Critical Problems for Interstellar Propulsion Systems

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Abstract

Four basic problems that are posed by the challenge of interstellar space travel are explained and discussed: 1.) The propellant mass problem, 2.) The " round trip time "problem, 3.) Relativistic time dilation and mass increase and 4.) The reliability problem. These four problems drive the investigation of propellant-less propulsion and the transference of energy and information at speeds beyond the speed of light. The underlying problems of propellant-less propulsion are: 1) the need for an enormous and accessible reservoir of energy in nature, and 2.) The existence of a physical "structure" within space to provide a reaction to field induced forces that allows conservation of momentum and energy. The speed of light, c, is a basic, fundamental, speed limit of the universe. The limit is physically imposed by the rate of relativistic mass increase which becomes infinite as the speed of a body approaches c. Although the relativistic speed limit, c, is an "old" problem of physics, it remains unconquered.

1. Introduction

Interstellar space travel poses many difficult scientific problems, in some ways, far more difficult than the "Manhattan Project" of World War II. During the Manhattan Project, US nuclear physicists already had at their disposal the theoretical "tools" of Quantum Mechanics, Special Relativity, Nuclear physics, Statistical Thermodynamics, and Classical Electromagnetic Field Theory. Physicists had the theory and level of understanding needed to solve their technological problems. However, Interstellar space travel is a "tougher" problem. ***The problem transcends mere engineering complexity and in seeking a solution, we are forced to go back to fundamental physics from which technology emerges and search for a deeper understanding of nature***. Why study the physics problems posed by interstellar space travel? Eventually, these studies will lead to either a great ***breakthrough in propulsion physics*** or a greater ***understanding of the universe.*** In addition, there is the possibility of a great breakthrough in energy conversion technology. The problem is to enable space travel (comfortably, safely, and affordably) to our neighboring star systems. At the present time, this appears to be beyond the *foreseeable (or "easy")* solutions -- solutions based on well-understood science and projected technology. Will we establish (at the very least) a direction in which to search for answers over the first decade of the 21st century? Will we be able to theorize that some "exotic" conditions might be permitted by nature, which provide possible approaches or solutions to our problem? New ideas are leading to new theories. New theories will have to ***contain*** the older theories in a restricted range of application: ***the correspondence principle of Physics.*** Theories have to make predictions, which can be tested by experiments. Above all we must search for scientific truth in this endeavor. Our interim results must all make sense. We must constantly ask ourselves: Does this really make sense? Do we believe it? We must also be prepared for the kind of answers that we may not want. We might encounter a demonstration (theoretical or experimental) that some exotic physical conditions that are predicted by existing theories ***may (in the end) be prohibited by nature.*** However, new ideas, theories, and experiments which emerge out of our existing science, and conform to ***the correspondence principle of Physics***, could lead to propulsion breakthroughs -- the kind of breakthroughs that would make interstellar travel practical.

2. The Propellant Mass Problem

High mass requirements for chemical propellants needed for Interplanetary space missions are ***expensive***. Chemical propellant mass requirements for interstellar travel are nothing less than “astronomical”. In order to send a vehicle the size of the space shuttle to our nearest star at the leisurely pace of a thousand years, equipped with shuttle-style chemical rockets, we would need about 10^{119} kg of propellant.” [1]
It may seem at first, that the interstellar propulsion problem is really a problem of developing rockets that have greater and greater thrust capability and greater conversion efficiency of fuel mass-to-exhaust energy. ***However, there is a very serious constraint. There is an absolute limit to how efficient a rocket can possibly be.*** The constraint is derived from The Special Theory of Relativity, or more precisely, by Relativistic Dynamics. Physical energy cannot leave a rocket with an exhaust velocity **greater than c**, the velocity of light.

2. The “Round Trip time” Problem

If we are patient, we can wait for a unmanned space vehicle to reach the Alpha-Centauri system, perform science experiments, and broadcast the data signals to earth. However, a mission in which we send human beings to the Alpha-Centauri system, or to even further stars, now encompasses the importance of human life: the responsibility to provide safety, health, purpose, and connection with earth society. In addition we cannot assume that human beings should be willing to accept life as an astronaut on the order of **decades** in order to carry out exploration of nearby star systems. In the endeavor of manned interstellar space travel we have a responsibility to significantly reduce and to minimize round-trip time. ***The round-trip time problem is critical because of the immense interstellar distances***. The nearest star, Alpha Centauri, is approximately 4.3 light-years from earth.

3. The Propellant Mass Problem and the Round Trip Time Problem are “Linked”

In order to clearly demonstrate how serious the propellant mass problem is, we analyze here the perfect rocket. A perfect rocket would have a propellant of matter and anti-matter, which reacts in a controlled way producing a photon exhaust. Indeed, a fuel of Anti-matter (and ordinary matter to react with it) would have the smallest ratio of stored energy E, to total mass M , that is physically possible, namely, $E/M= c^2$. Even with a perfect rocket we are faced with a “trade off “ between required initial vehicle mass and round-trip time. A table of values can be computed by finding the exact solution for equation (A1.1) in Appendix A1. {For the details see Appendix A1, A2, and A3} ***Essentially, the ratio of initial vehicle mass to payload mass can be substantially reduced but with a considerable penalty on round-trip time.***

Note the following table.

