\left(\partial\beta_{gas} - \partial\beta_{N_r}\right)^2 \sqrt{l_p / \bar{R}_r} - \left(\partial\beta_r - \partial\beta_{N_{gas}}\right)^2 \sqrt{l_p / \bar{R}_{gas}}\right) \tag{33}$$

The phase in equations (32) and (33) is given by equation (26) and is dependent on the hot gas relaxation time τ and retardation time $\Delta\tau$. The hot gas relaxation time τ is taken to be the hot gas travel time across a distance equivalent to twice the hot gas radial factor $\bar{R}_{gas}$. Whereby, the hot gas relaxation time is give as

$$\tau \approx 2\bar{R}_{gas} \big/ v_{gas}, \tag{34}$$

where v_{gas} is the velocity of the hot gas. The retardation time $\Delta\tau > \tau$ is taken to be the total burn time of the propellant given by

$$\Delta\tau \approx m_{ex} / \dot{m}, \tag{35}$$

where $\dot{m}$ is the propellant mass flow rate through the nozzle. The mass exhausted from the nozzle

$$m_{ex} = m_r - \partial m_r,$$

where m_r is the initial mass of the rocket gives the changing rocket mass

$$\partial m_r = m_r - m_{ex}. \tag{36}$$

Motion and Radial Factors

The rocket's motion factor $\partial\hat{\beta}_{C_r}$ is given from equation (12) as

$$\partial\hat{\beta}_{C_r} \approx 1/3 \left(\partial\beta_r^2\right)^{-1} \left(M_E^2 \big/ \partial\rho_r \partial\bar{R}_r \sqrt{l_p \partial\bar{R}_r}\right) \left(2M_{PL}^4 / \rho_0\right)^{1/3} \left(1 - \left(\rho_0 / \partial\rho_r\right)^{1/3}\right), \tag{37}$$

where the rocket's changing density

$$\partial\rho_r = 3\partial m_r \big/ 4\pi\partial\bar{R}_r^3 \tag{38}$$

and the rocket's changing radial factor is given from equation (2) as

$$\partial\overline{R}_r \approx \left(\vec{F}_{N_r} \Big/ \left(\vec{F}_{N_r} + \vec{F}_r\left(\partial m_r / m_r\right)\right)\right)^{1/3} \overline{R}_r = \left(\vec{F}_{N_r} \Big/ \left(\vec{F}_{N_r} + \partial m_r a_r\right)\right)^{1/3} \overline{R}_r \,. \tag{39}$$

The hot gas's motion factor $\partial\hat{\beta}_{C_{gas}}$ is given in like to equation (38) as

$$\partial\hat{\beta}_{C_{gas}} \approx 1/3\left(\partial\beta_{gas}^2\right)^{-1}\left(M_E^2 \Big/ \partial\rho_{gas}\partial\overline{R}_{gas}\sqrt{l_p\partial\overline{R}_{gas}}\right)\left(2M_{PL}^4/\rho_0\right)^{1/3}\left(1-\left(\rho_0/\partial\rho_{gas}\right)^{1/3}\right) \tag{40}$$

and the changing radial factor of the hot gas is then given in like to equation (40) as

$$\partial\overline{R}_{gas} \approx \left(\vec{F}_{N_r} \Big/ \left(\vec{F}_{N_r} + \partial m_r a_r\right)\right)^{1/3} \overline{R}_{gas} = \sqrt{2}\left(\vec{F}_{N_r} \Big/ \left(\vec{F}_{N_r} + \partial m_r a_r\right)\right)^{1/3} r_{nozzle} \,. \tag{41}$$

The change $\partial\rho_{gas}$ in the hot gas density is used as the hot gas is in motion with a velocity v_{gas}. The rocket-hot gas system is then like the collision mass model, where the change $\partial\rho_{gas}$ in the hot gas density is given in like to equation (65) from Robertson (2009) with $a_1 = a_{gas}$ as

$$\partial\rho_{gas} \approx \left|\vec{a}_{gas}/\vec{g}_N\right|\rho_{gas} \approx 3m_{gas} \Big/ 4\pi\partial\overline{R}_{gas}^3 \,, \tag{42}$$

