Particle Beam Propulsion and Two-Way EML Propulsion

Introductory note.

This presentation was made at the 4th Advanced Space Propulsion Workshop in 1993. The slides were scanned and published in the proceedings (1). Those pages were scanned in 2011 to create this electronic PDF version.

The particle beam propulsion presentation was based on my JBIS paper (1) published that year, but extends the concept a bit further, including my first mention of self-steering particles as a means of keeping the mass beam collimated (p.470), and the possibility of intergalactic travel for a civilization able to build 1% of a Dyson sphere around a solar luminosity star (p.474).

The two-way EML presentation came from a challenge from Dr. Forward who wanted to know if it was possible to push oneself away from the Earth by shooting particles around it. He had asked someone at MIT and gotten a negative response. My answer was that it was possible in a rotating frame of reference, and I had already used this in a science fiction novel (still unpublished, sadly). As this scheme amounts to a sort of space drive, reacting against a central gravitational field with no net loss of mass, I thought it worthy of a paper (2) which I submitted to the AIAA Journal of Propulsion and Power.

Gerald Nordley, 11 July 2011

(1) Nordley, G. D., "Particle Beam Propulsion and Two-Way EML Propulsion," in Frisbee, R.H. ed., JPL D-10673: NASA/OAST Fourth Advanced Space Propulsion Workshop April 5-7, 1993, Jet Propulsion Laboratory, Pasadena CA, pp. 463-474, (1993)

(2) Nordley, G. D., "Relativistic Particle Beams for Interstellar Propulsion," JBIS 46:4, pp 145-150, 1993

(3) Nordley, G. D., "Stationkeeping with two-way electromagnetic launchers," Journal of Propulsion and Power (ISSN 0748-4658), vol. 10, no. 6, (Nov-Dec 1994) p. 912-914

RELATIVISTIC PARTICLE BEAMS FOR INTERSTELLAR PROPULSION

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In a 1980 JBIS paper, C. E. Singer discussed the possibility of using a pellet stream to propel an interstellar vehicle. Here, the author has added a simple relativistic mission study, described how certain technological developments might enhance this concept, and commented on some energy issues.

The pellet, or particle, beam propulsion concept is conceptually similar to photon beam propulsion systems discussed by Forward and others. While the concept is feasible, the reflected photons must still move at the speed of light and so carry away much of the energy used to generate them. The velocity of a beam of particles, however, can be varied so that the reflected particles are left dead in space and thus waste much less energy.

A "magnetic sail" (magsail) is proposed here as the reflector, following a suggestion by Singer. Andrews and Zubrin presented a extensive treatment of magnetic sails in the June 1990 JBIS, and though they did not consider magnetic sails pushed by particle beams or exploded pellets as Singer proposed, their discussion certainly applies. Very briefly, a magnetic sail is a device that generates thrust by reflecting an incoming charged particle and thus gaining some fraction of twice its momentum. A magsail designed to reflect an incoming beam of relativistic particles might be smaller than the 100 km and carry higher fields than the 10^{-5} T that their article envisioned, however a magsail could still present an impressively large target area for total reflection.

Reflector concepts are not, however, limited to magnetic sails, and the general mission kinematics model used here should be able to approximate the performance of any such device.

Of course, any propulsion system that would work for interstellar travel would make interplanetary travel seem trivially easy.

GRAVITATIONAL MIRROR PROPULSION WITH 2-WAY EML

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The use of electromagnetic launchers (EML) for space propulsion goes back to Clarke's 1950 proposal of an EML to launch payloads from the moon. O'Neill's The High Frontier, provides a good summary of much of the early work and ideas in this field.

A recent AIAA paper by R. L. Forward mentioned this author's concept, developed as background for a novel, of an EML which I called a "tethertube," to keep a space station at the L1 point of the Earth - Moon orbit from drifting inward or outward (the L1 point is stable with respect to east - west or north - south perturbations).

This involved sending a mass out from the L1 point along the classic "free return" or "figure eight" trajectory and catching it on the way back. This trajectory was used (in essence) by Jules Verne in his novel From the Earth to the Moon and a Trip Around It and by the Apollo 13 mission. The "figure eight" shape comes from viewing the trajectory in a frame of reference rotating with the same angular velocity as the moon.

In this frame, if the mass is sent toward the moon, the EML is pushed toward the earth, *both* when sending the mass out and when catching it on its return. If the mass is sent toward the earth and back on a related trajectory, the EML is pushed toward the moon.

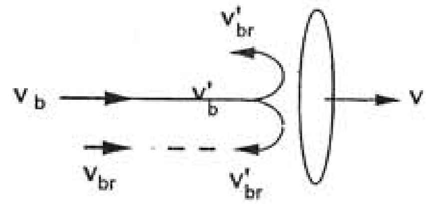
This "gravitational mirror" concept can be applied in general to repel EML in rotating frames of reference from gravitational wells, given the right orbital configuration.

PARTICLE BEAM PROPULSION

AND TWO-WAY EML PROPULSION

BY:

GERALD DAVID NORDLEY*



WHAT ARE THEY

RELATIVELY UNDEVELOPED CONCEPTS THAT:

- Exploit advances in technology
- To propel spacecraft without loss of on-board mass
- Require significant space infrastructure - mid 21st century.

MOTIVATION

These, or things like these, may someday make space economically viable. Need something better than warp drives and unobtainium rockets for Science Fiction. Entertainment educates, conditions expectations, whether intended to or not.