ALPHA-CENTAURI MISSION
ANALYSIS USING RELATIVISTIC ROCKET EQUATION
where:
v = required vehicle speed,
c = speed of light,
β = fraction of light-speed
M_0/M = Ratio of Initial vehicle mass to payload mass,
T = round trip time as measured by clocks on earth
See Appendix A1,A2, and A3 for Calculations.

β= v/c	(M_0/M)	(M_0/M)mission = $(M_0/M)^4$	T (in years)
.98	9.9498976	9801.0915	8.7755102
.95	6.2449963	1520.9983	9.0526316
.90	4.3588977	360.99959	9.5555556
.85	3.5118836	152.11094	10.1176 47
.80	3.0000013	81.00014	10.750000
.75	2.6457505	48.99994	11.466667

.70	2.3804760	32.111103	12.285714
.60	2.0000000	16.000000	14.333333
.50	1.7320508	8.9999998	17.200000

Calculations show that for a round-trip mission to Alpha Centauri, (which is 4.3 light years from our sun [2]), the ratio of initial vehicle mass to payload mass can be reduced to a value of 9, but the estimated round trip time extends to about 17.2 years. (as measured by clocks on earth) If one wishes to reduce the round-trip time to about 10.75 years, then the ratio, $(M_0/M)_{mission}$, increases to 81. Even with a ***perfect*** matter-antimatter photon exhaust rocket, there is a rather extreme fuel mass penalty just for a mission to a nearby star such as Alpha Centauri.

Some relief on the fuel mass penalty can be obtained if the range of space exploration is restricted to interplanetary missions where a maximum vehicle speed of .5c would result in reasonable round-trip times. Another approach to relieve the fuel mass penalty would be to simply reduce the payload mass. Suppose that by technological advancements in the coming decades, the mass of all structure and equipment (hardware) required for a life supporting vehicle could be reduced to the mass of the NASA ACTS (The Advanced Communications and Telemetry Satellite) , which is about 2.9 tons. Then, the mass of matter-antimatter fuel needed to complete a round trip mission to Alpha-Centauri in 17.2 years (by clocks on earth) at a maximum speed of .5c, is only about 23.2 tons. (11.06 tons of antimatter!) [Appendix B]

The "perfect" rocket based upon a matter-antimatter fuel with photon exhaust, has some other serious hazards associated to it. Containment of anti-matter, if possible and practical, is absolutely safety critical. Failure of antimatter containment will result in explosive energy, an lethal radiation exposure to astronauts. A perfect rocket with a requirement for a maximum speed of 0.8c, a payload mass requirement of 10 tons, on an interstellar mission, would have to have 800 tons of matter-antimatter fuel . This could provide a gamma ray energy of about 6.538×10^{22} joules , which is about 6.167×10^{19} BTUs. [Appendix C] The payload and crew would have to be shielded very well from even the slightest leakage of gamma ray radiation. However, the entire problem of safe containment for anti-matter is overshadowed by the technical problem of producing anti-matter **in large enough quantities to serve as a fuel** (This methodology for massive production of anti-matter is a complete unknown) [3]

4. The Time-Dilation and Relativistic Increase of Mass

Time (as experienced by an observer on a space vehicle) is drastically compressed at relativistic speeds. The Special Theory of Relativity predicts that a clock on board an interstellar space ship in route to a distant star at relativistic speed ticks at a much slower rate than clocks on earth. This phenomenon is called time dilation. Time dilation becomes more pronounced as vehicle speeds approach the speed of light. Consider a round-trip mission to Alpha Centauri, which assumes a 1-month stay on a planet which orbits Alpha Centauri. At a speed of .98c, the round-trip time to Alpha Centauri is estimated as 8.77 years as measured by clocks on earth. ($\Delta t_0 = 8.77$ yrs.) At v = .98c, $\beta = v/c = .98$ and,

$$\sqrt{1-\beta^2} = .198997. \quad (1)$$

The elapsed mission time Δt , on the space vehicle clock as determined by earth observers is calculated as,

$$\Delta t = \Delta t_0 \sqrt{1-\beta^2} = (8.77\text{years})(.198997) \approx 1.745 \text{ years} \quad (2)$$

At first, the relativistic time dilation effect appears to be an advantage for space travelers. It would appear that if we could attain ultra-relativistic speeds for a space ship (speeds very close to "c" , the speed of light) time slows down for the space traveler and this slows down aging. Thus, time dilation should permit us to travel to the very distant stars and perhaps even to other galaxies. However there is a serious problem: As we accelerate an object to speeds which approach the speed of light in a vacuum, more and more energy is required to continue acceleration, because there is a apparent ***mass increase*** of a material object as it approaches the speed of light. This increase of mass is predicted by the Special Theory of Relativity and has been experimentally confirmed in particle accelerators. [4]

