

EmDrive – A Challenge for Scientific Orthodoxy

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- 1. Basic EmDrive science**
- 2. Problems of scientific and academic bias**
- 3. Motivations for funding EmDrive development**
- 4. Implications of current technology status**

What is EmDrive ?

EmDrive is the first true Propellantless Propulsion technology

High frequency electrical energy is directly converted to thrust

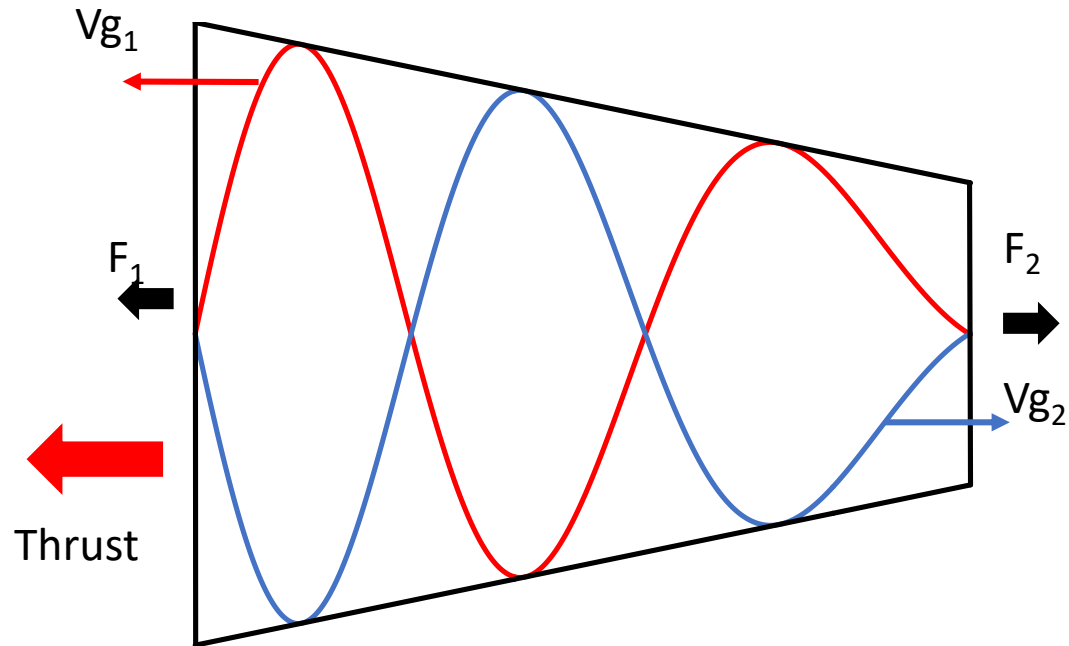
It is a resonant microwave cavity, shaped to obtain different group velocities at each end, and thus achieve a force difference as the EM wave reflects off each end plate

Large end V_{g1} \longrightarrow speed of light

Small end V_{g2} \longrightarrow zero

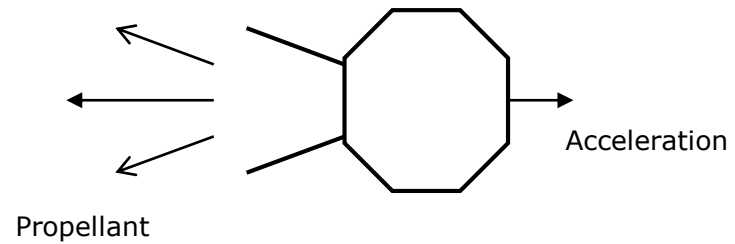
Therefore $F_1 > F_2$

Thrust = $F_1 - F_2$

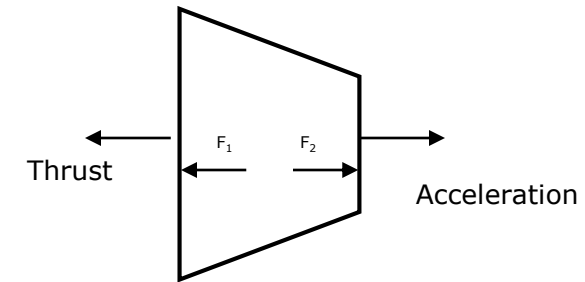


EmDrive is not a challenge for science

Conventional Rocket



EmDrive Thruster



EmDrive is not a reactionless thruster, it is simply a new class of electrical machine

Classic Physics can answer all questions about EmDrive

How is Momentum Conserved? EmDrive obeys Newton's Laws

How is force produced? Radiation Pressure. Maxwell.