where the moving mass acceleration is given as

$$\vec{a}_{gas} \approx \vec{v}_{gas}^2 \Big/ 2\overline{R}_{gas} \tag{43}$$

and the normal hot gas density

$$\rho_{gas} \approx 3/4\left(P_{gas}/v_{gas}^2\right) \approx 3m_{gas} \Big/ 4\pi\overline{R}_{gas}^3 \tag{44}$$

with respect to a constant (average) gas pressure P_{gas} on the nozzle and constant (average) hot gas velocity v_{gas} and where the hot gas mass

$$m_{gas} \approx \pi P_{gas}\left(\overline{R}_{gas}^3 / v_{gas}^2\right). \tag{45}$$

and the radial factor

$$\overline{R}_{gas} \approx \left(m_{gas}v_{gas}^2 / \pi P_{gas}\right)^{1/3} \tag{46}$$

Now noting that the force on the hot gas

$$\vec{F}_{gas} = P_{gas}A_{Nozzle} = m_{gas}\left(v_{gas}^2 / 2\overline{R}_{gas}\right), \tag{47}$$

where A_{Nozzle} is the nozzle cross sectional area, gives the radial factor

$$\overline{R}_{gas} = 1/2\left(m_{gas}v_{gas}^2 / P_{gas}A_{Nozzle}\right), \tag{48}$$

which when combined with equation (45) or (46) gives the hot gas mass

$$m_{gas} \approx \left(P_{gas}/v_{gas}^2\right)\left(8\left(A_{Nozzle}\right)^3/\pi\right)^{1/2}. \tag{49}$$

Further, combining equations (49) and (50) reduces the radial factor to

$$\overline{R}_{gas} = \left(2A_{Nozzle}/\pi\right)^{1/2} = r_{nozzle}\sqrt{2} \,. \tag{50}$$

Conservation of Momentum

Equations (40) and (42) imply that

$$\partial\overline{R}_r / \overline{R}_r \approx \partial\overline{R}_{gas} / \overline{R}_{gas} \,. \tag{51}$$

Now in like to equation (43), equation (42) is equivalent to the mass collision form of equation (66) from Robertson (2009), given as

$$\partial\overline{R}_r / \overline{R}_r \approx \partial\overline{R}_{gas} / \overline{R}_{gas} \approx \left(\left|\vec{g}_N / \vec{a}_{gas}\right|\right)^{1/3}, \tag{52}$$

which when combined with equation (40) or (42) yields the rocket momentum equation

$$\left(m_r\vec{a}_{gas}\right)\partial t \approx \left(\partial m_r\vec{a}_r\right)\partial t + \left(\vec{F}_{N_r}\right)\partial t$$

or

$$m_r v_{gas} \approx \partial m_r v_r \,, \tag{53}$$

where $\left(\vec{F}_{N_r}\right)\partial t \to 0$ as the rocket moves upward and away from the Newtonian mass.

Example 4 — This example uses the data from example 2-1 in Sutton and Ross (1976) converted to metric units. The example appears to be a Sidewinder, AMRAM or Similar Missile. Figure 3 is an AMRAM missile given to show the general dimensions. Table I gives the parameters given in example 2-1 (Sutton and Ross, 1976), the parameters surmised from a Sidewinder missile, and the parameters calculated from these values. The parameters of Table I was used to calculate the parameters of the rocket mass in Table II and the parameter of the hot gas in the nozzle in Table III, and the parameters of the fifth force in Table IV. One assumption made is that the total missile weight is equivalent to the solid rocket motor weight.

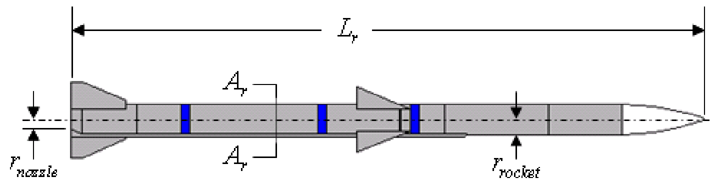

Figure 3. General Missile Dimension

Table I. The given, surmised and calculated values for the hot-gas rocket

Given	Surmised	Calculated
$m_r = 90.72\ kg$	$r_{rocket} \approx 0.064\ m$	$A_r \approx 0.0127\ m^2$
$m_{ex} = 31.75\ kg$	$L_r \approx 2.98\ m$	$V_r \approx 0.0377\ m^3$
$v_{gas} \approx 2355.49\ m/s$	$r_{nozzle} \approx 0.05\ m$	$\rho_r \approx 2403.83\ kg/m^3$
$\dot{m} = 10.58\ kg/s$	$P_{gas} \approx 1.97\times10^6\ N/m^2$	$A_{nozzle} \approx 0.008\ m^2$

