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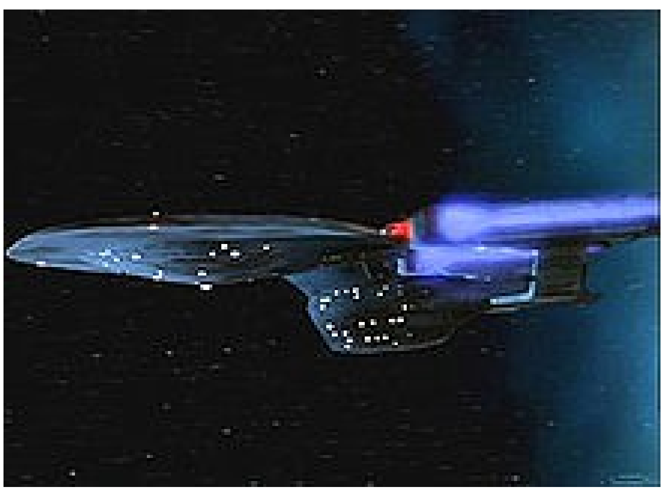
Is the Warp Drive Possible?

The Earth is a very boring place to live. If humanity is forced to live on Earth until it all dies at the hands of the Sun, then It would be hard to see how human life could be considered anything except as a complete and utter failure. To this end, a way to travel to alien worlds needs to be discovered to free humanity from eternal boredom. Conventional speeds would not get anything anywhere in a reasonable amount of time, due to the distances involved and the effects of time dilation. So obviously, we need to discover a way to travel faster than the speed of light. One of the most interesting ways to accomplish this to be proposed is called the Alcubierre Drive, which bends space-time in order to achieve this seemingly impossible feat. This bears a marking resemblance to the Warp Drive from the science fiction show Star Trek.



http://en.wikipedia.org/wiki/File:STYestEnterprise.jpg

Is this the future of space travel?

This "warp drive" has drawn heavy criticism from the scientific community, who do not see the Alcubierre Drive as a feasible option.

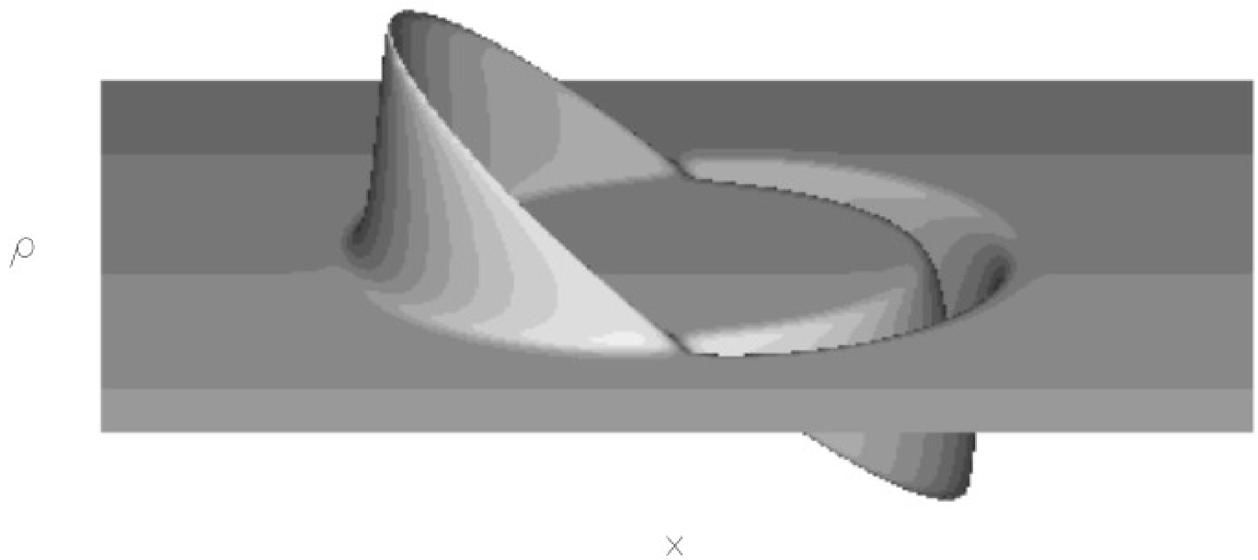
The speed of light serves as a cosmic speed limit because of General Relativity, ending all hope for accomplishing superluminal speeds, so it would seem. However, General Relativity only says that an object cannot move locally faster than the speed of light, meaning that an object cannot go faster than the speed of light with respect to its own reference frame. Hence, all that is necessary to break the light barrier is to rethink the word move. For example, the universe is expanding at a constant rate of approximately 70.8 ± 4.0 (km/s)/Mpc. This means that if an object were 4300 megaparsecs from Earth, then, although it would be completely stationary, it would me moving at faster than the speed of light away from the Earth. Similarly, if the Universe was contracting, then an object could travel towards Earth at a speed greater than the speed of light while remain perfectly stationary from its own reference frame[1]. Thus, according to Alcubierre, the easiest way to break the light barrier would be to expand space-time behind an object while contracting it by the exact same amount in front of the object, which would effectively be on the inside of a "bubble", where space-time is flat. The object would then be observed to be moving at a velocity not limited in any way by the speed of light(Alcubierre) He did this by using the space-time metric given by