Why are the end plate forces different? Different group velocities due to different diameters. Cullen 1952

How is the force multiplied? EmDrive is a Resonant cavity with a multiplication factor Q. Bailey 1955

Why is EmDrive an Open System? Einstein's theory of Special Relativity

Why are there no side wall forces? Thrust due to travelling waves not standing waves.

How is energy conserved? EmDrive is an electrical machine.

What limits thrust in high Q thrusters? Internal Doppler shift.

How is thrust calculated? Thrust equation.

How is thrust measured? With great care.

How is the thrust equation derived?

The EmDrive equation for static thrust is easily derived from two of the most famous equations in physics.

$$\mathbf{F=ma} \quad (\text{Newton}) \quad -1$$

$$\mathbf{E=mc^2} \quad (\text{Einstein}) \quad -2$$

Where F=Force (N) m= mass(kg) a =acceleration (m/s²)

E =Energy (J) c=speed of light (m/s)

Substituting 2 in 1

$$\text{Then } F=\frac{Ea}{c^2} \quad -3$$

$$\text{But } E=Pt \quad \text{and} \quad a=\frac{V}{t}$$

Where P=Power (W) t=Time period (s)

V=velocity change over t (m/s)

Substituting in 3

$$F=\frac{PV}{c^2}$$

For an EM wave reflected from the end plate of a cavity

$$F_1=\frac{2PVg_1}{c^2} = \frac{2P}{c} \times \frac{Vg_1}{c}$$

Where F₁ = End plate 1 force (N)

Vg₁ = Group velocity at end plate 1

For the Thrust on a tapered cavity

$$T=\frac{2PQ}{c} \left(\frac{Vg_1}{c} - \frac{Vg_2}{c} \right)$$

Where F₂ = End plate 2 force (N)

Q = Cavity Q factor

Where Df = Design Factor

$$\text{Then } \mathbf{T=\frac{2PQ Df}{c}}$$

Experimental Data Supports Simple Thrust Equation

Experimental data from:

SPR Ltd (UK)

NWP University (China)

NASA (US)

