Evaluating NASA's Futuristic EM Drive

April 29, 2015 by José Rodal, Ph.D, Jeremiah Mullikin and Noel Munson - subedited by Chris Gebhardt

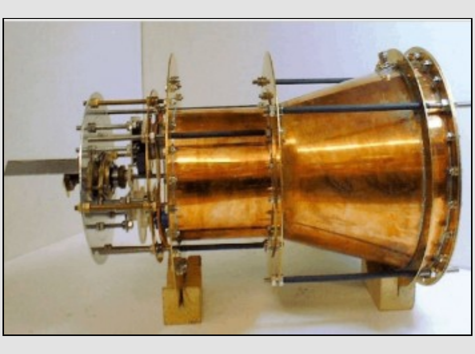
A group at NASA's Johnson Space Center has successfully tested an electromagnetic (EM) propulsion drive in a vacuum – a major breakthrough for a multi-year international effort comprising several competing research teams. Thrust measurements of the EM Drive defy classical physics' expectations that such a closed (microwave) cavity should be unusable for space propulsion because of the law of conservation of momentum.

EM Drive:

Last summer, NASA Eagleworks – an advanced propulsion research group led by Dr. Harold "Sonny" White at the Johnson Space Center (JSC) – made waves throughout the scientific and technical communities when the group presented their test results on July 28-30, 2014, at the 50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference in Cleveland, Ohio.

Those results related to experimental testing of an EM Drive – a concept that originated around 2001 when a small UK company, Satellite Propulsion Research Ltd (SPR), under Roger J. Shawyer, started a Research and Development (R&D) program.

The concept of an EM Drive as put forth by SPR was that electromagnetic microwave cavities might provide for the direct conversion of electrical energy to thrust without the need to expel any propellant.

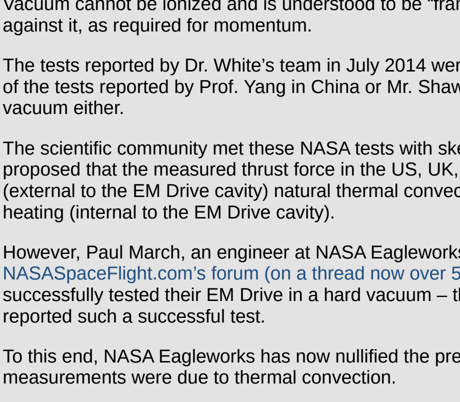


This lack of expulsion of propellant from the drive was met with initial skepticism within the scientific community because this lack of propellant expulsion would leave nothing to balance the change in the spacecraft's momentum if it were able to accelerate.

However, in 2010, Prof. Juan Yang in China began publishing about her research into EM Drive technology, culminating in her 2012 paper reporting higher input power (2.5kW) and tested thrust (720mN) levels of an EM Drive.

In 2014, Prof. Yang's papers reported extensive tests involving internal temperature measurements with embedded thermocouples.

It was reported (in SPR Ltd.'s website) that if the Chinese EM Drive were to be installed in the International Space Station (ISS) and work as reported, it could provide the necessary delta-V (change in velocity needed to perform an on-orbit maneuver) to compensate for the Station's orbital decay and thus eliminate the requirement of re-boosts from visiting vehicles. Despite these reports, Prof. Yang offered no scientifically-accepted explanation as to how the EM Drive can produce propulsion in space.



Dr. White proposed that the EM Drive's thrust was due to the Quantum Vacuum (the quantum state with the lowest possible energy) behaving like propellant ions behave in a MagnetoHydroDynamics drive (a method electrifying propellant and then directing it with magnetic fields to push a spacecraft in the opposite direction) for spacecraft propulsion.

In Dr. White's model, the propellant ions of the MagnetoHydroDynamics drive are replaced as the fuel source by the virtual particles of the Quantum Vacuum, eliminating the need to carry propellant.

