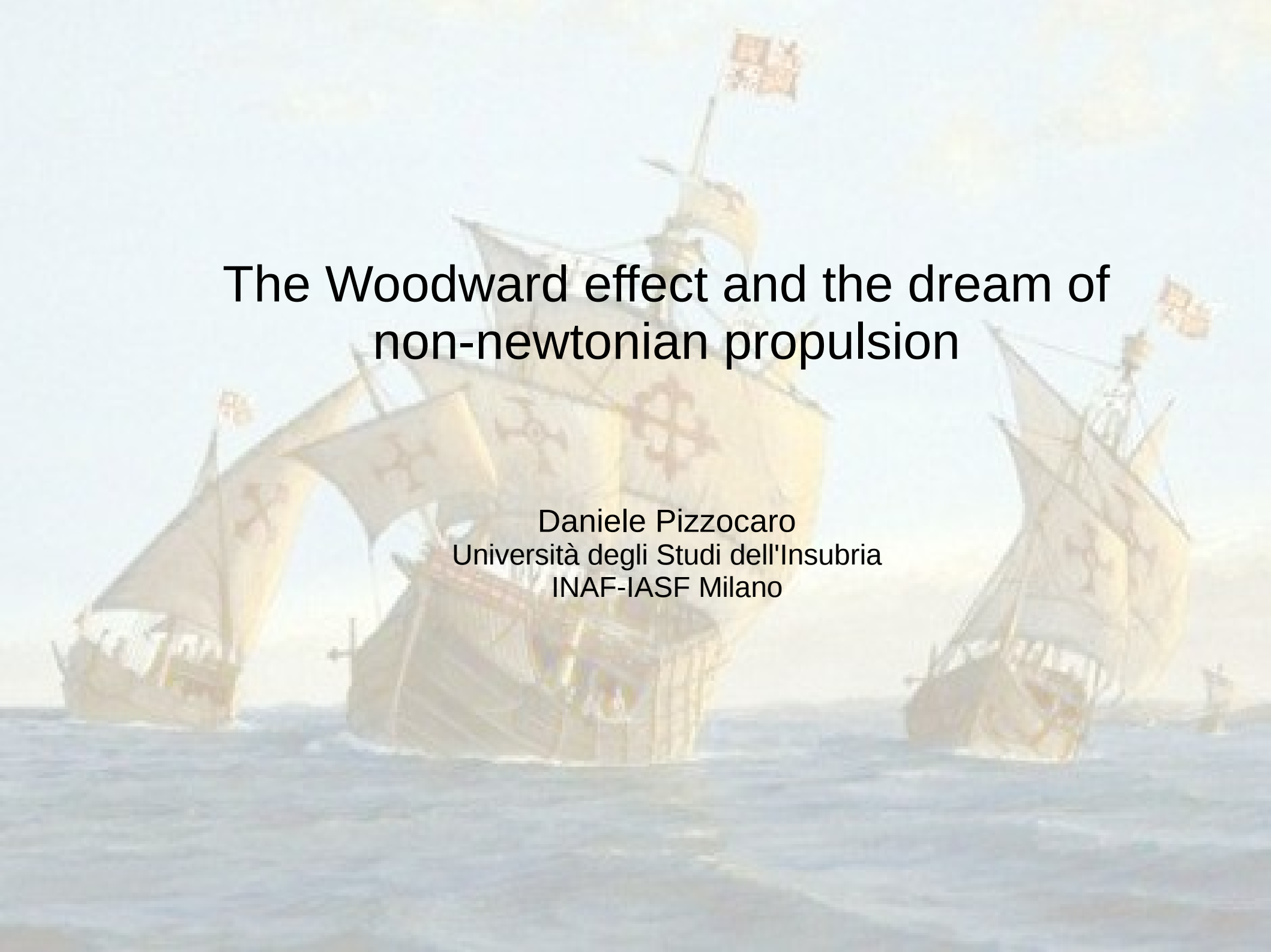


The Woodward effect and the dream of non-newtonian propulsion

Daniele Pizzocaro
Università degli Studi dell'Insubria
INAF-IASF Milano

Summary

- The non-newtonian propulsion
- The Woodward effect
  - Theory
  - Application
  - Experimental tests
- Conclusions

The non-newtonian propulsion

UN ITALOAMERICANO PROGETTA IL MOTORE SPAZIALE AD ENERGIA INFINITA. LA NASA: "FUNZIONA!"

Promette di funzionare senza carburante e per sem
permettere di esplorare la galassia senza problemi

Il motore del futuro senza carburante nell'infinito e oltre

Si chiama Cannae Drive, è un dispositivo in grado di produrre energia

Anomalous Thrust Production from an RF Measured on a Low-Thrust Torsion Pe

David A. Brady, Harold G. White, Paul March, Jam
NASA Lyndon B. Johnson Space Cente

This paper describes the eight-day August 2013 test campaign viability of using classical magnetoplasmadynamics to obtain a quantum vacuum virtual plasma. This paper will not address t thruster, but instead will describe the test integration, test oper campaign.

