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The Space Voyage of Future—a Brief Study on NASA's EM Drive and Mach-Effect Thruster

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ABSTRACT

Recent technologies of spacecraft propulsion work on the basis of reaction mass. This makes then unsuitable for long space journey. Hence propellant-less propulsion is always been considered as a true replacement. But photon rockets or solar sails have an extremely low and weak thrust which makes them impractical for any heavy spacecraft carrying big scientific instruments or people. Therefore, scientists are looking in the forces which are latent tin the quantum vacuum of spacetime mainly the Hawking's radiation and Unruh Temperature and also the Casimir effect. The purpose of this paper is to compare and evaluate the research being developed in two models: NASA's EM Drive and Mach-Effect Thruster. EM Drive works on the concept of a truncated cone-shaped cavity which is claimed to produce thrust. But it's unclear how this propulsion works as there is no theoretical basis that is firmly attached to it. Some even believe it violates the Newton's Third Law. Whereas Mach-Effect Thruster works by generating mass fluctuations in a piezo-crystal stack that creates non-zero time-averaged thrusts. The results are then analyzed between them. Here the results show that the magnetic interaction form unshielded or not sufficiently shielded cables or thruster models are a source of error and needs to be rectified for accurate and precise micro-Newton(μN) thrust measurements for this kind of devices. The goal of the scientists is to refute whether these thrusters work as they claim and hopefully discover their working mechanisms that would enable to upscale these fuel-less propellant thrusters.

Keywords: *EM Drive, Mach-Effect thruster, fuel-less spacecraft, propellant-less propulsion, breakthrough propulsion*

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INTRODUCTION

Since the beginning of modern civilization mankind has always been fantasized by space. The notion that one day mankind would be able to travel to the depths of the interstellar space has always been exhilarating. Even ancient humans gazed upon the sky and wondered upon the stars of the night sky and maybe even yearn to be there. Fuel propelled rockets are the only propulsion technology to put spacecraft into Earth's orbit. Since rockets have their on board propellant, Tsiolkovsky's equation creates a specific boundary for the maximum achievable velocity. Even nuclear propulsion with a specific impulse of 10,000 Newton seconds or more requires a propellant mass on the order of the mass of the sun to propel a spacecraft to the nearest star

within a lifetime. Recent projects therefore concentrate on using propellant less laser propulsion. There has been an entirely new project called The Space Drive Project, in which the scientists and engineers are currently assessing several propellant-less propulsions, mainly: EM Drive and Mach-Effect Thruster [2, 4].

In what follows are the collective research papers and experiments done by Mohamed S. El Naschie published in Scientific Research Publishing and by Martin Tajmar, Matthias Kößling, Marcel Weikartand and Maxime Monette published in Elsevier Publications to prove that NASA's proposal for an EM Drive is in principle possible. The quantum wave five-dimensional empty set side of the universe is sufficient to support a fuel-less EM Drive enabling interstellar navigation throughout the vastness of space. Scientists say that an engine is needed for manoeuvring only and the thrust comes naturally from the local form of one-sided Casimir effect of spacetime. At the end, NASA's proposal does not in its true form violate Newton's third law. The research stresses that the theory goes as far as saying that the thrust is inbuilt into the geometry and topology of the five-dimensional vacuum of a fractal spacetime and therefore, the motion of the spacecraft is in principle possible with or without an engine. Thus, the main problem that needs to be solve mathematically is just 1% and the rest of 99% is done by real engineering. [1, 2, 4, 6]

SPACE DRIVE PROJECT

In the Space Drive Project, the following research topics are being visited and explored for the needed understanding of the Project:

- Thrust Balance
- Electromagnetic Drive (EM Drive)
- Mach-Effect Thruster
- Analysis of EM Drive on the basis of Newton's Third Law

THRUST BALANCE

For the testing of propellant-less propulsion concepts, the researchers require a highly advanced thrust balance system which was required to detect even minute thrust with a high resolution of up to a nano-Newton range. It must block any kind of interference may it be electromagnetic or thermal by a high degree and limit the interactions between thrust balance and the wall of the vacuum chamber. This is paramount to obtain reliable measurements [2, 3].

The researchers created a large vacuum chamber of the order of 0.9 m in diameter and 1.5 m in length and a torsion balance is kept in. This is the basis for accurate and reliable measurement. The angular displacement produced by a thrust is then measured by a laser interferometer. To achieve sub-micronewton (μN) resolution, two C-flex E-20 torsion springs were used due to their high sensitivity (2×0.0033 Nm/s), also keeping enough weight which could be supported on the balance arms. To reach a vacuum of the order of 10^{-7} millibar range, the vacuum chamber used a vibration isolated Edwards XDS35i scroll pump. But the scientists insisted on using the vacuum chamber with a vacuum level of down to 10^{-2} millibar only as it was sufficient to suppress buoyancy and provide faster turnaround times. The chamber is also fitted to a separate concrete block which is then mounted with vibration isolation to separate the vibrations which may originate from the building's foundation (Figure 1). [1, 2, 4, 3] The following are the features which the researchers incorporated into the thrust balance:

- The total weight of the thruster that can be installed on the balance is 25 kg. Both the thruster assembly box and the

electronics and data acquisition box are separately shielded.