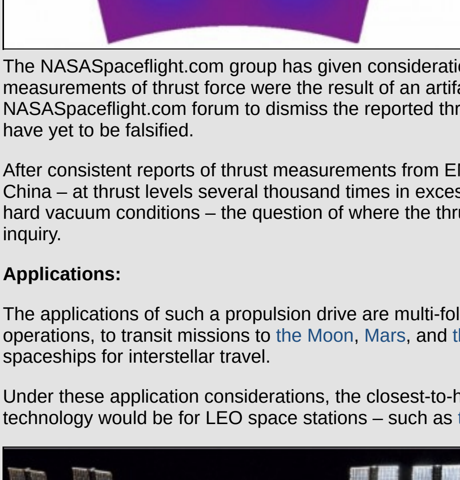
This model was also met with criticism in the scientific community because the Quantum Vacuum cannot be ionized and is understood to be "frame-less" – meaning you cannot "push" against it, as required for momentum.

The tests reported by Dr. White's team in July 2014 were not conducted in a vacuum, and none of the tests reported by Prof. Yang in China or Mr. Shawyer in the UK were conducted in a vacuum either.

The scientific community met these NASA tests with skepticism and a number of physicists proposed that the measured thrust force in the US, UK, and China tests was more likely due to (external to the EM Drive cavity) natural thermal convection currents arising from microwave heating (internal to the EM Drive cavity).

However, Paul March, an engineer at NASA Eagleworks, recently reported in NASASpaceFlight.com's forum (on a thread now over 500,000 views) that NASA has successfully tested their EM Drive in a hard vacuum – the first time any organization has reported such a successful test.

To this end, NASA Eagleworks has now nullified the prevailing hypothesis that thrust measurements were due to thermal convection.



A community of enthusiasts, engineers, and scientists on several continents joined forces on the NASASpaceflight.com EM Drive forum to thoroughly examine the experiments and discuss theories of operation of the EM Drive.

The quality of forum discussions attracted the attention of EagleWorks team member Paul March at NASA, who has shared testing and background information with the group in order to fill in information gaps and further the dialogue.

This synergy between NASASpaceflight.com contributors and NASA has resulted in several contributions to the body of knowledge about the EM Drive.

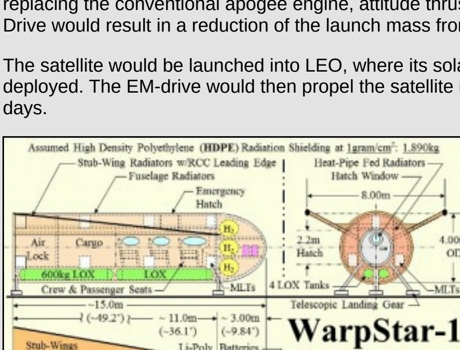
The NASASpaceflight.com group has given consideration to whether the experimental measurements of thrust force were the result of an artifact. Despite considerable effort within the NASASpaceflight.com forum to dismiss the reported thrust as an artifact, the EM Drive results have yet to be falsified.

After consistent reports of thrust measurements from EM Drive experiments in the US, UK, and China – at thrust levels several thousand times in excess of a photon rocket, and now under hard vacuum conditions – the question of where the thrust is coming from deserves serious inquiry.

Applications:

The applications of such a propulsion drive are multi-fold, ranging from low Earth orbit (LEO) operations, to transit missions to the Moon, Mars, and the outer solar system, to multi-generation spaceships for interstellar travel.

Under these application considerations, the closest-to-home potential use of EM Drive technology would be for LEO space stations – such as the International Space Station.



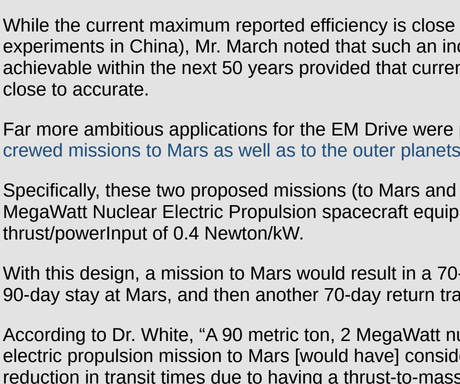
In terms of the Station, propellant-less propulsion could amount to significant savings by drastically reducing fuel resupply missions to the Station and eliminate the need for visiting-vehicle re-boost maneuvers.