Table II. Parameters of the Rocket Mass

Parameter	Equation	Parameter	Equation
$\bar{R}_r \approx 0.012925\ m$	29	$\Delta\tau \approx 3\ s$	36
$\partial\bar{R}_r \approx 0.0042\ m$	40	$\partial\beta_r \approx 7.06\times10^5$	33
$\partial m_r \approx 58.97\ kg$	37	$\partial\hat{\beta}_{C_r} \approx 0.0035$	38
$\partial\rho_r \approx 1.89\times10^8\ kg/m^3$	39	$\partial\hat{\beta}_{N_r} \approx 16.52$	31

Table III. Parameters of the Hot Gas in the Nozzle

Parameter	Equation	Parameter	Equation
$m_{gas} \approx 0.043\ kg$	50	$\partial\rho_{gas} \approx 1.10\times10^8\ kg/m^3$	43
$\bar{R}_{gas} \approx 0.0718\ m$	51	$\partial\beta_{gas} \approx 7.06\times10^5$	33
$a_{gas} \approx 3.86\times10^7\ m/s^2$	44	$\partial\beta_{C_{gas}} \approx 0.169$	41
$\rho_{gas} \approx 27.96\ kg/m^3$	45	$\partial\hat{\beta}_{N_{gas}} \approx 2.38$	32
$\partial\bar{R}_{gas} \approx 4.55\times10^{-4}\ m$	42	$\tau \approx 3.05\times10^{-5}\ s$	35

Table IV. Parameters of the Fifth Force on the rocket

Parameter	Equation
$\varphi \approx 1.02\times10^{-5}$	26
$\theta_r \approx 74.81$	27
$\theta_{gas} \approx -31.73$	28
$\sum\theta_{L_r} \approx 43.08$	61

The burn out weight given in example 2-1 (Sutton and *Ross,* 1976) was $\bar{F}_N \approx 578.74\,N$ and the thrust was given as $\bar{F}_r \approx 2.49\times10^4\ N$. From equation (41) from Robertson (2009), the sum of the fifth force coefficients $\sum \theta_{L_r} \equiv \theta_m$ such that $\bar{F}_r = \theta_m \bar{F}_N \approx 43.08 \times 578.74\ N = 24932.12\ N$, which is the given thrust.

Discussion

The a radial factor $\bar{R}_r \approx 0.012925\ m$ was adjusted to give the correct thrust and was found to be on the order of the expected nozzle throat (as it was not given) rather than the rocket cylindrical radius r_{rocket} as was assumed for a mass collision. This indicates that the radial factor $\bar{R}_r$ be the radial parameter where the thin-shells of the two hot-gas masses interface, which is the throat opening between the combustion chamber and the nozzle. It is also noted that the calculated thrust is very sensitive to the radial factor or throat size. This is also the case in rocket motors as changes in the throat dimension changes the internal pressure; reducing the exit velocity of the hot-gas.

GENERALIZED ROCKET MODEL

Generally rocket engine thrust can be determined without knowing the total propellant and vehicle weight and their density change. To investigate this in terms of the models in this paper, the solid rocket model of Figure 2 is given as a rocket engine model (no payload and propellant mass) in Figure 4. The fifth force coefficients across the rocket motor are represented by θ_{RE} - the fifth force coefficient of the rocket engine (RE) forward the combustion chamber, and θ_{Nozzle} - the fifth force coefficient of the rocket engine aft of the nozzle. This gives the sum of the fifth force coefficients as

$$\sum \theta_L = -\left(\theta_{RE} - \theta_{Nozzle}\right) = \theta_{Nozzle} - \theta_{RE} , \quad (54)$$

where the negative sign is due to the motion of the rocket moving away from the virtual Newtonian mass.

