A Note on the Principles of EmDrive force measurement

1. Introduction

A number of research groups have asked questions about methods of measuring EmDrive forces. Answers to these questions require a basic understanding of the theory of operation of EmDrive, and a rigorous understanding of classic mechanics and Newton's Laws. This note describes simple examples of test methods which will clarify experimental results.
The most important point to be made, is that to measure force, the cavity must experience acceleration. In a fully restrained cavity, thrust and reaction force cancel out.
Demonstration of this point clearly shows that EmDrive is a Newtonian machine, and the law of conservation of momentum is maintained.

2. Operation of an EmDrive thruster

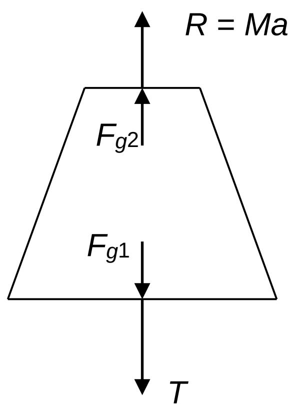

Fig 1. Thruster Force Diagram

The net force (F) created within the thruster is given by the basic equation

$$F = Q\left(F_{g1} - F_{g2}\right)$$

where F_{g1} and F_{g2} are the radiation forces caused by group velocities V_{g1} and V_{g2} at the two ends of the thruster.

This internal force F is measured by an outside observer as the Thrust T, a force acting against the observer in the direction shown.

Newton's laws state that T must be opposed by an equal and opposite reaction R, such that

$$R = Ma$$

where M = mass of the thruster
a = acceleration of the thruster in the direction shown.

Note that the reaction is either the acceleration a, or a force equal to Ma, but not both.

Clearly, in a static situation, where T and R both exist as forces, they will cancel out. Thus any attempt to measure them by simply placing the thruster vertically on a set of scales will fail. If however the thrust is sufficient such that $a = -g$, then the thruster could be made to hover above the scales.

A rigorous examination of measurement techniques is required, to determine how these forces can be measured.

3. Measurement of EmDrive forces in free space.

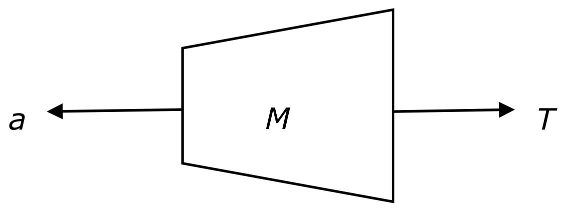

Fig 2. Thruster in Free Space

In free space, the thruster will simply accelerate at a m/s/s, and R will not be measurable. To measure R it is necessary to restrain the thruster against a fixed reference point.

However at rest, no force can be measured as R will cancel out T as in Fig 1.

This situation is unique to a propellantless thruster such as EmDrive and analogies with conventional devices are pointless.

To illustrate further, assume the thruster is mounted on a friction free trolley, (or is suspended from a pendulum), and is restrained against a fixed wall by a load cell as shown in Fig 3.

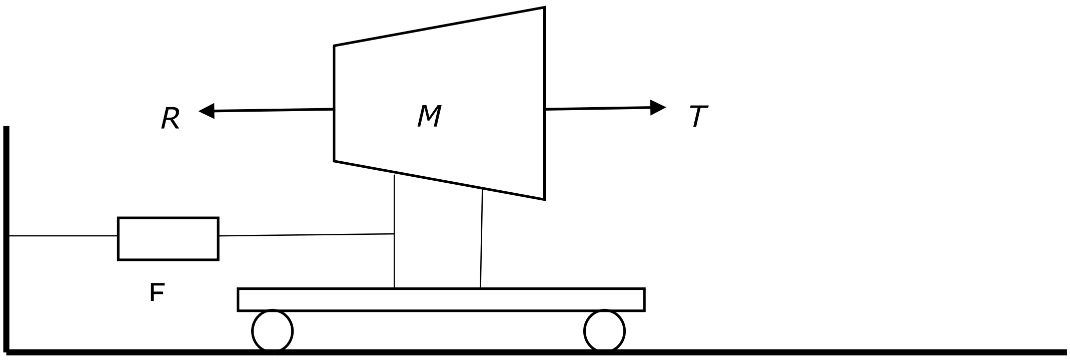

Fig 3. Restrained Thruster

Because the thruster is at rest, no force will be measured on the load cell.
i.e. $F = T\text{-}R = 0$

It therefore appears that a force measurement can only be made in a dynamic environment, ideally by allowing the thruster to accelerate, measuring that acceleration, and then calculating the thrust from $T = -Ma$.