$$ds^2 = -dt^2 + \left(dx - v_s f(r_s)\, dt\right)^2 + dy^2 + dz^2 \ .$$

Where $f(r_s)$ approaches a top hat of 1 at the radius of the warp bubble. Alcubierre chose the formula

$$f(r_s) = \frac{\tanh\left(\sigma\,(r_s + R)\right) - \tanh\left(\sigma\,(r_s - R)\right)}{2\tanh(\sigma R)} \ ,$$

This metric can be visualized like it is shown in Alcubierre's paper



space is contracted in front of the object and expanded behind the object, propelling the center to the right

Many physicists, including Alcubierre, have found problems with the warp drive. For example, the energies required to construct the “warp bubble” would be negative[2]. This is in clear violation of the weak energy condition, which clearly states that in order for something to be physically feasible, it must have a positive energy density to all observers. Since the Alcubierre Drive does not meet this condition (in addition to the strong energy condition, which ironically, is not taken seriously at all because of the plethora of counter-examples), it is said to be impossible. This is not the case, as the energy conditions may be merely guidelines. For example, the Casimir Effect, which attracts or repels objects at microscopic distances, requires negative energy densities, yet is a physical certainty. To create the requisite negative energies, it is necessary to create “exotic matter”, which is capable of producing negative energy densities. Some have argued that exotic matter is made impossible by the standard model of particle physics, but it is impossible to deny that negative energy densities are allowed in certain circumstances[3].

In addition to breaking some of the laws of physics (no matter how weak), it may be impossible to create a warp drive in the first place. Obviously, the warp drive must be created before it can travel at superluminal speeds, so the matter required to build the warp drive must be distributed before the warp drive can form. In order to distribute the matter before the geometry is affected, Coule argues that the matter must be moved at hyper-fast speeds[4]. However, the Alcubierre drive is meant to be a solution to the problem of being unable to do just this, and as such presupposes that doing so is impossible without altering space-time. Since one needs to be able to move objects at speeds surpassing the speed of light before being able to do so means that the Alcubierre drive suffers from the “need one to make one” paradox[5]. It seems that this objection could be engineered away quite easily, as there is no set speed to create a warp drive provided by Coule in his paper, just a blanket assertion with no proof provided to support it.

Assuming that the warp drive is fully constructed, that does not necessarily end the problems associated with the exotic matter. The negative energy drops off quickly outside the Alcubierre drive, but it does not do so immediately. Since the negative energy must travel along with the drive, then outside of the warp drive, there must be exotic matter traveling locally faster than the speed of light, which is expressly forbidden by general relativity[6]. This means that a portion of the exotic matter keeping the warp drive in place is fundamentally unable to keep up with the warp drive it is supporting, leading to the outer shell being left behind the moment superluminal speeds are hit, leading to the sure destruction of the warp drive. It is possible to circumvent this problem (and the one previous) by having an exotic matter “highway” of sorts, but doing so would require traveling the entire path to be taken to be traversed in some manner, and without superluminal travel, this would take at least the amount of time that it takes to travel between the stars using subluminal speeds (which is to say a really long time). This may be an acceptable sacrifice, as there would be no time dilation, but being able to travel faster than the speed of light is the purpose of the Alcubierre drive. Without this ability, the warp drive loses much of its appeal, as it would still take years to travel the stars instead of an arbitrarily short time.