Approximately 30-50 micro-Newtons of thrust were recorded f consisting primarily of a radio frequency (RF) resonant cavity Testing was performed on a low-thrust torsion pendulum that i micronewton level, within a stainless steel vacuum chamber wit pressure. Several different test configurations were used, inclu reversal of the test article orientation. In addition, the test arti the force was not being generated by effects not associated with designed by Cannae LLC of Doylestown, Pennsylvania. The to operated by Eagleworks Laboratories at the NASA Johnson Sp

Approximately six days of test integration were required, follow which, technical issues were discovered and resolved. Integration of the two test equipment was performed in an iterative fashion between the test bench and the words, the test article was tested on the bench, then moved to the chamber, then resolve issues. Manual frequency control was required throughout the test. Thr articles, even though one of the test articles was designed with the expectation th thrust. Specifically, one test article contained internal physical modifications tha thrust, while the other did not (with the latter being referred to as the "null" test

Test data gathered includes torsion pendulum displacement measurements whic generated force, still imagery in the visible spectrum to document the physical co the infrared spectrum to characterize the thermal environment, and video image static and animated graphics produced during RF resonant cavity characterizati Multiphysics® software application. Excerpts from all of the above are included

Numerical and Experimental Results for a Novel Propulsion Technology Requiring no On-Board Propellant

Guido P. Fetta*

Direct Thrust Measurements of an EM Drive and Evaluation of Possible Side-Effects

M. Tajmar[1] and G. Fiedler[2]
Institute of Aerospace Engineering, Technische Universität Dresden, 01062 Dresden, Germany

The EMDrive has been proposed as a revolutionary propellantless thruster using a resonating microwave cavity. It is claimed to work on the difference in radiation pressure due to the geometry of its tapered resonance cavity. We attempted to replicate an EM Drive and tested it on both a knife-edge balance as well as on a torsion balance inside a vacuum chamber similar to previous setups in order to investigate possible side-effects by proper thermal and electromagnetic shielding. After developing a numerical model to properly design our cavity for high efficiencies in close cooperation with the EM Drive's inventor, we built a breadboard out of copper with the possibility to tune the resonance frequency in order to match the resonance frequency of the magnetron which was attached on the side of the cavity. After measuring the Q-factor of our assembly, we connected the EMDrive to a commercial 700 W microwave magnetron. Our measurements reveal thrusts as expected from previous claims (due to a low Q factor of <50, we observed thrusts of +/-20 μN) however also in directions that should produce no thrust. We therefore achieved a null measurement within our resolution which is on the order of the claimed thrusts. The

The non-newtonian propulsion

Producing a net thrust acceleration without the equal and opposite acceleration of a reaction mass -> “circumvents” (or violates) the III Newton's Law (locally at least)

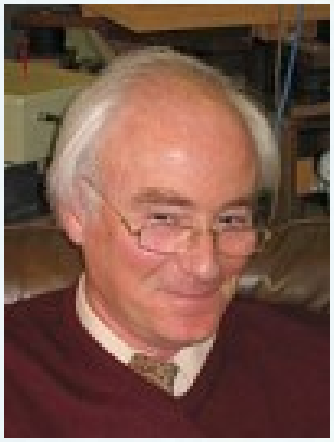
Tipically an electromagnetic device to produce a net thrust without any expulsion of matter -> no need of expelling gas/ions

No need of conventional (chemical) propeller nor of any reaction mass (ionic propulsion) -> only electric supply (solar cells, nuclear reactors)

Dramatically **reduce the mass of the fuel** and the space occupied->**higher velocity**

Physically based upon the ***Woodward effect*** and ***other em effects(?)***

The Woodward effect



James Woodward, California State University, Fullerton

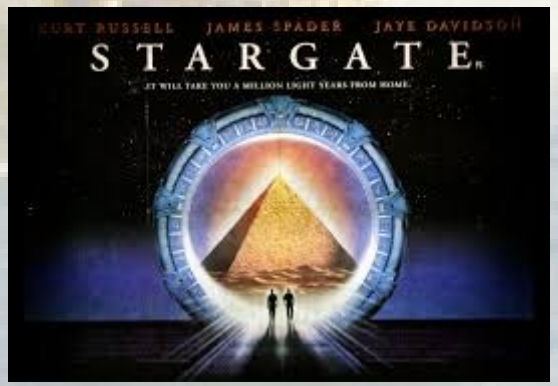
Mach's principle of inertia implies that a transient rest mass fluctuation arises in an object when it absorbs "internal" energy as it is accelerated

Measurable effects need high frequency in energy transfer -> em devices (capacitors at radio frequencies)

“When the dielectric of an accelerated capacitor is submitted to a varying electric power (charge or discharge), a transient mass fluctuation arises”
->propellantless propulsion + other effects

-> space vehicle engine

but also...



...and maybe...

