# Laser ablation requirements for practical acceleration to the Asteroid Belt, and beyond. A concepts in the works study

**Andrew Walcott Beckwith**

[Received date; Accepted date] – to be inserted later

## Abstract

**T**he rocket equation and the low exhaust velocity of chemical fuels are at the root of the high cost of most NASA approved current inter planetary travel platforms. Laser boosting of space crafts are a way about this problem If sails are used for travel to the asteroid belt and beyond with incident laser beams providing acceleration, prior to interstellar power, the problem of how to keep a constant laser power flux to the accelerating space craft necessitates a re thinking of where to place lasers, i.e. the Lagrange points of the Earth-Moon system, as well as batteries of lasers in the Lagrange points, for continual application of power for applying sail drives . The conclusion, as outlined by the author, is that major development of stable large scale lasers, far in excess of performances obtained for the MIRACL 3um laser are essential for any practical development work taking place..

## 1. BASE LINE ACCELERATION REQUIREMENTS AS FAR AS THE SOLAR SYSTEM.

Millis [1] has identified three different forms of sail drives, for use which may be, if practically utilized, make travel in the solar system far more economical than today's propulsion systems would indicate. We will briefly summarize what Millis wrote, as of {1} , and then talk about what would be a reasonable way to have lasers place in the Earth- Moon system to add the best chance for continual acceleration for space craft . The author, in AIBEP 6 [2] identified the Lagrange points as a useful way to get about the logistics, and geometric constraints of earth bound and lasers
in Earth orbit to supply power boost at least to the Asteroid belt.

### 1.1 Brief summary of Millis's hypothetical sail drives : Force equation considerations, and the light sail.

From Millis (2009), the following variations, with P pressure from a laser hitting a light sail of area A, and with a fudge factor of $\delta$ put in, in the case of real Radiometers, taking into account what could be expected in terms of sail material properties, and sail geometry, plus the degree energy impinging upon the sail has been locally altered , reciprocally across the front and back of the sail. As Millis writes it, for force upon the sail

$$F \equiv \frac{P}{A} - Differntial - Sail : \text{Analogous to an ideal Radiometer vane} \qquad (1)$$

$$F \equiv \left(\frac{\delta^2 - 1}{\delta}\right) \cdot \frac{P}{A} - Induction - Sail : \text{Analogous to a real Radiometer vane} \qquad (2)$$

$$F \equiv 2 \cdot \frac{P}{A} - Diode - Sail : \text{Analogous to a one way mirror} \qquad (3)$$

The question to ask is how is one going to get a continual power input P into a light sail from a laser boost. . Hint, if one is even at MARS orbit, using lasers in low Earth orbit, is unrealistic. Having said that, the author will briefly review what is known about the Earth-Moon Lagrange points.

## 1.2 The Earth- Moon Lagrange point system, as a proto type place to "park" a laser battery

Precisely put, Lagrangian points are the stationary solutions of the circular restricted three-body problem.[3] For example, given two massive bodies in circular orbits around their common center of mass, there are five positions in space where a third body, of comparatively negligible mass, could be placed which would then maintain its position relative to the two massive bodies, For the Earth-Moon system there are no fewer than five Lagrange points. The important ones for our consideration are given via the nomenclature of L4 and L5. The L4 and L5 points lie at the third corners of the two equilateral triangles in the plane of orbit whose common base is the line between the centers of the two masses, such that the point lies behind (L5) or ahead of (L4) the smaller mass with regard to its orbit around the larger mass. The reason these points are in balance is that, at L4 and L5, the distances to the two masses are equal. The Earth–Moon L4 and L5 points lie 60° ahead of and 60° behind the Moon as it orbits the Earth. As points of where to put a laser battery system, it appears intuitively obvious that placing a laser system battery would be most efficient if positioned at both L4 and L5.