In addition to these problems, it has been argued that the warp-drive cannot be controlled once it has been created. Since the metric is taken to be traveling at faster than the speed of light, it is impossible for any event on the interior of the bubble to interact causally with the exterior of the bubble[7]. This is because information can only travel at the speed of light, and the metric would be folding space in the folded part at the speed of light, which is to say that the speed of light is at least canceled, if not more than reversed by the contraction and expansion of space-time at the bubble, meaning that light (and by extension, information) is unable to enter the bubble, so the inside of the warp drive is causally unlinked from the outside of the bubble. This necessarily means that there is no means by which to determine the direction, speed or anything else about the warp drive once it has been created. Having an uncontrollable spacecraft hurtling through space is hardly a good thing, it would naturally lead to whatever is inside the warp drive being taken on a trip into infinity until the craft hits something that causes the warp-drive to collapse. However, this is only true once the warp drive hits superluminal speeds, until then, it is possible to control the vessel. All of this, of course, assumes that the fact that the outer shell would be lost the moment it hit superluminal speeds is irrelevant. In reality, the collapse of the warp-drive would leave the fact that the warp-drive is uncontrollable moot, as it would never get the opportunity to become uncontrollable. However, this still means that traveling the stars in a reasonable amount of time is impossible.

Assuming that it is possible to create a warp drive, that it can travel at faster than the speed of light without losing stability, and that is possible to steer and stop the warp drive, the stress tensor required would render the warp drive impossible to build, no matter how advanced a civilization gets. William Hiscock made this determination by converting the Alcubierre metric into a two dimensional space-time, with just time and the direction of movement being relevant. He then gave the warp drive a constant velocity, so that there would be a reference point at which the warp drive is stationary. He then derived a metric for this two dimensional warp drive and used this metric to derive the stress energy density for the drive as follows.

$$\langle \rho \rangle \sim \frac{-(f')^2}{48\pi}\left[f - \left(1 - \frac{1}{v_0}\right)\right]^{-2} + ...$$

Clearly, the stress energy density will diverge when f approaches $1-1/v_0$, which is equals 0 when $v_0=1$, which is at the speed of light. The function f is defined as a function approaching 0 at infinity. This means that when moving at the speed of light, infinite amounts of energy will be needed in order to counter the stresses of the warp drive, at least in two dimensions[8]. The reason for this is that the warp drive acts like a two dimensional black hole, with the associated Hawking Radiation. Since the temperature of the universe is not equal to the natural temperature of the “black hole” formed, the stress tensor will inevitably diverge[9]. This calculation was done on a two dimensional warp drive, whereas the original warp drive was in

4 dimensions. This calculation has not been replicated in four dimensions, so it has not yet been definitively shown that the stress tensor of the real Alcubierre drive is also infinite.

However, there has been much work done on the total energy of the Alcubierre Drive, most notably Pfjenning and Ford, who did this by calculating the thickness of the outer shell by modeling the shell as a pair of lines going to the peak of the shell from zero, and determining the maximum thickness. The result they came up with was a thickness of approximately 100 Planck Lengths (the smallest unit of distance possible, about 16 x 10^{-35}m), which is enormously small in of itself, but even more so compared to the size of the craft, estimated at 100 m in diameter. They then came up with an equation for the total energy of the warp drive, which is approximately proportional to the square of the radius of the bubble divided by the thickness of the bubble. Since the bubble must be large enough to fit a craft capable of creating the warp drive, and the walls must be infinitesimally thin, the total energy for a bubble with radius of 100 metres and thickness of 100 Planck lengths would wind up being equivalent to -6.2 x 10^{62} kg at the speed of light, which is 10 orders of magnitude greater than the mass of the observable universe[10] Clearly this is an immense problem to deal with. However, if one wishes to move an electron at greater than the speed of light, only -400 times the mass of the sun in order to accomplish this feat[11].

To be fair to the Alcubierre Drive, the energy required has since been reduced to more reasonable levels. Chris Van Den Broeck lowered the energy by altering the space-time metric slightly to make the warp drive infinitesimal from the outside, but large enough to fit the spacecraft on the inside[12]. He did this by expanding the space inside the bubble while not changing the observed size of the bubble. In order to do this, he had two areas in which space-time was distorted, one for the warp drive, and one that fit the spacecraft into the warp drive. Reworking the numbers with the new values gave an energy on the order of 10^{30} kg, which is close to stellar magnitude[13]. This is still a massive value, with absolutely ridiculous energy densities, but it shows that by subtly changing the geometry involved, it is possible to drastically reduce (by 32 orders of magnitude in this case) the energy required for the system.