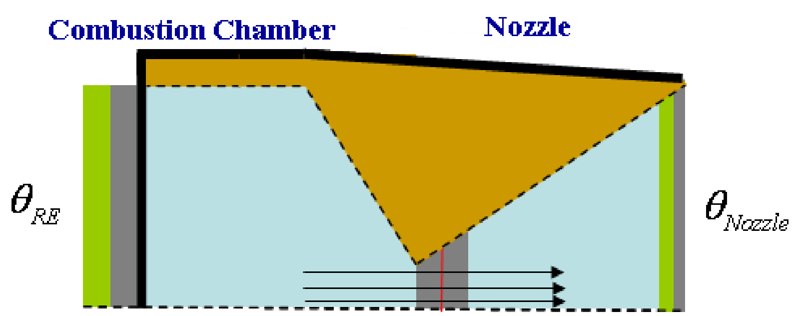

Figure 4. Rocket Engine Model

The motion of the hot-gas in the rocket engine produces a decrease in the hot-gas density in the combustion chamber and an increase in the hot-gas density in the nozzle; relative to the hot-gas velocity, whereby at high hot-gas velocities $\theta_{RE} >> \theta_{Nozzle}$. Since the fifth force coefficients are a result of the hot-gas motion, the rocket engine fifth force coefficient $\theta_{RE} \approx \partial\theta_{gas}$. That is, the rocket engine fifth force coefficient θ_{RE} is a direct result of the change in the hot-gas fifth force coefficient $\partial\theta_{gas}$. The sum of the fifth force coefficients can now be reduced to factors only of the hot-gas as

$$\sum \theta_L \approx -\theta_{RE} \approx -\partial\theta_{gas} . \quad (55)$$

Equation (33) allows

$$\partial\beta_{gas} \approx \left(\vec{F}_{gas} \big/ \vec{F}_{N_{gas}}\right) \Big/ 6\varphi , \quad (56)$$

where by noting that the thrust

$$F_r = -\vec{F}_{gas} = -\sum \theta_L \vec{F}_{N_{gas}} , \quad (57)$$

and equating equation (58) to equation (57), yields the sum of the fifth force coefficients as

$$\sum \theta_L \approx 6\varphi \cdot \partial\beta_{gas} \tag{58}$$

and is equivalent to the general sum of the fifth force coefficients of equation (25) where $\sum \theta_L \equiv \theta_m \equiv \theta_{gas}$ and $\varphi << 1$ as is shown in Table IV.

Further, equations (59) and (57) yields

$$\sum \theta_L \approx \vec{F}_{gas} \Big/ \vec{F}_{N_{gas}} \ , \tag{59}$$

again as it should be and equation (57)

$$\vec{F}_{N_{gas}} \approx \vec{F}_{gas} \Big/ 6\varphi \cdot \partial\beta_{gas} \ . \tag{60}$$

Since $\partial\theta_r \equiv \theta_{RE} \equiv \partial\theta_{gas}$ and $\partial\beta_r \approx \partial\beta_{gas}$, equation (28) gives

$$\partial\theta_{gas} \approx -6\partial\beta_{gas}\left(\partial\Delta R_{gas} \big/ \bar{R}_{gas}\right) \approx -6\partial\beta_{gas}\left(\partial\beta_{gas} - \partial\beta_{N_{gas}}\right)^2 \sqrt{l_p \big/ \bar{R}_{gas}} \tag{61}$$

Now equating equations (59), (60) and (56) yields the phase

$$\varphi \approx \left(\partial\beta_{gas} - \partial\beta_{N_{gas}}\right)^2 \sqrt{l_p \big/ \bar{R}_{gas}} \tag{62}$$

and the sum of the fifth force coefficients as

$$\sum \theta_L \approx 6 \cdot \partial\beta_{gas}\left(\partial\beta_{gas} - \partial\beta_{N_{gas}}\right)^2 \sqrt{l_p \big/ \bar{R}_{Nozzle}} \ , \tag{63}$$

Placing equation (64) and (61) into equation (58) yields

$$-\vec{F}_{gas} = -\left[\left(\partial\beta_{gas} - \partial\beta_{N_{gas}}\right)^2 \sqrt{l_p \big/ \bar{R}_{Nozzle}} \Big/ \varphi\right] \vec{F}_{gas} \ , \tag{64}$$

again showing that the fifth force model is arbitrary for hot-gas rocket engine thrust models as the formula in the […] =1.