- Using the attocube IDS3010 laser displacement sensor they were able to read out the balance position and reduce the thrust noise to the nano-Newton range with a sub-Nanonewton resolution.
- Variable damping is then provided using eddy-currents and permanent magnets. Stepper motors are also used to change the position of the copper disc to adapt the intensity of damping.
- Stepper motors are used to level the balance and to change the orientation of the thruster. Thereby enabling scientists to investigate shifts in the center of gravity which are caused due to thermal expansion from forward to backward and then inferencing the change in thrust measurement.
- To make the balance accurate and precise, two different calibration techniques were performed by the scientists. One was using a voice coil and the other using electromagnetic combs which provide a constant thrust by the application of a defined current (in coil) or voltage(comb) which were in turn calibrated using a Sartorius AX224 balance.
- Complete shielding of the balance arm and thruster/electronics boxes using high permeability Au-metal.
- The system could be operated wirelessly using an infrared serial port by which Weeder modules or the LabJack T7 Pro was connected. This allowed analog input/output, digital control of relays as well as temperature measurements on the balance. In addition, infrared cameras were added which could detect overheating of the electronics and the thruster.
- Power and other data signals was supplied using four pairs of liquid-metal-contacts with twisted, paired cables as shown in Figure 2.
- A LabView program was created which could operate and control the complete vacuum facility, thrust balance and the ongoing experiments.

The entire experiment from calibration to measurement is automated using a script language, thereby ensuring repeatable measurements.

A picture of the vacuum chamber as well as the schematic of the balance is shown in Figure 1.

An example of a one micronewton (μN) calibration pulse is shown in Figure 3 using the voice coil. Researchers performed calibration pulses along a wide range with small steps as shown in Figure 4 that shows the high linearity of our balance. Figure 4 also shows how the calibration constant micronewton/micrometer (μN/μm) changes for different setups with different weights. The scientists always performed calibration before and after every single thrust measurement for ensuring the same sensitivity of balance [3, 4, 6, 7].

ELECTROMAGNETIC DRIVE (EM DRIVE)

Electromagnetic Drive or Radio Frequency Cavity thruster is a hypothesized concept proposed by Roger Shawyer in the year of 2001. It works on the basis of radio frequency particularly microwaves which are directed into a truncated resonator cavity or a frustum which produces thrust. Due to the difference in diameter of the truncated cone at the ends, Roger Shawyer believed that the radiation pressure would be different and create a net thrust force. But not all of the scientific community agree with him as they found it to be violating electromagnetism and conservation laws. The scientific community has always been sceptical with this propulsion technology [2].

However, the researchers at *Technische Universität Dresden, Germany* created a version of EM Drive partly based on NASA's own model. 1.5 mm thick Copper sheets were pressed into correct geometry to make the cavity as shown in Figure 6. The inner surface was polished. Usage of standard connectors like SMA/N-Type was made throughout all components. A loop antenna is shown in the Figure 6 along with the complete EM Drive with cavity and its associated electronics on a side of torsion balance. Due to the size of cavity, it was inefficient to encapsulate it with Au-metal sheets for reduction of possible magnetic interference. [1].

Scientists used an Anritsu MS46121B vector network analyzer to analyze resonance frequencies and the Quality factors of the cavity. Figure 7 shows the obtained quality factors from a range of 20,000-300,000+(unloaded) which is dependent on the peak. This quality factor was obtained for a frequency of 1865 MHz which was matched using a Maury 1878 B 3- stub tuner. NASA also performed their own experimentation and development of this propulsion at the Advanced Propulsion Physics Laboratory. The values obtained by the German researchers were quite similar or even higher than what NASA obtained for the same experiment. Hence the scientists believed that they would be getting similar thrusts values or more as Quality factor was believed to be directly attached to the generated thrust of a thruster. But as it is seen the researchers were not able to. Scientists also carried out COMSOL simulations which helped them to find the optimum and efficient position for the antenna shown in Figure 8 and also to simulate few generated modes within the cavity of the thruster.

The German researchers made the EM Drive as similar as possible to the NASA's one as shown in Figure 9. It consists of a frequency generator, a voltage-controlled attenuator, a 50 W amplifier, a bi-directional coupler with power-meters for input and reflected output and optional fixed 40dB attenuator with a Maury 3-stub tuner all included along with the cavity. Everything was operated in vacuum without and required modification and the researchers set the limit of total power to be 2 Watts as to prohibit overheating. They monitored the temperature using thermocouples. The optional attenuator of 40 dB was used to reduce power by a factor of 10,000 without the need to change anything else in the system. This gives the scientists a powerful "zero-thrust" measurement capability. Resonance frequency was also tracked to compensate for frequency shifts in operation.

Steppers motors were used to change the direction of the thruster by rotation only. 0° directions meant a positive thrust which went from large back are to small front area in the cavity, 180° direction meant a reversed or negative thrust direction and 90° meant that the thruster point parallel to the balance arm of the thrust balance and hence is zero thrust.

