The impact of EmDrive on Future Warfare

Roger Shawyer SPR Ltd

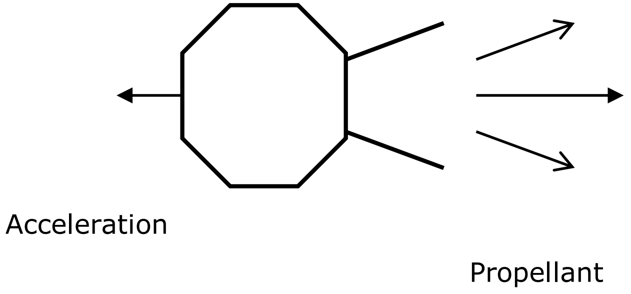
12th February 2019

1. EmDrive, what is it and where did it come from?
2. Basic EmDrive Science
3. Development of the technology
4. A proposed Moon mission
5. Defence applications of EmDrive
6. Conclusions

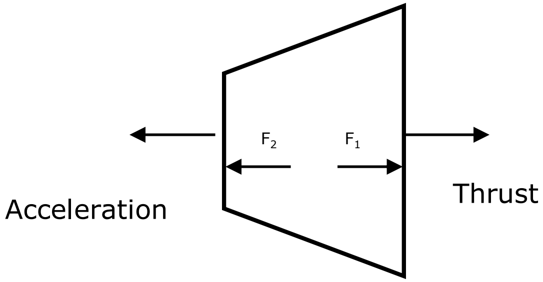
What is EmDrive

EmDrive is the first true Propellant-less Propulsion technology

Conventional Rocket



EmDrive Thruster



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

As with all machines, EmDrive obeys:

The Law of conservation of momentum

The Law of conservation of Energy

Where did EmDrive come from?

The origin of EmDrive was the result of **three wars**.

In the 1970s the **cold war** was driving missile technology

The UK nuclear warhead programme Chevaline was suffering from problems with the Hot Gas Propulsion system.

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.

Chevaline Warhead. Imperial War Museum

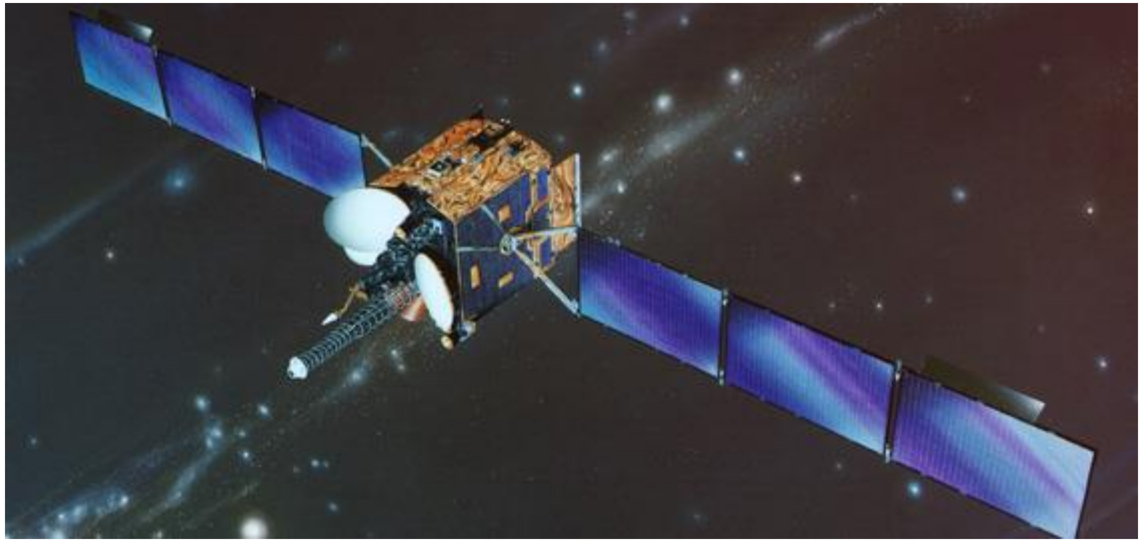
Where did EmDrive come from?

I continued with electromagnetic sensor research for surveillance and targeting applications, which led to my accidental involvement in the start of the **Iran/Iraq war** in 1980.
This led to me joining the Space Industry.

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".* Military satellites were vulnerable!

In 1994 I was payload project manager for the NATO 1VB payload which played a significant part in bringing an end to the **Bosnian War**. Military satellites were essential for peace!