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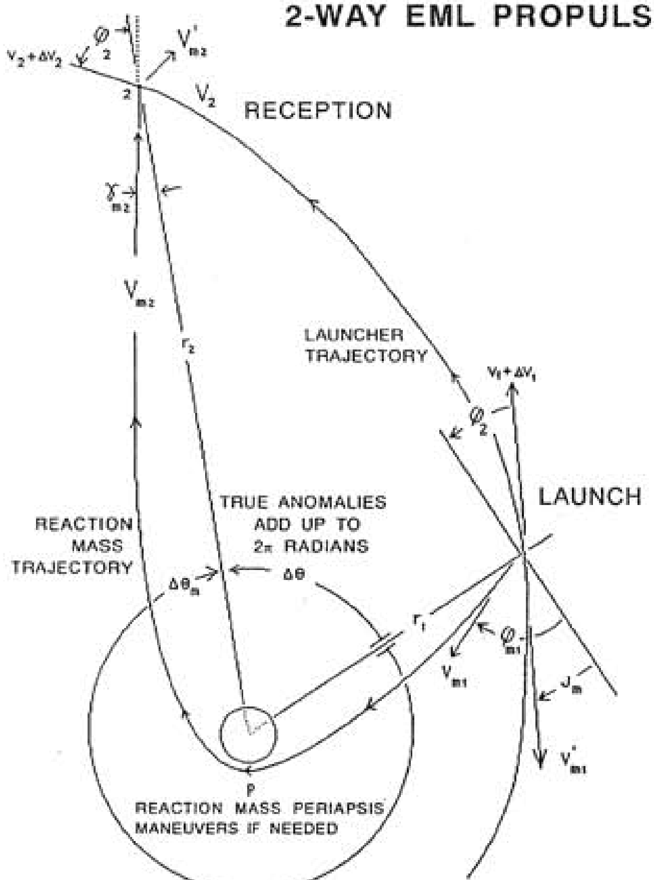
2-WAY EML PROPULSION CONCEPT



IDEA: ***SEND REACTION MASS AROUND PLANET ON A RETROGRADE TRAJECTORY AND RECOVER***

WHY: ***GAINS DELTA V WITH LITTLE OR NO MASS LOSS, EFFECTIVELY REACTING AGAINST THE PLANET'S GRAVITATIONAL FIELD.***

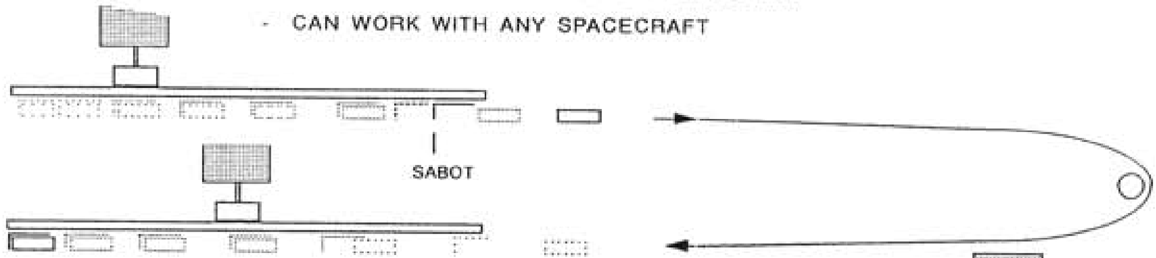
WHAT FOR: ***STATIONKEEPING AND OTHER MANEUVERS OF LARGE MASSES***

NEEDS: ***2-WAY ELECTRO-MAGNETIC LAUNCHERS AND SOPHISTICATED TERMINAL GUIDANCE***

TWO-WAY EML PROPULSION: TWO TYPES OF LAUNCHERS

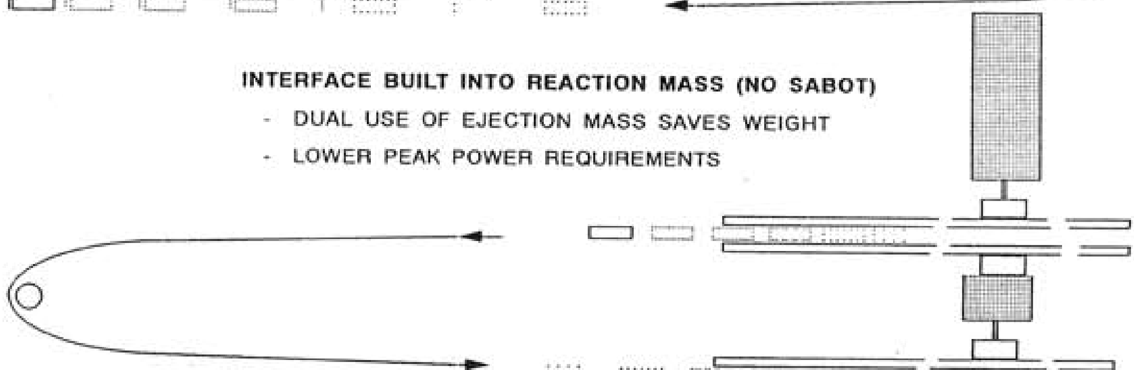
INTERFACE (SABOT) MAY REMAIN ATTACHED TO LAUNCHER (FORWARD'S CABLE CATAPULT)

- LONGER, HEAVIER, LAUNCHER
- SIMPLE DOCKING ENGAGEMENT MANEUVER
- CAN WORK WITH ANY SPACECRAFT

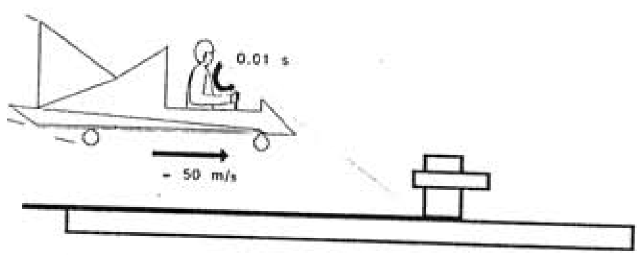


INTERFACE BUILT INTO REACTION MASS (NO SABOT)