Figure 10 give the thrust measurement for the EM Drive in all directions. Power level of 2 Watts and 4 μN at an amplifier corresponded to an amplifier current of 2.5 Amps. 75° was the maximum temperature obtained for the amplifier. Quality factor was 50,000(unloaded). Scientists observed that the thrust direction was reversed for 180° direction just as predicted. But as soon as the researchers pointed it at 90°, they see a similar thrust as in the same 180° direction where it was supposed to be zero thrust. And even more alarming was that if the researchers kept the 0 direction and use the optimal 40 dB attenuator to reduce power by 5 orders of magnitude, the thrust nearly remained the same as without the 40 dB attenuator used.

This made the scientists step aback. They concluded that the "thrust" is not coming from the EM Drive but due to some form of electromagnetic interaction. They found out that even though use of twisted or coaxial cabled was done to the fullest extent, some magnetic field would had eventually leaked through the cables and connectors. Later the scientists then calculated the magnetic field strength of the Earth's magnetic field of 48 μT with an inclination of 70° in Germany, and hence found out that with a few centimetres of cables and a current of 2 Amps which is similar to what they used for the application of the amplifier they obtain the Lorentz forces of a few μN. This was indeed similar to their observed "thrust" values. Therefore, they reached a reasoning that the interaction between the powers feeding to the amplifier with the Earth's magnetic field masked any real thrusts that could have been below the observed value. Hence, further research in the field is essential [6, 7, 9].

MACH-EFFECT THRUSTER

The next fuel-less propulsion concept is the Mach-Effect Thruster which is also known as Woodward Effect as it was developed by JF Woodward. This has been in development for much longer than the EM Drive as EM Drive had just been proposed in 2001. This was developed by JF Woodward since the 1990s and is more recently developed by H. Fearn. By using Mach's Principle which states that Inertia experienced by a body is due to the interaction of gravitational masses with the whole universe or in simple words Inertia here is due to mass out there, Woodward and others proved that linearized general relativity theory with time-varying solutions and Sciama's analysis when combined together leads to mass fluctuations that could be up to 11 orders of magnitude higher for typical devices other than what is classically expected from

$$E = m \times c^2.$$

Thruster works by exciting a stack of clamped piezo crystals using a frequency in the tens of KHz range. According to Woodward, the energy oscillations lead to transient Machian-mass variations which could then eventually direct to time-averaged stationary thrusts when properly pushed and pulled with correct frequency and phase (Machian-mass here relates to the Mach's principle with the interaction of the masses). Due to the piezoelectric and electrostrictive properties of piezo crystals, this indeed could happen. But at smaller amplitudes, electrostriction occurs at twice the applied frequency and a 90° phase shift. The scientists here created models which are both analytical as well as finite element models and predict accurately the oscillation movements on the thruster in order to enhance the thrust produced.

This experiment was also carried out at the *Technische Universität Dresden, Germany.* [9]

For the thruster, an amplifier based on Apex PA04 with a frequency range of up to 180 kHz was used, 150 W and a voltage capability of 150 Vpp. The scientists didn't want to use audio amplifiers as they cut the power close to thruster's operating frequencies that is 35 kHz.

The frequency response spectrum for the thruster developed by Woodward and H. Feran is shown in Figure 12.

The first resonance frequency is 31 kHz. Computer software is used to control the amplifier with various arbitrary waveforms such as sine wave mixed with single or double frequency signals at a phase shift. Arbitrary waveform was given by the Pico scope 2405A oscilloscope. The current, phase signals and voltage are then read

back into the computer for results. Since it is necessary for the thruster to operate at resonance always, the researchers implemented a tracker which adapts frequency to maximum current even during operation and heating of the thruster. [3]

The thruster was mounted inside the thruster balance's thruster assembly box and was provided with Au-metal shielding. The amplifier electronics were separate and liquid-metal feedthrough was used for the powering of thruster on the balance. Figure 12 shows the results obtained by the researchers at Germany in all three directions for 150 Vpp and applied sine wave at 31 kHz in vacuum. Everything goes as expected, the apparent thrust had a value of 0.6 µN which reversed for 180° and is eliminated at a 90°. But when the researchers moved the thruster box back to 0° direction and manually changed only the thruster inside to 180° direction, the thruster signal was not affected. This did not go with the scientists proposed theory. After several more tries, the scientists concluded that there is somewhere an electromagnetic interaction or thermally induced shift in the centre of mass which is hiding the real thrust value. Hence, they expected only a pure 0.02 µN which could very well be present in the thrust data but hidden due to electromagnetic/thermal interference [1, 2, 8, 4].