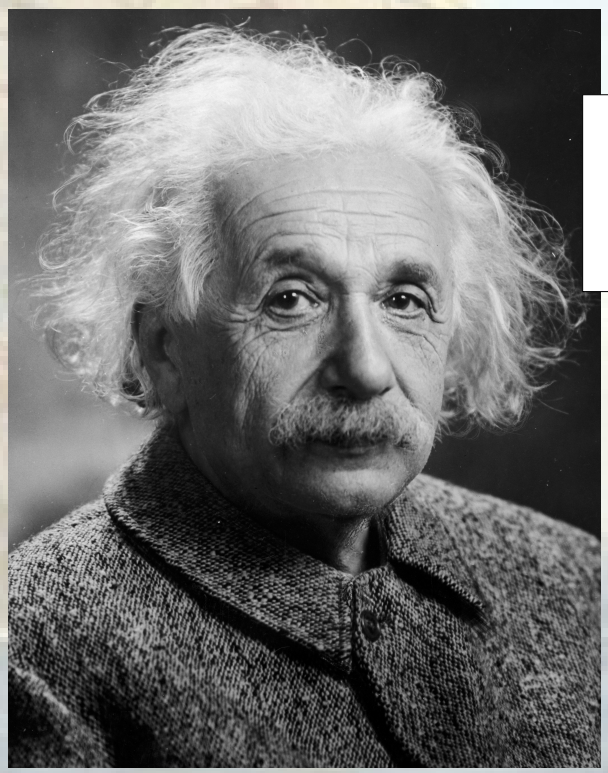
The Woodward effect

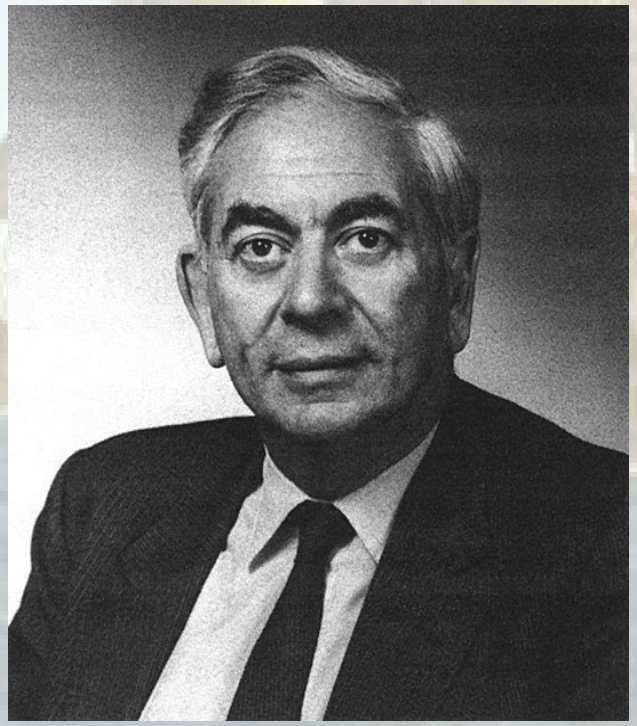
Physical/mathematical foundations:

Mach interpretation of inertia

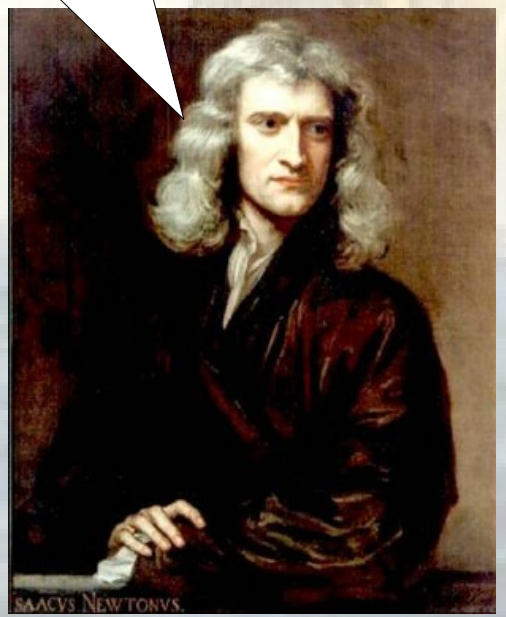
Einstein's Relativity Theory (SRT, GRT)

Sciama's interpretation





Controversial!
(apparently?)

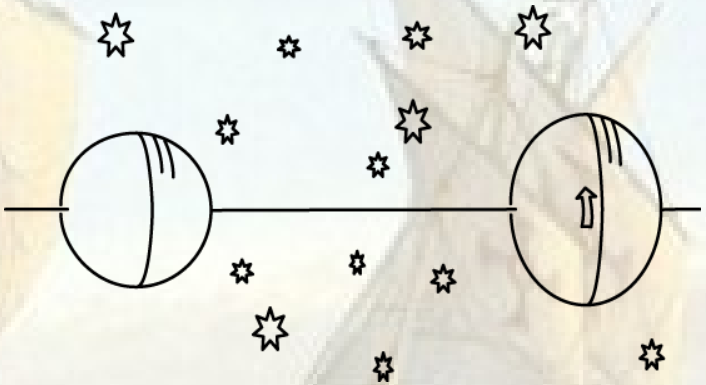


The Mach's principle

The inertia of every system is the result of the interaction between the system itself and the rest of the universe

"**The inertial mass of a body is determined by the distribution and flow of mass-energy in the universe"**

(Local inertial frames are determined by the large scale distribution of matter)



➡ inertia is gravitational in its origin!

Einstein tried to make it a consequence of GRT

Problem: GRT admits solutions to the Einstein's equations that do not satisfy the Mach's principle (de Sitter's vacuum solution and asimptotically empty solution, with full inertial structure)

The cosmological constant was (also), uselessly, hoped to make the equations solutionless in absence of matter!

Sciama's calculations

'50: revival of the Mach's principle

$$R_{\mu\nu} - \tfrac{1}{2} R\, g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Dennis William Sciama

Equations of gravitational field: simplest mathematical scheme

-> vector potential

Field -> antisymmetrical tensor: the only linear II order eqs that conserve the source are Maxwell's equations:

develope a vector theory of gravity analogous to Maxwell's theory of electromagnetism --> **vector approximation of GRT** (linear approx.)

Test particle vith **v** in **homeogeneous and isotropic universe** (steady)

Additional term: change of vector potential in “gravelectric” field

$$\boldsymbol{E}_g = -\nabla\phi - \frac{1}{c}\frac{\partial \mathbf{A}_g}{\partial t} \qquad \boldsymbol{H} = \nabla \wedge \boldsymbol{A}$$

~1/R ->distant bodies!

$$\mathbf{B} = \nabla \times \mathbf{A}, \quad \mathbf{E} = -\nabla\phi - \frac{\partial \mathbf{A}}{\partial t},$$

$$\boldsymbol{A}_g = \frac{1}{c}\int_V \frac{\rho \boldsymbol{v}}{r} dV = \frac{\boldsymbol{v}}{c}\int_V \frac{\rho}{r} dV \cong \frac{\boldsymbol{v}}{c}\frac{GM}{R} = \frac{\boldsymbol{v}\phi}{c}$$

