Microwave Energy Injection into a Conical Frustum:
The NSF-1701 Phase I Test Report

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I. Introduction

Several institutions and private individuals have claimed to have measured "thrust" from asymmetric resonant cavities (frustums) when RF energy is applied. The thrust, which I will refer to as "The Emdrive Effect" or simply "Effect", has been described as propellant-less, using only electromagnetic energy without solid or liquid propellant (fuel) being expelled and therefore consumed. If true, it is a revelation in physics that will have far-reaching implications. Controversy has arisen, claiming the Effect would violate Newtonian Laws; the Conservation of Momentum and Energy. Some proponents of the Effect claim there is no violation while others claim it is an as-yet-unknown force. Regardless, additional data is needed to validate the claims.

II. Background and Definitions

My decision to proceed privately and independently with experimentation is due to simple curiosity. Though semi-retired, professionally I have spent the better part of 35 years in the RF and Microwave industry, from a technician to quality control, to sales and application engineering, leading to other senior-level management positions including product management. The industry segments I served were primarily military and aerospace. Privately, I have designed and built RF communications systems and maintain an Extra Class Amateur Radio license, though no longer active.

A frustum is an asymmetric cone or pyramid[1] with one end plate being larger than the other. A variety of common mathematical calculations are used to define a round, symmetric, resonant cavity (cylinder shaped) but a frustum cavity is a rarely, if ever, used cavity structure within the RF and Microwave Industry. All frustums constructed for prior experimentation have been fabricated using solid metal[2]. The materials used include aluminum and copper. Gold and silver plating have been applied, but results are inconclusive at the time of this paper. Copper is one of the best conductors of electricity. Silver and gold are used to plate the inner surface of the cavity with a coating that does not adversely affect RF or electrical conductivity due to bare copper oxidation in normal air. I have chosen copper as the material for the frustum as complete oxidation requires a longer time that it will take to conduct my experimentation.

Being solid metal, previous frustums were a "closed" system, (semi) hermetically as well as electrically sealed. This results in air becoming trapped inside and heated by high RF power levels, creating a "balloon" effect and potentially giving false "thrust" or movement readings. In addition, recent experiments[18] have been conducted on frustums (in a vacuum environment) to alleviate the ballooning effect.

Speculation has arisen whether the Effect is hampered or enhanced by Q within the frustum.

Initially, I will use copper mesh to construct the side walls to lighten the overall assembly, reduce the "balloon" effect due to trapped hot air, save cost and simplify fabrication. Q in a cavity is normally defined by a 2 port measurement, but since the device is a single port, a return loss measurement is used. The best return loss (peak) is compared with a 3dB (half power) bandwidth. An experiment in China took the 3dB points up from the peak return loss resonance while NASA and others measured 3dB down from the 0db return loss reference. This provides wildly differing Q values. Any claims of Q must be referenced by which methodology was used. It is my belief that both should be used and a ratio of Q (Qr) should be determined as follows:

$$Qr = (F/A)/(F/B)$$

Where Qr = The Ratio of (Center Frequency F divided by 3dB bandwidth against reference (0dB) return loss) divided by (Center Frequency F divided by 3dB bandwidth from peak (best) return loss). This unifies the relative Q measurements and incorporates both measurement methodologies. Q is highly dependent on frustum dimensions and materials, including the surface resistance and conductivity at high frequencies.

The frustum dimensions are 11.01 inches (279.65 mm) diameter for the large end, 6.25 inches (158.75 mm) for the small end and 10.2 inches (259.08 mm) overall height which closely mimics recent test frustums. The frustum will contain no dielectric or resonator which would lower the Q andt shorten the overall height to about 9.0 inches (228.60 mm).

The end plates of the frustum will be mechanically interchangeable in my experiments. All will be made of copper-plated double-sided ½ ounce printed circuit boards to minimize the chance of dissimilar metals creating inter-modulation products and save weight (mass).