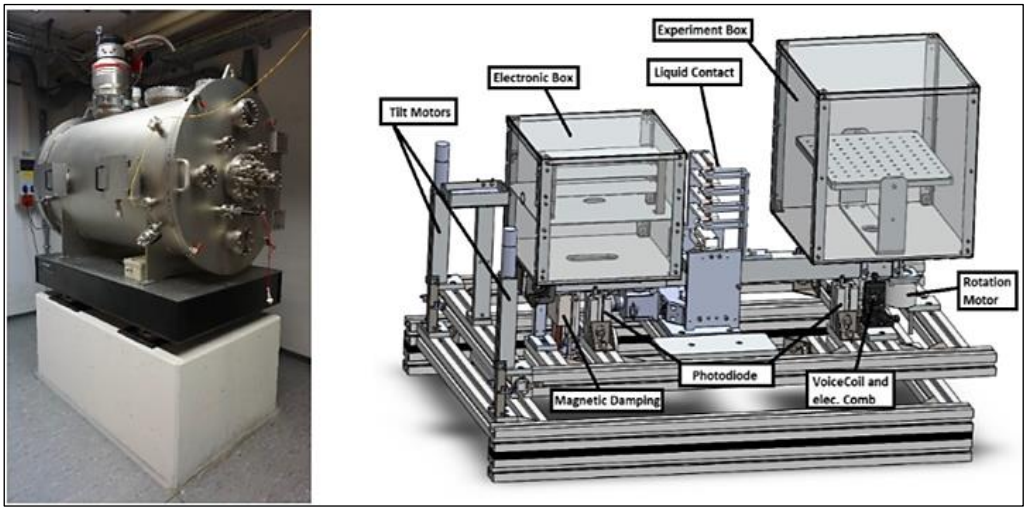

Fig. 1. *Vacuum chamber on concrete block.*

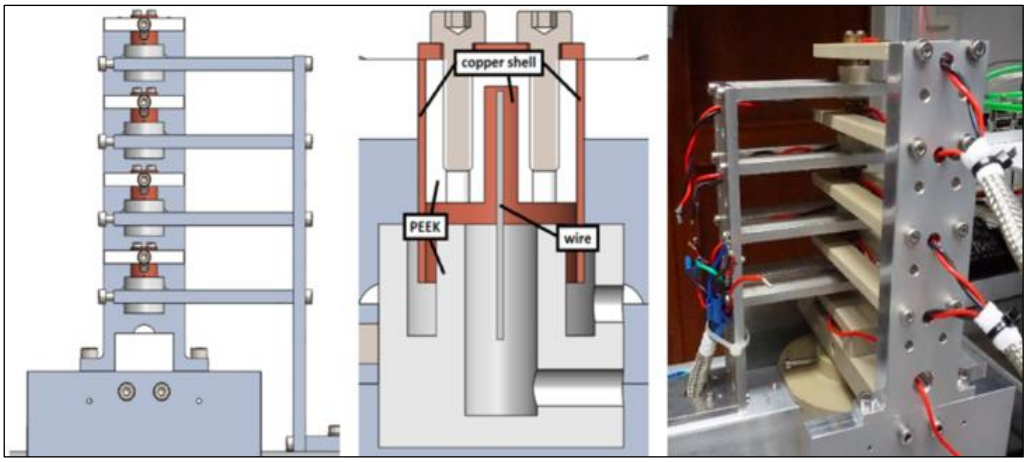

Fig. 2. *(a) Liquid metal contacts and schematic sketch of thrust balance.*

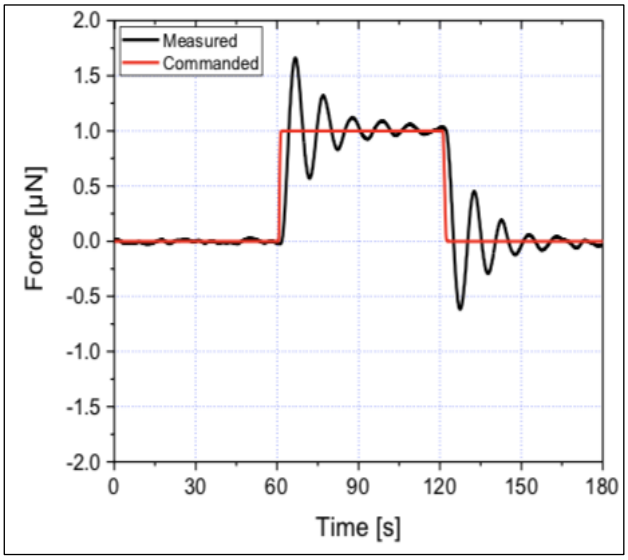

Fig. 2. *(b) Voice coil 1 µN step response (200 profile averaged).*

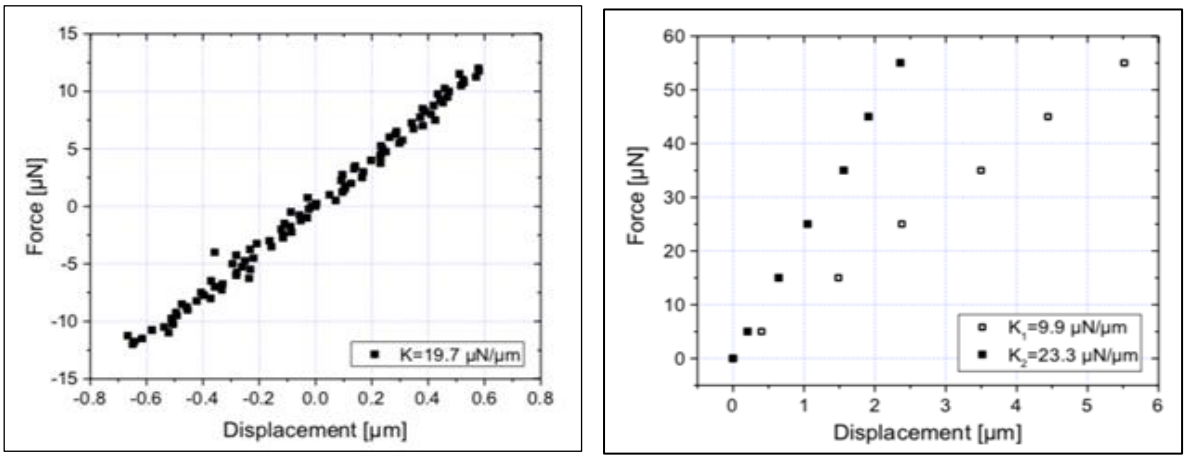

Fig. 3. *Calibration linearity. 0.25 µN steps (left) and different slopes for different setups/weights (right).*