The elimination of these currently necessary re-boost maneuvers would potentially reduce stress on the Station's structure and allow for a pro-longed operational period for the ISS and future LEO space stations.

Likewise, EM drive technology could also be applied to geostationary orbit (GEO) satellites around Earth.

For a typical geostationary communications satellite with a 6kW (kilowatt) solar power capacity, replacing the conventional apogee engine, attitude thrusters, and propellant volume with an EM Drive would result in a reduction of the launch mass from 3 tons to 1.3 tons.

The satellite would be launched into LEO, where its solar arrays and antennas would be deployed. The EM-drive would then propel the satellite in a spiral trajectory up to GEO in 36 days.



Moving out from LEO, Mr. March, from NASA EagleWorks, noted that a spacecraft equipped with EM drive technology could surpass the performance expectations of the WarpStar-I concept vehicle.

If such a similar vehicle were equipped with an EM Drive, it could enable travel from the surface of Earth to the surface of the moon within four hours.

Such a vehicle would be capable of carrying two to six passengers and luggage and would be able to return to Earth in the same four-hour interval using one load of hydrogen and oxygen for fuel cell-derived electrical power, assuming a 500 to 1,000 Newton/kW efficiency EM Drive system.

While the current maximum reported efficiency is close to only 1 Newton/kW (Prof. Yang's experiments in China), Mr. March noted that such an increase in efficiency is most likely achievable within the next 50 years provided that current EM Drive propulsion conjectures are close to accurate.

Far more ambitious applications for the EM Drive were presented by Dr. White and include crewed missions to Mars as well as to the outer planets.

Specifically, these two proposed missions (to Mars and the outer planets) would use a 2 MegaWatt Nuclear Electric Propulsion spacecraft equipped with an EM Drive with a thrust/powerInput of 0.4 Newton/kW.

With this design, a mission to Mars would result in a 70-day transit from Earth to the red planet, a 90-day stay at Mars, and then another 70-day return transit to Earth.

According to Dr. White, "A 90 metric ton, 2 MegaWatt nuclear electric propulsion mission to Mars [would have] considerable reduction in transit times due to having a thrust-to-mass ratio greater than the gravitational acceleration of the Sun (0.6 milli-g's at 1 Astronomical Unit)."

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Furthermore, this type of mission would have the added benefit of requiring only a "single heavy lift launch vehicle" as compared to "a current conjunction-class Mars mission using chemical propulsion systems, which would require multiple heavy lift launch vehicles."

Presenting at the "Human Outer Solar System Exploration via Q-Thruster Technology" panel at IEEE, 2014, Mr. Joosten and Dr. White explained that "only 12 days would be utilized spiraling up from a 400 km low Earth orbit to achieve escape velocity and only 5 days spiraling down to a 400 km low Mars orbit."

While these spiral trajectories around Earth would have to be carefully designed to avoid or minimize time in the most problematic regions of the Van Allen radiation belts that could expose crewmembers to undesirable levels of radiation, Mr. Joosten and Dr. White note that "These relatively rapid transits would argue for mission strategies where the 'Q-Ship' (EM Drive ship) operates between the lowest orbits possible to minimize the launch requirements of crew and supplies from Earth and lander complexity at Mars."

Moreover, this type of EM Drive-enabled mission could negate the need to bring along, for the duration of the mission, a high-speed reentry vehicle to return a Mars crew back to the Earth's surface because "By quickly spiraling into Earth orbit at the end of the mission, the crew could readily be retrieved via a 'ground-up' launch.

"While the fast Mars transits that Q-Thruster technology [EM drive] could enable would be revolutionary, the independence from the limitations of departure and arrival windows may ultimately be more so," added Mr. Joosten and Dr. White.

This means that an EM drive ship mission could be designed without consideration of the every-two-year interplanetary conjunction launch windows that currently govern Earth-Mars transit missions and could help stabilize and provide more routine Mars crew rotation timetables.

This same elimination of inter-planetary conjunction-enabled launch windows would be applied to crewed missions to the outer planets as well.