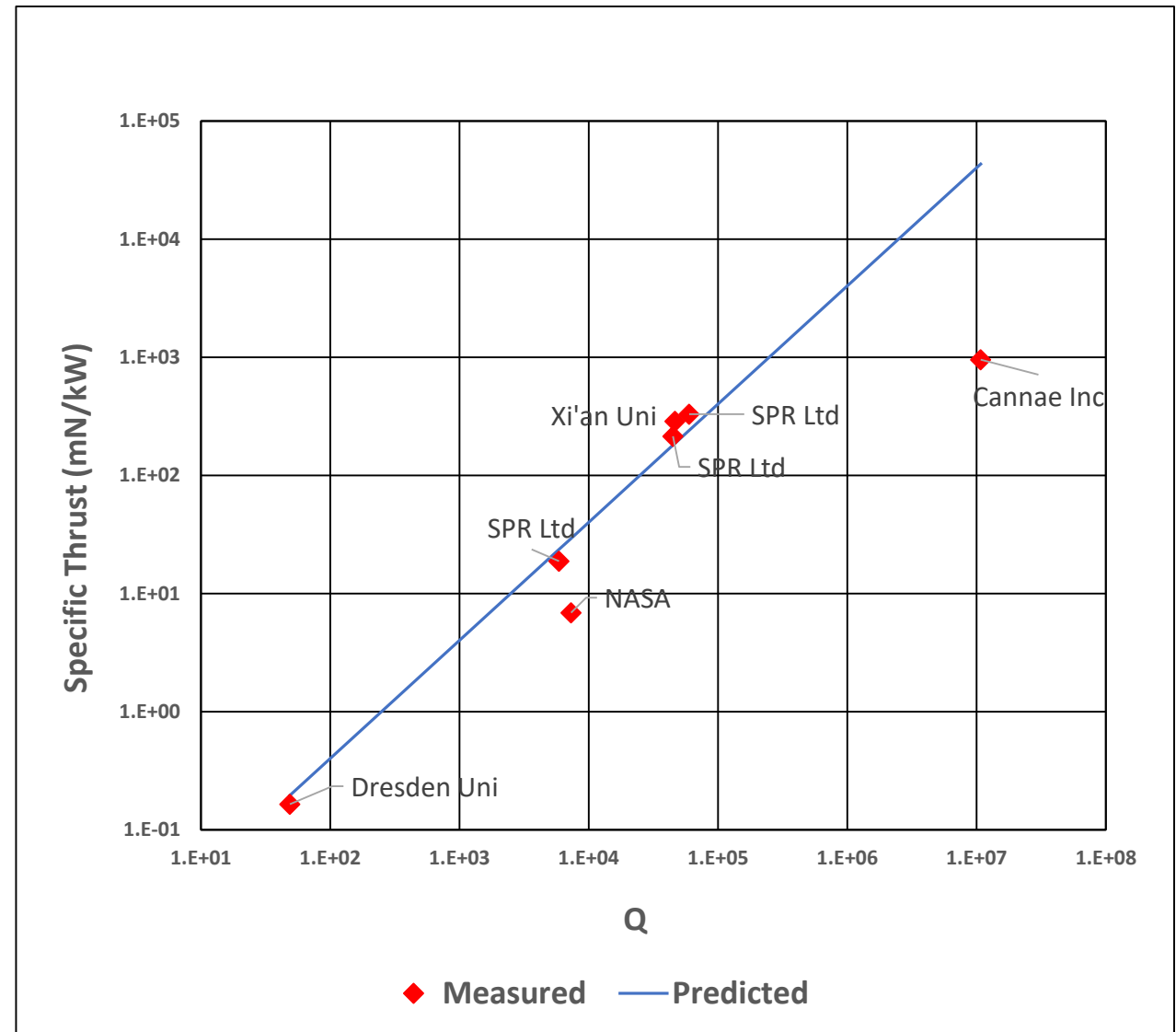
Cannae Inc (US)

Dresden University (Germany)

Predicted data assumes $D_f = 0.6$

Further reading on EmDrive theory
and experiments

www.emdrive.com



If the science is sound why is it not universally accepted?

EmDrive theory requires the convergence of a number of basic laws of Physics in an unfamiliar way.

Understanding the theory requires knowledge, patience and the ability to do the maths.

“Extraordinary claims require extraordinary evidence”

EmDrive is a difficult technology to design, build, test and thus difficult to prove to exacting standards.

Design requires special software

Build requires precision engineering

Test requires expensive test equipment and sophisticated facilities. (e.g. NWPU)

EmDrive thrusters giving significant thrust(100s mN) are potentially lethal.

Magnetron or TWTAs require High voltage power supplies

High Q, high power thrusters store significant energy levels.

High power microwaves cause blindness and can kill.

Proof of EmDrive theory and operation takes time, money and intellectual effort, which requires significant funding.

It is much easier to limit funding and criticise the level of experimental proof.

How is funding obtained?

Funding comes from four motivations:

Fear.

Defence applications provided initial motivation for EmDrive development.

Greed.

Industry provides motivation both for and against.

e.g. Boeing for, Airbus and Shell against.

Huge potential profits, but highly destructive to existing business models

Curiosity.

Universities should lead.

UK Academia has shown almost zero interest due to “*Laithwaite effect*” and lack of resources.

However world wide interest from Universities and individual researchers is increasing

Hope.

Optimists hope that technology will lead to a better world, and have provided significant UK funds.

How have these motivations been applied to EmDrive and what has been their effects?

Fear. The initial motivation for EmDrive

In 1970s the cold war was causing considerable fear.

The UK nuclear warhead programme Chevaline was undergoing guidance & propulsion problems.

