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The SpaceDrive Project – Developing Revolutionary Propulsion at TU Dresden

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Abstract

Propellantless propulsion is believed to be the best option for interstellar travel. However, photon rockets or solar sails have thrusts so low that maybe only nano-scaled spacecraft may reach the next star within our lifetime using very high-power laser beams. Since 2012, a dedicated breakthrough propulsion physics group was founded at the Institute of Aerospace Engineering at TU Dresden to investigate different concepts based on non-classical/revolutionary propulsion ideas that claim to be at least an order of magnitude more efficient in producing thrust compared to photon rockets. Most of these schemes rely on modifying the inertial mass, which in turn could lead to a new propellantless propulsion method. Our intention is to develop an excellent research infrastructure to test new ideas and measure thrusts and/or artefacts with high confidence to determine if a concept works and if it does how to scale it up. At present, we are focusing on two possible revolutionary concepts: The EMDrive and the Mach-Effect Thruster. The first concept uses microwaves in a truncated cone-shaped cavity that is claimed to produce thrust. Although it is not clear on which theoretical basis this can work, several experimental tests have been reported in the literature, which warrants a closer examination. We are building several models of different sizes to understand scaling laws and the interaction with the test environment. The second concept is theoretically much better understood and is believed to generate mass fluctuations in a piezo-crystal stack that creates non-zero time-averaged thrusts. Apart from theoretical models, we are testing and building several such thrusters in novel setups to further investigate their thrust capability. In addition, we are performing side-experiments to investigate other experimental areas that may be promising for revolutionary propulsion. To improve our testing capabilities, several cutting-edge thrust balances are under development to compare thrust measurements in different measurement setups to gain confidence and to identify experimental artefacts.

Keywords: Breakthrough Propulsion, Propellantless Propulsion, EMDrive, Mach-Effect Thruster

1. Introduction

Interstellar travel is one of mankind's biggest dream and challenge. Rockets routinely put spacecraft into Earth's orbit, however Tsiolkovsky's equation puts a strong limit on the achievable Δv if onboard propellant is used, even using advanced materials and futuristic engines. For example, even nuclear propulsion with a specific impulse of 10,000 s or more (nuclear pulse, combined electric/nuclear, fusion propulsion, etc.) requires a propellant mass on the order of the mass of our sun to propel a spacecraft to our nearest star within our lifetime [1].

Recent efforts therefore concentrate on using propellantless laser propulsion. For example, the proposed Breakthrough Starshot project plans to use a 100 GW laser beam to accelerate a nano-spacecraft with the mass of a few grams to reach our closest neighbouring star Proxima Centauri in around 20 years [2]. The technical challenges (laser power, steering, communication, etc.) are enormous but maybe not impossible [3]. Such ideas stretch the edge of our current technology. However, it is obvious that we need a radically new approach if we ever want to achieve interstellar flight with spacecraft in size similar to the ones that we use today. In the 1990s, NASA started its Breakthrough Propulsion Physics Program, which organized workshops, conferences and funded multiple projects to look for high-risk/high-payoff ideas [4]. The project culminated in a book that summarized the ideas studied and presented a roadmap with unexplored areas to follow up [5].

Since 2012, a dedicated breakthrough propulsion physics group was founded at the Institute of Aerospace Engineering at TU Dresden to propose and investigate concepts based on non-classical/revolutionary propulsion ideas that claim to be at least an order of magnitude more efficient in producing thrust compared to photon rockets [6]. Most of these schemes rely on modifying the inertial mass, which in turn could lead to a new propellantless propulsion method. Our intention is to develop an excellent research infrastructure to test new ideas and measure thrusts and/or artefacts with high confidence to determine if a concept works and if it does how to scale it up.

Recent work by our group include a critical evaluation of the EMDrive [7], a replication of the Wallace gravitational generator [8], a superconducting gravitational impulse generator [9],[10], the evaluation of error sources when testing weight changes of mechanical gyroscopes [11], an evaluation of the claimed electrostatic torque effect [12] as well as a possible space drive concept [13],[14] and theoretical work on a connection between electromagnetism, mass and quantum theory [15].