III. RF Frequency and Power

A variety of Radio Frequencies have been used to test the effect. Most reside in the 900 MHz to 3 GHz spectrum[2]. A new experiment in Germany is being conducted well into the microwave spectrum at 25 GHz[3]. Experimenters claim the exact center frequency is not critical, only the amount of power applied and the frustum design. An initial test has been completed and a paper presented by Dr. Tajmar of the Technical University of Dresden[6].

An experimenter in Romania[4] has reportedly duplicated the Effect by using a common household magnetron from a microwave oven. The frequency was approximately 2.45 GHz and the RF power level was approximately 850 watts. Utilization of this high power level comes with dangers, as the magnetron tube requires about 4,000 volts to operate and the power supply needed has enough amperage (current) to make it lethal.

I have chosen to use 2.4 GHz +/- 40 MHz and a common kitchen magnetron rated by the manufacturer at 900 watts.

IV. Emdrive Effect Measurement

Validation of the Effect will be made by constructing a simple knife-edge balancing fulcrum and measuring deflection of the opposite moment arm with a laser displacement sensor (LDS). Data collection will occur via a data acquisition unit (serial DAQ) and a common personal computer. The measurement resolution goal is below 20 mg equivalent weight deflection.

V. Final Bill of Materials

1. Magnetron – Unmodified 900 watt Sanyo model 2M218J

2. Laser Displacement Sensor – Unmodified Omron Z4M-40RA with 470 ohm shunt resistor to convert current measurement to voltage output within the measurement range of a DAQ sensor.

3. DAQ Sensor - Unmodified Dataq model DI-145

4. Computer - Compaq desktop, AMD microprocessor modified with DAQ sensor installed inside case. CD/DVD drive removed.

5. Power Supply/Controller – 900 Watt Kenmore Microwave Oven, 0.9 cubic feet internal cooking volume, modified to disable cooling fan and rotary turntable. Magnetron wires were routed out and connected to a high voltage terminal strip affixed to the rear of the microwave case.

6. Frustum Sidewalls – Copper wire mesh, 16 weaves per inch, 99+% pure, wire diameter. 0.011 inches, hand cut and formed. Vertical seam stitched together with individual copper filament wires taken from edges of screen mesh. 100% solder seam to top of innermost end plate (see below).

7. Frustum End Plates – Four ½ ounce (0.7 mil thick each side) double-sided, blank printed circuit boards; double layer stacked as top and bottom plates. The innermost board layers has circular cutouts for large and small frustum diameters. The outermost layers are separated from the innermost layers by RFI gasket (on contacting surfaces only). This material is of the same copper mesh as used on the frustum sidewalls. 11 screw and nut sets connect the large diameter plates and 6 sets connect the small diameter plates; just outside the frustum maximum diameters. See NSF-1701 Frustum Exoskeleton and NSF-1701 Assembly for a video description.

8. Frustum Support Hardware – 4 individual 1/8 inch square hollow copper tubes in each corner, soldered to innermost frustum end plates. 4 smaller printed circuit boards (same material as end plates) on each side, soldered vertically for structural support. Approximately 2 additional square tubes cut and soldered to innermost plates, outside of frustum sidewalls for structural support.

9. Fulcrum Beam – Wooden, 1 inch square hardwood approximately 7 feet total length supported by 18 inch vertical mast and single-strand steel wire affixed 14 inches from each end. About 18 inches from the end opposite the frustum is a dampener system which extends downwards and consists of.a vertical aluminum rod, a 3 inch diameter stainless steel drain cover (oriented parallel with the ground) with 1.2 inch vertical bars suspended mid-way down into common motor oil. This significantly dampens beam oscillations horizontally with the vertical bars and vertically with the drain cover.

10. Knife Blades - 3 common "carpet knife" blades, highest-strength steel type. 2 affixed to opposite, center sides of beam along horizontal axis, 1 held in heavy duty shop vise, perpendicular to fulcrum axis. Vise located on sturdy aluminum ladder approximately 4 feet off the ground. 2 blades balance on perpendicular vise (balancing) blade, creating 2 points of contact. See NSF-1701 Fulcrum Test for a video description.