- DUAL USE OF EJECTION MASS SAVES WEIGHT
- LOWER PEAK POWER REQUIREMENTS



2-WAY EML RENDEZVOUS - THE CYBER CONNECTION

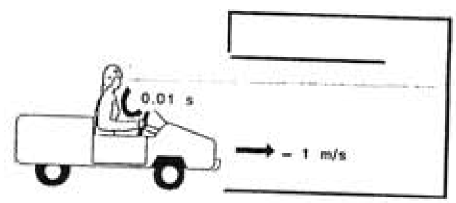


SPEED OF NERVE IMPULSES ~ 100 m/s
LENGTH OF NERVE (HEAD TO ARM) ~ 1 m
TIME FOR IMPULSES TO REACH HAND ~ .01 s
RETINA - BRAIN PROCESSING TIME ~ .04 S

REACTION TIME ~ .05 s

RELATIVE VELOCITY ~ 50 m/s

REACTION LENGTH
= 2.5 m



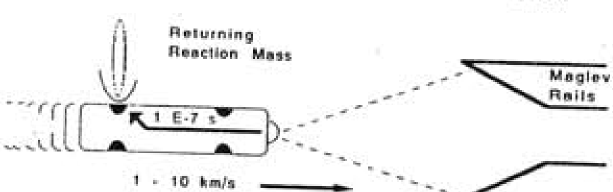
REACTION TIME ~ .05 s

RELATIVE VELOCITY ~ 1 m/s

REACTION LENGTH
= 5 cm

IF ONE COULD THINK AS FAST AS MODERN ELECTRONICS, FLYING INTO AN ELECTROMAGNETIC LAUNCHER WOULD BE LIKE DRIVING INTO YOUR GARAGE *IN SLOW MOTION*

PROCESSOR CYCLE TIME ~ 7.9 E-9 s (128 MHz)
CYCLES FOR FINE CORRECTION ~ 10
PROCESSOR REACTION TIME ~ 8 E-8 s



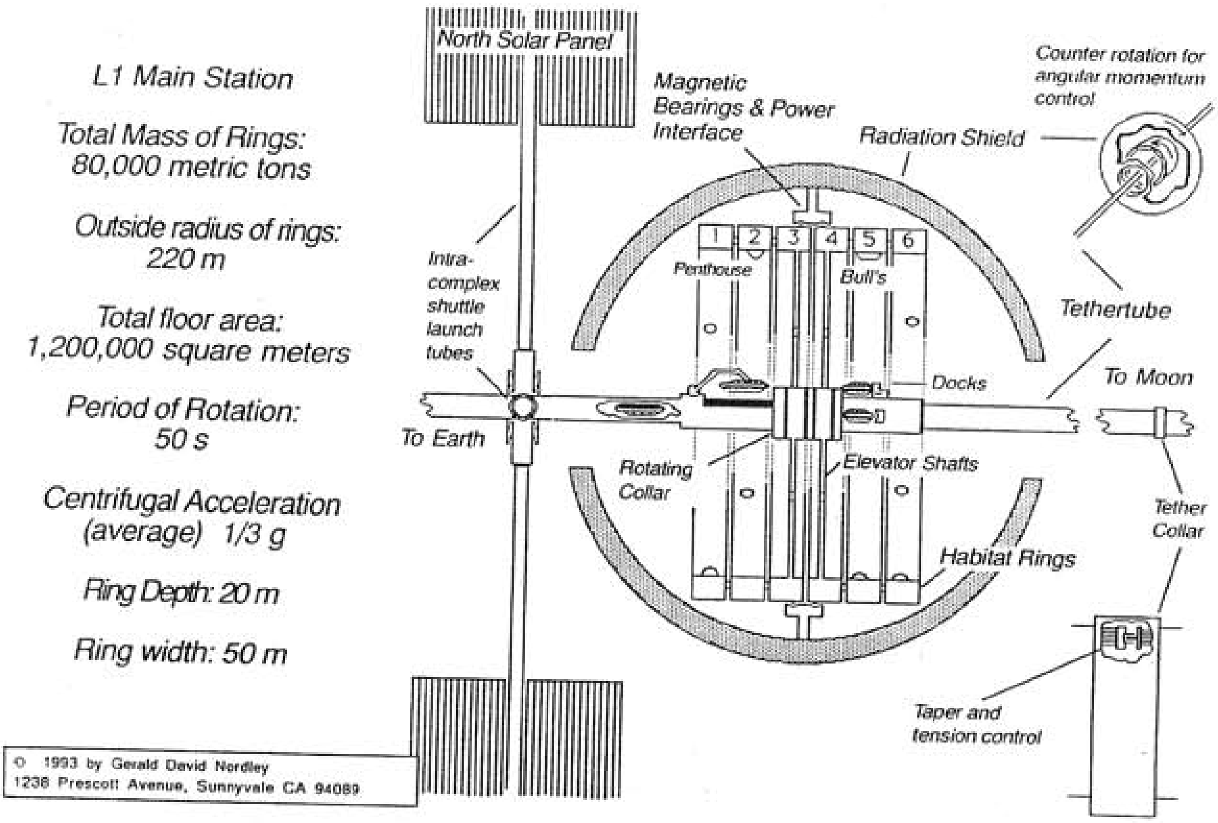
SIGNAL PATH LENGTH ~ 10 m
SIGNAL VELOCITY ~ 3 E8 m/s
SIGNAL TRANSIT TIME ~ 3 E-8 s