The particular reason why the Relativistic mass increase effect constitutes a serious problem, has to do with the ***rate-of-change*** in relativistic mass as the speed of light is approached. In particular, from the Lorentz transformations of Special Relativity and from conservation of momentum and energy, it is possible to deduce that,

$$M = M_0 \,(1-\beta^2)^{-1/2} \qquad (3)$$

where M is the relativistic mass of a payload moving at a certain fraction of the speed of light, β, and M_0 is the mass of the payload at rest relative to an observer in an inertial frame. An alternative way to express equation (3) above is:

$$M = M_0 \,[\, \Delta t_0 / \Delta t \,] \,. \qquad (4)$$

Remember that Δt_0 is the round-trip time as measured by clocks on earth, and Δt is the round trip time as determined by clocks on-board the space vehicle. [Equation (4) is developed here for ease of computation in the following example] In order to really show how drastic the time dilation effect can become, we now consider a round-trip to the great spiral galaxy M 31 (Andromeda), which is approximately 2 million light years from earth. What average speed would be required to really take maximum advantage of time dilation and make such a galactic journey possible? This average speed has already been calculated many years ago [5] and is equal to 0.999999999999995 c , where c is the speed of light. At this speed the "impact" of time dilation is incredible. At this speed, astronauts who complete the round trip journey to galaxy M31 will age only 56 years, but on earth clocks, four million years will have elapsed. This appears to be a satisfactory solution to overcome the vast distance and enormous round-trip time involved in the Andromeda mission on "the surface" . The relativistic kinetic energy K, required to accelerate the payload to the required speed would be given by the equation:

$$K = Mc^2 - M_0c^2 \qquad (5)$$

$$= M_0 \,[\, \Delta t_0 / \Delta t \,]\, c^2 - M_0c^2 \,.$$

In the Andromeda mission problem, Δt_0 is 4,000,000 years, and Δt is 56 years. Thus, it turns out that K, the relativistic kinetic energy required to accelerate the rest mass M_0 to the "required" speed for this mission is 70,428 M_0c^2 . The rest energy of a macroscopic size body is large. If a payload has a mass of one pound, its rest energy M_0c^2 would satisfy the electric power needs of the United States for 5 whole days based on the year 1965 power consumption rate. [6] This energy is about 11 billion kilowatt hours, or 40 million BTUs. Thus, the relativistic kinetic energy needed to push a 1 pound payload to the "Andromeda mission speed" of 0.999999999999995 c , is 70,428 x 11 x 10^9 kilowatt hours.

4. Relativity and Reliability

There is yet another serious problem that must be "hurdled" for interstellar travel. This is the *Reliability* problem. ***Reliability is defined as the probability that a device will perform its intended functions (according to performance specifications) for a specified operating time within a specific environment.*** In the case of an interstellar mission, the device is an interstellar space vehicle, the specified operating time is roughly the required mission time, and the environment is that of interplanetary and interstellar space. Note that the definition of reliability refers to operating time. As we have seen, time (as experienced by an observer on a space vehicle) is drastically compressed at ultra-relativistic speeds. Consider the Alpha Centauri mission once again which assumes a negligible stay on a planet, which orbits Alpha Centauri, and a transit speed of .98c. The round-trip time to Alpha Centauri is estimated as 8.77 years as measured by clocks on earth, and we found that the relativistically compressed elapsed mission time for the crew on the space vehicle was 1.745 years.

The 1.745 years of required operating time for the space vehicle hardware does not ***appear to be*** an overwhelming challenge for reliability engineering. However, in the event of a mission critical failure, there will be no emergency spares re-supply mission and no emergency return to earth. Thus, the reliability design requirement must be very high. A very "forgiving" reliability requirement might be that the reliability of a mission critical device must be .999 after 1.745 years of operation. The required MTBF (mean-time-between-failure) design target (to meet or exceed) for the mission critical device will be 1,774 years. [See Appendix D]

However, even with a shorter effective mission time resulting from the relativistic time dilation effect, there is still a considerable burden to produce ultra-high reliability equipment. This can be seen by merely doing a calculation for a single critical device. Suppose that we now consider an interstellar mission beyond Alpha Centauri, perhaps to a star which requires a round-trip time of about 50 years at a speed of .98c. Now, the elapsed mission time of a clock on board the space vehicle will be 9.95 years. This is about the planned operating time of the International Space Station. Once again, we impose a reliability requirement of .999 , for 9.95 years of required operation. The MTBF design target for a mission critical device will now be 9,945 years. [Appendix E] The MTBF design target to meet or exceed increases dramatically for interstellar missions beyond Alpha Centauri , in spite of the relativistic time dilation effect at extreme relativistic speeds. Note that the analysis does not even consider the problem of attaining a high reliability for a complete space vehicle on an interstellar mission, which would be even more difficult to achieve. The failure of at least one major component on an interstellar mission is highly likely if current state-of-the-art devices were to be used. In order to avoid the difficult reliability burden on design, critical spares would have to be take along on interstellar missions, which would increase payload. Other strategies are also available [Appendix F].

Space vehicle reliability will have to be "ultra-high" and must "transcend" the reliability of any space vehicle hardware, which we design and build today.