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



NATO 1VB satellite

Basic EmDrive Science

High frequency electrical energy is directly converted to thrust

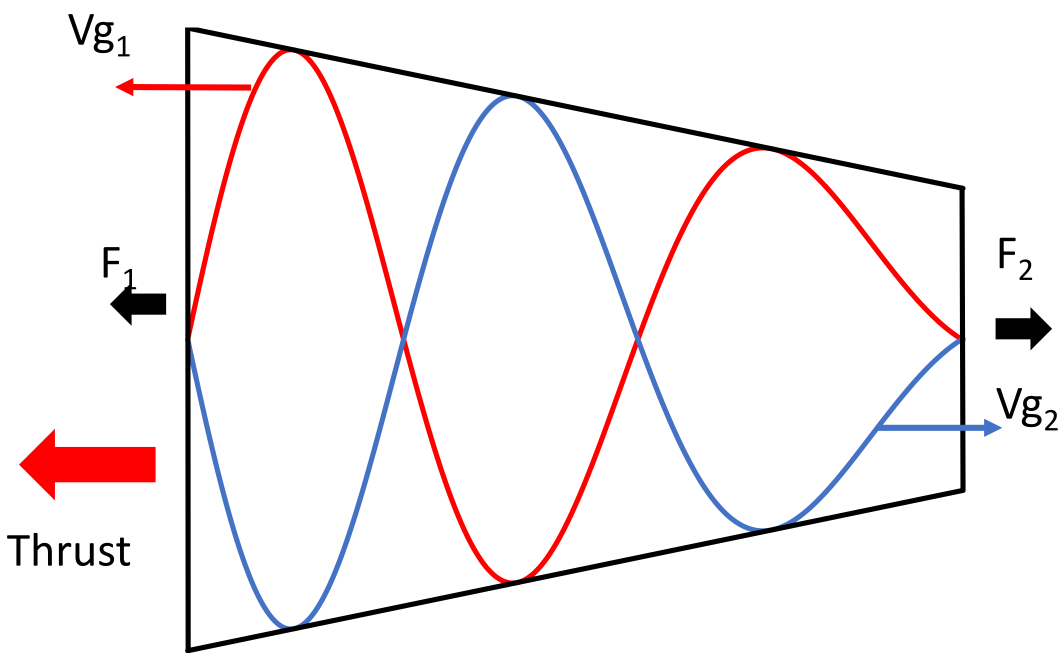
An EmDrive Thruster is a resonant microwave cavity, shaped to obtain different group velocities at each end, and thus achieve a force difference as the EM wave reflects off each end plate

Large end Vg_1 ⟶ speed of light

Small end Vg_2 ⟶ zero

Therefore $F_1 > F_2$

Thrust = $F_1 - F_2$



How is the thrust equation derived?

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

$F=ma$ (Newton) -1 Where F=Force (N) m= mass(kg) a =acceleration (m/s^2)

$E=mc^2$ (Einstein) -2 E =Energy (J) c=speed of light (m/s)

Substituting 2 in 1

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

But $E=Pt$ and $a=\frac{V}{t}$ 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 F_1 = End plate 1 force (N)

Vg_1 = Group velocity at end plate 1

For the Thrust on a tapered cavity

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

Where F2 = End plate 2 force (N)

Q = Cavity Q factor

Then **$T=\frac{2PQ\,Df}{c}$** Where Df = Design Factor

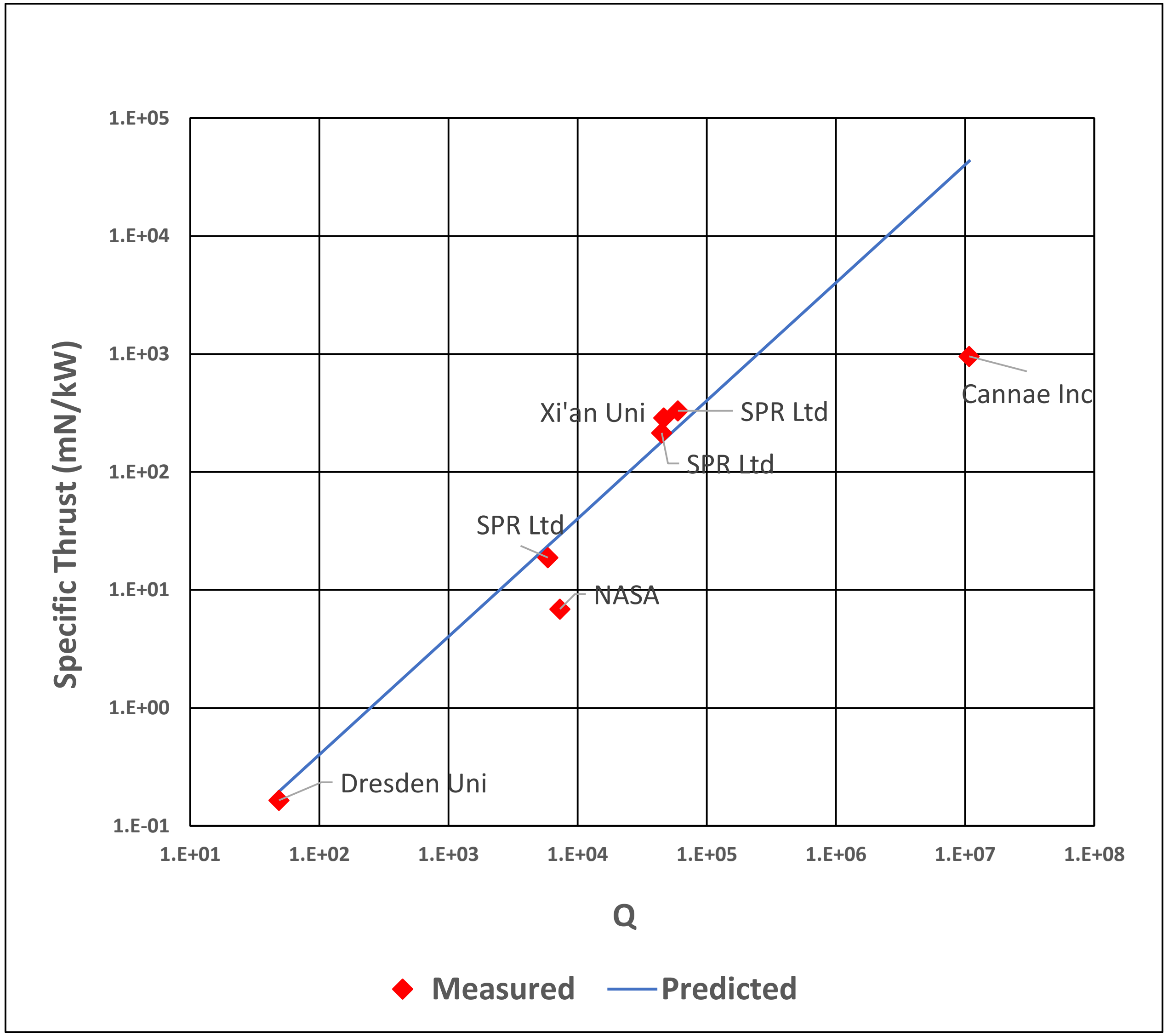
Experimental Data Supports Simple Thrust Equation