As classical propulsion (force and Tsiolkovsky rocket equation, etc.) is based on Newton's mechanics, which in turn rely on inertia, it is quite straightforward to think that any new type of propulsion will probably involve a change in the inertial mass. Two main approaches have appeared so far:

1. Negative mass: If we find or create a substance with negative inertial mass, put it next to a normal positive inertial mass and allow for a force between them (e.g. by charging them up with opposite polarity), this so-called gravitational dipole will start to self-accelerate. That is a consequence of Newton's mechanics extended to negative inertia which does not violate energy or momentum conservation as negative inertia also represents negative energy/momentum. The self-accelerating system therefore produces no net energy/momentum itself. This concept was first proposed by Forward [16] and recently even experimentally verified in an optical analog experiment with self-accelerating photons [17].

2. Variable/Oscillating mass: It may not be necessary for a revolutionary propulsion device to have negative inertial mass, it could be sufficient to have an inertial mass that is oscillating. If we imagine such a mass that we push when it is heavy and pull back when it is lighter, such a system could indeed produce a net momentum without spending propellant. As recently explicitly shown by Wanser [18], momentum conservation does only apply to a system with constant mass. Our oscillating mass system clearly violates this condition providing a method of producing real propellantless thrust. Of course energy must be spent in order to modify mass and to push/pull it back and forth. By taking into consideration its relation with the environment, it can be shown that such system does not violate any physical conservation principle.

Of course, the real challenge here is to produce macroscopic quantities of negative or oscillating inertial mass. So far, the properties of negative inertial mass have been mimicked in experiments using effective mass within certain boundaries only (e.g. neutrons inside a crystal [19], or photons inside fibers [17]). How shall real negative mass exist outside such special boundaries? Oscillating inertial masses are much simpler to imagine. For example, charging and discharging a capacitor will change its mass by simply following $E=m.c^2$. Unfortunately, c^2 is a large number so the resulting mass fluctuation will be very small. Of course, the availability of high-frequency technology up to the THz range may compensate some of that if properly done.

All our efforts are now concentrated in the SpaceDrive project, which aims at critically evaluating the two most promising concepts (Mach-Effect Thruster and EMDrive) by experiments and analysis and by performing complementary experiments that can provide additional insights into the thrusters under investigation or open up new concepts.

2. SpaceDrive Project

2.1 Thrust Balance

Testing of propellantless propulsion concepts requires a highly sophisticated thrust balance that must be able to reliably detect very small thrust with a resolution down to the nano-Newton range, block electromagnetic interactions as much as possible and limit any balance-vacuum chamber wall interactions. Vibration and thermal expansion/drifts are the two most important artefacts that must be carefully isolated to obtain reliable measurements.

The basis for our measurements is a torsion balance in our large vacuum chamber (0.9 m diameter, 1.5 m length) that has undergone various improvements over more than 4 years. The vacuum chamber uses a 2300 L Pfeiffer turbo pump and a scroll pump, which is vibration-isolated, to reach a vacuum in the 10^{-7} mbar range. The vacuum chamber is fixed to a separate concrete block that is mounted with vibration isolation to decouple it from the vibrations in the building's foundation. Based on our prior experiments with Mach-Effect and EMDrive thrusters, an upgraded balance is now under development with the following features:

- A total weight of up to 25 kg of thruster and electronics can be installed on the balance. There are two separately-shielded boxes on each side: one for the thruster assembly and one for the electronics.
- Thrust noise reduced to the nano-Newton range with a sub-Nanonewton resolution. We use the attocube IDS laser displacement sensor to digitally read out the balance position. This is the best laser interferometer that is commercially available with a pm digital resolution and a noise only limited by thermal vibration.
- Variable damping using eddy-currents and permanent magnets. A stepper motor can change the position of a copper disc to adapt the strength of damping. We can therefore find an optimum balance behaviour for different experimental setups.
- Stepper motors to level the balance once it is completely set-up inside the vacuum chamber.

