Fig. 1. Stoppable Ship in Braking Approach to Target Star:
(1) Target star (e.g., Alpha Centauri A); (2), (3) Planets of approached star; (4) Primary mirror of flyby braking system; (5) Diverged laser beam illuminating primary mirror; (6) Laser/diverging lens assembly; (7) Focused stellar energy; (8) Collector mirror; (9) Perforation in collector mirror; (10) Interplanetary space of target star; (11) Laser beam focused by primary mirror; (12) Braking rocket exhaust; (13) Braking rocket; (14) 140,000-Lb. Stoppable payload; (15), (16) Stopped Payloads, already orbiting target star; (17) Direction of motion of flyby braking system.

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LIQUID SPACE OPTICAL THEORY OF
MANNED STARFLIGHT WITH EARTHLY
APPLICATIONS

Abstract

Key discovery is Ta Li's 1960 variational treatment of liquid-hydrogen physical and surface chemistry in Apollo Spacecraft Second-Stage fuel tanks. Li's results—comprising the foundations of "zero-gravity capillary epihydrostatics," after the term coined in 1960 by his colleague, fellow North American Aviation scientist Elliott Benedikt—led to author's 1965 precise synthetic/analytic formulation of "liquid space optics". The latter consists of technology for fabricating ultra-low-cost, self-forming, vast, precision (diffraction-limited), unfurlable, liquid-plastic (nominally Dow-Corning #200 silicone)-surfaced, liquid-metal (nominally pure gallium)-plated, reflective (membrane) optics and refractive (liquid) optics, in "zero-g" (orbit or unpowered trajectory), respectively. Today's space technology is severely energy-limited. The present is a proposal to use the new optics to harness the energy of stars for propulsion as well as for consumer "free" electricity, and simultaneously to harness the mass of the cooler heavenly bodies for raw materials. Consequently it is a proposal to use the new optics to initiate both the interstellar era in space and a quantum-leap in personal fortunes on earth.

1. Overall Strategy

Outlines of "liquid space optics" and "solar energy handling satellite" technology have been sketched by the present author in four earlier publications (Ref.'s 1,2,3,6), to which the reader is referred for general introduction.

General principles are those of permitting capillary forces ruling liquids in "zero-gravity" (orbit or unpowered trajectory) to do the work of fabrication of large astronomical optical surfaces—mirrors or lenses. Previous studies have shown surface errors locally and about the boundary can nominally be held to less than those at the threshold of diffraction limited resolution for optics even on the order of a mile or more in diameter. Quality of liquid optical surfaces already is ideal, a perfection which all lapped and polished solid optical surfaces can only approach. Optical substrates in orbit or unpowered trajectory can be expanded and rigidized from very compact and convenient packages according to well-known military and other tested techniques.

Energy of the sun and stars can be collected, manipulated and redirected in any practical quantity, and with ultimate precision, by sufficiently large, astronomical-quality, zero-gravity, capillary or "epihydrostatic" optics. Both civilization itself and advanced astronautics depend critically on energy. That energy is superabundant in space. Collecting, handling and redirecting solar/stellar energy is perhaps the only bar both to advanced civilization and to advanced astronautics. It is believed joint invention of the laser and of liquid space optics may offer the desired solution for both, one that has been obscured heretofore by excitement over discovery of nuclear physics.

2. Arbitrary Rules and Proportions

Here a number of arbitrary rules and proportions will be assumed:

1) "Seed" LSO satellite mass of 200,000 lb. is presumed lifted into synchronous (22,240-mile-high) orbit by an appropriate chemical booster. Therefrom is assembled the 5,290-ft.-diameter "seed" solar collector, and the 88-ft-diameter "seed" liquid optical primary, etc.

2) Exponential "bootstrap" growth rate of "seed" LSO satellite is set at 1/80th per day, requiring 3.2 years to assemble itself into a 53.5x1010 lb, 1640-mile-diameter "permanent" accelerator system for transfer to a 1/4th A.U. solar orbit.

3) Speed of interstellar rocket is set at one-quarter the speed of light or C/4, which gives relativistic mass increase 3%.

4) rocket exhaust ("expellant") velocity is set at approximately spacecraft terminal velocity = c/4, to earn best (lowest) ratio of initial spacecraft rest mass m0 to payload mass, mP.