REACTION TIME ~ 1 E-7 s

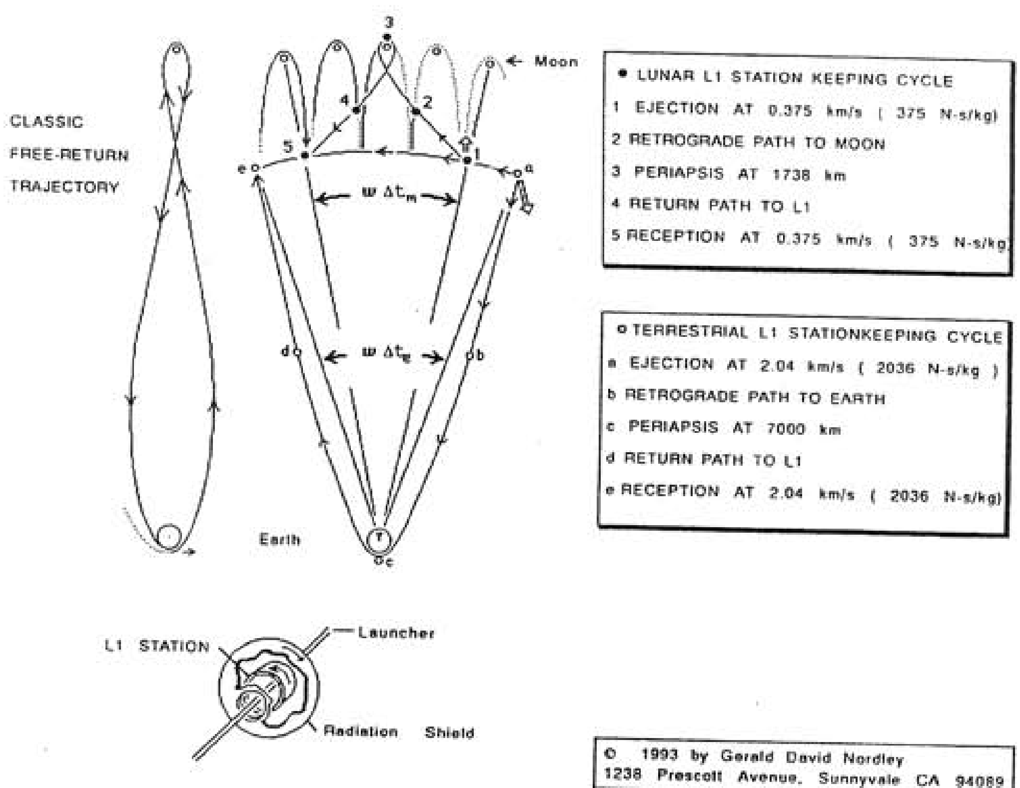
RELATIVE VELOCITY ~ 1-10km/s

REACTION LENGTH
= 0.1 - 1 mm

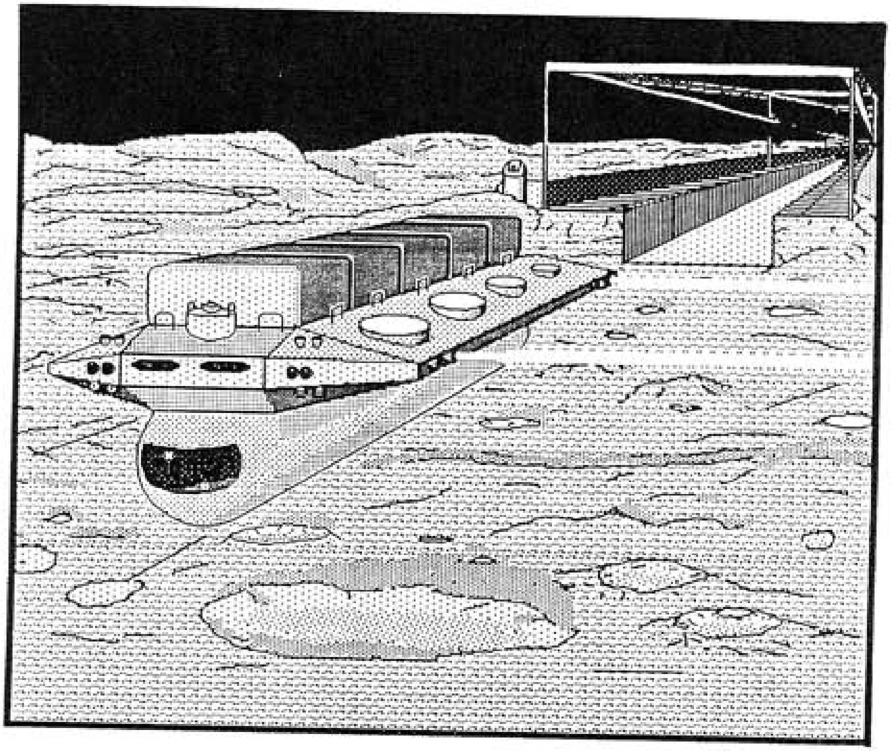
LAGRANGE POINT 1 MAIN STATION



GRAVITATIONAL MIRROR PROPULSION - L1 STATIONKEEPING



TWO-WAY EML PROPULSION - EML MOON LANDING



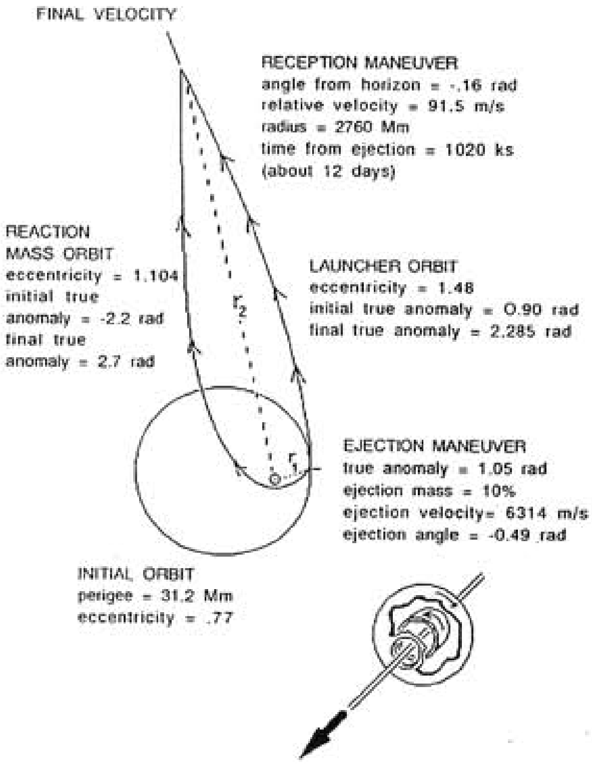
Velocity = 2.34 km/s

Altitude = 10 m

Location: Congreve Crater, Farside

Heading: 270 (West)

GRAVITATIONAL "MIRROR" PROPULSION



GRAVITATIONAL MIRROR MANEUVER

Escape From 135 x 31 Mm earth orbit:

- ***2.236 km/s** hyperbolic excess velocity*
- *Enough to reach Venus*
- *Enough to reach Mars at favorable opposition*
- *Minimum net launcher energy needed: 3.97 MJ/kg.*
- *Reaction mass recovered*