- Stepper motors to change the orientation of the thruster. This enables us to investigate e.g. shifts in the center of gravity due to thermal expansion by changing the thruster direction from forward to backward and observing the change in the thrust measurement. All this can be done inside the vacuum chamber without breaking vacuum and changing any cables that can influence the analysis.
- Two different calibration techniques, one using a voice coil and one using electrostatic combs.
- The possibility of operating the balance in displacement- or compensated-thrust-mode. In the displacement-mode, the laser interferometer records the change of the angle of the balance arm and we use the spring constant of the balance that was calibrated by e.g. the voice coil to determine thrust. In compensated-mode, the thrust balance is kept in its zero position e.g. by using the voice coil. The thrust value is determined by the force used on the coil. Here, no spring constant influences the measurement. This can eliminate drifts and thermal expansion issues. The second calibration technique also allows to calibrate this compensation-mode.
- Complete shielding of the balance arm and thruster/electronics boxes using high permeability Mu-metal.
- Wireless control of experiment by on-board data aquisition using a LabJack T7 Pro with WiFi and an infrared serial port. This allows analog input/output, digital control of relais as well as temperature measurements on the balance. In addition, we added infrared cameras that can detect overheating of the electronics and the thruster. We also implemented a USB-WiFi connection to use e.g. oscilloscopes directly on the balance in vacuum.
- Four pairs of liquid-metal-contacts with twisted, paired cables to supply the balance and experiments with power and other data signals.
- LabView program that can operate and control the complete vacuum facility, thrust balance and experiments. A script language is used to automate the whole experiment, from calibration to measurement. This procedure ensures repeatable measurements and allows to check the validity of the balance calibration and perform signal averaging and filter operation to obtain very low noise signals.

A schematic of the balance is shown in Fig. 1 as well as a picture of the thrust balance inside our vacuum chamber in Fig. 2.

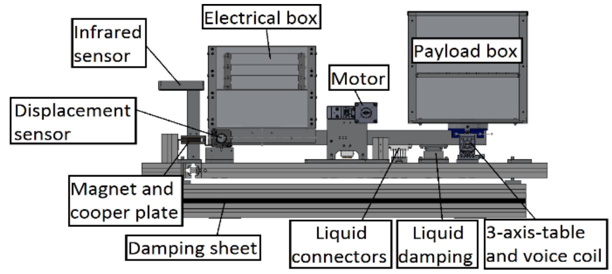

Fig. 1. Thrust Balance Schematic


Fig. 2. Thrust Balance in Vacuum Chamber

Calibration and optimization of the balance is ongoing. In addition, we are designing a new balance testbed that will allow the thruster to rotate 360° in order to exclude any thruster-chamber interactions or interactions with the Earth's magnetic field.

2.1 EMDrive

The EMDrive is a concept developed by Shawyer [20] in which microwaves are directed into a truncated resonator cavity/frustum which is claimed to produce thrust. He believes that the radiation pressure is different at the small and large ends which results in a net thrust force [21]. This was highly criticized as not being compatible with electromagnetism and conservation laws [22]. Alternative theories have appeared [23],[24] including a variable mass approach as outlined above [25], however, the community remains highly sceptical on the theoretical grounds of this concept.

On the other hand, there is a significant amount of experimental data available with tests both on a normal/knife-edge [26],[27] as well as on a torsion balance [7],[28],[29]. Initial concern concentrated on buoyancy effects due to testing in air, however, the more recent tests in high vacuum [7], especially NASA's latest test results by White et al [29] revealed that air is not an issue. Several experimental artefacts still need to be examined and higher quality thrust data must be obtained in order to validate the production of thrust. Thermal drifts were especially significant in the latest reported test by White et al. [29] and possible magnetic interaction with feeding cables has yet to be assessed.

We plan to build an EMDrive model similar to White et al. on our upgraded thrust balance as shown in Fig. 3. Our vacuum chamber is much larger allowing for better electromagnetic shielding. We plan to optimize the thermal design to limit any centre of gravity shifts due to thermal expansion. In addition, other geometries will be extensively tested as well.