Under this conditions:

$$\boldsymbol{E}_g = -\nabla\phi - \frac{1}{c}\frac{\partial \boldsymbol{A}_g}{\partial t} = -\nabla\phi - \frac{\phi}{c^2}\frac{\partial \boldsymbol{v}}{\partial t}$$

$$\nabla\phi = 0$$

Sciama's calculations

If an external acceleration is present, and if $\frac{\phi}{c^2} = 1$ we obtain

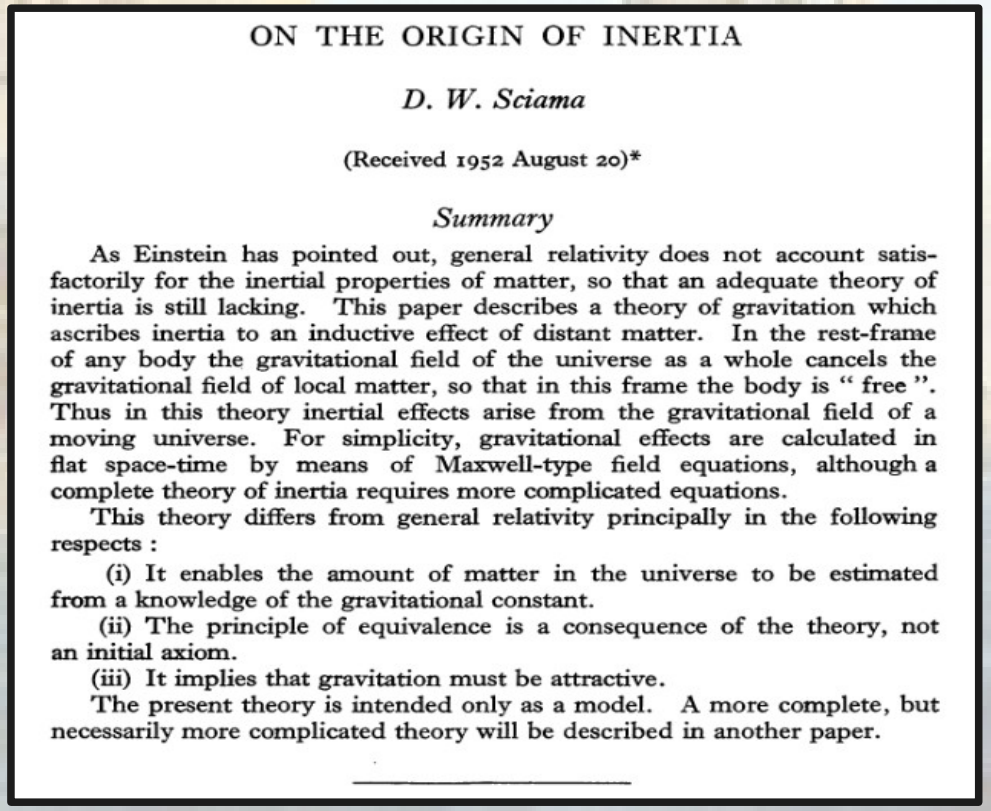
$$\boldsymbol{E}_g = -\boldsymbol{a}$$

The gravielectric field exacltly produces the equal and opposite inertial reaction force the **accelerating** agent experiences --> **the inertial reaction forces are exclusively gravitational in origin**

Inertial reaction forces are independent of time and place <-> the masses of things be equal to their total gravitational potential energies.

Introducing a body of mass M in the nearby of the test particle, we recover the Newton's law of gravity

But:
Is it actually $\frac{\phi}{c^2} = 1$?
Yes if the spacetime is flat – critical amount of matter in the universe -> confirmed by observations. Locally true (if phi changes for local masses, also c do the same), *Brans 1962*



ON THE ORIGIN OF INERTIA

D. W. Sciama

(Received 1952 August 20)*

Summary

As Einstein has pointed out, general relativity does not account satisfactorily for the inertial properties of matter, so that an adequate theory of inertia is still lacking. This paper describes a theory of gravitation which ascribes inertia to an inductive effect of distant matter. In the rest-frame of any body the gravitational field of the universe as a whole cancels the gravitational field of local matter, so that in this frame the body is " free ". Thus in this theory inertial effects arise from the gravitational field of a moving universe. For simplicity, gravitational effects are calculated in flat space-time by means of Maxwell-type field equations, although a complete theory of inertia requires more complicated equations.

This theory differs from general relativity principally in the following respects :

(i) It enables the amount of matter in the universe to be estimated from a knowledge of the gravitational constant.

(ii) The principle of equivalence is a consequence of the theory, not an initial axiom.

(iii) It implies that gravitation must be attractive.

The present theory is intended only as a model. A more complete, but necessarily more complicated theory will be described in another paper.

Sciama's calculations

Other bjections:

2) Instant action needed: assumed an action-at-a-distance "*a la* Feynman-Wheeler"