Serguei Krasnikov used this idea to develop a similar metric which only requires a about 10^{-3} grams of energy in order to maintain[14]. He did this by abandoning the spherical symmetry demanded by the original metric, he chose the following metric

$$\mathrm{d}s^2 = -\mathrm{d}t^2 + 4(\varepsilon^2(\eta) + \eta^2)(\mathrm{d}\eta^2 + \eta^2\mathrm{d}\psi^2) + \rho^2\mathrm{d}\phi^2,$$

Where ε is a smooth even function in the area of the curve. This metric resembles a pair of hoops of bent space[15]. He found that the energy of this configuration is roughly equal to the radius of the hoops, which can be made arbitrarily small. He then expanded the inner space as per Van Den Broeck, resulting in a total energy of about 10^{-3} grams of exotic matter, which is much more reasonable than ten orders of magnitude greater than the observable universe. In fact, this value is comparable to the amount of energy released by a single hydrogen bomb. He also changed the equation by which space was expanded, which both reduced the amount of energy required while not breaking the quantum inequality[16]. This metric has not garnered as much attention as the original Alcubierre metric, but it too is subject to infinite stress, uncontrollability, inconstructability, and everything else limiting the warp drive, meaning that it is not a successful way to travel at faster than the speed of light, despite the comparatively small energy requirements.

The Alcubierre Drive has been critiqued very heavily by the scientific community, and it has been largely rejected as a candidate for traveling between the stars at faster than the speed of light. It was derided by Coule as the inevitable result when "one first chooses an interesting geometric structure $G_{\mu\nu}$, or equivalently the metric $g_{\mu\nu}$, before finding the matter source to support this geometry. "[Coule] Clearly, breaking the laws of physics is much harder to do than just bending space-time any way that will accomplish a given task. However, in proving the Alcubierre Drive to be impossible, physicists have shown that manipulating space-time in general is not an adequate procedure for superluminal travel. Since this was the most promising way to accomplish faster than light travel, it seems that another way to achieve superluminal speeds must be found. Hopefully it will have more success than the Alcubierre drive. The warp drive has been revealed to be impossible to build, impossible to control, impossible to maintain, and requires astronomical amounts of energy. Clearly, this is not the solution to traveling the stars. Humanity is still stuck on planet Earth for all of eternity, doomed to live out its existence while only making an impact on a single world.

http://www.bdc.brain.riken.go.jp/~rpaine/SciFiImages/EnterpriseD6.html

This is an accurate representation of how warp drive looked when proposed.

http://stafterearth.atspace.com/Timeline.html

This is an accurate representation of what has been done to the warp drive.

Notes

1. Miguel Alcubierre, "The Warp Drive: Hyper-Fast Travel Within General Relativity." Class.Quantum Grav. 11-5, (1994): 2, http://arxiv.org

2. Ibid., 8

3. Ibid., 9

4. D. H. Coule, "No warp drive," Class. Quantum Grav. 15 (1998): 2524, http://arxiv.org

5. Ibid.

6. Ibid.

7. Jose Natario, "Warp drive with zero expansion," Class. Quantum Grav. Vol.19 (2002): 1162, http://iopscience.iop.org/

8.William A. Hiscock, "Quantum effects in the Alcubierre warp drive spacetime," Class. Quantum Grav. Vol. 14-11 (1997): 7, http://iopscience.iop.org/

9. Ibid.

10. Michael J. Pfenning and L. H. Ford, "The unphysical nature of "Warp Drive," Class. Quantum Grav. 14-7 (1997): 10, http://arxiv.org

11. Ibid.

12. Chris Van Den Broeck, "A 'warp drive' with more reasonable total energy requirements." Class. Quantum Grav. Vol. 16-2 (1999): 3, http://iopscience.iop.org/

13. Ibid 7

14. S. Krasnikov, "The quantum inequalities do not forbid spacetime shortcuts," Class. Quantum Grav. Vol. 67-10 (2003): 19, http://arxiv.org

15. Ibid 16

16. Ibid 19

17. D. H. Coule, “No warp drive,” Class. Quantum Grav. 15 (1998): 2524, http://arxiv.org

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