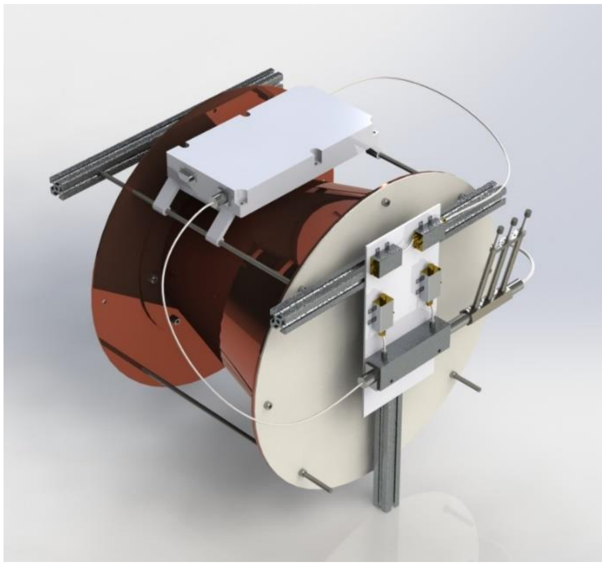

Fig. 3. Planned EMDrive Model Design

2.2 Mach-Effect Thruster

The second concept to be studied in detail is the so-called Mach-Effect thruster which is being developed by J.F. Woodward since the 1990s. Here the theoretical case is much more sound and has been published extensively in peer-reviewed literature [30]–[33]. It is based on one interpretation of Mach's principle (inertia here is due to mass out there), that inertial mass is due to the gravitational interaction with the whole universe. Sciama calculated the gravitational back-reaction from the universe on a local accelerating mass and found that this actually leads to Newton's famous second law [34]. Woodward and others showed that linearized general relativity theory with time-varying solutions and Sciama's analysis altogether leads to mass fluctuations that can be up to 11 orders of magnitude higher for typical devices than classically expected from $E=m.c^2$. Tajmar recently showed that only the time-derivate of mechanical power is responsible for these mass fluctuations [35].

This provides a solid basis for investigating pushing and pulling of such an oscillating/fluctuating mass to result in actual propellantless propulsion that is more effective than radiation pressure. Woodward is using a stack of clamped piezo crystals to perform both push-and-pull as well as vary the mechanical energy by using their expansion and contraction. A schematic sketch and a picture of an actual thruster is shown in Figs. 4 and 5. In addition to his theoretical work, Woodward performed many experiments that seemed to show an effect similar to his predictions, although at a very small thrust level (on the order or less than one µN). Recently, Buldrini [36] obtained similar results and also our lab is actively testing Mach-effect thrusters [6].

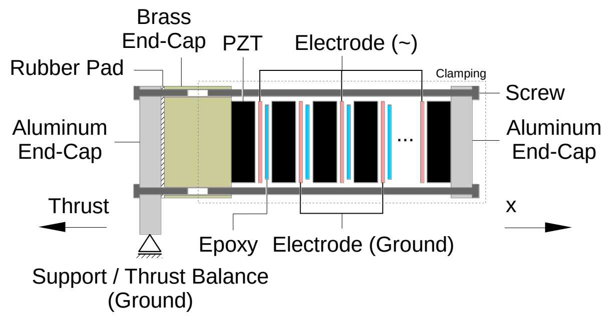

Fig. 4. Schematic Sketch of a Mach Effect Thruster [35]

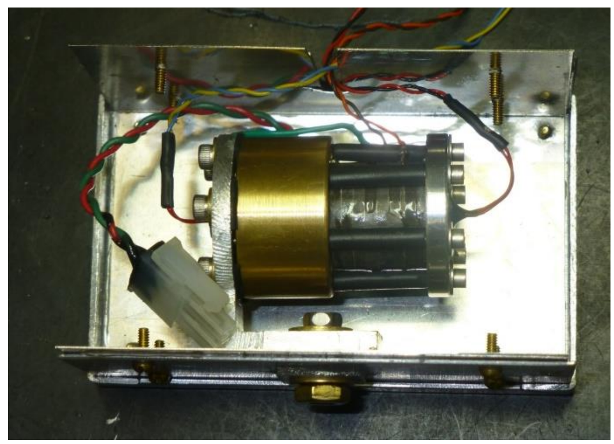

Fig. 5. Typical Mach-Effect Thruster Model (provided by J.F. Woodward)

Similar to the EMDrive, there are a number of experimental artefacts that should be critically assessed in order to obtain reliable results. Most notably, vibration and thermal effects are critical. We are planning to test older and more recent thruster models built and verified by Woodward in his own lab. In addition, we will design and build our own models, varying geometry, design and material to investigate scaling issues and to check the theoretical assumptions. Dedicated electronics (piezo amplifiers, signal generators, etc.) are under development that will allow integration of all required electronics on the balance [6].

We recently finished a detailed engineering model of the Mach-effect thruster that accurately takes geometry and material parameters into account [35]. Our next step is to verify our assumptions by finite-element modelling and through our experimental program.