3) **Non-machian solutions of Einstein's equations exist!**

A final three-laws system

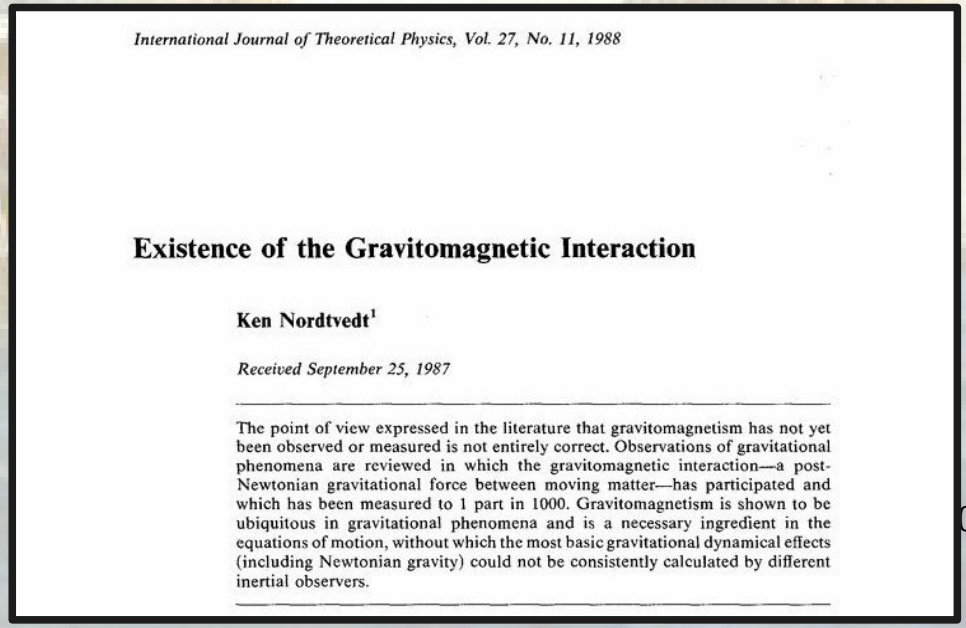
First law: ***φ=c^2 locally always***, *or,* ***inertial reaction forces are due to the gravitational action of causally connected matter*** *(everything that gravitates)*

Second law: ***m=E/φ***, *or the mass of an entity, isolated and at rest, is equal to its* ***non-gravitational energy divided by the locally measured total gravitational potential***

Zeroth law*: Inertial reaction forces are* ***instantaneous***

Ken Nordtvedt -> same basic results as Einstein-Sciama

...after 100y: **NO CONSENSUS!**



International Journal of Theoretical Physics, Vol. 27, No. 11, 1988

Existence of the Gravitomagnetic Interaction

Ken Nordtvedt[1]

Received September 25, 1987

The point of view expressed in the literature that gravitomagnetism has not yet been observed or measured is not entirely correct. Observations of gravitational phenomena are reviewed in which the gravitomagnetic interaction—a post-Newtonian gravitational force between moving matter—has participated and which has been measured to 1 part in 1000. Gravitomagnetism is shown to be ubiquitous in gravitational phenomena and is a necessary ingredient in the equations of motion, without which the most basic gravitational dynamical effects (including Newtonian gravity) could not be consistently calculated by different inertial observers.

The Mach (Woodward) effect

Assume the Mach's principle is true: inertial reaction forces are produced by the gravitational action of the matter of the universe through a field (spacetime)

Sciama's theory + Lorentz invariance:

Lorentz-invariant generalization of Newton's mechanics: write field equation for inertial reaction force F for a test particle

gravitational 4-field strength that causes the inertial reaction force (again electrodynamics analogy)

$$\mathbf{F} = -\mathbf{F}_{ext} = -\frac{d\mathbf{P}}{d\tau} \quad , \quad \mathbf{P} = (\gamma m_0 c, \boldsymbol{p}) \qquad \mathbf{F} = -\frac{d\mathbf{P}}{d\tau} = -\left(\frac{\partial m_0 c}{\partial t}, \mathbf{f}\right) \quad , \quad \mathbf{f} = \frac{d\mathbf{p}}{dt} \qquad \rho_0 = \frac{E_0}{c^2}$$

In the instantaneous frame of rest:

Field=force/unit charge (mass)

$$\boldsymbol{F} = \frac{\mathbf{F}}{m_0} = -\left(\frac{c}{\rho_0}\frac{\partial m_0}{\partial t}, \boldsymbol{f}\right) = -\left(\frac{1}{\rho_0 c}\frac{\partial E_0}{\partial t}, \boldsymbol{f}\right)$$

4-divergence -> field equation

$$-\frac{1}{c^2}\frac{\partial}{\partial t}\left(\frac{1}{\rho_0}\frac{\partial E_0}{\partial t}\right) - \bigtriangledown \cdot \boldsymbol{f} = 4\pi G \rho_0$$

The Mach (Woodward) effect

Servant's calculations

$$-\frac{1}{\rho_0 c^2}\frac{\partial^2 E_0}{\partial t^2}+\frac{1}{\rho_0^2 c^2}\frac{\partial \rho_0}{\partial t}\frac{\partial E_0}{\partial t}-\nabla\cdot\boldsymbol{f}=4\pi G\rho_0 \qquad \rho_0=\frac{E_0}{c^2}$$

Irrotationality

$$\boldsymbol{f}=-\nabla\phi$$

proper active gravitational matter density

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

(Wave equation)-like Lorentz invariant:

Only choice $E_0=\rho_0\phi$

...straigthforward...using $\frac{\phi}{c^2}=1$

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

That is a relativistically invariant wave equation – the field equation of inertial response

The Mach (Woodward) effect

Thus we have:

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

Transient source terms

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

E.g.: capacitor charged/discharged while accelerated

$$\delta m_0 \approx \frac{1}{4\pi G}\left[\frac{1}{\rho_0\, c^2}\frac{\partial P}{\partial t} - \left(\frac{1}{\rho_0\, c^2}\right)^2\left(\frac{P^2}{V}\right)^2\right]$$

P=istant power to the capacitor, V=volume

Transient proper matter density fluctuation when *variation of non-gravitational internal energy* and under *acceleration* -> **proper mass fluctuation**

always negative -> production of “exotic matter” (negative mass)

“wormhole” term!