This is not a very easy method, although the SPR Demonstrator Thruster was successfully tested in this way on a rotary air bearing.

4. Practical static measurement techniques

A number of methods have been used in the UK, the US and China to measure the forces produced by an EmDrive thruster. In each successful case, the EmDrive force data has been superimposed on an increasing or decreasing background force, generated by the test equipment itself.

Indeed, in the UK when the background force changes were eliminated, in an effort to improve force measurement resolution, no EmDrive force was measured. This was clearly a result of attempting to measure the forces on a fully static thruster, where T and R cancel each other.

UK flight thruster measurements employ this principle to calibrate the background noise on the force balance prior to carrying out force measurements.

To illustrate one possible measurement method, assume the thruster is restrained, in a composite force measurement apparatus, by two load cells with different spring constants *K1* and *K2* (mm/kg).The restraining points are on the end plates of the thruster as shown in Fig. 4.

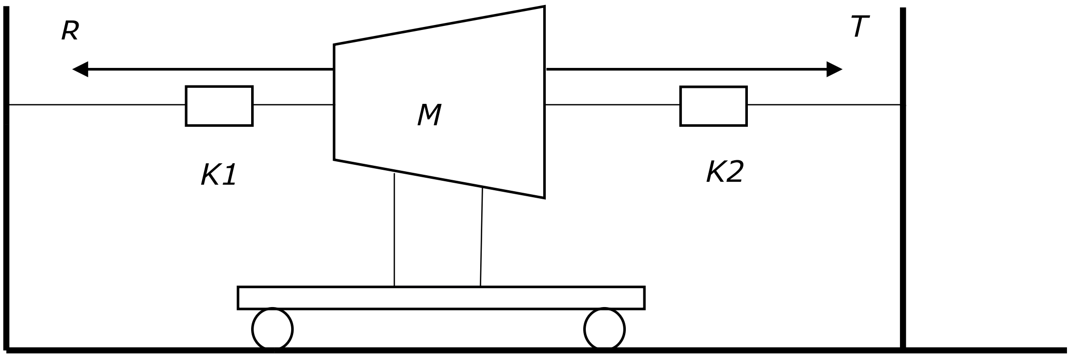

Fig 4. Composite force measurement.

If there is no acceleration of the thruster, *T* and *R* will balance out, and no forces will be measured on the load cells.

However, in a practical measurement, dissipation of the input microwave energy will cause the thruster wall temperatures to increase, and the walls to expand. The axial length of the thruster will increase, as illustrated by the dashed end plate positions shown in Fig. 5, and this will be registered on the load cells as forces *F1* and *F2*.

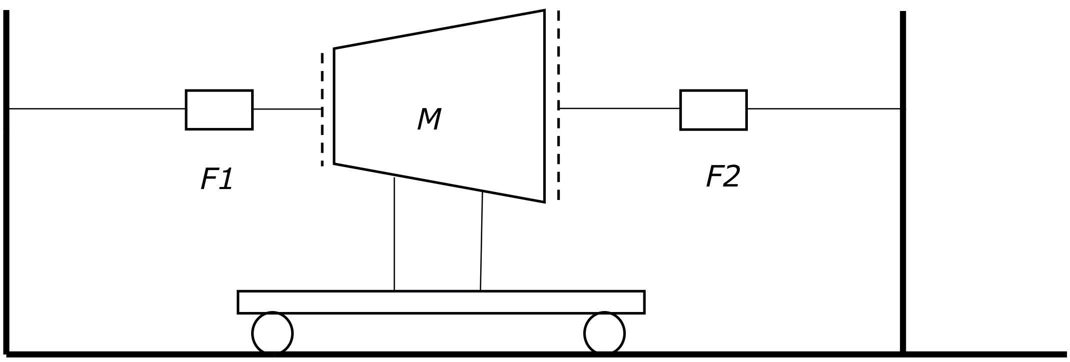

Fig 5. Force measurement with thermal expansion effects

The different values of *K1* and *K2* will cause the centre of mass of the thruster to move, thus artificially creating a dynamic situation where *R* or *T* can be measured as an increase or decrease in acceleration, whilst the centre of mass of the thruster is accelerating due to thermal expansion.

Clearly the values of *K1* and *K2* will determine whether *R* or *T* is measured, and what calibration factor must be applied to the raw data.

The value of *R* or *T* can be determined by the change in *F1* or *F2* after switch-on and switch-off of the microwave input. This is easily subtracted from the slow increase in *F1* or *F2* due to the wall expansion, which has a much longer time constant.

A review of the published test data from US and Chinese test programmes, together with UK measurements, supports the above principles.