Experimental data from:

SPR Ltd (UK)
NWP University (China)
NASA (US)
Cannae Inc (US) 2G thruster
Dresden University (Germany)

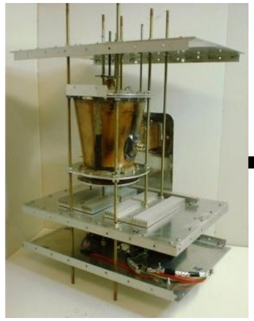
Predicted data assumes $D_f = 0.6$

Further reading on EmDrive theory and experiments
www.emdrive.com



UK Experimental Programme

2003



Experimental Thruster

2.45 GHz

Q=5.9x10^3

T=19mN/kW

Magnetron

2006

Demonstrator Engine

2.45 GHz

Q=4.5x10^4

T=243mN/kW

Magnetron

2010

Flight Thruster 3.8 GHz

Q=5.8x10^4

T=326mN/kW

2008

Experimental Superconducting Thruster 3.8 GHz

Q=6.8x10^6 (liquid nitrogen)

Predicted T=36N/kW

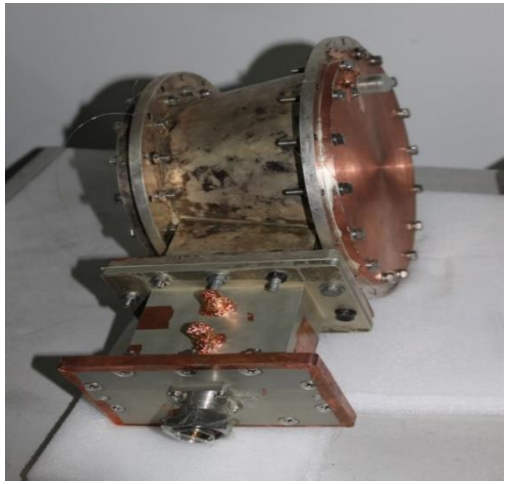
Both Flight and superconducting thrusters used narrow band inputs, requiring low manufacturing tolerances

EmDrive in China Russia and the US

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

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.



NWPU Experimental Thruster

Yubileiny Satellite

Engineering Challenges

Microwave cavities are difficult
ESA Olympus satellite used an incorrect cavity design for the first 8 years of the programme, leading to major delays.

High Q asymetric EmDrive cavities are very difficult!

Machining tolerances and end plate alignment are critical
1 micron error for Q=50,000 means total path length error =50mm (equivalent to approx half a wavelength)

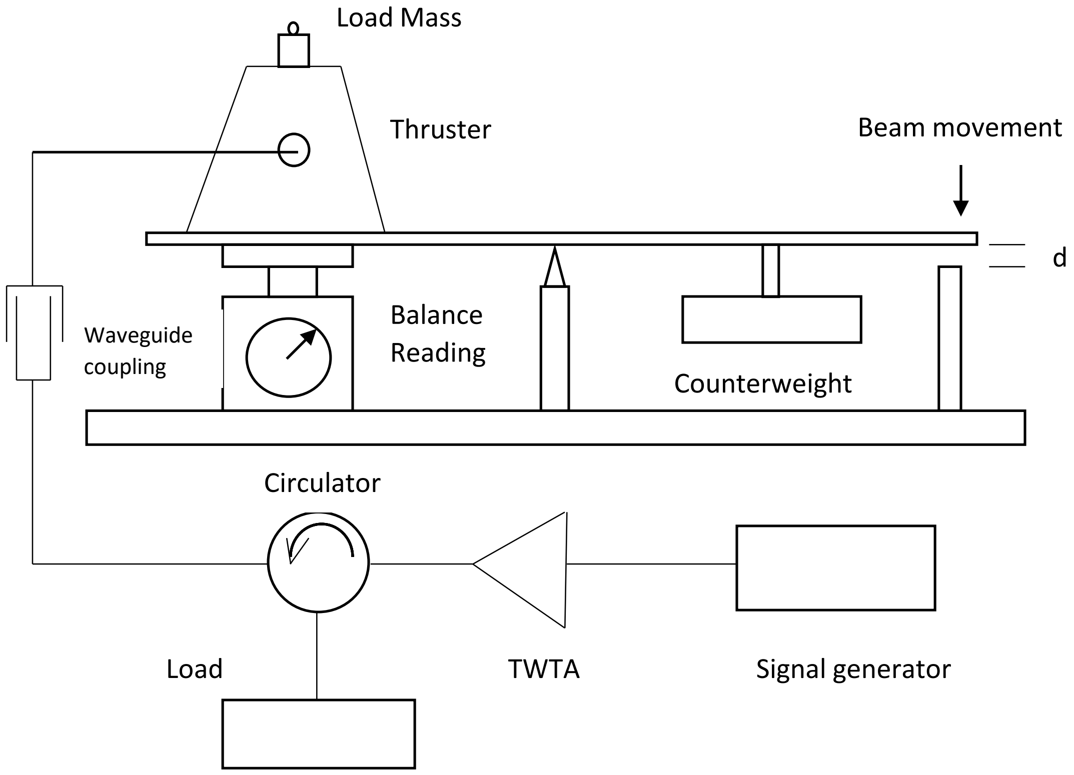
Input elements whether slot, loop or probe require careful tuning and must match wave impedance at the input position and resonant frequency

Input elements and cavity have very different thermal responses under high power operation. For Q=50,000 and Pin =1kW instantaneous power =50MW

Test methods must take account of basic EmDrive Physics and ensure thruster is loaded.