The author notes that a similar result can be reached by letting

$$\varphi \approx \left(\left(\partial\beta_{gas} - \partial\beta_{N_r}\right)^2 \sqrt{l_p \big/ \bar{R}_r} - \left(\partial\beta_r - \partial\beta_{N_{gas}}\right)^2 \sqrt{l_p \big/ \bar{R}_{gas}}\right) \tag{65}$$

in equation (33) of the solid rocket motor model, which is of similar form to equation (64).

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Another way of looking at this is by noting that

$$\vec{F}_{gas} = \sum \theta_{L_{gas}} \vec{F}_{N_{gas}} = \partial\theta_{gas} \vec{F}_{N_{gas}} \approx \dot{m}_{gas} v_{gas} \tag{66}$$

and

$$F_r = \sum \theta_{L_r} \vec{F}_{N_r} \approx \theta_{RE} \vec{F}_{N_r} = m_r a_r \ . \tag{67}$$

where $\dot{m}_{gas}$ is the mass flow rate of the hot-gas, v_{gas} is the velocity of the hot-gas, m_r is the mass of the rocket and a_r is the acceleration of the rocket. Now since the thrust $T = m_r a_r = \dot{m}_{gas} v_{gas}$ and $\partial\theta_{gas} \approx \theta_{RE}$, the Newtonian forces

$$\vec{F}_{N_{gas}} \approx \vec{F}_{N_r} \ . \tag{68}$$

Equation (68) implies that no matter how much weight is added to the rocket engine, Newtonian force associated with the hot-gas will be ~ equivalent to that of the rocket; indicating that the fifth force model is arbitrary for hot-gas rocket engine thrust models.

Differential Fifth Force Coefficient Model

The rocket engine model also presents the case for differentials in the fifth force coefficients across a mass due to excited mass particles in the pressurant coupling to the thin-shell. That is, forces produced by atmospheric pressure differentials on opposite sides of a mass are the same as forces produced by atmospheric coupling to the thin-shell. For example, Figure 5 gives a plate mass (say a small piece of the rocket nozzle) of an arbitrary thin material of infinite radial dimension, where the lines represent the mass particles in the pressurant impinging on the thin material. Now by letting, the pressures $P_{Right} > P_{left} \approx P_{atm}$, the force is to the left as shown. Similarly, the excited mass particles in the pressurant with determinate velocities induce a force on the thin material (similar to the mass collision model), that cause an additive effect on the thin-shell on the opposite side to produce the fifth force coefficient $\theta_{Right} > \theta_{Left}$; producing a force outward from the applied pressure as is the case with the rocket engine model.

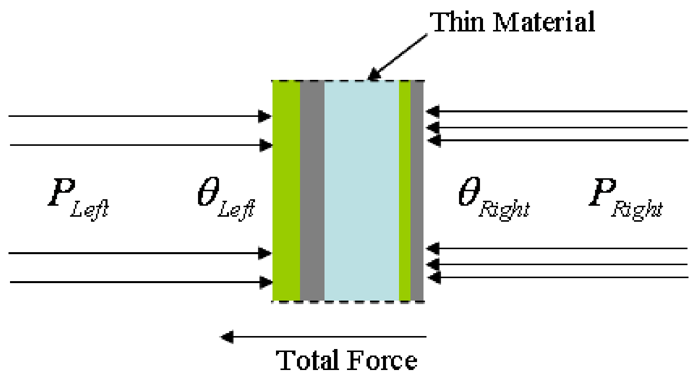

Figure 5. Differential Pressure Model

In the differential pressure model of Figure 5, the total force on the thin material (TM) with surface area A_{TM} is given by

$$\vec{F}_{TM} = F_{Right} - F_{Left} = \sum \theta_L \vec{F}_{N_{TM}} \equiv \theta_{TM} \vec{F}_{N_{TM}}, \tag{69}$$

where

$$\vec{F}_{Right} = \vec{P}_{Right} A_{TM} = \theta_{Left} \vec{F}_{N_{TM}} \tag{70}$$

and

$$\vec{F}_{Left} = \vec{P}_{Left} A_{TM} = \theta_{Right} \vec{F}_{N_{TM}}. \tag{71}$$

Combining equations (60-71) yields

$$\vec{F}_{TM} = \left(\vec{P}_{Right} - \vec{P}_{Left}\right) A_{TM} = \theta_{TM} \vec{F}_{N_{TM}} \tag{72}$$

Then given $P_{Right} >> P_{left}$, the pressure on the thin-shell is given as

$$\vec{F}_{TM} = \vec{P}_{Right} A_{TM} = \theta_{TM} \vec{F}_{N_{TM}} \tag{73}$$

where

$$\theta_{TM} = \vec{F}_{TM} \big/ \vec{F}_{N_{TM}} \tag{74}$$

as it should.