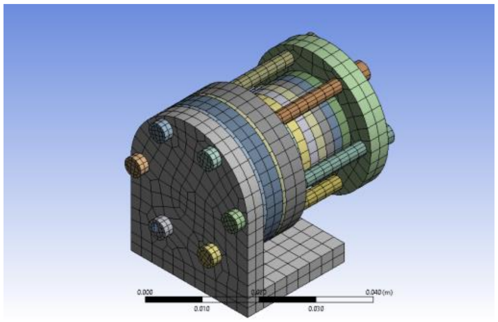

Fig. 6. Ansys Mach-Effect Thruster Model

2.3 Complementary Experiments

Here we are planning many student experiments that can help us explore important aspects of the ongoing thruster developments, as well as consider new concepts in case our main thruster investigations turn out to trace back the claimed thrusts to only experimental artefacts. Concepts under investigation are as follows:

- Rotating mass fluctuation device: By applying constant acceleration to ceramic capacitors, we may directly measure Machian mass fluctuations when applying power to the capacitors. The mass changes will be resolved by using piezo transducers that measure any change in the centrifugal force of the capacitor stack. Our initial setup as shown in Fig. 7 is based on an earlier experiment from J.F. Woodward [37], who kindly supplied his hardware for our initial investigation.

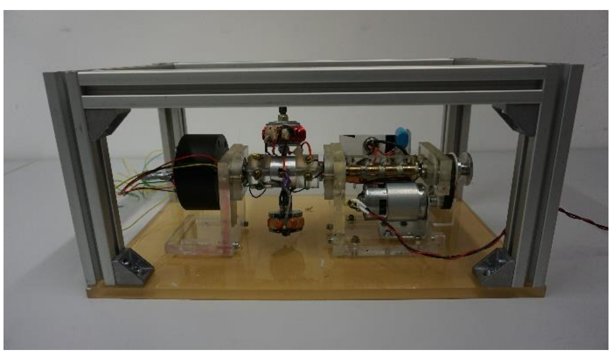

Fig. 7. Rotating Mass Fluctuation Experiment

- Weight change of mass at high temperature: We are designing a magnetic suspension balance to measure the weight of a sample that can be heated up to 1000 °C. Here we will also investigate piezo materials that are heating up in typical Mach-Effect thrusters. Dmitriev et al. published a number of measurements claiming a link between mass and temperature [38],[39]. Tajmar et al. previously investigated a mass-temperature link in the low temperature regime [40], this new experiment shall evaluate the high temperature regime with an unexplored accuracy and add to our analysis of thermally-induced artefacts.

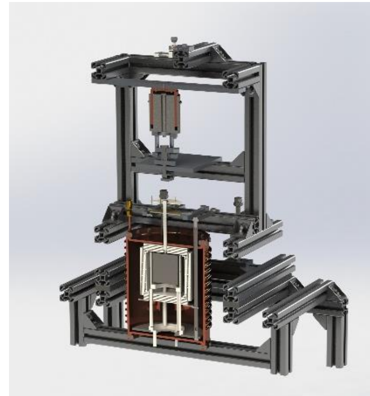

Fig. 8. Magnetic Suspension Balance Experiment

- Influence of electric polarization on mass: We recently evaluated patent claims of weight anomalies of electrets (permanently polarized dielectrics) [41]. Here we want to test the influence of electric polarization of ceramic capacitors similar to the piezo-material used in the Mach-effect thruster on any direct weight change.

- Inertial mass change in charged Faraday cage: Assis calculated that the inertial mass of an accelerated charged inside a Faraday cage should change depending on the cage's charge [42]. This is a consequence of Weber electrodynamics, which was actually developed before Maxwell and can explain all electromagnetic phenomenon in one single force equation [43]. Alternatively, one can also view this as a consequence of electrostatic energy converted to mass (electromagnetic mass). Although some controversial experiments were published in the past [44]–[46], recent experiments seem to favour the prediction of Weber electrodynamics [47],[48]. Here we are planning experiments that can clearly show if such an electrostatic-mass effect exists that can be used for thruster or energy-production concepts [14].

3. Conclusions

The SpaceDrive project aims at developing cutting-edge measurement equipment to thoroughly test the latest EMDrive and Mach-Effect thruster models, the two most promising revolutionary thruster concepts that are presently under investigation at various labs. Our thrust balances shall provide the necessary resolution and investigate electromagnetic and thermal artefacts to obtain reliable measurements in order to confirm or refute the claimed thrusts.

It is a high-risk/high-payoff effort. Each thruster concept has its supporters and critics and each of them can be attacked on theoretical grounds and possible experimental artefacts. However, the gain could be enormous with propellantless propulsion capabilities orders of magnitude better than radiation pressure, which could result in a real prospect for interstellar flight. The wealth of existing experimental data makes it very interesting from a measurement perspective to track and trace down the cause of the anomalous thrust signals. At least, SpaceDrive is an excellent educational project by developing highly demanding test setups, evaluating theoretical models and possible experimental errors. It's a great learning experience with the possibility to find something that can drive space exploration into its next generation.

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