## 1.3 What can be stated about a configuration of lasers in L4 and L5 Lagrange points in the Earth- Moon system.

Obviously, a single laser cannot fire indefinitely, and that a battery of lasers firing in either or both L4 and L5 would have to have some periodic rotation, in order to avoid over stressing the lasers, and to give adequate down time for repair and over haul, in order to have an optimal laser performance over several weeks of laser firing. Two candidates for long term firing of lasers ought to be considered. The optimum performance needed to be considered is length of duration of a relatively stable power source, for lasers.

## 1.4 Optimal power generation for a laser, versus length of duration of generation of power output, for maximizing efficiency of BEP ( Beam energy propulsion)

BEP is achieved when energy is beamed at a distance to a 'surface" in order to initiate propulsion of an object receiving/ reflecting the beam. Lasers, in order to be efficient at such for interplanetary travel power source boosts should be 'relatively' continuous in output. . For reaching low earth orbit, the conventional rule of thumb is that that it takes a megawatt of power beamed to a vehicle per kg of payload while it is being accelerated to permit it to reach low earth orbit [4]. For a longer duration flight to the planets and the asteroids, a far less stringent limit would be needed in terms of power output per kilogram, but the issue of relative laser stability would become paramount. For planetary travel, and inter stellar travel, as evidenced by Forwards article [5] , there has been much study with relatively idealized laser power platforms, and exotic systems, as given by Parkin's PhD dissertation on a prototype system at CalTech [6] but little said about the stability and performance requirements of the laser. A suitable round off would be to extrapolate that for planetary travel, that a relatively stable application of 1/20th to 1/30th of a megawatt of power beamed at a vehicle per kg, of weight, and one would have to go further in order to improve upon what Landis [7] wrote, namely specify something about the stability of the power output requirements. Forwards 1984 article [8] specifies an acceleration to an appreciable fraction of the speed of light for a light sail using an acceleration $a$ , efficiency $e_m$ ( usually about ~ .84) , maximum amount of efficient power at the light sail, $P$ , and a mass M for a sail ( or space craft ) . Note that in this, the power for the laser [8]

$$a = 2\,e_m P / M \cdot c \tag{4}$$

I.e. it would take an ultra light space craft up to five weeks to accelerate within a measurable fraction of the speed of light, whereas the issue of the power generation, P and its stability is what would have to be addressed. Note that Many lasers emit beams with a Gaussian profile, in which case the laser is said to be operating on the *fundamental transverse mode*, or "$\mathrm{TEM}_{00}$ mode" of the laser's optical resonator. When refracted by a lens, a Gaussian beam is transformed into another Gaussian beam (characterized by a different set of parameters), which explains why it is a convenient, widespread model in laser optics. Using a Gaussian profile, a good approximation is to work with , when $P_0 = (\pi / 2) \cdot I_0 \cdot w_0^2$, with $w(z)$ being the width of the beam, a distance z from the start of the beam, and $w_0$ the initial width of the beam, and with $I_0$ the initial intensity of the beam. Note, then that function r is the width of a circle on a light screen , presumably on a target light sail , and z is the distance from a targeted light sail to the laser, while $w(z)$ is the de facto width of the beam itself , at a distance z. There is nothing which forbids, here, $w(z) \neq r$ with respect to the laser beam impacting a laser sail. Generally for a Gaussian beam [9], [10]

$$P = P(r, z) = \dot{P}_0 \cdot (1 - \exp(-2r / w(z)) \tag{5}$$

For our purposes, it would be appropriate to find a way to maximize the intensity function $I_0$ for say several hours, in a (rotating) grjd of lasers. Assume that the two laser batteries, one at L4 and andother at L5 would fire for up to five weeks., and that the lasers in question at Lagrange points L4 and L5 would fire for up to an hour at a time, while rotating through a rack of lasers. Let us now say something about what would be appropriate for getting a one hour firing time for an intensity function $I_0$

## 2. Optimizing appropriate behavior for intensity function $I_0$ for either L4 and L5 laser batteries for one hour duration, with regards to an individual laser .