ESA Olympus Satellite

Prediction of Thrust /Load for Low Thrust First Generation EmDrive Thruster



Assume Thrust =1 gram
Assume ideal balance with zero deflection/force

Test No	Load Mass (gm)	Balance reading (gm)	Beam movement (mm)
1	2	2	0
2	0.5	0	d
3	0	0	0

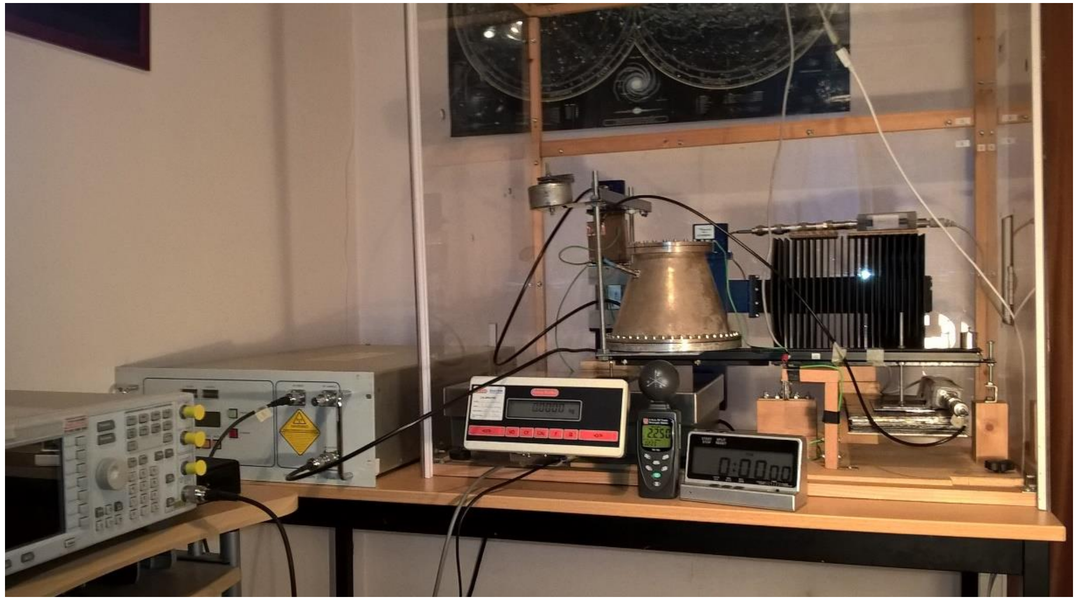
Test 1. Illustrates compliance with conservation of momentum
Thrust + Reaction Force = 0

Test 2. Demonstrates "Lift 0ff"

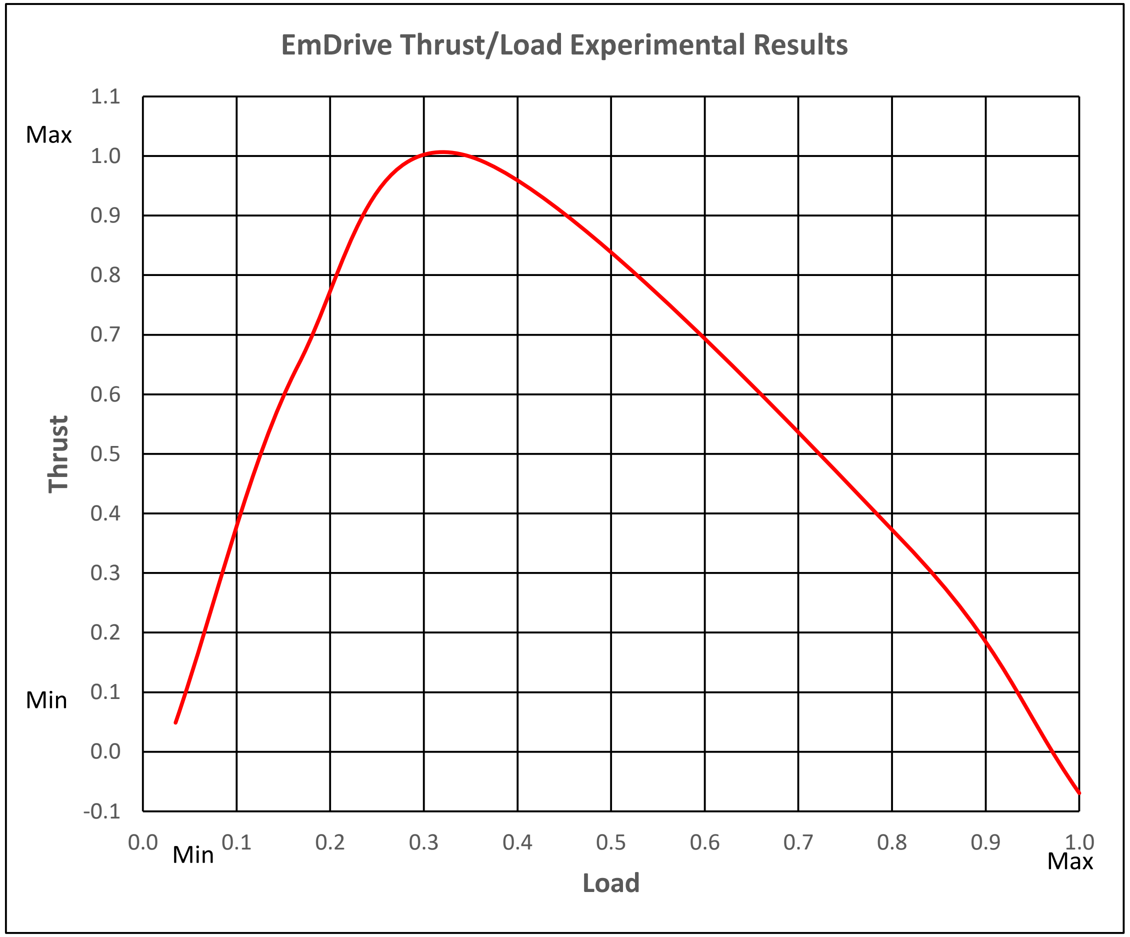
Test 3. Illustrates compliance with conservation of energy
Stored energy $\longrightarrow$ 0
Thrust $\longrightarrow$ 0