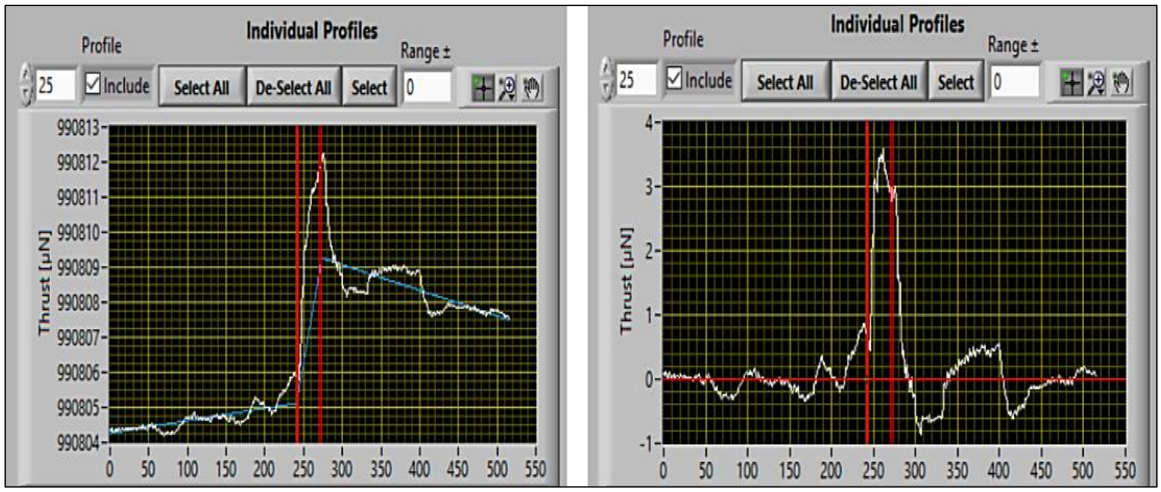

Fig. 4. *Thermal drift compensation- original thrust profile (White) and drift compensation fitting line (blue)—left, compensated profile without thermal drift—right.*

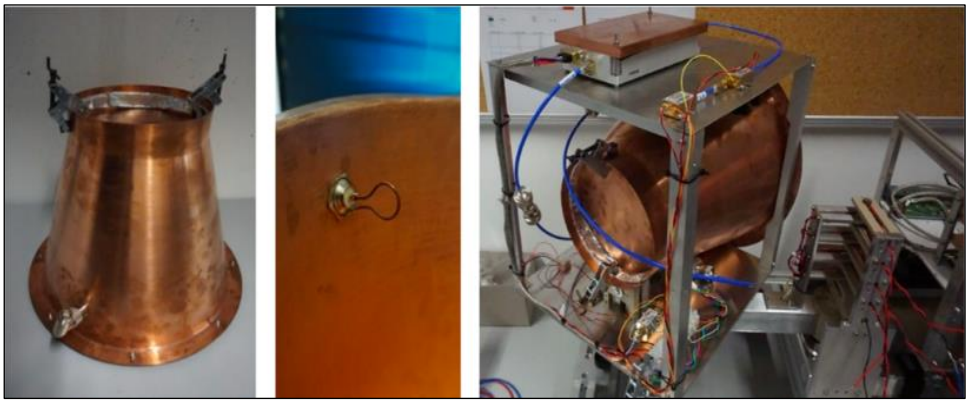

Fig. 5. *EM drive thruster—cavity (left), antenna (middle) and on balance (right).*