Optimization and perigee maneuvers should yield even better performance.

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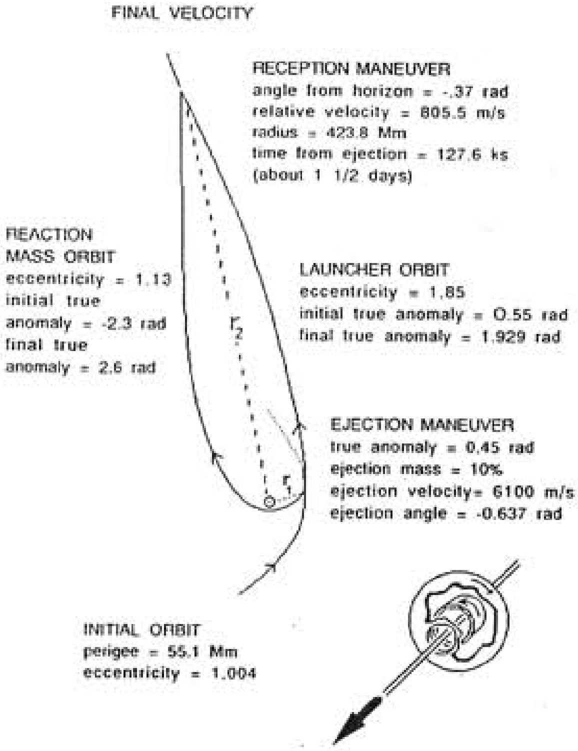
GRAVITATIONAL "MIRROR" PROPULSION



GRAVITATIONAL MIRROR MANEUVER

Hyperbolic Orbit Boost

- ***2 km/s*** *gain in hyperbolic excess velocity*
- *Suggests addition to a "delta VEGA" maneuver*
- *Enough to reach Mars at favorable opposition*
- *Minimum net launcher energy needed: 2.45 MJ/kg.*
- *All reaction mass recovered*

Optimization and perigee maneuvers should yield even better performance.

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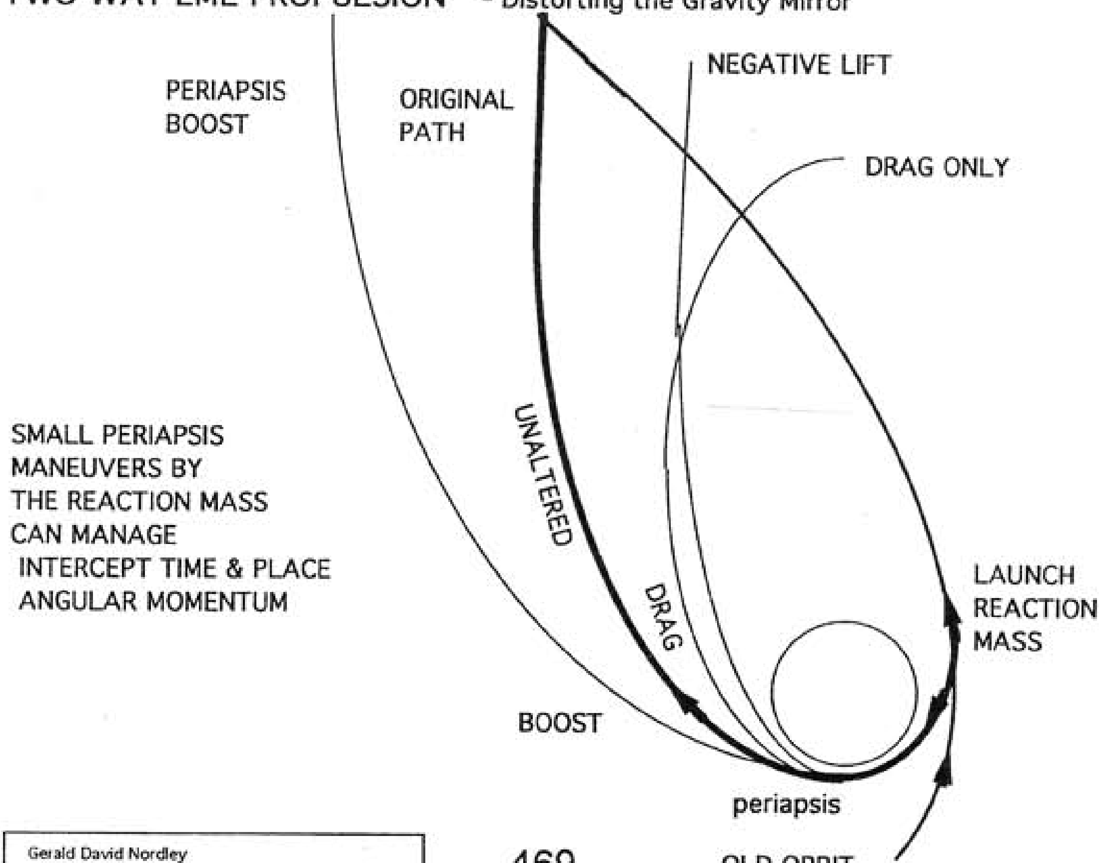
TWO WAY EML PROPULSION - Distorting the Gravity Mirror