Discussion

Although the differential pressure model appears arbitrary, it represents a case where an energy source (gas pressure) acts on a mass (thin material), forcing a change to the thin-shin shell only on one side, whereby a differential thin-shell is produced about the mass, which induces a force on the mass. Further understanding of the thin-shell mechanism could then produce a device where a differential thin-shell is produced by other means.

EM FIELD MOMENTUM

In a previous paper (Robertson, 2008), the author looked at the Chameleon Model in terms of time varying cross EM fields imposed on a material of volume V. The Chameleon field-force was presented as

$$F_{C_{EM}} = -\beta^2 \cdot g_{EM} \cdot V \ , \tag{75}$$

where

$$g_{EM} = \frac{1}{c^2} \omega E_0 H_0 \sin(\varphi') \tag{76}$$

is the standard EM field momentum with an externally applied (maximum) electric field E_0 and (maximum) magnetic field H_0 of the same frequency ω, where φ' is the phase between the two fields.

The EM model is a time-varying Chameleon Model with internal electron motion, where the phase shift φ in the electron motion is a function of the total electron perturbations N per time t of the distribution of electric charge and magnetic moments each occurring over the dielectric relaxation time $\tau \approx t/N$ corrected by a time dilation $\tau + \Delta\tau$. Such that, the phase shift in the electron motion is given by

$$\varphi = \frac{\tau}{\tau + \Delta\tau} \ . \tag{77}$$

Rewriting equation (5) in terms of equation (75) yields

$$F_{C_{EM}} \approx -\theta_m \vec{F}_N = -6\partial\beta_m \left(\tau/(\tau+\Delta\tau)\right)\vec{F}_N = -\beta^2 \cdot g_{EM} \cdot V \tag{78}$$

where using equation (26)

$$\theta_m \equiv 6\partial\beta_m\varphi \approx \left|\frac{F_{C_{EM}}}{\vec{F}_N}\right| = \beta^2 \cdot \left(\frac{g_{EM} \cdot V}{\vec{F}_N}\right), \tag{79}$$

which yields

$$\partial\beta_m \approx \frac{1}{6}\left(\frac{\beta^2}{\varphi}\right) \cdot \left(\frac{g_{EM} \cdot V}{\vec{F}_N}\right), \tag{80}$$

It can be argued that since β^2 was shown (see; Robertson, 2008) to be a function of the materials dielectric properties, that $\beta^2 \approx \varphi$; such that,

$$\theta_m \approx \left(\frac{V}{\vec{F}_N}\right)\varphi \cdot g_{EM} \tag{81}$$

implying that the sum of the fifth force coefficients about the material changes with respect to both the field momentum g_{EM}, which varies as the applied time varying fields, and the total electron perturbations N per time t of the distribution of electric charge and magnetic moments each occurring over the dielectric relaxation time $\tau \approx t/N$ corrected by a time dilation $\tau + \Delta\tau$.

Discussion

Many EM field momentum experiments failed to prove the standard field momentum of equation (76) or the Abraham field momentum (see; Robertson, 2008), which does take into account a material's electric and magnetic properties. This simple analysis however shows that this failure was due to not taking into account the electron phase shift φ, which differs from the phase φ' between the two fields and infers more than just the material properties. That is, the effects of dark energy interactions were left out.

THE EMDRIVE

Recently Shawyer (2008) presented a 160 mm diameter 850W experimental EMDrive thruster that demonstrated a thrust of ~16 mN and several demonstrator EMDrive engine that produced thrust in the 80mN/kW, 214 mN/kW and 243 mN/kW ranges; all using a 2.45 GHz microwave source. A generalization of Shawyer's EMDrive is shown in Figure 6.