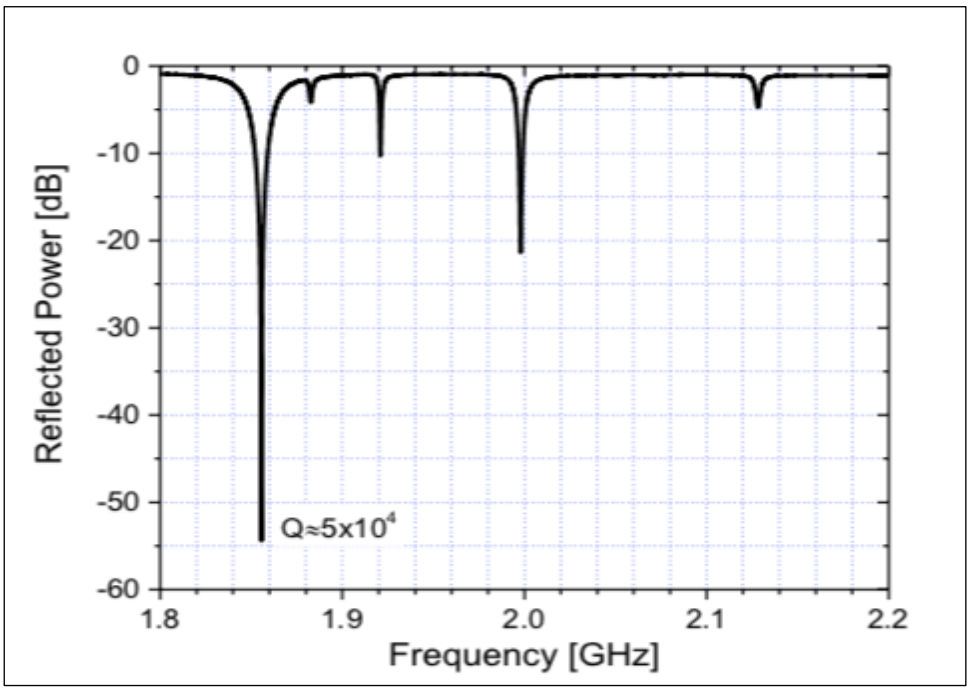

Fig. 6. *Cavity S11 reflection plot from vector network analyzer.*

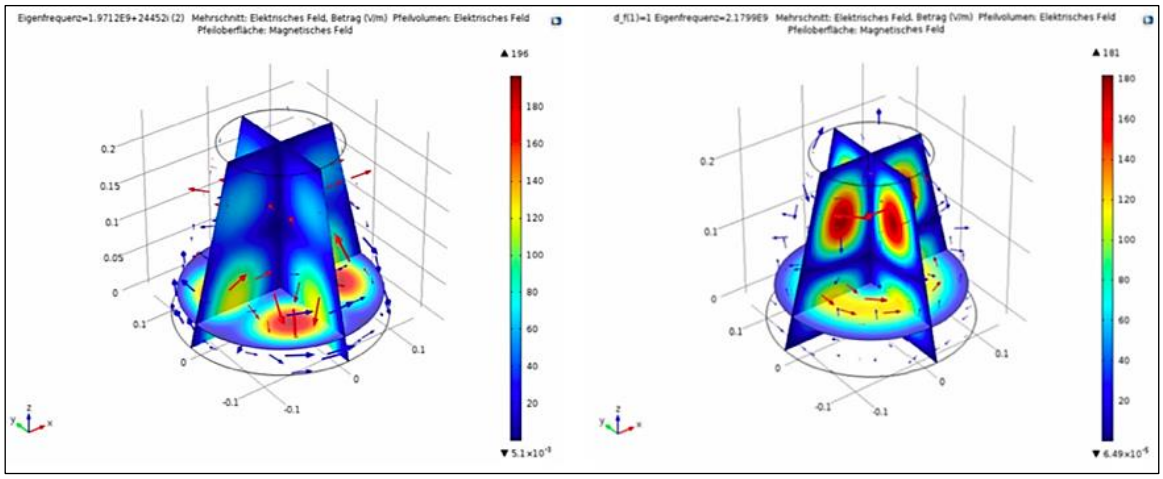

Fig. 7. *EM drive COMSOL simulation.*

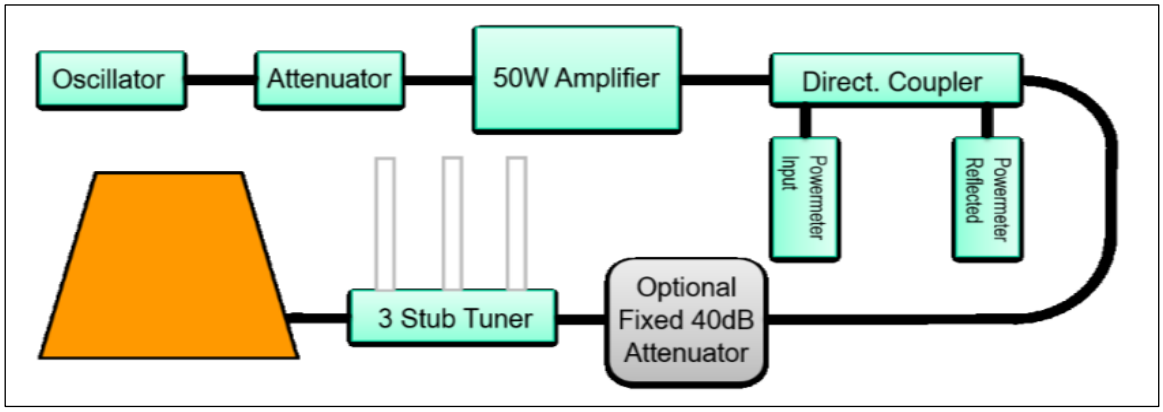

Fig. 8. *EM drive setup.*

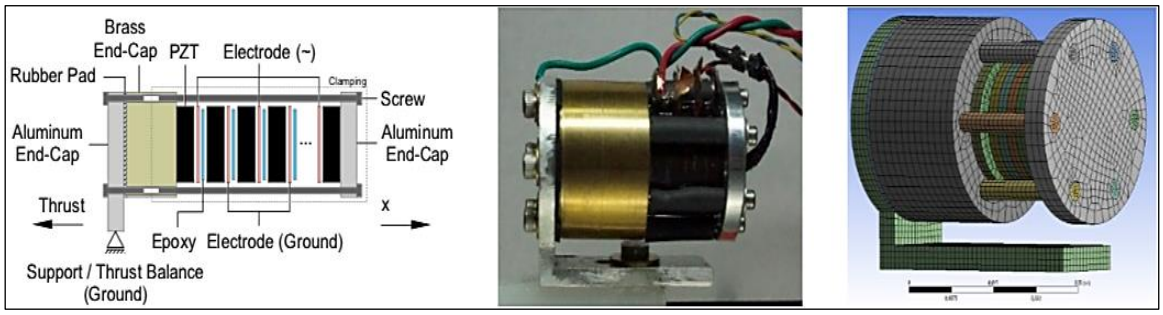