In his 1974 Royal Institution lecture Professor Eric Laithwaite suggested that gyroscopes could provide a means of reactionless propulsion. He was scorned by the academic establishment.

Sperry Gyroscope were asked to investigate. I joined the team that was tasked with *“think the unthinkable”*.

We concluded that a mechanical system could not provide such propulsion but an electromagnetic one might, but with very low thrust.

I returned to electromagnetic sensor research, for a variety of autonomous weapon systems, used as advanced minefields for land and sea deployment. *“Robotic weapon systems are not new”*.



Curiosity. Sustaining the initial concept.

Whilst the official project had been shelved, I maintained interest in the Electromagnetic concept out of simple curiosity.

In the mid 1980s I was working for Marconi Space and Defence systems on the Skynet 4 programme.

Fear. The start of a new concept.

The Skynet 4 processing channel, for which I was responsible, gave good protection from jamming.

However as was succinctly pointed out, nothing would protect the satellite from *“a couple of ounces of C4 and a bag of nails”*. The Mine Warfare course at HMS Vernon now proved useful !

Continuous propulsion is required to provide a countermeasure to orbital mines by random manoeuvring.

I decided to design and test an experimental thruster in my garage.



Greed. The death of company interest in EmDrive.

After considerable part time effort I was confident a working thruster could be built.

The concept was rejected by my employers who were, by then, Matra Marconi Space, (now Airbus).

There had been heavy company commitment to the Arienne 5 programme and *“no new propulsion concepts would be considered for at least a decade”*.



Hope (+ Fun!). Satellite Propulsion Research Ltd

In 2001 I formed SPR Ltd to see how far I could take the concept.

Within 6 months we won a SMART award from the DTI.

Financial support from DTI continued for 5 years and we produced a Demonstrator Engine.

In 2006 we obtained significant private investment enabling dynamic testing and the start of a superconducting thruster programme.



Fear. China and the US take an interest.

Following the 2006 New Scientist article, NWPU in China started work on EmDrive

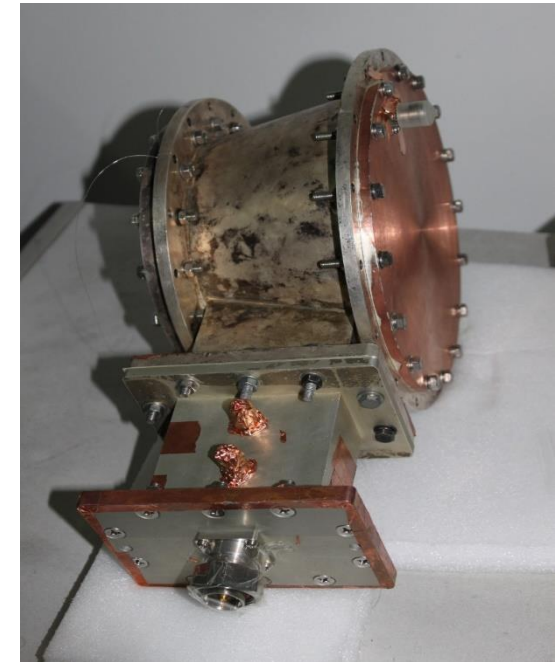
In April 2010 NWPU revealed that they had measured 720mN of thrust for 2.5kW input

In 2012 NWPU published their first peer reviewed paper

In 2008 we attended a meeting at the Pentagon. USAF, USMC, RAAF, NASA & DARPA attended. Chaired by Director NSSO.

An export licence and TAA were set up and a technology transfer to the US was agreed