5. "Propulsion without Propellant" and "Faster than Light"

The propellant mass problem, the round trip time problem, time dilation, and the reliability problem drive the pursuit of two very interesting (futuristic) problems for space travel propulsion. One challenge is to develop a means of propulsion, which *does not require a propellant such as chemical, ionic, or even matter-antimatter fuel.* This is the idea of Propulsion without propellant. The inspiration for such an idea really comes from nature. Ponderable bodies of matter, (e.g. stars, comets, and planets) or elementary particles (e.g. electrons, protons, and anti-protons) can be accelerated by fields (gravity and electromagnetic forces) without ejecting any exhaust from burning a chemical propellant. In fact, *acceleration without ejecting exhaust is the primary way in which nature creates the acceleration of physical objects. The chemical reactions and thermal energy which "drive" a rocket exhaust (the entire impulse of a rocket) can be broken down into atomic and molecular collisions involving forces that are ultimately the result of electromagnetic fields.* Simply stated, "Why can't we use fields to propel a space vehicle instead of a fuel which must undergo some type of physical re-action and create an exhaust?" Creating "field drives" for propulsion requires techniques to safely *induce or harness fundamental forces within nature, with the ability to direct, and control them.* ***Field drives must obey the conservation laws in nature, such as conservation of energy, momentum (linear and angular), and electric charge.*** Since Momentum and energy must be conserved, and there is no propellant exhaust from a vehicle, then space would be required to have a physical "*structure*" of some type which can be re-acted against. [7]

How could such a field drive system work? When the field drive mechanism is energized, it will take some time for the field to be set up and induce a force on the vehicle causing it to accelerate up to its maximum required speed. To satisfy Newton's Third Law of Motion and conservation of momentum, the surrounding space has to react in an equal and opposite way. How can space react? Why should it react? What is there in space itself that could react at all? The essential underlying concept of field drive propulsion (or zero-propellant propulsion) is: ***space is not a state of absolute void or nothingness***. ***It is a physical entity, or has some physical structure which can be re-acted against under the right conditions.*** This structure may be a result of any or all of the four fundamental forces of nature: Electromagnetic forces, gravity, the weak nuclear decay force, and the strong nuclear binding force within the vacuum. We can surmise that at least two equations can be written to describe momentum and energy conservation for this physical "picture" in the most elementary way. Let $P_{vehicle}$ (t) be the momentum of a space vehicle, and let $\mathbf{P}_{\mathbf{field}}$ (t) be the momentum of the field producing the acceleration of the vehicle, and let $\mathbf{P}_{\mathbf{space}}$ (t) be the "effective momentum" of the "space imbedded" structure at a time t, measured by clocks in a particular reference frame. If the field drive mechanism is energized at time t = 0, then at t > 0,

$$\mathbf{P}_{\mathbf{vehicle}} (t) + \mathbf{P}_{\mathbf{field}} (t) + \mathbf{P}_{\mathbf{space}} (t) = \mathbf{0} \; . \tag{5}$$

The zero on the right hand side of this equation is necessary because prior to energizing the field drive system of the space vehicle, the vehicle momentum is zero, the external propulsion field has not been created (and thus it has a momentum of zero) and space is not reacting to the propulsion field thus its reactive momentum is zero. Likewise, the energy must be conserved.

$$E_{\mathbf{vehicle}} (t) + E_{\mathbf{field}} (t) + E_{\mathbf{space}} (t) = E_{\text{total system}} . \tag{6}$$

Equations (5) and (6) are easy to write down, but the precise and unambiguous definition of field and space-reactive energies and momenta must be determined. This is will not be a trivial task.

The problems of propellant mass, round trip time, time dilation, and reliability, also drive us to consider the problem of transferring energy and/or information at speeds greater than the speed of light. Recall from Special Relativity that:

$$M = M_0 \, (1-\beta^2)^{-1/2} \tag{7}$$

where M is the relativistic mass of a body moving at a certain fraction of the speed of light, β, and M_0 is the mass of the body at rest relative to an observer in an inertial frame. **In the limit, as** $\beta\rightarrow 1$, $\mathbf{M}\rightarrow\infty$. ***In physical terms, the required force to accelerate a particle of matter to the speed of light is infinite.*** Is relativistic mass increase a reality? Not only is the relativistic mass increase confirmed by experiment, but the theory which predicts it (Einstein's Special theory of Relativity) is also completely compatible with The Maxwell field equations of Classical Electromagnetism. [8] This speed limit is of a deeply fundamental nature. Many other associated problems which concern **length contraction, time dilation,** and **causality** also arise with "faster-than-light" motion. [9] Of course we do know that some forms of energy can attain a speed of c in the vacuum. Electromagnetic radiation and neutrinos (to the best of our knowledge at this time) have a zero "rest mass" which means that they 1.) cannot exist at a state of "rest" relative to an observer , and 2.) can move at exactly the apparent relativistic speed limit ,c, of the universe.