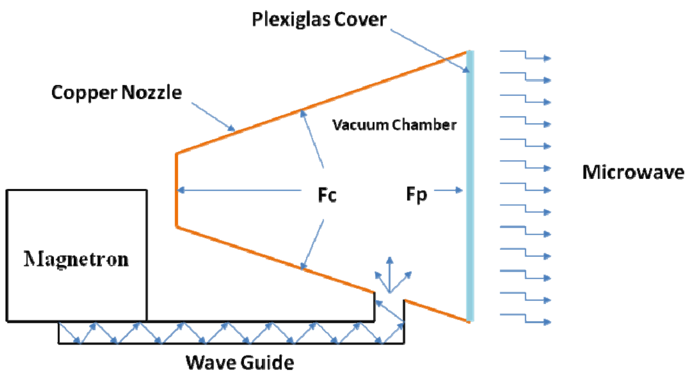

FIGURE 6. Generalization of Shawyer's EMDrive

The thrust of the EMDrive is given as

$$T = -Q\left(F_C - F_P\right) = \left(\left(\lambda_P - \lambda_C\right)/\lambda_C\lambda_P\right)\left(2QP_0\lambda_0/c\right) \tag{82}$$

where F_C is the force on the copper nozzle and F_P is the force on the Plexiglas cover and where P_0 is the power of the incoming microwave energy, Q is a power loss factor, λ_C is the cross-section of the smallest end of the copper nozzle, λ_P is the cross-section of the largest end of the copper nozzle or the cross-section of the plexiglass cover and λ_0 is the free-space propagation wavelength. From relativity (see; Shawyer, 2008), the microwave velocities are related by

$$v_P - v_C = \lambda_0\left(\left(\lambda_P - \lambda_C\right)/\lambda_C\lambda_P\right)c\,, \tag{83}$$

which implies that microwave average velocity v_P near the Plexiglas is larger than the average velocity v_C near the copper nozzle.

Time-Varying EMDrive Model

The EMDrive represents a time-varying system as illustrated in Figure 7 with relativity like phase given by

$$\varphi \approx x/c/\left(x/c + \Delta t\right) = x/\left(x + c\Delta t\right). \tag{84}$$

where x is the average length of the cavity and the time change

$$\Delta t \approx x/\left(v_P - v_C\right) = x/\left(\lambda_0\left(\left(\lambda_P - \lambda_C\right)/\lambda_C\lambda_P\right)c\right); \tag{85}$$

using equation (83). In like to equation (4) and with small acceleration on the nozzle system, the sum of the fifth force coefficient

$$\theta_m = 6\partial\beta_m\left(\partial\Delta R_C/R_C - \partial\Delta R_P/R_P\right) \equiv 6\partial\beta_m\left(\partial\Delta R_C/\lambda_C - \partial\Delta R_P/\lambda_P\right) \approx 6\partial\beta_m\varphi \tag{86}$$

or letting $\lambda_P >> \lambda_C$ and $\partial\Delta R_C >> \partial\Delta R_P$

$$\varphi \approx \partial\Delta R_C/\lambda_C\,; \tag{87}$$

whereby by combining with equations (84) and (86) yields the change in the thin-shell by

$$\partial\Delta R_C \approx \lambda_C\left(x/\left(x + c\Delta t\right)\right) = \lambda_0\lambda_C\left(\lambda_P - \lambda_C\right)/\left(\lambda_0\left(\lambda_P - \lambda_C\right) + \lambda_P\lambda_C\right). \tag{88}$$

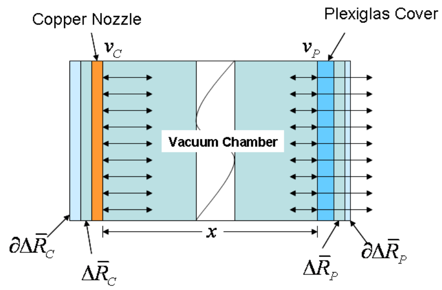

Figure 7. Time-varying EMDrive Model

The motion coupling factor $\partial\beta_m$ is given in like to equation (10) as

$$\partial\beta_m \approx -(1/6\varphi)\vec{F}_m/\vec{F}_N = 1/6\left(\left(x+c\Delta t\right)/x\right)F_m/F_N \tag{89}$$