11. Power Supply Wires – Approximately 10 feet total length. High voltage (4 KV) supply is multi-strand, clear insulator rated at 50 KV. Ground and filament wires via 2 conductor common household appliance cord, multi-strand rated at 240 VAC, twisted and wrapped in their own separate insulation making a single cord. The 2 separate supply cords were twisted together along their lengths except where drop loops were created to permit beam and frustum movement with the least resistance.

VI. Phase I Test Results

Test Number	Date	Objective	Video
Static Test #1	**07/28/15**	**Static thermal test**	**https://youtu.be/QFPTQMX8R0I**
Static Test #2	**07/31/15**	**Static thermal test**	**https://youtu.be/hAejcKgIHqg**
Static Test #3	**08/01/15**	**Static thermal test**	**https://youtu.be/cEIinPFO6gE**
Static Test #4	**08/04/15**	**Static thermal test**	**https://youtu.be/sOdV12MN85w**

Flight Test #1	**08/25/15**	**Measure for displacement**	**https://youtu.be/FPBs6zDmhwU**
Flight Test #2	**08/26/15**	**Measure for displacement**	**https://youtu.be/P3_XtcjinRs**
Flight Test #2A	**08/29/15**	**Measure for displacement**	**https://youtu.be/Oq44P8b87L8**
Flight Test #2B	**09/24/15**	**Measure for displacement**	**https://youtu.be/HPm2oPUPi2Q**
Flight Test #2C	**09/26/15**	**Measure for displacement**	**https://youtu.be/J0JtHqG5cPc**
Flight Test #2D	**09/27/15**	**Measure for displacement**	**https://youtu.be/djhxm1Ep12I**

Once satisfied that no arcing or magnetron overheating (improper impedance match to frustum) occurred on Static Test #4, the frustum was mounted on one end of the fulcrum with counterweights on the other (approximately 3.35 kg each end).

Flight Test #1 provided a null result with the magnetron mounted on the small plate (beneath the frustum) with its power feed positioned 1/4 wave distance from the edge. The test stand configuration did not use the laser displacement sensor, but a simple laser pointer and mirror to provide approximately 28 feet of laser beam travel to the target. The initial testing also used Galinstan liquid metal in copper cups for power connection to the frustum.

Flight Test #2 moved the magnetron to the center of the large diameter plate, on top of the frustum. No other changes to the test stand were made. The results were inconclusive.

Flight Test #2A was a longer duration with the same configuration as Test #2 in an attempt to improve the laser targeting with the laser pointer. It was also inconclusive.*

**After Flight Test #2A, a decision was made to improve the test stand by:*

1) *Removing the Galinstan, which added several milligrams of "drag" against electrode movement and unwanted vibrations transmitted along the support and electrode copper wires when controller keypad entries were made.*

2) *Changing from the laser pointer/spot display to a laser displacement sensor and DAQ system (inclusive of the LDS, capable of logging and displaying beam displacement).*

Flight Test #2B contained all aforementioned improvements and the Final Bill of Materials. At the time, only a video of the computer monitor could be recorded, as additional data-logging software had not yet been integrated and screen recording was not possible with the slower PC. It also became apparent that any natural thermal lift caused by the heating of the magnetron must be filtered out of the recorded data to show any potential thrust. The magnetron heat sink temperature typically increases to between 170 and 200 degrees C. A non-null test was deemed likely by myself for the first time but I wanted to conduct further flight tests before reaching a conclusion.

Flight Test #2C had the same test stand equipment, hardware and software. The magnetron ON cycle duration was varied from 20, 30, 50 and 70% power on cycles in order to differentiate frustum movement from thermal lift and natural mechanical oscillations. 50% power cycle was deemed best to avoid natural beam oscillations and fast thermal lift. Another non-null test was deemed likely by myself but I desired one additional flight test to complete Phase I testing.