The effect demonstrated in test 3 implies an EmDrive thruster will not work in a true free space situation without a load compensation technique being used. This has been noted in reports of simulated and in-orbit tests.

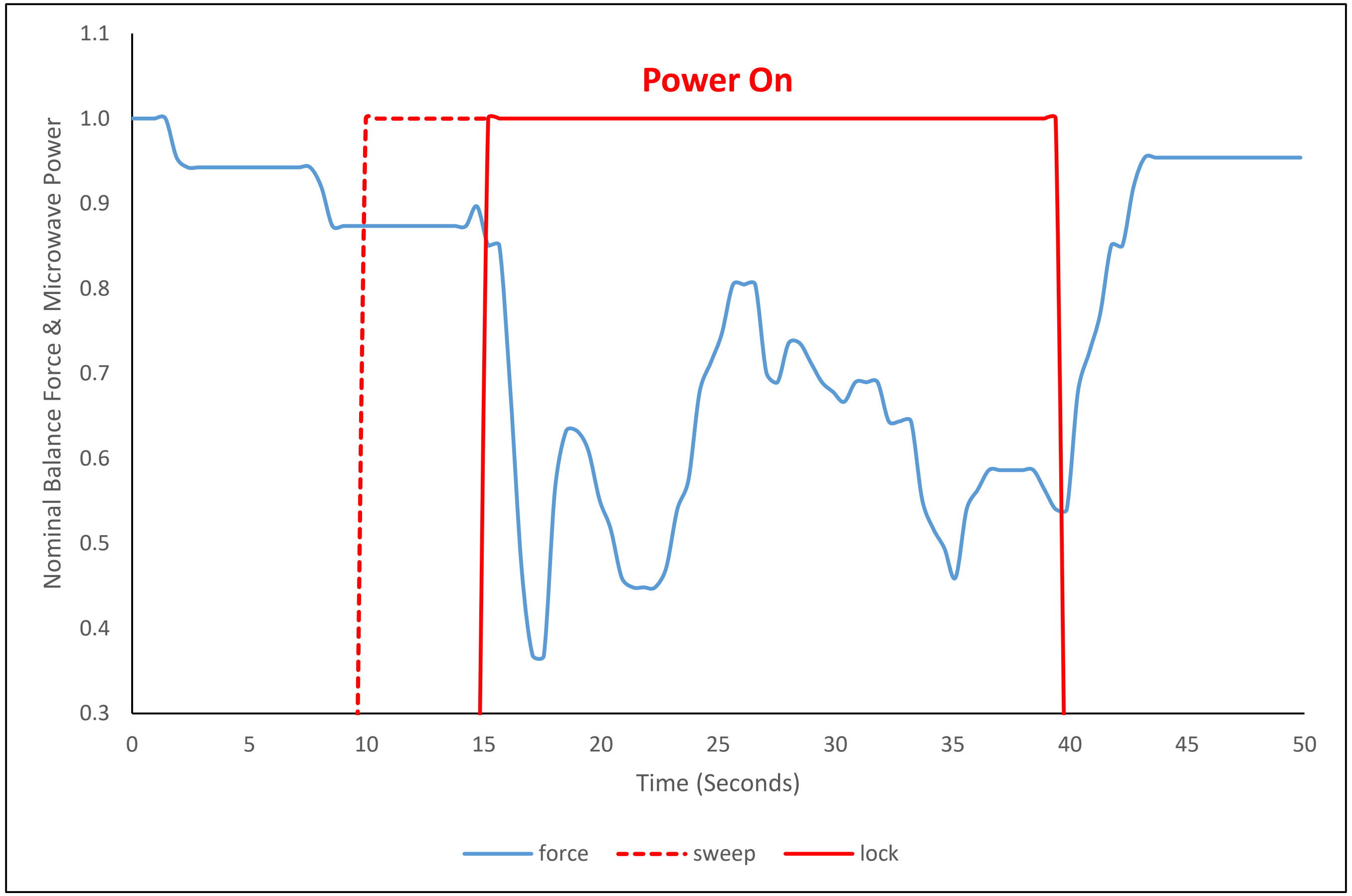
Measurement of Thrust/ Load for Low Thrust First Generation EmDrive Thruster



Experimental work was carried out under a commercial agreement therefore the following experimental results are shown on nominal axis scales.