5) "Permanent" solar-system-based, solar-energy-handling "accelerator" satellite or SEHS, will be flown in a one-quarter-astronomical-unit solar orbit, to keep mass down to 1/16th and diameter down to 1/4th the equivalent-output unit in an earth orbit.

6) Instantaneous LSO primary-mirror diameter, will be held to 1/60th that of its associated (solid) solar collector mirror.

7) Masses of individual "stoppable" unmanned (freight) or manned (passenger) payloads dispatched to Alpha Centauri, is set arbitrarily at 140,000 lb. each.

8) No A.C.-going or-return spaceship acceleration or deceleration will significantly exceed 1 g at any time.

9) Each solar/stellar collector will be fabricated as a 0.0007-inch-thick, aluminized-mylar, closed, inflated, spherical segment of one base, aluminized on the inside concave surface with overall density 2.0.

10) Lasers used will be of the CO2 type.

11) Ratio of collector mass to primary/secondary/laser/"pump"/focus-control (all precision optics and assemblies) mass will be 4-to-1.

12) Solar collector efficiency = 0.9.

13) (Sunpumped, liquid-end-mirror) laser efficiency = 0.1.

14) Primary and Secondary Mirror Efficiency = 0.9.
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(1) Solar ray; (2) Subliming-propellant microrocket for altitude control; (3) Extreme possible position of spline if spline is attached along its length to the skin of the 1-mile-diameter bellows; (4) Accordion-pleats around circumference of bellows; (5) Spline (attached to bellows) in opposite extreme position; (6) Solar ray after reflection from solar mirror; (7) Envelope of final focused high-energy coherent beam; (8) Short-focus surface of 1-mile-diameter liquid metal mirror "pool"; (9) Instantaneous liquid surface of 1-mile-diameter "primary" mirror; (10) Envelope of laser beam which illuminates primary mirror; (11) Structure of posterior of primary mirror; (12) Pivot bearing for spline; (13) Interior liquid metal mass, constrained by bellows, for figuring; (14) Cylinder containing piston used for varying bellows shape; (15) Piston used for varying bellows shape; (16) Piston position for extreme short-focus of liquid mirror; (17) Piston position for extreme long-focus of liquid mirror; (18) Interior of reservoir for massive liquid; (19) Flexible conduit for massive liquid; (20) Flexible conduit position for extreme long-focus; (21) Plastic-foam boundary ring; (22) Toroidal surface of cast-plastic mirror boundary, fabricated in space; (23) Channel for plastic; liquid plastic is "cast" by surface tension forces, results in toroidal surface; (24) Aluminized mylar material of solar collector mirror; (25) Plastic-foam structural border of solar mirror; (26) Subliming-propellant microrocket for solar mirror attitude control; (27) Interior of bellows for extreme short-focus configuration of liquid mirror; (28) Bottom surface of enclosure for 1-mile-diameter liquid metal mirror "pool"; (29) Membrane structure of bellows; (30) Envelope of laser beam which illuminates primary mirror; (31) Solar ray before reflection from solar mirror; (32) Envelope of final focused high-energy coherent beam; (33) Solar ray after reflection from solar mirror; (34) Long-focus position of liquid mirror (surface).

At the extreme left of Figure 2 is the great solar mirror (1). It focuses solar energy onto the semi-silvered collar-like pumping mechanism (9). Energy trapped by multiple reflections in collar (9) is transferred to the transparent, hollow laser cylindrical cavity (8). Rod (8) is maintained concentric with collar (9) by strut-supports (10). The laser cavity is filled with a gas which absorbs the reflected solar energy and "fases", i.e., transmits a coherent beam normal to the rod's end-surfaces. The end-mirror nearest the great solar mirror (1) is partially silvered, so that a portion of the coherent energy in the rod continuously escapes. The "escaping" beam is diverged by "secondary" lens (6). The latter is rigidly attached to laser-rod (8) and "pump" (9), by strut-supports (7). The diverged coherent beam (4) illuminates the large (1-mile diameter) liquid-surface "primary" mirror (3). High-precision "primary" (3) is bordered by a rigid plastic-foam boundary-ring (2). Laser energy (5), focused by reflection from primary (3), passes through the empty interior of collar (9) and emerges in the form of focused high-energy coherent beam (11). The beam (11) supplies energy at or near its focus to disc-like craft (12), which might carry a protected payload as shown at (13).