Fig. 9. *Mach-effect thruster (MET).*

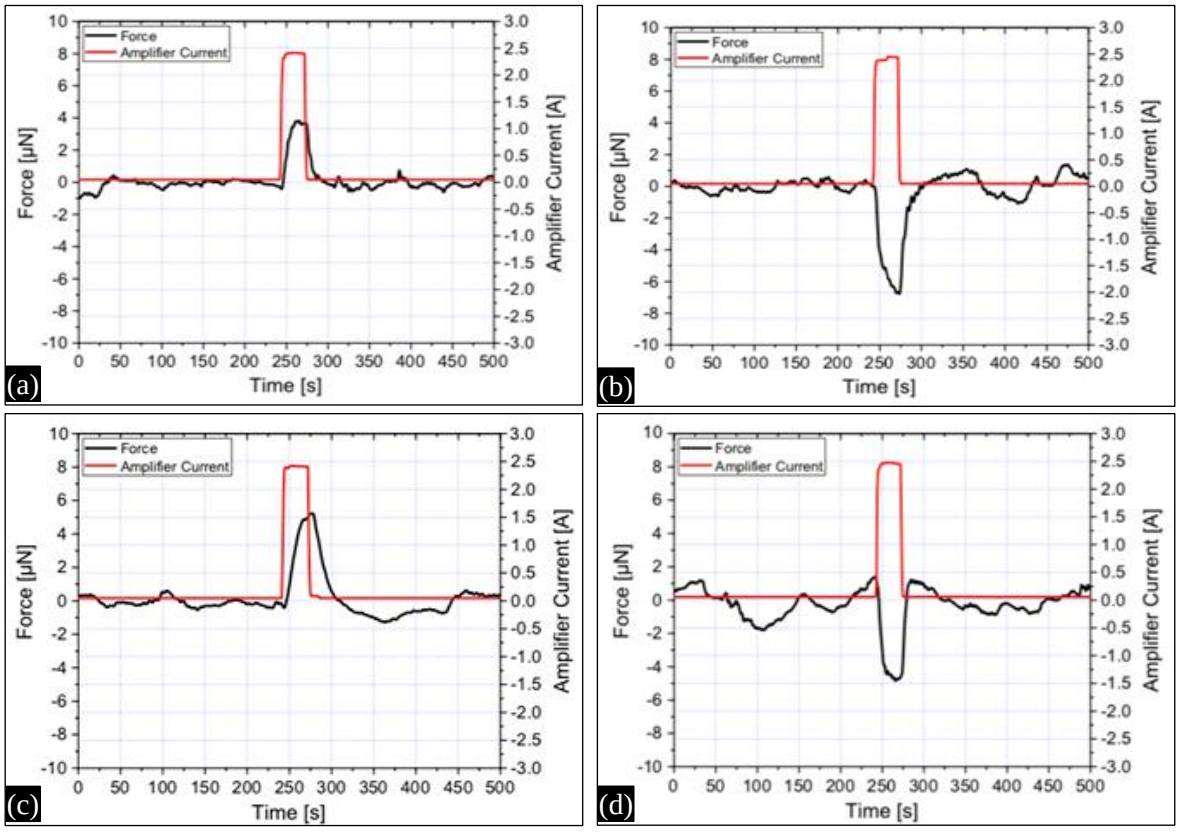

Fig. 10. *EM drive thrust measurements with 2W in vacuum (0.01 mbar), 40 runs average. (a) direction 0°, (b) direction 180°, (c) Direction 0° with 40 db attenuator and (d) direction 90°.*