Typical Test Run with No Lift - Off



Load set to 0.45max

Slide 11 shows Thrust = 0.9 Max

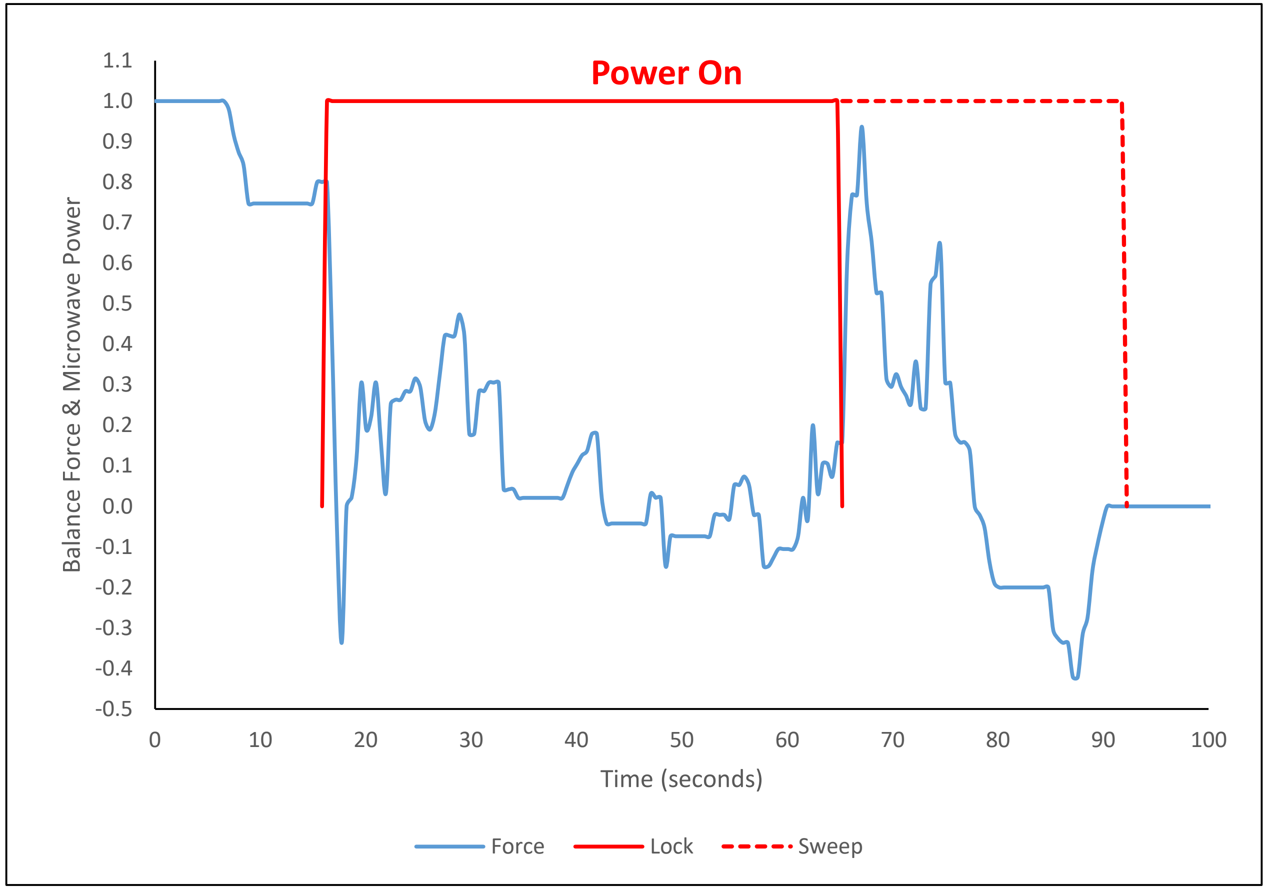
Initial power on with frequency sweep to stabilise input circuit