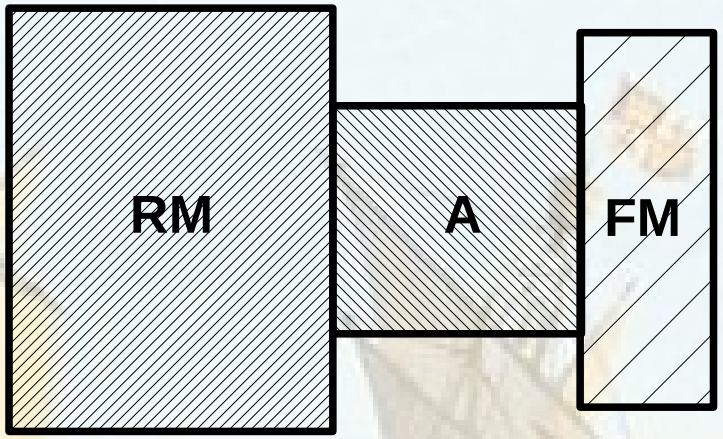
Application of the Woodward effect (for test and use)

Ingredients:

- High variation in internal energy of the system

  Mechanical systems are too slow
  -> electro-magnetic devices:
  inductors/capacitors supplied at radio-frequency

- Acceleration (oscillation)



Basic design:
Capacitor (**FM**, fluctuating mass): radio-frequency pulse (sinusoidal) -> the charge/discharge process produces a periodic variation in the internal energy of the dielectric between the plates
Actuator (**A**, lead-zirconium-titanate PZT piezoelectric crystal – expands and contract according to a pulsed electric polarity change (with suited frequency) in a way that, when A expands the mass of FM is maximized and is minimized when A contracts: provides the acceleration (oscillation) to the capacitor
Reaction mass (**RM**)

Application of the Woodward effect (for test and use)

When A expands, RM moves leftward of Δx.

When A contracts, the mass of FM is smaller – RM moves rightward of -Δx', but Δx'<Δx

This produces a net ΔX leftward

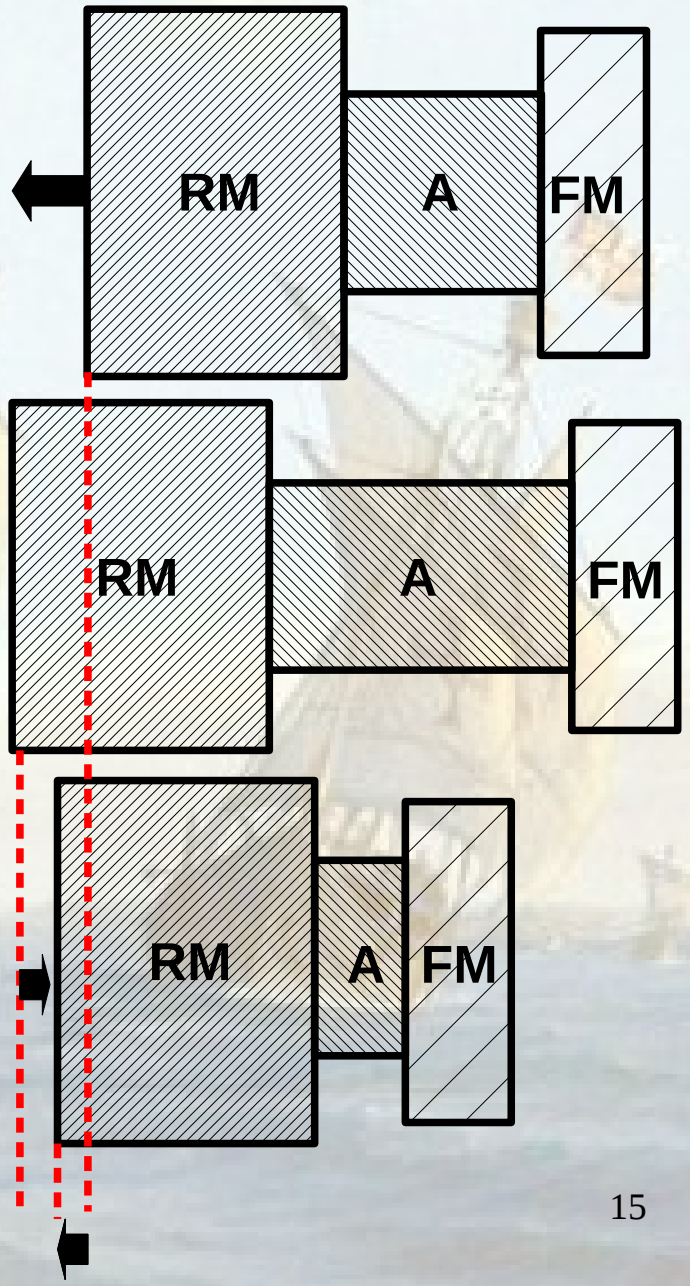
-> non-zero time-averaged force

A stationary force!

$$\langle F \rangle = -2\omega^2 \delta l_0 \delta m \cos\phi$$

MOMENTUM CONSERVATION VIOLATED? NO!

The device sets up a **momentum flux** in the "gravinertial field", coupling FM to the mass of all the bodies in the Universe.