For such a mission, such as a crewed flight to the outer planets – specifically, a Titan/Enceladus mission at Saturn – an EM Drive would allow for a 9-month transit period from Earth to Saturn, a 6-month in-situ mission at Titan, another 6-month in-situ mission at Enceladus, and a 9-month return trip to Earth. This would result in a total mission duration of just 32 months.

However, EM drive applications are not limited to Mars or outer solar system targets.

Applications of this technology in deep space missions have already received conceptual outlines.

In particular, the Alpha Centauri system, the closest star system to our solar system at just 4.3 lights year's distance, received specific mention as a potential mission destination.

Mr. Joosten and Dr. White stated that "a one-way, non-decelerating trip to Alpha Centauri under a constant one milli-g acceleration" from an EM drive would result in an arrival speed of 9.4 percent the speed of light and result in a total transit time from Earth to Alpha Centauri of just 92 years.

However, if the intentions of such a mission were to perform in-situ observations and experiments in the Alpha Centauri system, then deceleration would be needed.

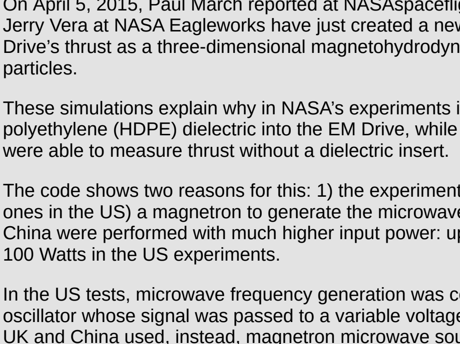
This added component would result in a 130-year transit time from Earth to Alpha Centauri – which is still a significant improvement over the multi-thousand year timetable such a mission would take using current chemical propulsion technology.

The speeds discussed in the Alpha Centauri mission proposal are sufficiently low that relativity effects are negligible.

Bringing EM Drives to reality:

While such mission proposals are important to consider, equally as important are the considerations toward development of the needed technology and procurement long-lead items necessary to make this power technology a reality.

Specifically, a useful EM Drive for space travel would need a nuclear power plant of 1.0 MWe (Megawatts-electric) to 100 MWe.



While that sounds significant, the U.S. Navy currently builds 220 MW-thermal reactors for its "Boomer" Ohio class ICBM vehicles.

Thus, the technology to build such reactors is available, and the technology needed to build such a device for space-based operations has been around since the 1980s.

The limiting factors for further testing and development of this potentially revolutionary space exploration technology are funding to verify and characterize its operations, and the political will to develop nuclear power for space applications.

Progress Update:

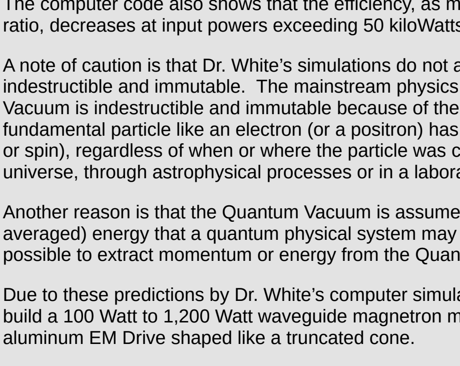
On April 5, 2015, Paul March reported at NASAspaceflight.com's Forum that Dr. White and Dr. Jerry Vera at NASA Eagleworks have just created a new computational code that models the EM Drive's thrust as a three-dimensional magnetohydrodynamic flow of electron-positron virtual particles.

These simulations explain why in NASA's experiments it was necessary to insert a high density polyethylene (HDPE) dielectric into the EM Drive, while the experiments in the UK and China were able to measure thrust without a dielectric insert.

The code shows two reasons for this: 1) the experiments in the UK and China used (unlike the ones in the US) a magnetron to generate the microwaves and 2) the experiments in the UK and China were performed with much higher input power: up to 2.5 kiloWatts, compared to less than 100 Watts in the US experiments.

In the US tests, microwave frequency generation was controlled via a voltage-controlled oscillator whose signal was passed to a variable voltage attenuator. The tests performed in the UK and China used, instead, magnetron microwave sources (as used in home-use microwave ovens) for their experiments.