Balance force decreases immediately when frequency lock is reached

Underdamped balance response

Balance force returns to initial level when power is switched off

Test Run with Lift- Off



Load set to 0.3Max

Slide 11 shows max thrust

Immediate frequency lock

Force decreases below balance zero

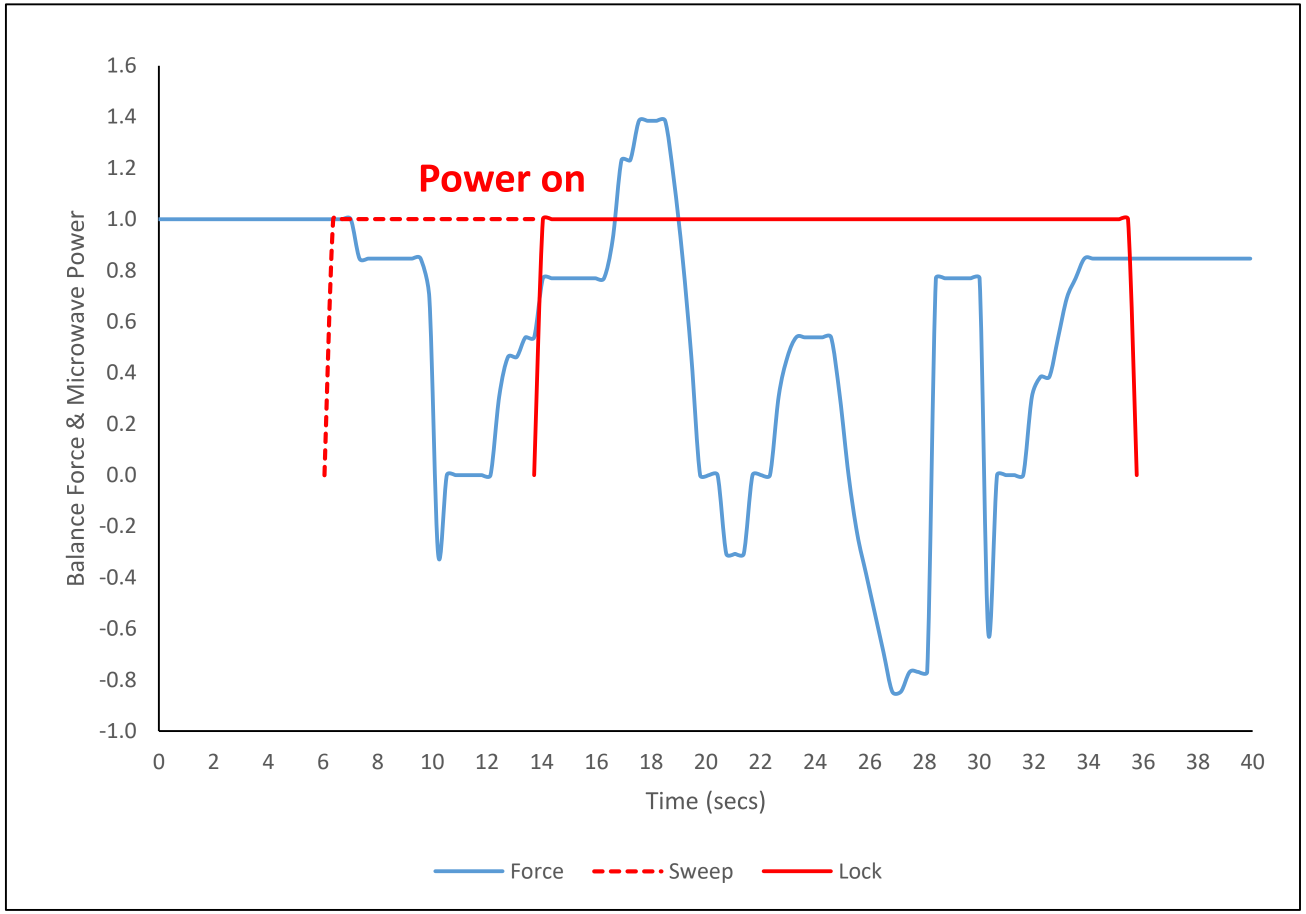
Frequency lock lost followed by sweep

Force increases to initial value, then decreases as lock is re-established

Lift-off leaves balance at zero

Power off.

Test Run with minimum Load . Produces Negligible Thrust



Load set to 0.04Max

Slide 11 shows Thrust = 0.05 max

Balance force is below noise floor

These tests illustrate why many experiments have shown zero thrust on very high resolution balances.

EmDrive Development Generations

Thrust equation shows static thrust increases linearly with Q and Power.

First Generation (1G). Uncooled microwave cavity. Low specific thrust.
In-orbit space applications.
$Q = 5x10^4$ Specific Thrust = 0.3N/kW

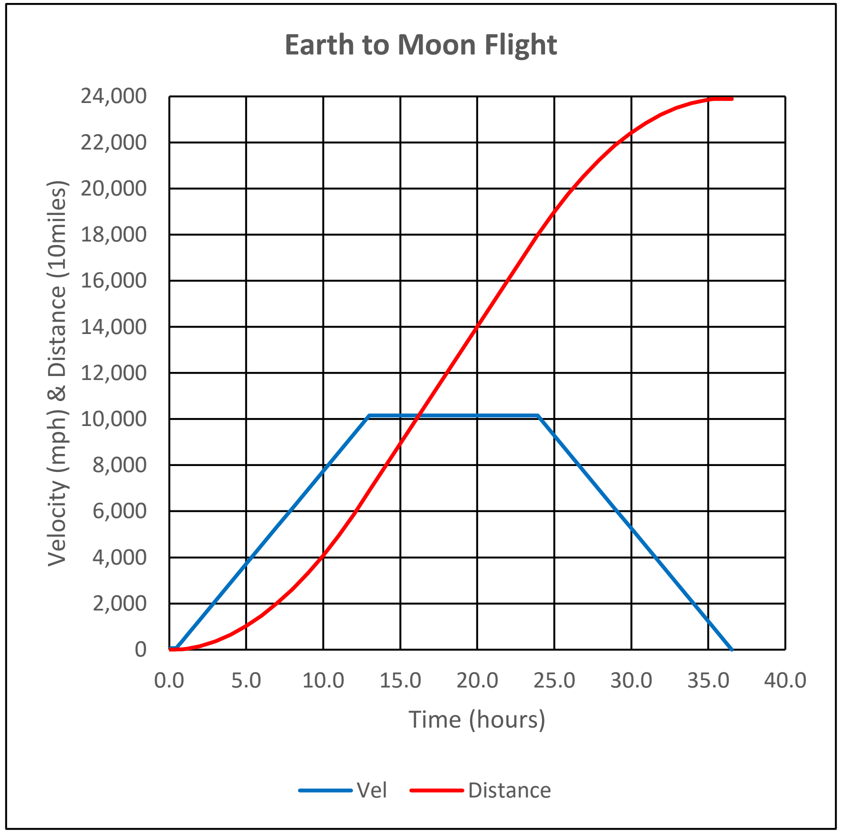
Second Generation (2G). Superconducting cavity cooled by liquid Hydrogen.
High Specific thrust. Low acceleration due to internal Doppler Shifts.
Marine applications.
$Q = 1.1x10^8$ Specific Thrust = 470N/kW Acceleration = 0.05 m/s^2