July 2010 Boeing Flight Thruster contract was completed



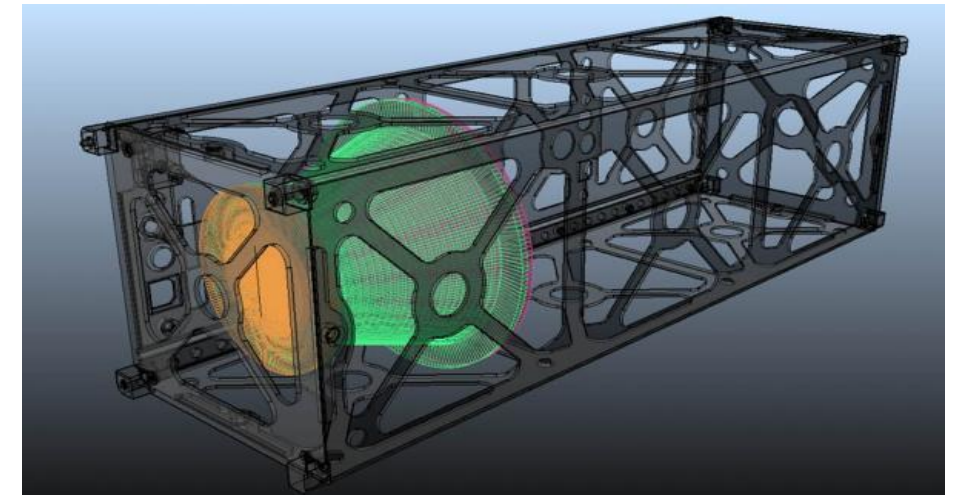
Fear. Russian Interest

In 2009 I was asked by USAF to comment on a report that Russia had launched a “perpetual motion machine “ in their Yubileiny satellite.

If this was an EmDrive thruster, data indicated it was operating around 8GHz and was powered by a standard 40W X-Band TWTA, as commonly used on military comsats.

A few weeks ago an image appeared on the internet illustrating how an 8GHz EmDrive thruster would fit into a modern, off-the-shelf, 3 unit Cubesat.

Any country with LEO capability can now deploy low cost orbital mines to GEO.



Curiosity. The rest of the world takes an interest
“Science is not democratic”

Companies and organisations that are known to have built and tested EmDrive thrusters include:

NWPU Xi'an China
Chinese Academy of Space Technology (CAST)
Boeing USA
Cannae USA (superconducting test)
NASA USA
Unidentified US company
Unidentified Israeli company
University of Dresden Germany

Individual researchers who are known to have built and tested EmDrive thrusters in the following countries:

USA (3 separate researchers)
Germany
Australia
Canada
South Africa
Romania

Theoretical studies known in:

France
Argentina
Brazil
Finland

There may not yet be universal agreement how EmDrive works, but there is agreement that if you build a thruster according to SPR design rules, it does work.

Why should the UK take note of foreign EmDrive Developments ?

In orbit testing of EmDrive has been reported by CAST, suggesting commercial use of EmDrive has now been authorised by China

Implies military applications of first generation technology are now operational. **Western space assets vulnerable.**

January 2014. Information from US (AIM) and China (NWPU) reveal they both have a detailed knowledge of EmDrive theory, and **a solution to the High Q Acceleration Problem.**

Further work at SPR Ltd has also solved High Q acceleration problem (3G design).

2015. Gilo Industries Research + SPR Ltd
New superconducting cavity design
YBCO thin film technology
LN2 and LH2 cooling

Supertanker Propulsion System (2013 Shell Proposal)

Batillus class supertanker 555,000 tonnes, 64,800 bhp

Approximate thrust 648 tonnes, (100bhp/tonne)

Conventional Electrical Specific Thrust = 0.13kN/kW(e)

2G 900MHz LH2 YBCO thruster gives estimated microwave specific thrust 10kN/kW(m)

Closed cycle cooling system (e.g. Turbo-Brayton type) efficiency 4%

Thus predicted 2G EmDrive Electrical Specific Thrust = 0.4kN/kW(e)

Use of LNG boil-off in a total loss cooling system would enable much higher specific thrust.



Conclusions

Hope and Fear are the main UK motivations for EmDrive development.

Hope.

EmDrive can lead to a transport revolution, (including flying cars). Also low cost access to space, which will enable Solar Power Satellites to solve the worlds energy problems, sunshade satellites to give climate control, and short flight times to Mars.

Fear.

1G EmDrive is probably now operational and thus will make all military space assets (LEO, MEO and GEO) vulnerable to future attack from small countries, or high-tech terrorist organisations.

2G EmDrive is at the experimental phase and will give low acceleration propulsion for many applications.

3G EmDrive was at the theoretical stage Jan 2014.