Flight Test #2D was a 50% power cycle test run in two separate 10 minute increments with an approximate 10 minute delay in between. New data-logging software was installed and the test provided over 2,700 data points per channel at a rate of about 75 samples per minute. The video was simply to show the computer time stamp and allow data synch with magnetron ON/OFF time via the audio track. This permitted insertion of a data set denoting the magnetron power state. The LDS was on channel 1, the other channels were open (unloaded) which permitted an analysis of system noise. The collected data was analyzed by a professional data analyst* using advanced algorithms. It was his conclusion that with a probability of greater than .95, there was an anomoly causing the data (displacement) to be distinctly different during ON cycles versus OFF cycles[8-14]. This professionally confirms the visual changes I witnessed, which included displacement opposite of thermal lift, holding steady against lift, and the attenuation of thermal lift while the magnetron was in the ON cycle. This was the most rigorous review of any of the other Flight Tests.

** The data analyst has over 30 years of experience in biometric and logistics data analysis and is currently a partner in his own business consulting firm. The analyst is also contracted by a global telecommunications firm and although I personally know their identity, they wish to remain anonymous to others for now.*

VII. Conclusions

For the purpose of public release, NSF-1701 Flight Test #2D on 9/27/15 at approximately 3:40 PM EST is considered the first private, non-null (positive) test of the EM Drive Effect outside of Europe.

- While an Effect was noted outside of thermal lift, the author, analyst and experimenter cannot speculate on a theory as to why the Effect is present.
- System noise was ruled out by an overlay of high resolution noise, or random micro-voltage variances in the measurement system using an open data channel. The overlay to the chart of the total deflection of FT #2D showed randomness and no correlation to the magnetron ON/OFF states.
- Through a series of calibrated weight tests on both a preheated and cold frustum, the Emdrive Effect averaged about 18 milligrams or 177 micronewtons of downward force, with the small

end of the frustum facing the ground and magnetron positioned atop the frustum injecting RF energy into the big end. This was visually determined and recorded in Flight Test #2B through #2D. Reference weights of 20 mg, 50 mg and 100 mg were added to the balance beam directly above the frustum to provide a reference displacement at various times throughout the videos.

- The copper mesh was able to contain the magnetron's energy, provide less mass and help manage heat, but is inconclusive whether or not it limited thermal lift compared to solid copper.

VIII. References and Links

1. *Wikipedia.org, http://en.wikipedia.org/wiki/Frustum, retrieved 6/2/2015*

2. *http://forum.nasaspaceflight.com Forum » General Discussion » Advanced Concepts » EM Drive Developments - related to space flight applications (threads 1-3)*

3. *An EM Drive, Brian Benchoff, Aachen Germany, http://hackaday.com/2015/05/08/hackaday-prize-entry-an-em-drive/, retrieved 6/2/2015*

4. *Masina Electrica RO, website http://www.masinaelectrica.com/emdrive-independenttest/#comment-10348, retrieved 6/2/2015.*

5. *NASA Eagleworks Lab paper*

6. *Dr Tajmar, Institute of Aerospance Engineering, Dresden, Germany AIAA paper*

7. *Development of Packaging and Products for Use in Microwave Ovens, M W Lorence, P S Pesheck, Elsevier, Jul 30, 2009*

8. *Data Analyst raw data spreadsheet*

9. *Data Analyst initial spreadsheet*

10. *Data Analyst secondary spreadsheet*

11. *Binomial Stat Calculator used by Analyst*

12. *Data analyst commentary #1 on FT #2D*

13 *Data analyst commentary #2 on FT #2D*

14. *VBA code supplement to data sheet analysis of FT #2D*

15. *Enhanced noise channel versus magnetron ON/OFF graph*

16. *Nasaspaceflight Forum on Emdrive Thread 4*

17. *Reddit Emdrive Forum*

18. *Emdrive Wiki*

IX. Acknowledgements and Future Plans

The author wishes to thank the countless numbers of people on both the NSF and Reddit forums for donations, moral support and useful critique as well as the Other Side of Midnight radio listeners.

Phase II testing will begin in 2016 with the goal of generating about 100 times the above-noted noted Emdrive Effect, or 17.7 millinewtons. Those wishing to donate to offset the projected significant cost of this goal can do so privately and securely at: https://www.paypal.me/NSF1701