This is where the real development work needs to be done. Currently, C02 lasers may be able to get up to 100 GW, but the duration of the time for firing of the laser has to be worked upon, [11] . The authors own preference would be to perhaps work with a variant of a Nd-YAG laser, and to have the lasers placed in a rack configuration, at the L4 and L5 Lagrange points of the Earth-Moon system . Using the simplification of up to 20-30 lasers at a single battery, with each laser firing , in tamdem with its partner in the L4 and L5 points to boost in a several week session to move perhaps a 10 kilogram space craft, with its sail of perhaps up to a kilometer in width to an economically feasible rate of travel in the solar system. The rates of intensity duration would require a very different design than given in such short term duration experiments [12] , and would necessitate ruggedness, simplicity and durability of the design, to withstand increment space 'weather' and solar system hazards. Note that for linking $I_0$ to $P_0$, $I_0 \equiv \left[ 2P_0 / \pi \cdot w(z) \right]$.

The result of this presentation of how to find appropriate $I_0$ leads to the inescapable conclusion that a lot of development work is wide open to be done.. Note that Northrop has a 100kW average power CW Nd laser, and that the Airborne laser at 1.315um is "MW-class," as is the MIRACL 3um laser at White Sands [13].

A laser an order of magnitude greater in power has to be developed for resolution of this issue. And **NO ONE** has addressed how to obtain a multi mega watt laser which could run up to half an hour. Lawrence Livermore's laser effort is, as is known dominated by laser implosion for pellets for fusion research, i.e. the duration maybe for a few nano seconds, with a peak power in the region of [12]s peak power. Having a high power laser for longer than a second, has not been worked upon.

## 3. Technical challenges needed to be met for development of a suitable accelerator boost system with lasers

First of all would be in finding mega watt lasers, of suitable time duration, up to half an hour. The author's suggestion would be that this is ground zero, in development. The work done with the MIRACL 3um laser at White Sands, New Mexico, would be a start, but note that the MIRACL 3um laser is a deuterium fluoride (DF) chemical laser with energy spectra distributed among about 10 lasing lines between 3.6 and 4.2 microns wavelength. Since it first lased in 1980, it has accumulated well over 3000 seconds of total lasing time. It remains the highest average power laser in the US.

I.e. right intensity, and yet, factor in 3000 seconds in lasing time. Since 1980. i.e. 50 hours for over 30 years of test runs. That for 150 tests. One needs a laser lasting up to HALF an hour, and perhaps a functioning battery of up to 30 of them, at each Lagrange point, L4 and L5. With a recycling time of up to 15 hours

Secondly is how to get a suitably focused narrow laser beam to propel a space craft out to, say, the orbit of Jupiter. If a space craft has a solar sail the size of one kilometer in diameter, this means a minimum amount of dispersion of the beam. Note that in a Gaussian beam profile, that this stated requirement places a premium upon w(z) with no effective dispersion traveling a distance up to at least 630 Million Kilometers in distance, z , and nearly double that to go to Saturn, which is about 8.883 AU from the Sun. I.e. not only will the beam have unbelievably narrow focus, it would also have to be not affected by space junk, plasmas, or other space medium dispersive characteristics.

Three, is getting logistical support for a battery of 30 lasers each, for Lagrange points L4 and L5. TRW and Hughes Aircraft have supported the MIRACL 3um laser, at White Sands. What would be needed, as a first test would be determining how such a laser could be put in Earth orbit, and then serviced with its logistical needs. That would be far from trivial.

After that, the fourth challenge would be getting to the L4 and L5 Lagrange points, and working with an adequate transportation system to, starting with ONE laser, each in both L4, and L5 geometric points, to work upon how to get a laser beam able to travel for up to the orbit of Saturn without having the laser width, w(z) spread appreciably.