Fig. 4. Fabrication of Macro-Optics in Space

(1) Subliming-propellant microrocket for attitude control; this rocket is embedded in a plastic-foam section of mirror—or lens—boundary; (2) Astronaut engaged in extending diameter of macro-optic; (3) Plastic unit boundary section; (4) Channel guide for spool carrying plastic sheet for circumferential optic augmentation (5) Escape rocket for Apollo Command module; (6) Apollo Command module used for initial steps in fabrication of GROM mechanism; (7) SIV-B stage of jettisoned Apollo ferry vehicle; (8) Beam of macrolaser used to "bootstrap" augmentation of latter, via SCT (Spacekill Civilian Transport) ferry vehicle; (9) SCT ascending via macrolaser energy, ferrying load of building material to astronauts; (10) Plasma exhaust of SCT; (11) Releasable joint between two boundary unit sections; (12) Body of giant solar-collecting mirror; (13) Plastic-foam unit boundary section; (14) Channel-follower, integral with spool; (15) Old circumference of macro-optic; (16) Pod carrying spool would with sheet material for construction; (17) Unrolled sheet material for macro-optic construction.
respectively.

(15) Laserpowered Remote Electricrocket Motor (LREM) collector disc efficiency = 0.9.

(16) Rocketmotor thrust-producing efficiency = 0.2.

(17) Overall total (nonself-contained) propulsion process efficiency = 0.01 = 1%.

(18) LREM Specific Impulse is \( \left( \frac{I_s}{I_p} \right)_{\text{LREM}} = 7,500,000 \) sec.

(19) Blastoff-to-Cutoff, and Retrorocket-to-“Halt” stages respectively require 88.5 days = .24 years.

(20) Artificial 1g during unaccelerated portion of each one-way jaunt, is provided by independent living module rotation (centrifugal force).

(21) Distances Blastoff-to-Cutoff and Retrorocket-to-“Halt” respectively are 0.18 trillion miles.

(22) Astronauts spend approximately 17.2 years in transit to Alpha Centauri, 3% of that time in acceleration-deceleration (artificial) 1g, the balance in centrifugal rotation (artificial) 1g.

(24) Astronomical study is accomplished in advance using solar-orbital SEHS primary mirror as a telescope, to disclose raw materials (by photograph and spectrograph) for construction of A.C.-orbital SEHS (stellar energy handling satellite) to accelerate return spaceship.

(25) Required number (estimated 300) of “stoppable” freight-and-tool spaceships (@ 140,000# each) is sent to A.C. for later astronaut-collection and robot-fabrication into “return” SEHS accelerator.

(26) Individual “stoppable” payloads’ associated decelerator (collector-and-precision optics — laser/pump/primary/secondary) is assembled by robots (automation) in zero-g enroute to A.C. @ c/4.

(27) In a later study, power levels for acceleration to and declaration from c/4, must be increased to account for “redshift” of supply source radiation toward redder (less energetic) photons.

(28) Diameter of an earth-orbital “permanent” accelerator, to launch 140,000#-payload “stoppable” ships each @ c/4, would be 6550 miles (compare to earth-diameter, about 8000 miles).

(29) Power delivered by a 6500-mile-diameter “permanent” earth-orbital accelerator would be \( 11.9 \times 10^{12} \) kW. This same power would be delivered by a 1640-mile-diameter-collector system in a 1/4th A.U. solar orbit (compare to world energy demand predicted for 1990 by Zarem-Erway (Ref. 7) of 7.35x10^16 kW, about half a percent of the former (propulsion) requirement.)

(30) Ratio of “permanent” solar orbital “accelerator” assembly mass, to (each, respective) “A.C. flyby” decelerator assembly mass (to “stop” 140,000 lb. per) is about 2,000-to-1.

(31) Alpha Centauri-orbiting accelerator size to launch a 52x10^6-lb. manned spaceship (with “coccooned” stoppable package - payload + expellant) to earth will be 680 miles overall (collector) diameter (presuming a sun-equivalent A.C. star).

(32) Mass of 680-mile-diameter A.C.-orbiting “permanent” accelerator systems to launch (takeoff-mass) 52x10^6-lb. spaceships to earth respectively enclosing “coccooned” stoppable packages (payload + expellant) will be 93 billion pounds.