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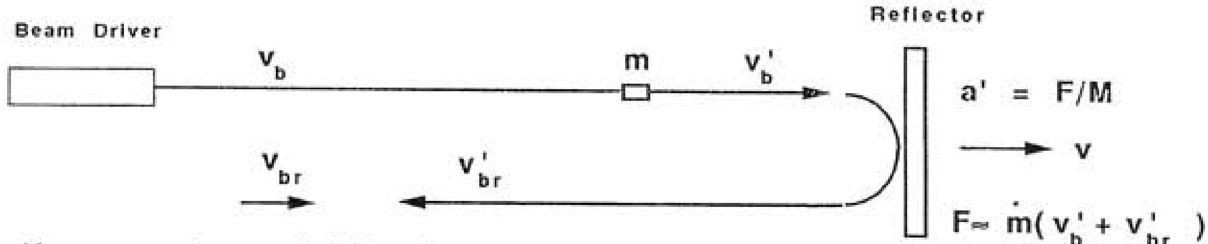
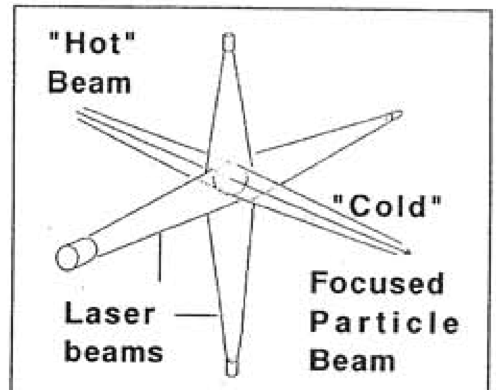
PARTICLE BEAM PROPULSION



If $v_{br} \approx 0$, $\approx$ all kinetic energy goes into M

Engine, energy, & reaction masses remain stationary

Technological advances:
- Photon Field Lens
- Superconductors
- Cybernetics:
  - Von Neumann machines?
  - "Smart" Particles?



Laser Cooling & Focusing

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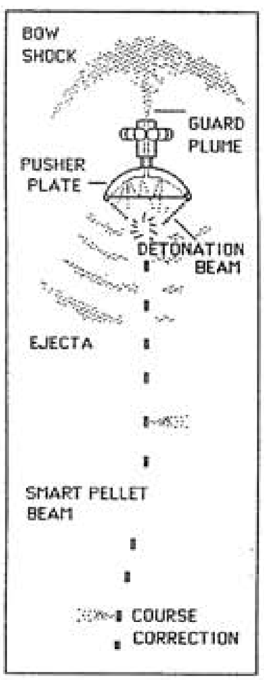
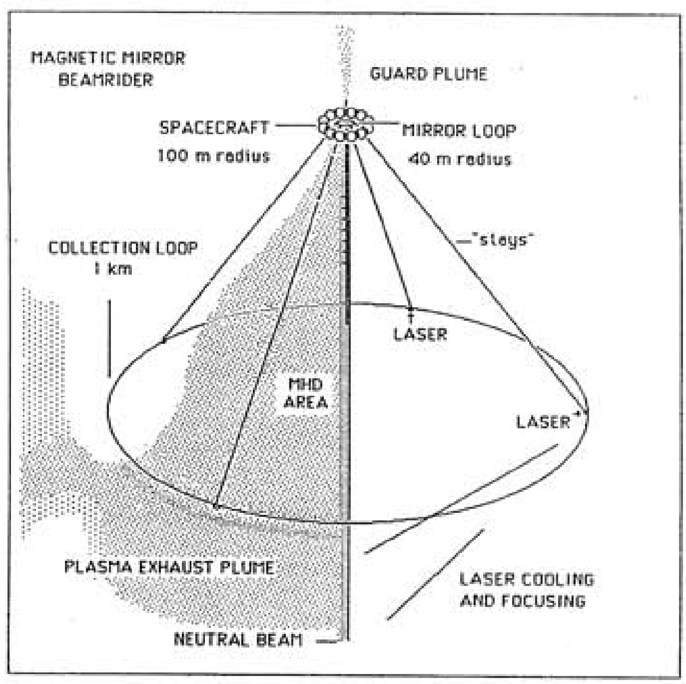
PARTICLE BEAM PROPULSION Concepts