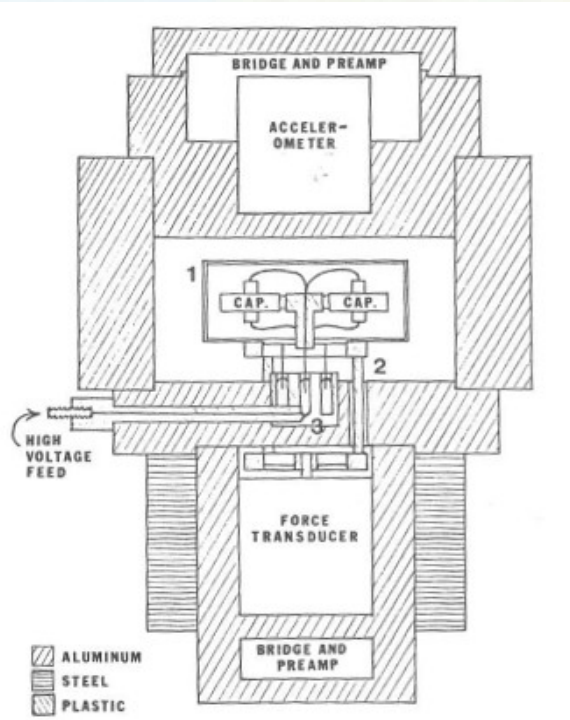


Experimental tests

Tests performed by Woodward

First device – 1989:

couple of **capacitors mounted on aluminium rod**, working at the resonant frequency of the rod – 50Hz – 3kV



A new experimental approach to Mach's principle and relativistic graviation

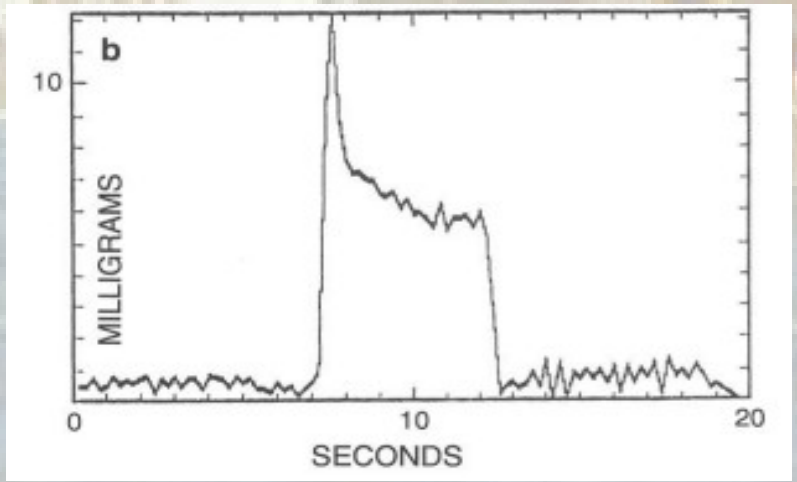
Woodward, J. F., 1990
Foundations of Physics Letters, Volume 3, Issue 5, pp.497-506

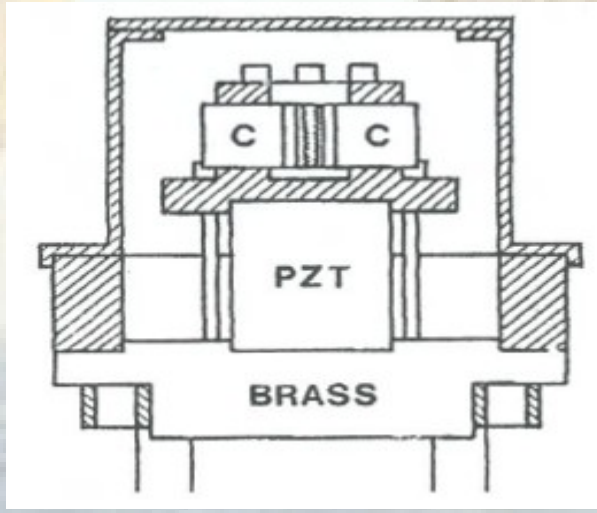
"...An experiment using this technique gives preliminary results that, to order of magnitude, corroborate GRT."

Following tests

PZT actuators – phase shifted signal subtracion:

First result?





Issues:

Large **offsets** in signal (unknown)
Acoustic resonance

Experimental tests

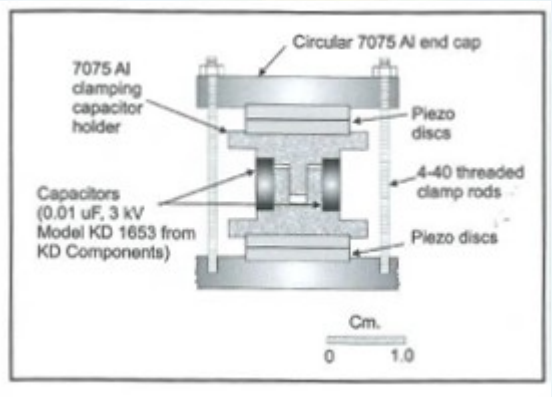
1997-2002

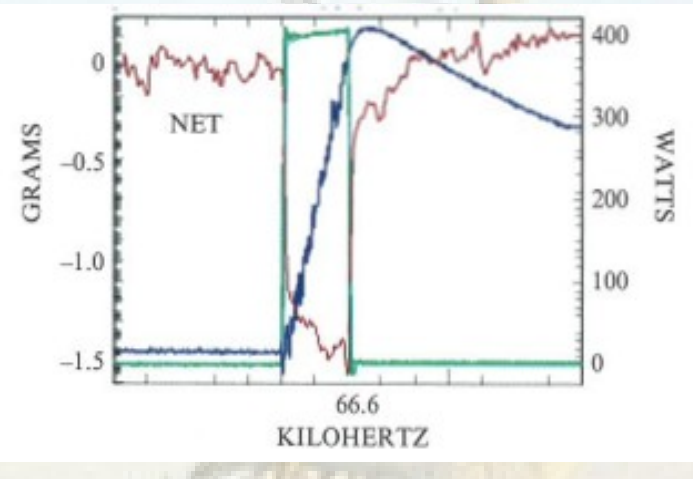
New design: **double PZT layer**
Torsion pendulum with laser beam in vacuum
mu metal shield

Apparent thrust of ~1μN, too small! No evidence of the effect

Refinement of the apparatus (acoustic resonance mainly)

Measure of weight reduction (wormhole term)
-> positive evidence
mechanical vibrations -> abandoned!!!