Where is an which gives the force

$$F_m \approx 6\partial\beta_m\left(x/\left(x+c\Delta t\right)\right)F_N \tag{90}$$

Now equating equations (82) and (90) yields the change in the mass coupling factor

$$\partial\beta_m \approx 1/3\left(\left(\lambda_P-\lambda_C\right)/\lambda_C\lambda_P\right)\left(QP_0\lambda_0/cF_N\right)\left(\left(x+c\Delta t\right)/x\right) \tag{91}$$

The sum of the fifth force coefficient can now be given by combining equations (84), (86) and (91) to yield

$$\theta_m \approx \left(\left(\lambda_P-\lambda_C\right)/\lambda_C\lambda_P\right)\left(2QP_0\lambda_0/c\right)/F_N \equiv T/F_N \tag{92}$$

as it should.

DISCUSSION

It is noted that this analysis uses the thrust and velocity factors given by Shawyer (2008). Therefore, the fifth force factors calculated related to those values. Further analysis is needed to fully understand how the EMDrive fits into the fifth force model present herein. Specifically, equations (1-3) need to be understood as well as many of the retardation equations. However, this model if well understood could lead to new propulsion devices not requiring exhausted mass.

CONCLUSION

This paper further investigated the notion that our universe is composed of scalar fields and that such notion can be used to calculate the same forces as attainable from the standard Newtonian force models. This was done through the development of fifth force models base on the Chameleon scalar field model present by Khoury and Weltman (2004a; 2004b) with further work by Brax *et al* (2004a and 2004b).

The author notes that these models are incomplete, but with further development, could lead others to develop force producing devices using unforeseen methods not visible under our current models. Most prominent is the notion that forces can be attained from time dilation and retardation effects cause by particulate matter motion in an object. This concept was demonstrated using the fifth force models in this paper to calculate the correct thrust for the hot gas-rocket in Example 1.

The author further notes that forces being detected in EM modulated capacitor (Brito, 2005; Woodward, 2008) and superconductor (Podkletnov, 2001 and 2002) experiments could be the result of time dilation and retardation effects due to the EM nonlinearity (Robertson, 2006 and 2007) in these materials.

Further, the reported EMDrive (Shawyer, 2008) can also be placed in this model, which could open new propulsion systems with no mass ejection.

NOMENCLATURE

a = acceleration (m/s^2)
$\hat{\beta}_C$ = Chameleon (thin-shell) coupling factor
β_m = mass to field coupling factor
β_N = Newtonian (field to mass) coupling factor
ρ = mass density (kg/m^3)
ρ_m = local mass density (kg/m^3)
ρ_0 = ambient mass density (kg/m^3)
P = pressure (N/m^3)
g_{EM} = standard EM field momentum (N/m^3)
E_0 = electric field (V/m)
H_0 = magnetic field (A/m)
F_m = force on mass (N)
F_N = Newtonian gravitational force [$\equiv mg$ (N)]
κ = geometric correction

$\partial\beta_N$ = small change to the Newtonian coupling factor
$\partial\beta_m$ = small change to the mass to field coupling factor
$\partial\rho_r$ = change in rocket mass density (kg/m^3)

m = mass (kg)
∂m_r = change in rocket mass (kg)
N = number of perturbations
ΔR = thin shell thickness (m)
$\partial\Delta R$ = small change to the thin shell thickness (m)
$\overline{R}$ = radial factor (m)
$\partial\overline{R}$ = change to the radial factor (m)
θ_m = sum of the local fifth force coefficient
θ_L = local fifth force coefficient
T = thrust (N)
t = time (s)
τ = relaxation time (s)
$\Delta\tau$ = retardation time (s)
ω = angular frequency (Hz)
φ = phase

Constants

M_E = energy scale [$\approx 10^4\ m^{-1}$]
M_{PL} = Reduced Planck mass [$\approx 4.34\times10^{-9}\ kg$]
g = Earth's gravity [$= 9.8\ m/s^2$]
l_p = Planck length [$\approx 1.616252\times10^{-35}\ m$]

Subscripts

ex = exhaust
i = given particulate matter
m = local mass
gas = hot gas
0 = Ambient field
N = Newtonian
$1, 2$ = given interacting mass
R = retarded
NR = non-retarded
r = rocket
RE = rocket engine

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