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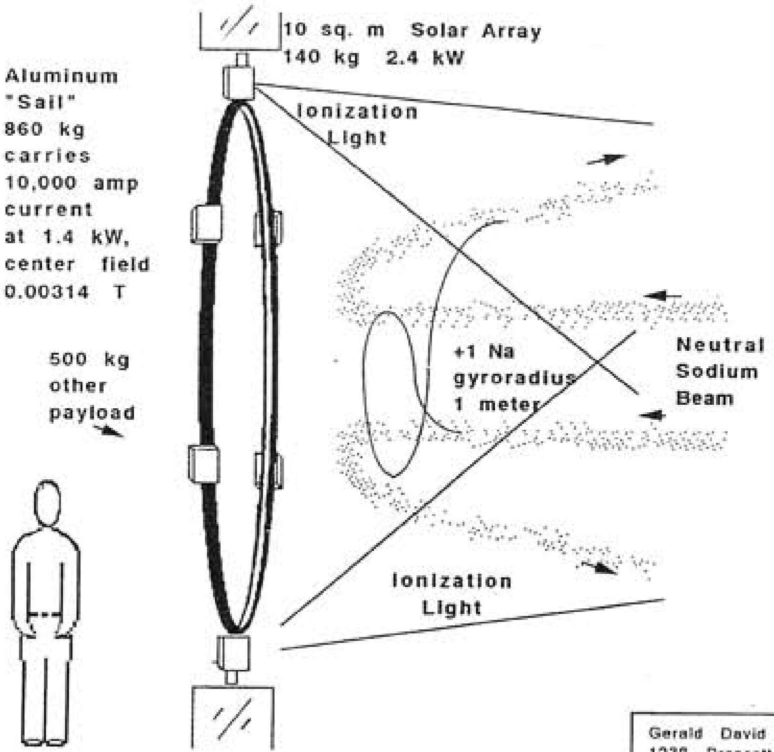

Non-superconducting Magnetic Reflector Experiment.

Neutral Sodium Beam
- 58 g/s
- 13 km/s relative vel.

Reflection ~ 50%

Force ~ 750 newtons

Acceleration
~ 50 cm/s/s (1/20 g)

If beam can be maintained for 10 hrs and focused out to 324 Mm, Δv ~ 18 km/s

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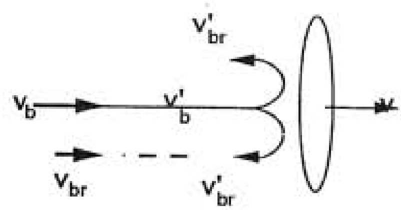
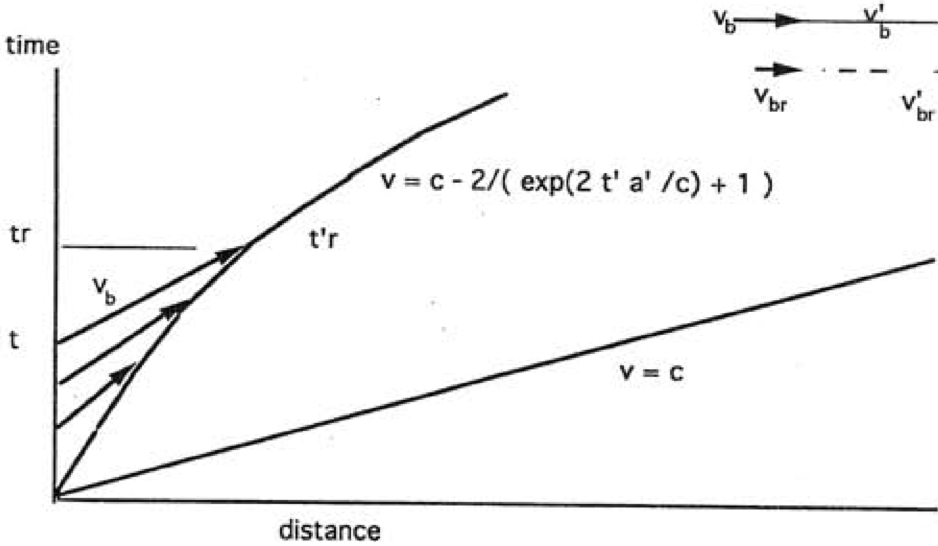
PARTICLE BEAM PROPULSION





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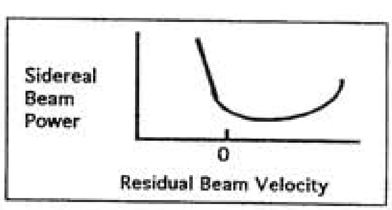

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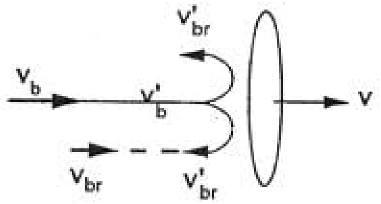

MARS IN ONE DAY? Some Preliminary numbers

Superconducting beam-blown magsail.

Constant Reflected Velocity of 300 km/s in proper frame (V'br)

Acceleration at 25 m/s ^{2}

Magsail loop (*rough* scaling from Zubrin & Andrews, equations in JBIS and Analog),
2 km in diameter, superconducting wire and support, 500 kg
central magnetic field ≈ 25 microtesla
average beam particle mass to charge: 12
gyroradius 1.6 km (suggest this is too high, in which case use higher field and mass)

Beam:
maximum mass flow 42 up to 80 g/s on reflecting area (use more to insure impact)
velocity starts at 300 km/s, ramps up to 1172 km/s
drivers fire for 27,164 s, peak power on the order of 50 GW (10 SSME's)
final beam increment arrives at magsail at 30 Mm (need to focus that far)
- at which time a beam from Phobos (Mars opposition perihelion) can start deceleration, getting the spacecraft to Mars in about one day,
OR
- one can continue on to 1000 AU in about 4.34 years.

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PARTICLE BEAM PROPULSION

To α Centauri with a 1000 tonne ship

3 gravity mission with zero residual beam velocity and 0.95 reflection.