Although the apparent speed limit of the universe has been known about for the greater part of the 20th century, ***we cannot say*** *with complete certainty, that it is clearly* impossible *for energy and information to be translated through space at a speed beyond the speed of light.* There are too many unanswered questions [10]. **A fundamental proof** would be required to demonstrate that such a speed limit in our universe is absolute**.** People continue to explore several areas of research which have not lead, as yet, to any firm proofs of impossibility or any repeatable detections of superluminal particles, or radiation. Other studies concentrate on possible superluminal ("faster-than-light") loopholes in General Relativity and Quantum Mechanics. Some continued areas of research are: faster-than-light particles (Tachyons) [11], the Warp drive- Hyper-fast travel within general relativity [12], Wormhole "physics" [13], Physics of Additional Space Dimensions [14], the existence of negative mass particles [15], Complex Speed [16], Euclidean four Space [17], and time-reversed electromagnetic [18] and quantum mechanical [19] waves. We need to continue research in the area of "superluminal physics" in at least two ways. We should continue to probe theoretical physics for possible new paradigms which involve physical ideas and mathematical ways of expressing theory. Experiments should also be pursued. We should also re-visit
"old" physics and probe its foundations once again and ask "Was there something that went misunderstood? "

6. The Abundant Energy Source Problem

Another problem which is naturally connected to the field drive propulsion problem is that of the *abundant energy source. Abundant on-board energy conversion would be a physical process to extract vast amounts of energy that is contained in some "reservoir" of nature. Energy from this "reservoir" may be for support applications on interstellar missions, but to provide the really vast amounts of energy needed to set up field drives (to affect spacetime geometry) an enormous energy source may be required*.

A very good hypothetical example of what the very large energy requirements will be to develop a field drive propulsive effect, is the proposed Space Strain Propulsion System by Y. Minami [20]. This theory is further developed in [21]. The theory is also discussed by R. Forward [22]. The actual details of the space strain theory are somewhat controversial and the theory appears to be incomplete. However, it presents the possibility that a thrust producing effect could be produced by a change from flat space (zero curvature components) to curved space by using a controlled energy source, namely, a magnetic field. Using the formalism of General Relativity, it can be shown that the time-like component of the Ricci Tensor , R^{00} , is directly proportional to the square of the magnetic field. In particular, Miniami obtains,

$$R^{00} = (8.2x10^{-38})B^2 \qquad (8)$$

where B is the magnetic field in Tesla. An estimate can be made of space curvature, which results from a given magnetic field. Specifically, a space curvature of 10^{-23} (1/m.^{2}) which corresponds to the acceleration at the surface of the earth (9.8 m./sec.^{2}) , requires a magnetic field of 20 million tesla. There is another example of a field-drive propulsion that will not only require a vast amount of energy, but will require ***negative energy.*** [12] Alcubierre shows how, within the framework of general relativity and without the introduction of wormholes, it is possible to modify space-time in a way that allows a spaceship to travel with an arbitrarily large speed. By a purely local expansion of space-time behind the spaceship and an opposite contraction in front of it, motion faster than the speed of light (as seen by observers outside the disturbed region) is theoretically possible. (The space ship is contained in this warp-bubble of space-time.)

Alcubierre's analysis shows that to attain hyper-fast travel using the particular space-time geometry that he postulates, requires the use of matter, which has negative energy density. (i.e.violation of the Averaged Null Energy Condition from General Relativity) Whether this is physically allowed is still an open question in physics. This model is tentatively accepted by most physicists as being self-consistent, although details depend on aspects of quantum field theory. Recently, Michael J. Pfenning and L.H. Ford, [23] derive, and explain the relativistic mechanics of the Alcubierre Warp Drive "bubble" of space-time. The authors point out that just as in traversable wormholes, in order to achieve warp drive one must employ exotic matter, that is, *negative energy densities.* Although this is a violation of classical (General Relativity) energy conditions, it is pointed out that Quantum inequality restrictions in flat space-time *do allow negative energy to exist.* The Quantum Inequalities (derived from quantum field theory) restrict the magnitude and extent of negative energy in a space-time region. The authors apply the quantum inequality for the free scalar field in four-dimensional space-time. The quantum inequality integral is worked out. The Warp Bubble "wall thickness" is on the order of only a few Planck Lengths. (A Planck length is about 10^{-33}cm.)

Now, for a macroscopically useful warp drive, one might want the radius of the Warp-Drive Bubble to be at least 100 meters so that a space ship could fit inside. ***The authors calculate that for a bubble radius of 100 meters, the required amount of negative energy to create the warp drive bubble is ten orders of magnitude greater than the total mass of the observable universe.*** In an attempt to find a point of "relief" it is assumed that one can ***violate*** the quantum inequality restrictions, and the bubble wall thickness is allowed to be 1 meter, and with the same 100 meter radius . The warp drive would then require an enormous total negative energy on the order of 6 solar masses.

It should not be surprising that the energy requirements for field-drives or the Alcubierre warp-drive are so large. (In either the positive or negative energy case) The gravitational field at the surface of the Sun is sufficient to bend the path (trajectory) of a light beam by an angle of less than 1/1000th of a degree. We know that the Sun is very massive. The required energy (positive or negative which really represents mass because $E=Mc^2$) that is necessary to create exotic space-time curvatures or "structures" should be very large.

Although the energy requirement for field drives is a primary driver to develop an abundant on-board energy converter , consideration of advanced propulsion is not the only reason to pursue the problem of abundant energy conversion. Other reasons are *future power generation requirements* for (1) terrestrial application and (2) long term survival in space .(ie.-a base on Mars or on the moon).

Where can such a great source of energy be found? Perhaps from the quantum mechanical zero-point fluctuations of the vacuum.