(33) Number of “stoppable” payloads @ 140,000 lb. each required to be sent to A.C. to add up to 93 billion pounds would be 660,000 loads.

(35) Photographic and spectrographic, telescopic mapping of the A.C. system will be accomplished in advance by using the “permanent” solar-orbiting “accelerator” system’s 27-mile-diameter, primary, diffraction-limited, liquid-surfsed mirror as telescope. This mirror can resolve some 320 miles at A.C. distance.

(36) The primary liquid-plastic mirror is plated with a liquid-gallium thickness of 0.003-inch. If one mile in diameter and using gallium valued at $2,100 per ounce, 336 tons of gallium costing $22.5 billion would be required. For a 27-mile-diameter precision mirror, a new, far cheaper gallium source is required, or a far less expensive liquid metal is needed (for example, an appropriate liquid-metal alloy may be found).

(37) Search for a far less expensive liquid-metal alloy to replace gallium will concentrate on duplicating this metal’s many ideal properties for LSO; gallium is silver-white; reflectivity in the 4100-Angstrom region of the spectrum is a uniform 90%; melting point is 29.75°C (or 85.5°F); boiling point is 1983°C (or 3601°F—one of the longest liquid ranges known); solid density at 85.3°F is 5.9037; liquid density at 85.6°F is 6.0948 (hence this metal expands on freezing); surface tension at 86°F under hydrogen or CO₂ is 735 dyne/cm. Gallium is a member of the aluminum family and like aluminum in its chemical properties.
3. Some Potential Liquid Space Optic Design Problems

Evaluation of LSO perturbation and damage potentials should include: "ripples" (Ref. 8,9); "gravitational gradient distortion" (Refs. 1, 9); "distortion by temperature gradients" (Refs. 10, 11); "foreign-matter monolayers on the free liquid surfaces affecting contact angle and surface tension" (Refs. 12, 13); "micrometeorite potential damage to supporting surfaces and primary or secondary surfaces" (Refs. 12, 13); "difficulty in attitude control of large unmanned or manned orbital observatories" (Ref. 14). Preliminary investigation indicates none of these mechanisms are significant; a vote of thanks is due Dr. Bernard Oliver for contributing the above suggestions; reader comments are solicited on all aspects of present proposal.

4. A Chronological History of Starflight Studies

Consider the history of interstellar propulsion investigations and adapt anything useful:

Von Hoerner, Sebastian, concludes (1963) ... Space travel, even in the most distant future, will be confined completely to our own planetary system, and a similar conclusion will hold for any other civilization, no matter how advanced it may be ... (Ref. 15); Purcell, Edward, says (1963): "Let us consider taking a trip to a place 12 light-years away, and back... It is preposterous. And remember, our conclusions are forced on us by the elementary laws of mechanics... All this stuff about traveling around the universe in space suits—except for local exploration... belongs back where it came from, on the cereal box." (Ref. 16).

Marx, G., concludes (July 2, 1966) "...The laws of conservation of energy and momentum (do not necessarily) forbid the visiting of other planetary systems in the human lifespan" (Ref. 17); Dyson, Freeman J., says (October 1968) "...I predict that about 200 years from now, barring a catastrophe, the first interstellar voyages will begin" (Ref. 18); Norem, Philip C., says (June 1969) "An overall system employing a vehicle with a solar sail, a large laser array, and employing interactions with the interstellar magnetic field... is... capable of roundtrip interstellar... journey of 75 to 150 years..." (Ref. 19); Forward, Robert L. says (1976): "...a more practical method would be to carry along some mass to use as propellant and just use the laser beam to energize the propellant..." (Ref. 20); Jackson & Whitmire say (1978) "The laser rocket... can also accelerate directly into the beam since the ship uses the laser beam only as a source of energy and not momentum" (Ref. 21). Weiss, Pirri and Kemp say (1979): "In... (one way of)... beaming energy to a propulsion system with a high power laser... a thermal rocket system uses energy beamed from a remote laser to heat a chemically inert propellant" (Ref. 22).

Oliver, B.M. says (Oct. '87): "...interstellar travel... if such travel is to be accomplished in a human lifetime, the energy requirements are enormous... Our intent is to dispel the notion... that progress in rocket technology can reduce by orders of magnitude the energy needed for interstellar flight..." (Ref. 23).

