Excerpts from "It's Official: NASA's Peer-Reviewed EM Drive Paper Has Finally Been Published"

By Fiona McDonald, Science Alert, November 19, 2016

It works.

After months of speculation and leaked documents, NASA's long-awaited EM Drive paper has *finally* been peer-reviewed and published. And it shows that the 'impossible' propulsion system really does appear to work.

The NASA Eagleworks Laboratory team even put forward a hypothesis for how the EM Drive could produce thrust – something that seems impossible according to our current understanding of the laws of physics.

In case you've missed the hype, the EM Drive, or Electromagnetic Drive, is a propulsion system first proposed by British inventor Roger Shawyer back in 1999.

Instead of using heavy, inefficient rocket fuel, it bounces microwaves back and forth inside a cone-shaped metal cavity to generate thrust.

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But, there's a not-small problem with the system. It defies Newton's third law, which states that everything must have an equal and opposite reaction.

According to the law, for a system to produce thrust, it has to push something out the other way. The EM Drive doesn't do this.

Yet in test after test it continues to work. Last year, NASA's Eagleworks Laboratory team got their hands on an EM Drive to try to figure out once and for all what was going on.

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The new peer-reviewed paper is titled "Measurement of Impulsive Thrust from a Closed Radio-Frequency Cavity in Vacuum," and has been published online as an open access 'article in advance' in the American Institute of Aeronautics and Astronautics (AIAA)'s *Journal of Propulsion and Power*. It'll appear in the December print edition.

It's very similar to the paper that was leaked online earlier this month and, most notably, shows that the drive does indeed produce 1.2 millinewtons per kilowatt of thrust in a vacuum:

"Thrust data from forward, reverse, and null suggested that the system was consistently performing at 1.2 ± 0.1 mN/kW, which was very close to the average impulsive performance measured in air. A number of error sources were considered and discussed."

To put that into perspective, the super-powerful Hall thruster generates force of 60 millinewtons per kilowatt, an order of magnitude more than the EM Drive.

But the Hall thruster requires propellants, and that extra weight could offset the higher thrust, the team concludes.

Light sails on the other hand, which are currently the most popular form of zero-propellant propulsion, only generate force up to 6.67 micronewtons per kilowatt – two orders of magnitude less than NASA's EM Drive, says the paper.

But the team makes it clear that they also weren't attempting to optimise performance in these tests – all they were doing was trying to prove whether or not the drive really works. So it's likely that the EM Drive could get a lot more efficient still.

When it comes to *how* the drive actually works without messing up the laws of physics, that's a little less clear.

It's not the focus of this paper, but the team does offer a hypothesis:

"[The] supporting physics model used to derive a force based on operating conditions in the test article can be categorised as a nonlocal hidden-variable theory, or pilot-wave theory for short."

Pilot-wave theory is a slightly controversial interpretation of quantum mechanics.

It's pretty complicated stuff, but basically the currently accepted Copenhagen interpretation of quantum mechanics states that particles do not have defined locations until they are observed.

Pilot-wave theory, on the other hand, suggests that particles do have precise positions at all times, but in order for this to be the case, the world must also be strange in other ways – which is why many physicists have dismissed the idea.

But in recent years, the pilot-wave theory has been increasing in popularity, and the NASA team suggests that it could help explain how the EM Drive produces thrust without appearing to propel anything in the other direction.

"If a medium is capable of supporting acoustic oscillations, this means that the internal constituents were capable of interacting and exchanging momentum," the team writes.

"If the vacuum is indeed mutable and degradable as was explored, then it might be possible to do/extract work on/from the vacuum, and thereby be possible to push off of the quantum vacuum and preserve the laws of conservation of energy and conservation of momentum."

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The scientific community is also notoriously unconvinced about the propulsion system – just yesterday a Motherboard article on the EM Drive was deleted by the moderators of the popular subreddit r/Physics because they "consider the EM Drive to be unscientific."

But is the first peer-reviewed research ever published on the EM Drive, which firmly takes it out of the realm of pseudoscience into a technology that's worth taking skeptically, but seriously. The next step for the EM Drive is for it to be tested in space, which is scheduled to happen in the coming months, with plans to launch the first EM Drive having been made back in September.

If it produces thrust there, the scientific community will need to sit up and take note.

Alcubierre Warp Drive

Excerpt from Wikipedia Article, "Alcubierre drive," September 23, 2018

The Alcubierre drive or Alcubierre warp drive (or Alcubierre metric, referring to metric tensor) is a speculative idea based on a solution of Einstein's field equations in general relativity as proposed by theoretical physicist Miguel Alcubierre, by which a spacecraft could achieve apparent faster-than-light travel if a configurable energy-density field lower than that of vacuum (that is, negative mass) could be created.

Rather than exceeding the speed of light within a local reference frame, a spacecraft would traverse distances by contracting space in front of it and expanding space behind it, resulting in effective faster-than-light travel. Objects cannot accelerate to the speed of light within normal spacetime; instead, the Alcubierre drive shifts space around an object so that the object would arrive at its destination faster than light would in normal space without breaking any physical laws.

Although the metric proposed by Alcubierre is consistent with the Einstein field equations, it may not be physically meaningful, in which case a drive will not be possible. Even if it is physically meaningful, its possibility would not necessarily mean that a drive can be constructed. The proposed mechanism of the Alcubierre drive implies a negative energy density and therefore requires exotic matter. So if exotic matter with the correct properties cannot exist, then the drive could not be constructed. However, at the close of his original article Alcubierre argued (following an argument developed by physicists analyzing traversable wormholes) that the Casimir vacuum between parallel plates could fulfill the negative-energy requirement for the Alcubierre drive.

Another possible issue is that, although the Alcubierre metric is consistent with Einstein's equations, general relativity does not incorporate quantum mechanics. Some physicists have presented arguments to suggest that a theory of quantum gravity (which would incorporate both theories) would eliminate those solutions in general relativity that allow for backwards time travel (see the chronology protection conjecture) and thus make the Alcubierre drive invalid.[1]

[1] Commentary & Citation: A 2020 update: The Wikipedia article on "Interstellar travel" continues to state that the EM Drive ('RF resonate cavity thruster') did not work when tested by NASA and that any appearance of thrust generated was a non-repeatable anomaly:

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On October 16, 2019, Anton Petrov posted an 11-minute video "NASA Engineer Designs a Near Light Speed Engine But Does It Work?" to his channel discussing the Helical Engine proposed by NASA scientist Dr. David Burns in 2019 (which is also mentioned in the Wikipedia article, *Id.*). While he was critical of the concept, he also noted with disapproval, the vicious and mean-spirited attacks on the idea from the scientific community.

So highly educated scientists continue to propose novel interstellar travel propulsion systems, and get dogpiled by jealous colleagues for daring to step outside the bounds of current science. *Und so weiter.*