The zero-point energy of the vacuum is the result of unpredictable random fluctuations of the vacuum energy which is based upon the Heisenberg Uncertainty Principle. Theoretically, zero point energy has its origin in the quantum theory treatment of a harmonic oscillator. Quantum mechanics predicts that an oscillator has a "resting point" with a small amount of residual energy. The term "zero-point" indicates that there should be a random "jiggle" of the oscillator even when temperature is at absolute zero and there is (theoretically) no source of thermal agitation.

The zero-point energy of a harmonic oscillator is very apparent when solving for the permissible states of its total mechanical energy. This result comes about from the solution of Schroedinger's Equation for a harmonic oscillator. Further on, in advanced quantum mechanics, it is shown that the principles of quantum mechanics can be applied directly to the electromagnetic field. (first in a non-relativistic fashion, and later on in a relativistic way as well) **The electric and magnetic field solutions for a vacuum will exist and have a zero-point fluctuation**. In 1948, Casimir predicted that quantum fluctuations of the vacuum should produce a force on two parallel and perfectly conducting plates. Recently, this has been observed in an experiment conducted by Lamoreaux [24].

There are many unanswered questions about the zero-point fluctuations (ZPF) of the vacuum. Can the ZPF be the result of a classical and random electromagnetic background radiation in the universe as theorized by T. Boyer? Could the gravitational field be an effect brought about by changes in the ZPF of the vacuum due to the presence of matter? H. Puthoff [25] had a vision that the zero-point electromagnetic fields drive the oscillation of atomic particles, and that the combined effect of all the radiation from oscillating charged particles throughout the universe generate the zero-point fields of the vacuum. The whole process would be like a self-regenerating feedback cycle.

A major topic related to propulsion physics breakthrough has to be the subject of "zero-point vacuum fluctuations". R.L. Forward estimates [26] that the vacuum energy density is about 10^{108} joules per cubic centimeter. This corresponds to a mass density of about 10^{94} grams per cubic centimeter.

7. Physics is not complete

"Physics" is faced with a series of deeply profound questions to resolve which transcend mere complexity and are aimed at the very heart of the existence of matter, forces, and the universe. Here, we review some of these profound questions. [27] What are the elementary particles? Why are some elementary particles more massive than others? How are these exact masses related to the fundamental constants of nature, and to the origin and structure of the universe? Is mass truly fundamental? Why are there four forces in nature? How will the force of gravity enter into a unified field theory of fundamental forces of nature? What is the real relationship of the abstract spaces of elementary particle symmetries to the space-time we live in? How is the geometry of space-time related to fluctuations in the electromagnetic field of the vacuum? Why is the space we experience three dimensional? Why is the cosmological constant equal to zero? What is the dark matter that appears to make up 99.7% of the galaxies?

8. Recommendation

The purpose of this TM has been to explain some of the major unsolved problems associated to inter-stellar space travel and propulsion physics. Three critical drivers for a propulsion physics breakthrough have been discussed: 1) the enormous fuel mass-to-payload mass ratio required for interstellar missions, (2) the unacceptable round-trip time to distant stars at subluminal speeds and (3) the attainment of required space vehicle reliability for interstellar missions. The goal of "propellant-less propulsion" must be achieved for interstellar missions to be practical. We should continue our scientific research into theoretical field-drive techniques, the relationship between gravity, inertia, and electromagnetism, and the harnessing of the zero-point fluctuations of the vacuum electromagnetic field. NASA should pursue and support the NASA Breakthrough Propulsion Physics Program. [28]

APPENDIX A

A.1 Analysis of the Perfect Rocket at Relativistic speeds

A good approximation can be made of the ratio of initial vehicle rest mass M_{0}, to "final" vehicle mass M, by the analysis of rocket motion using Relativistic Dynamics. [29] This is quite involved but provides the relation,

$$\beta\gamma = (1/2)\ [\ (M_0/M)^{V/c} - (\ M_0/M)^{-V/c}\ ]\ . \qquad \text{(A1.1)}$$

The ratio of final vehicle speed v, to the speed of light c, is β . The symbol γ, is given by,

$$\gamma = (1-\beta^2\ )^{-1/2}\ . \qquad \text{(A1.2)}$$

The symbol V, is the exhaust velocity.

A perfect matter-antimatter rocket can be assumed with a photon exhaust whose velocity is the velocity of light.(V=c) What $(M_0\,/M)$ ratio is required if our perfect rocket is to attain extreme relativistic speed, say at about β=5, which corresponds to a final speed of .98c ? We assume that,

$$(M_0/M) >> 1\ .\ (\beta = .98) \qquad \text{(A1.3)}$$

Then, from equation (5.1) above, we can write down the approximation,

$$\beta\gamma \cong 1/2\ [(M_0/M)] \qquad \text{(A1.4)}$$

and, for the case of interest,

$$(M_0/M) \cong 2 \text{ x } .98 \text{ x } 5\ \cong 10. \qquad \text{(A1.5)}$$

To attain a final speed of 98% the speed of light from being at rest relative to the earth reference frame, with a perfect matter-antimatter rocket, requires the vehicle to exhaust approximately **90%** of its initial rest mass. To avoid imposing large forces on the crew of the interstellar vehicle, accelerations and de-accelerations must be kept small. The assumption is that at *a minimum*, a typical interstellar mission will require *at least two legs of the trip where acceleration is required and two legs along which a force must be exerted to achieve de-acceleration.* We should take note that there will be four separate steps as part of the round-trip Alpha Centauri mission. One step of acceleration and one step of de-acceleration while traveling to Alpha Centauri, and then upon the return journey to earth, a re-acceleration followed by final de-acceleration. The *initial vehicle mass-to-payload mass* equation applies to *each* step of the journey.