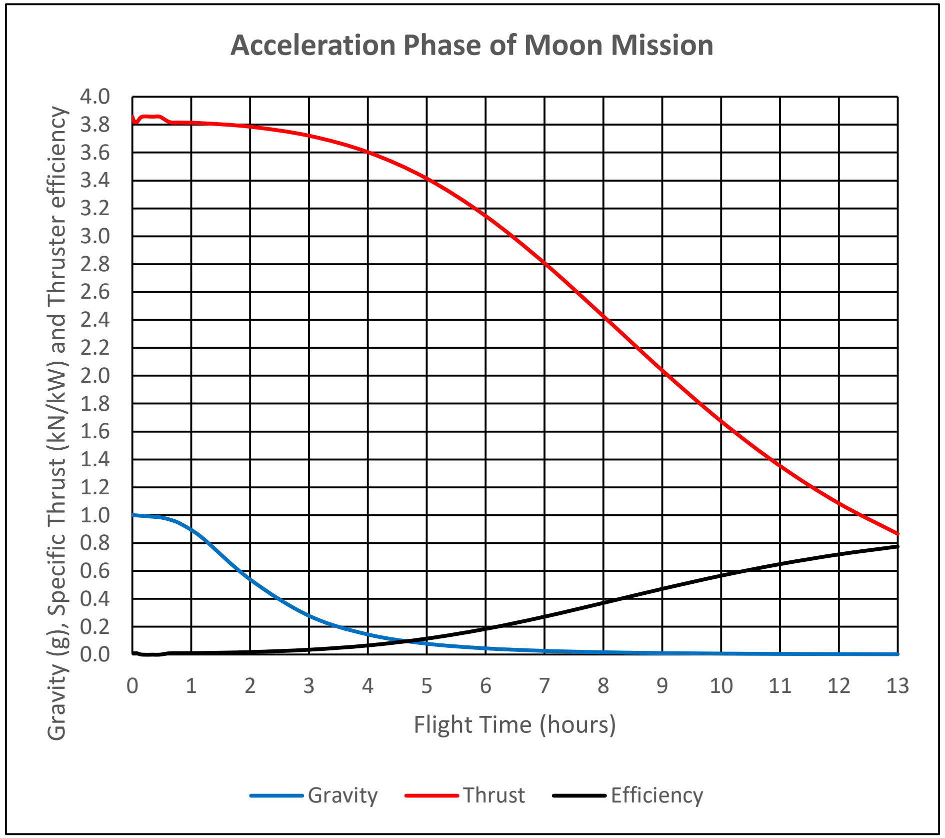
Third Generation (3G). Superconducting cavity cooled by liquid Hydrogen.
Very high specific thrust (high Q design). Doppler shift compensation.
Acceleration limited by conservation of Energy.
Aerospace applications
$Q = 7.7x10^8$ Specific Thrust =3,900N/kW Acceleration = 0.1 m/s^2

The Thrust/Load theory has been an essential input to many design studies covering applications from oil tankers to interstellar spacecraft.

3G Commercial Application. Moon Mission Analysis

3-man Personal Space Vehicle (PSV) for a Moon Landing Mission





Direct Flight path comprises:
1.Take-off & acceleration phase
2.Cruise phase
3.Deceleration & landing phase

During acceleration phase reducing gravity causes decreasing specific thrust, but increasing efficiency
This demonstrates the loading effect

Moon Mission Technology Comparison to Scale

3G EmDrive will cause big problems for current space companies reliant on conventional propulsion technology

An EmDrive propelled vehicle is only subjected to low mechanical and thermal stress levels. The construction is within the capability of a modern automobile company, including those with hydrogen powered fuel cell technology.

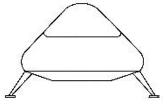
1960s Rocket

Saturn V

3 men to the Moon and back

110.6 m high

2,970 Tonnes



2020s EmDrive

PSV

3 men to the Moon and back

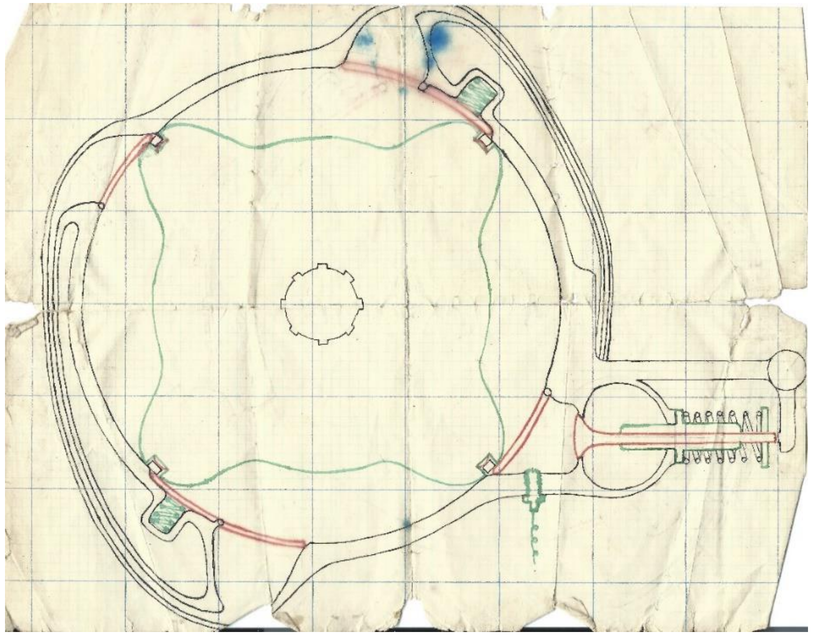
5.7 m high

10.4 Tonnes

Conclusions

3G EmDrive could take a long time to reach general acceptance due to vested interests and a reluctance to proliferate the technology beyond existing high technology countries. However basic physics says it works and experimental evidence proves it

Rotary engines for Flight applications took 85 years!



Early Rotary Engine Design RAF Halton 1931

Rotron Engine for Parajet application 2016

The demands of future warfare will accelerate EmDrive development