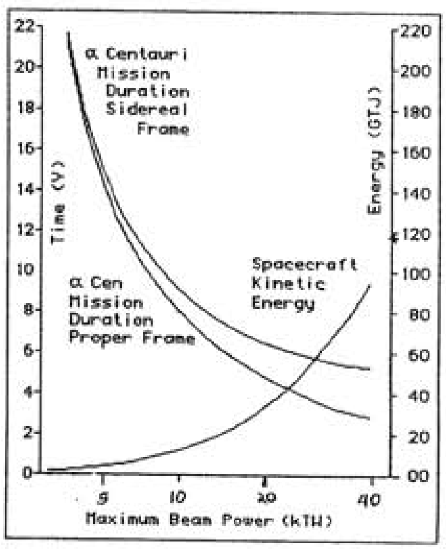
Peak power required ≈ 40 kTW

Peak velocity .886 C

Acceleration time: 200 sidereal days
≈ 152 days, proper frame

Transit time ≈ 5.33 years
≈ 3 years, proper frame

Total Energy ≈ 565 GTJ at 20%



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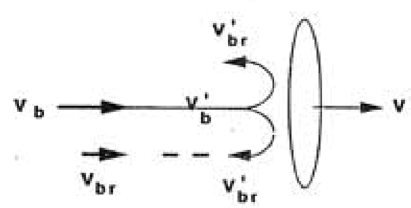
PARTICLE BEAM PROPULSION

Comparison Shopping

Ground rules (chosen to allow the rocket to compete): A one way trip to our colony at **Alpha Centauri.** (The colony has the means to rebuild the rocket or decelerated and reaccelerate the beamriders for a return trip, should that be desired). Our spacecraft payload (exclusive of its interstellar propulsion system) has a rest mass of one thousand metric tonnes. Our proper frame acceleration will be at **1.6 meters per second squared,** so to not discomfort residents of the Moon and other major satellites. We shall accelerate for about **1500 proper frame days** over a distance of 1.5 light years, reach a **peak velocity of 0.6c** and coast for 1.78 years, decelerate and arrive in ten years spacecraft time, **11.1 years universal time.**

Propulsion System	Antimatter Rocket	Photon Beam	Particle Beam
"Exhaust" Velocity	0.38 c	1.0 c	up to 0.89 c
Initial mass	1,774,440 tonnes	1600 tonnes	1260 tonnes
Final mass	42,854 tonnes	1600 tonnes	1260 tonnes
Propulsion mass	Engines: 1,685,670 t initial* 41,854 t final Antimatter: 87,767 tonnes	Sail and lines 600 tonnes	Loops and support 260 tonnes
Peak power	168,567 TW	784 TW	763 TW
Minimum power	4,185 TW	453 TW	Arbitrary (>1.62 MW)
Total Propulsion Energy	Twice the mass of Antimatter x c^2	Approximately $2 \times P_o t'$	Acceleration Energy plus a little to place deceleration mass
	15,798 GTJ	About 100 GTJ	About 30 GTJ
Energy needed to produce propulsion energy.	A factor of 200 to make antimatter	A factor of about 5 for laser efficiency	A factor of about 2 for power transmission and driver efficiency
	≈3,000,000 GTJ	≈ 500 GTJ	≈ 60 GTJ
Number of missions per year with a nano-sun-year of energy	.004 (250 years per trip) (≈12300 E21 J)	25	205
Other considerations	Antimatter factory, storage	Lasers and Megameter optics	Beam drivers and steering

PARTICLE BEAM PROPULSION

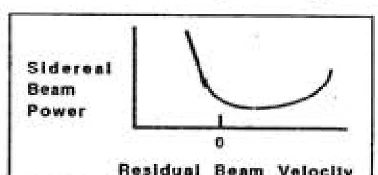


Modeling Results

"Low" Velocity: Up to .01 c
- High mass flow: Beam drivers resemble ion thrusters
- Relatively short focusing distances (Megameters vs. AUs)

Mid-range velocities: .01 c - .5 c (λ = 1.15)
- Keeping residual beam velocity low helps save energy
- Optimum residual velocity > 0 ; for efficiency < 1
- Beam drivers resemble accelerator front ends

Hard relativistic velocities: λ > 1.15
- Proper frame reflection velocity of λ = 2 yields e ≈ 90%
- Beam drivers resemble high energy accelerators
- Beams are "stiff" but focusing distances very long
- Relativistic effects



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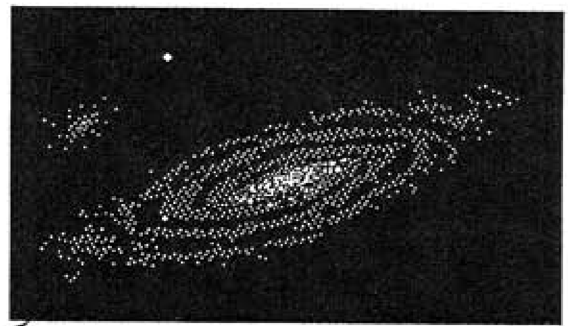
PARTICLE BEAM PROPULSION

Given 1% of a Dyson Sphere Intergalactic Missions are conceivable.



Distance at reception of final beam increment
≈ 1050 LY

Coast time: 200 Y (proper frame)
2,000,000.1 Y (sidereal frame)
Final distance (2,000,000 :LY)

Length of beam at launch
≈36 days

Acceleration ≈ 10 gravities
Acceleration time ≈ 347 days (proper frame)
Final Lorentz Factor ≈ 10,000

Final Power = 7000 GTW (≈0.2% Dyson Sphere)
Beam Projector Operating time ≈ 0.1 Year
Final Beam Lorentz Factor ≈ 41,259 (velocity = .9999999997 c)

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