The magnetron generates amplitude, frequency and phase modulation of the carrier wave (FM modulation bandwidth on the order of +/-20 MHz, at tested natural frequencies of ~2.5 GHz). Dr. White's computer simulation shows that the modulation generated by the magnetron results in greater thrust force.



Dr. White's computer analysis also shows that increasing the input power focuses the virtual particle flow from near omnidirectional at the low powers used in the NASA experiments, to a much more focused jet like beam at the higher power (kilowatts as compared to less than 100 Watts) used in the UK and China experiments.

The simulation for the 100 Watts input power (as used in the latest tests at NASA) predicted only ~50 microNewtons (in agreement with the experiments) using the HDPE dielectric insert, while the 10 kiloWatts simulation (without a dielectric) predicted a thrust level of ~6.0 Newtons. At 100 kiloWatts the prediction is ~1300 Newton thrust.

The computer code also shows that the efficiency, as measured by the thrust to input power ratio, decreases at input powers exceeding 50 kiloWatts.

A note of caution is that Dr. White's simulations do not assume that the Quantum Vacuum is indestructible and immutable. The mainstream physics community assumes the Quantum Vacuum is indestructible and immutable because of the experimental observation that a fundamental particle like an electron (or a positron) has the same properties (e.g. mass, charge or spin), regardless of when or where the particle was created, whether now or in the early universe, through astrophysical processes or in a laboratory.

Another reason is that the Quantum Vacuum is assumed to be the lowest possible (time-averaged) energy that a quantum physical system may have, and therefore it should not be possible to extract momentum or energy from the Quantum Vacuum.

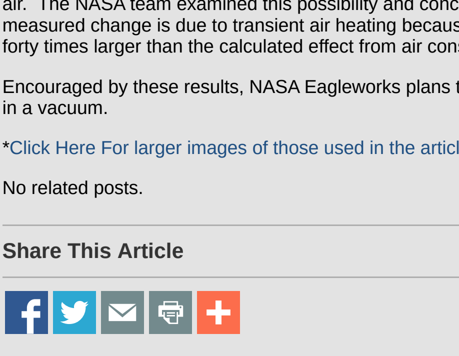
Due to these predictions by Dr. White's computer simulations NASA Eagleworks has started to build a 100 Watt to 1,200 Watt waveguide magnetron microwave power system that will drive an aluminum EM Drive shaped like a truncated cone.

Initially a teeter-totter balance system will be used in ambient conditions to see if similar thrust levels (0.016 to 0.3 Newton) as reported in the US and China can be reproduced at NASA with this approach.

For the last three years, Dr. White's team has been conducting experiments to find out whether it is possible to measure, with an interferometer, a distortion of spacetime produced by time-varying electromagnetic fields.

The ultimate goal is to find out whether it is possible for a spacecraft traveling at conventional speeds to achieve effective superluminal speed by contracting space in front of it and expanding space behind it. The experimental results so far had been inconclusive.

During the first two weeks of April of this year, NASA Eagleworks may have finally obtained conclusive results. This time they used a short, cylindrical, aluminum resonant cavity excited at a natural frequency of 1.48 GHz with an input power of 30 Watts.



This is essentially a pill-box shaped EM Drive, with much higher electric-field intensity, aligned in the axial direction. The interferometer's laser light goes through small holes in the EM Drive.

Over 27,000 cycles of data (each 1.5 sec cycle energizing the system for 0.75 sec and de-energizing it for 0.75 sec) were averaged to obtain a power spectrum that revealed a signal frequency of 0.65 Hz with amplitude clearly above system noise. Four additional tests were successfully conducted that demonstrated repeatability.

One possible explanation for the optical path length change is that it is due to refraction of the air. The NASA team examined this possibility and concluded that it is not likely that the measured change is due to transient air heating because the experiment's visibility threshold is forty times larger than the calculated effect from air considering atmospheric heating.

Encouraged by these results, NASA Eagleworks plans to next conduct these interferometer tests in a vacuum.

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