If M, represents the true payload mass for the final step of the journey (which is a de-acceleration on the return to earth) the initial vehicle mass-to-payload mass ratio value of 10 first applies to this last leg of the journey. The initial vehicle mass at the beginning of the last step must be equal to 10 times the true payload mass, which is 10M. However, for the next-to-last leg of the journey, when the space vehicle shall accelerate away from Alpha Centauri, it must have an initial mass of 10 times the mass of 10M, because the fuel required on the last leg of the journey must be transported (since it will be needed on the last leg) and is effectively like a payload.

If we carry this logic through to the very first leg of the trip, then the initial mass-to-payload mass ratio for the complete mission to Alpha -Centauri is estimated by,

$$\mathbf{(M_0/M)\ mission = \{ (M_0/M)\ from\ rest\ state \}^4} \qquad \text{(A1.6)}$$

Thus, for an interstellar mission with a perfect rocket and a required vehicle speed of .98c, the required initial vehicle rest mass is approximately 10^4 times its required payload mass.

A.2 Derivation of a Formula for Ratio of Initial vehicle Rest Mass to final Vehicle Mass for a Perfect Rocket moving at Relativistic Speeds.

What is the ratio M_0/M for several different cases of required maximum vehicle speed? This problem can be simplified by a simplification of the relativistic rocket equation which is expressed in equation (A1.1) of this report. Let $R= M_0/M$, and substitute R for M_0/M in the equation (A1.1), and note that V/c =1, since the exhaust velocity V=c. (The perfect rocket has photon exhaust) Then the equation (A1.1) just becomes a simple quadratic equation,

$$R^2 - 2\beta\gamma R - 1 = 0. \qquad \text{(A2.1)}$$

By simple quadratic formula there is two solutions,

$$M_0/M = \beta\gamma + (\beta^2\gamma^2+1)^{1/2} \qquad \text{(A2.2)}$$

$$= \beta\gamma - (\beta^2\gamma^2+1)^{1/2} \qquad \text{(A2.3)}$$

and ,

$$\beta\gamma = \beta/\sqrt{1-\beta^2}\ . \qquad \text{(A2.4)}$$

The second solution (where the radical is subtracted from $\beta\gamma$, as shown above) is discarded since it yields negative values for the ratio M_0/M. Recall that β= v/c, where v is the required maximum vehicle speed.

Appendix A3
Calculations Worksheet : Analysis for "Perfect Rocket"

D= Distance from the Sun to Alpha Centauri .(Which is 4.3 light years .)
The estimated round-trip time (the word "estimated" is used here since there would be periods of acceleration and de-acceleration on a interstellar mission) is symbolized by T, where T is given by,

$$T= 2D/v\ . \qquad \text{(A3.1)}$$

This can also be written as,

$$T= 2D/\beta c\ . \qquad \text{(A3.2)}$$

where, β= v/c , v= maximum required speed of vehicle, and c = speed of light

$$T = \{ 2(4.3)cN \}/ \beta c \text{, where N is the number of seconds in a year.} \qquad \text{(A3. 3)}$$

or,

$$T = 8.6\ N/\beta = (8.6/\beta)\ \text{years}\ (\textbf{\textit{As measured by clocks on earth}}) \qquad (A3.4)$$

$(M_0/M) = \beta\gamma + \sqrt{(\beta^2\gamma^2+1)}$

β	β^2	$1-\beta^2$	$\sqrt{1-\beta^2}$	γ	$\beta\gamma$	$1+(\beta\gamma)^2$	$\sqrt{1+(\beta\gamma)^2}$
.98	.9604	.0396	.198997	5.025201	4.924697	25.252641	5.0252006
.95	.9025	.0975	.312250	3.202562	3.042434	10.256405	3.2025623
.90	.8100	.1900	.435890	2.294157	2.064741	5.263155	2.2941567
.85	.7225	.2775	.526783	1.898315	1.613568	3.603602	1.8983156
.80	.6400	.3600	.600000	1.666667	1.333334	2.777780	1.6666673
.75	.5625	.4375	.661438	1.511857	1.133893	2.285713	1.5118575
.70	.4900	.5100	.714143	1.400280	0.980196	1.960784	1.4002800
.60	.3600	.6400	.800000	1.250000	0.750000	1.562500	1.2500000
.50	.2500	.7500	.866025	1.154701	0.577350	1.333334	1.1547008

β	(M_0/M)	(M_0/M)mission = $(M_0/M)^4$	T (in years)
.98	9.9498976	9801.0915	8.7755102
.95	6.2449963	1520.9983	9.0526316
.90	4.3588977	360.99959	9.5555556
.85	3.5118836	152.11094	10.1176 47
.80	3.0000013	81.00014	10.750000
.75	2.6457505	48.99994	11.466667
.70	2.3804760	32.111103	12.285714
.60	2.0000000	16.000000	14.333333
.50	1.7320508	8.9999998	17.200000

Appendix B-

ACTS Satellite Weight data:

2851 lbs.	Base Weight
545 lbs.	Hydrazine
34.7 lbs.	Reserve for hydrazine
2370 lbs.	Apogee "kick motor"
5800.7lbs.	Total = 2.9 tons

Consider a required maximum vehicle speed of .5c, and a required payload of 2.9 tons.