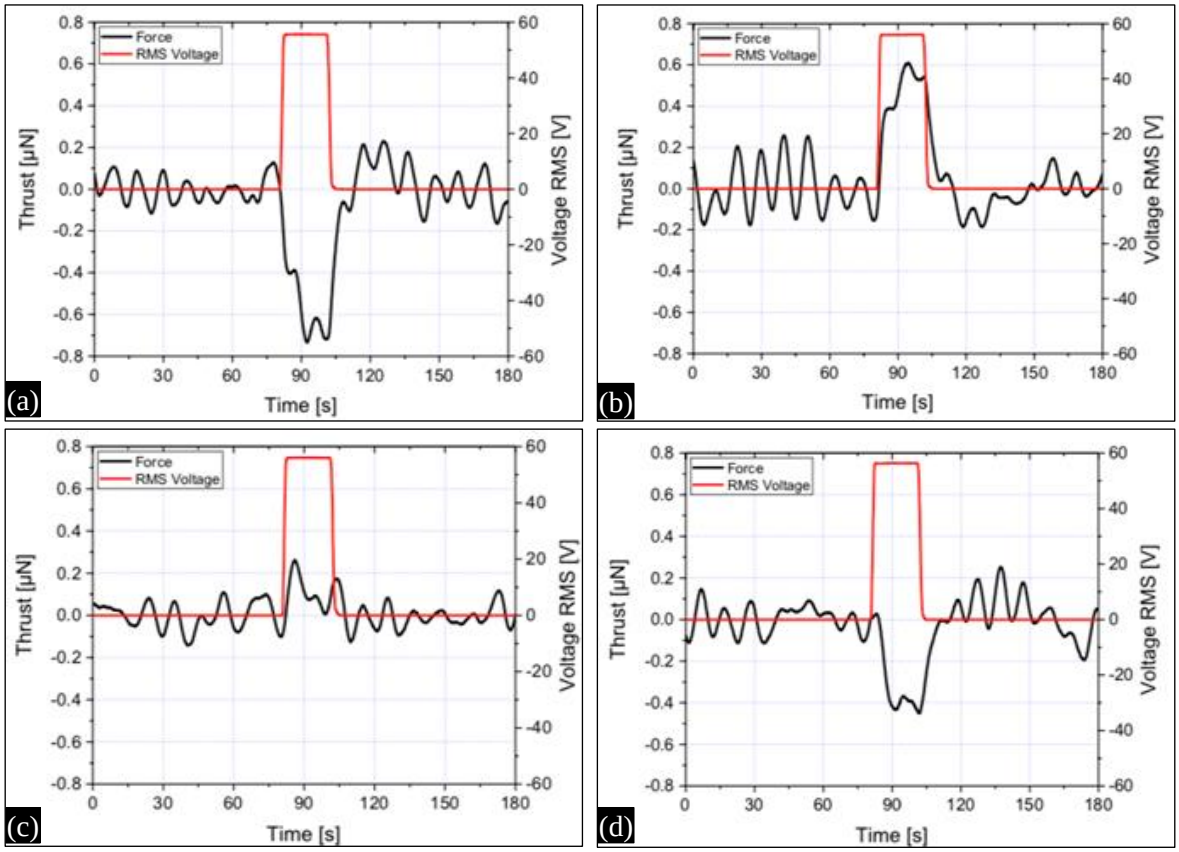

Fig. 11. *MET thrust measurements in vacuum (0.01 mbar) at 150 Vpp, 200 runs averaged. (a) direction 0°, (b) direction 180°, (c) direction 90° and (d) direction 180°—only thruster rotated.*

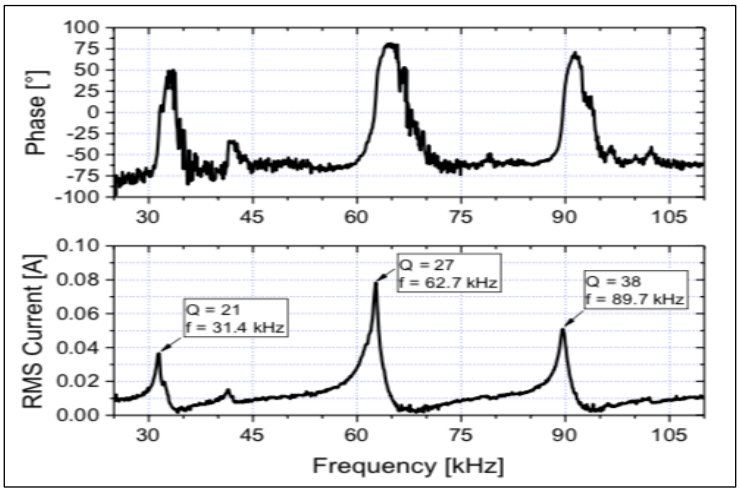

Fig. 12. *Mach-effect thruster spectrum.*

CONCLUSIONS

The space voyage is a treacherous and at the same time a thrilling exploration field, where numerous researches are undergoing. Creating and developing cutting-edge propulsion systems is the only purpose of the Space Drive. For this a very high precision is required to measure the minute thrust forces produced by the fuel-less propulsion system before it could be implemented in large scale.

The thruster balance made by these German scientists is though sophisticated but as the result shows it still falls below the needed requirements to measure thrust forces without any external forces acting on it. EM Drive and Mach-Effect Thruster are two of the most promising and revolutionary thrusters known right now although not in use.

The scientists here concluded the results on magnetic interaction from twisted-pair cables and amplifiers with the Earth's magnetic field is a major and most prominent source of error and promised to develop a much more sophisticated version of their thruster balance. This is of much importance as these tests enable scientists to see if these technologies are in fact viable to the industry.

At the least, Space Drive is an excellent education project which may turn into one of the most important research topics by developing highly demanding test setups, evaluating theoretical and simulation models and error. This has the possibility to drive the next generation of space exploration. The research will always continue to grow as we step into space exploration in interstellar level [1, 8, 9].

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