## ACKNOWLEDGEMENTS

This work has been in part inspired by comments the author received in his two presentations at the 6th AIBEP.org meeting in Scottsville, Arizona. In particular, Dr. Chipp, and Dr. Davis are thanked for their willingness to elucidate minimum technical requirements to the author. In particular, Dr. Chipp has advocated going far beyond simple Gaussian beam spread calculations, to narrow down the issue of minimization of spread of a laser beam at large distances. The author fully agrees with this comment by Dr. Chipp, and will for the next main conference, LASER ablation, pay attention to this essential comment.

## REFERENCES

[1] M. G MILLIS, “PREREQUISITE FOR SPACE DRIVE SCIENCE” IN FRONTIERS OF PROPULISION SCIENCE’ EDITED BY M.G. MILLIS, AND E. W. DAVIS, AIAA PRESS, 2009

[2] A.W. BECKWITH, AIBEP PRESENTATION, NOVEMBER 9TH, 2009, SCOTTSVILE, ARIZONA

**[3] W.S. KOON, W. S.; M. W. LO, J. E. MARSDEN, AND S. D. ROSS (2006). DYNAMICAL SYSTEMS, THE THREE-BODY PROBLEM, AND SPACE MISSION DESIGN. PP. 9.**

**[4] G. MARX, "INTERSTELLAR VEHICLE PROPELLED BY LASER BEAM," *NATURE, VOL. 211*, JULY 1966, PP. 22-23.**

**[5] R. L. FORWARD, "ROUNDTRIP INTERSTELLAR TRAVEL USING LASER-PUSHED LIGHTSAILS," *J. SPACECRAFT AND ROCKETS, VOL. 21*, PP 187-195 (MAR-APR. 1989)**

**[6] K. PARKIN, PHD DISSERTATION HTTP://ETD.CALTECH.EDU/ETD/AVAILABLE/ETD-06022006-160023/**

**[7] G. A. LANDIS, "SMALL LASER-PUSHED LIGHTSAIL INTERSTELLAR PROBE: A STUDY OF PARAMETER VARIATIONS", J. BRITISH INTERPLANETARY SOCIETY, VOL. 50, NO. 4, PP. 149-154 (1997); PAPER IAA-95-4.1.1.02,**

**[8] R.L FORWARD, "STARWISP, AN ULTRA LIGHT INTERSTELLAR PROBE ", J. SPACECRAFT, VOL 22, NO. 3, MAY- JUNE 1985 ; HTTP://WWW.BOOMSLANGER.COM/IMAGES/STARWISP.PDF**

**[9]A. YARIV, (1989). *QUANTUM ELECTRONICS* (3RD ED.). WILEY. ISBN 0-471-60997-8.**

**[10] F. PAMPALONI AND J. ENDERLEIN(2004). "GAUSSIAN, HERMITE-GAUSSIAN, AND LAGUERRE-GAUSSIAN BEAMS: A PRIMER". *ARXIV: PHYSICS /0410021*. HTTP://ARXIV.ORG/ABS/PHYSICS/0410021.**

**[11] E.L. SALDIN, E.A. SCHNEIDMILLER, M.V. YURKOV, "A NEW TECHNIQUE TO GENERATE 100 GW-LEVEL ATTOSECOND X-RAY PULSES FROM THE X-RAY SASE FELS", HTTP://ARXIV.ORG/ABS/PHYSICS/0403067**

**[12] V. YANOVSKY, V. CHYVSKOV, ET AL, "ULTRA HIGH INTENSITY – 300 TW LASER AT .1 HERZ REPTITION RATE", 2008 , HTTP://WWW.OPTICSINFOBASE.ORG/DIRECTPDFACCESS/28D9C05D-BDB9-137E-CD38A2E34E474C63_152180.PDF?DA=1&ID=152180&SEQ=0**

**[13]** C. PHIPPS **, PERSONAL COMMUNICATIONS WITH THE AUTHOR, JANUARY 13, 2010**