(M_0/M)mission = 9 => M_0 =9M => Initial vehicle mass required.
Initial Fuel mass required = Initial vehicle mass – Payload mass
= 9M – M = 8M.

Required fuel mass = 8 x 2.9 = 23.2 tons. => 11.06 tons of antimatter. (based on hypothesis that a 50%/50% mixture of matter and anti-matter would be required.)

Appendix C

At a maximum required vehicle speed of .8c, with a required payload mass of 10 tons, how much explosive energy would be available from matter-antimatter fuel in the event of antimatter containment failure ? (worst case hypothesis - assumes perfect conversion of all fuel mass into gamma ray radiation energy)

At Vmax = .8c , (M_0 /M)mission = 81. => $M_0 = 81M$

Required matter-antimatter propellant = Initial vehicle mass – Payload mass
= 81M – M = 80 * 10 tons = 800 tons.

$E_0 = M_0C^2$ = (800tons)(2000lbs./ton)(.454kg./lb.)($3x10^8$m./sec.)($3x10^8$ m./sec.)
= 6.538×10^{22} joules./ (1060 joules/BTU) = 6.167×10^{19} BTUs.

Appendix D-

The general expression for the reliability function R(t) for a specific device is,

$$R(t) = \exp \{- \int^{t} h(x)dx \} \quad (D.1)$$

where t , is the required mission time for a specific environment and application , and h(t) is the "failure rate" function.[30] More than one reliability function is required in the prediction model for a space vehicle since there is more than one type of device, and different mission environments must be considered such as pre-launch, launch, spaceflight, and return to earth. There are also periods of operation and non-operation. ***Both operation and non-operation*** have a contribution to the overall device failure rate.

However, device reliability is a function of mission time. As mission time elapses, the probability of successful operation decreases.(Probability of failure increases) The current state-of-the art in developing reliable equipment does not completely eliminate the effects of equipment dormancy which is caused by environmental factors. Stresses from actual operation of equipment cause the growth of imperfections and flaws with time and are even more of a factor in reduction of reliability. The non-operating condition significantly increases the probability of device failure when periods of non-operation extend beyond a year.

Consider the mission scenario to Alpha Centauri which assumes a 1 month stay at a planet which orbits Alpha Centauri. At a velocity of .98c, the round-trip time to Alpha Centauri is estimated as 8.77 years as measured by clocks on earth.

At v = .98c, $\sqrt{1-\beta^2} = .198997$. (D.2)

The Elapsed mission time measured on the space vehicle clock relative to earth observers is given by,

$\Delta t = \Delta t_0 \sqrt{1-\beta^2}$ = (8.77years)(.198997) ≈ 1.745 years (D.3)

where, Δt_0 is the elapsed mission time as measured on the earth "mission-control clock" , and the 1 month stay at Alpha Centauri has been neglected.

Let us further assume a device which has a duty cycle of 100% during the space voyage from Earth to Alpha Centauri and during the return voyage. (required to operate during the entire mission) The successful operation of this device is life critical. We further assume that all pre-launch burn-in testing removed 100% of the infant mortalities from the spacecraft hardware. The exponential reliability model is assumed for simplicity, which assumes that the failure rate function h(t), is given by $h(t)= \lambda$, where λ is a constant. Then,

$R(t) = \exp(-\lambda t)$ (D.4)

by using the general definition of the reliability function. Solving for λ in the above equation,

$\lambda = - \ln R(t) / t$. (D.5)

We must use the relativistically dilated time Δt, for mission time t, since all physical processes on-board the spacecraft , chemical reactions and other failure mechanisms are all slowed down by the relativistic

time dilation effect. We will also require a reliability of .999 for a mission critical device at end-of-mission since the mission is interstellar and spares resupply and/or rescue missions are not possible. This requirement corresponds to an allowable probability of failure equal to: $1x10^{-3}$.
(a " forgiving" requirement) Then,

$\lambda = -\ln(.999)/ 1.745$ years $= 1.0005003 \times 10^{-3} / 1.745$ years

$= 5.7335263 \times 10^{-4}$ failures per year ,. (D.6)

The required mean-time-between failures (MTBF) design target (to meet or exceed) for the device will be:

MTBF $= 1/\lambda = 1.7441273 \times 10^{3}$ years/failure. (D.7)

APPENDIX E

Interstellar mission scenario. Round trip travel time to a star is 50 years at a speed of .98c. Elapsed time on space vehicle clocks is found by using equation (D.3) is appendix D.

$\Delta t =$ (50 years)(.198997) = 9.95 years. (E.1)

We require a reliability of .999 after 9.95 years of operation.
What is the MTBF target to meet or exceed?

MTBF = $(1/\lambda) = (\Delta t / -\ln R)$ (E.2)
= (9.95 yrs./ 1.0005003×10^{-3})
= 9, 945 yrs.

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