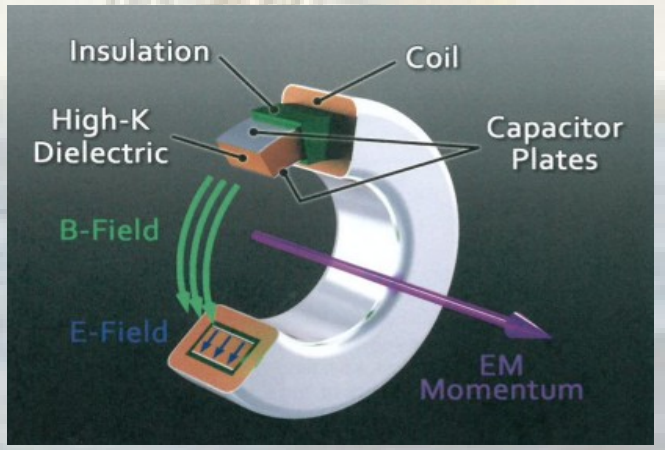
Slepian's circuit...

Mach-Lorentz thruster

First tests: Hector Brito - no clear results

Nembo Buldrini & Martin Tajmar (Austrian Research Center)

high precision measures -> **clear absence of signal!**

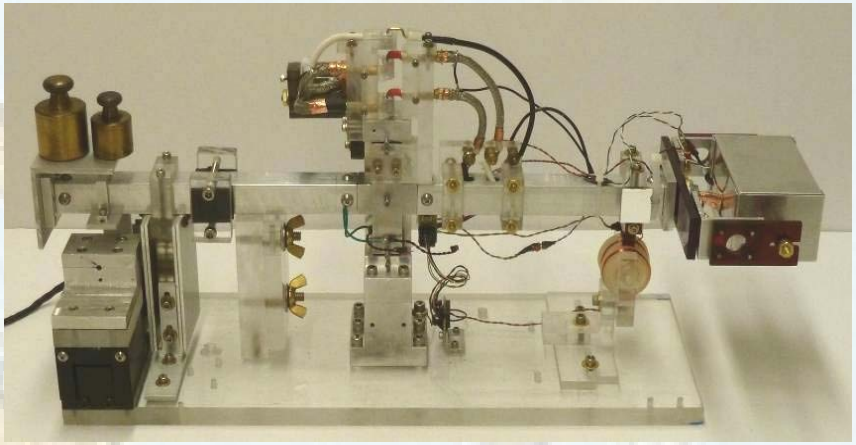


Buldrini&Tajmar, Experimental Results of the Woodward Effect in a Micro-Newton Thrust Balance.

Marc G.Millis, et al. Frontiers of propulsion science (AIAA, Reston, VA, 2009)

Experimental tests

Replicators (Oak Ridge National Labs – Sandia National Labs): no clear evidence (no papers!)
Due to "*variation in construction DETAILS*"?



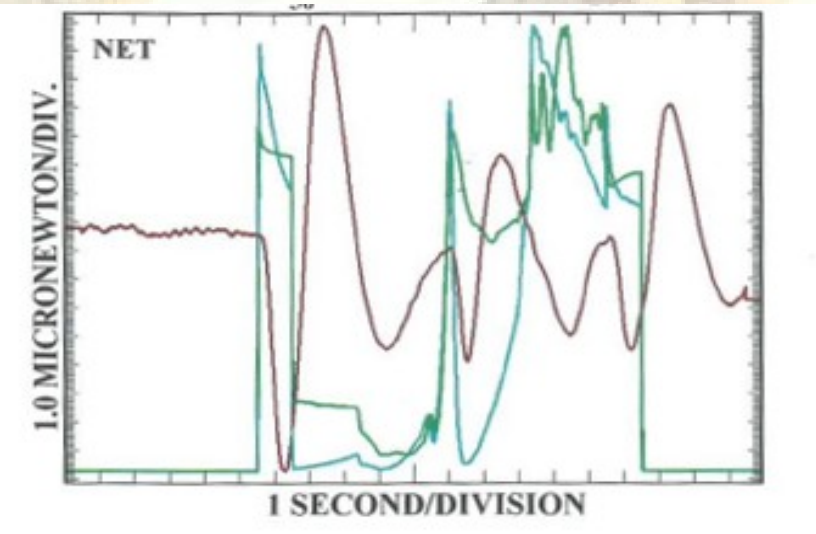
Other tests by Woodward:

High precision thrust balance

Mach-Lorentz thrusters -> substituted by PZT+capacitor (more simple) -> signal: ~10μN thrust (*Fern+Woodward2004*)

Moved to another lab: try to repeat-> fail! -> instead of try to repeat the results make tests for spurious effects!

Detected issues:



Dean effect: signal by vibrations
Thermal effects: thermal expansion -> force
-> loss of resonance condition for stability
-> lower power -> lower S/N
Residual air
Stray em fields

Discrepancy (factor 100!) due to instrumental effects -> agree with predictions

Conclusions

Woodward effect: Theory:

Works from first-class scientists

Published papers on peer reviewed journals

No clear consensus on the results

Woodward effect: Experiments

Many claims from scientists at the “border” of academic world

Many results presented at workshops

Relatively few papers published on peer reviewed journals (and not fully convincing – (my opinion))

No clear or repeatable evidence by now


Thank you