5. Starflight Summary Compendiums

Consider the recent booklength starflight introductions:

Mallove, Eugene and Matloff, Gregory say (1989): "Much faster probes and later missions bearing people will be launched toward the stars when advanced propulsion systems now only theoretically possible come to fruition..." (Ref. 24); Mauldin, John H. says (1992): "Very few stones have been left unturned in the general search for energy sources... More revolutions are needed to make interstellar travel easy..." (Ref. 25).

6. Earth-to-Orbit Exponential "Bootstrap" Freight Shuttle

Reversible send-receive paraboloidal-mirror orbital primaries and secondaries, presupposing Newtonian or Cassengrainian systems readily rendered real-time focusable (Fig., 2) as shown, would "bootstrap" themselves exponentially from an LSO/SEHS seed-satellite startup unit. Latter would operate by sending to earth a continuously-augmented beam from its unpumped liquid-end-mirror orbital laser, to exponentially supply energy to associated distant LREM (Laserpowered Remote Electric-rocket Motor)-fitted aero-space freighters, shuttling between earth and orbit to deliver LSO/SEHS construction materials.

Burgeoning laser beam from such a "send" self-grown, mile-plus-diameter, orbital-primary, solar-powered, liquid-mirror system, would dedicate itself first to economic-breakthrough ("Millenium-level") free-energy supply to all civilization on planet earth itself.

Next target would be low-cost, self-sufficient planetary astronomy/exploration/exploitation, using an early development stage of the same vast, solar-powered, laserbeam apparatus to supply energy to LREM-powered interplanetary freighters. The latter would operate each at one continuous gravity of acceleration/deceleration.

Follow-on purposes would be to (1) use this equipment in "receive" mode to effect high-resolution mapping/geological survey of all Alpha Centauri planets (as discovered), then (2) in "send" mode, to effect first a two-way cooperative interstellar expedition, then—by further extrapolation of the same technology—ultimately a relativistic shuttle roundtrip transportation system between any Alpha Centauri planets and earth.

An LSO/SEHS orbital "send-receive" optical station, operates as a vast, diffraction-limited space telescope in the "receive" mode, or as a laser energy pipeline (beam-tightener) in the "send" mode. See Fig. 3. It is constructed by respectively circumferentially augmenting its elements, automatically or under astronaut control, beginning with a 200,000-lb. (one "Saturn" rocket payload, but designed for GEO) "seed satellite" (See Fig. 4).
Distinguish these elements from Fig. 3. At the extreme left of Fig. 3 is the great solar collector mirror of aluminized mylar for "bootstrapping" freight shuttles from earth-to-orbit-and-return. It focuses (Fig. 2) solar energy onto the semi-silvered collar-like "pumping" mechanism. Energy trapped by multiple reflections in the collar is transferred to the transparent hollow laser cylindrical cavity. Rod is maintained concentric with collar by strut-supports. The laser cavity is filled with a gas which absorbs the reflected solar energy and "lases", i.e., transmits a coherent beam normal to the rod’s end-surfaces.

The end-mirror nearest the great 5,290-ft. dia. solar mirror is partially silvered, so that a portion of the coherent energy in the rod continuously escapes. The "escaping"beam is diverted by "secondary" lens or mirror. The latter is rigidly mounted to laser-rod and "pump", by strut-supports.

The diverged coherent beam illuminates the 88-ft-dia. "seed" orbital liquid-surface primary mirror (Fig. 3). High-precision primary is bordered by a rigid plastic-foam boundary ring. Laser energy, focused by reflection from primary, passes through the empty interior of collar and emerges in the form of focused high-energy coherent beam. The beam’s greenlight-diffraction-limited focus spot of 3 ft. dia. from synchronous (22,240-mile-high) altitude is diffused to match the earth-to-orbit freight shuttle’s collector diameter. The shuttle, dual-powered with rockets and airscrews according to the author’s “HOTJAAWSS” V/STOL aerospace-craft design (Fig. 5) "rides" (receives energy continuously from) the beam continuously in ascent and descent. (Note landing-energy normally is stored for out-of-beam emergency operation).

7. The Young-Laplace Equation

The basic equation of capillarity relating the pressure differential across a curved (or flat) liquid surface to the surface tension and the principal radii of the surface was introduced by Young and Laplace in the 1805:

\[ \Delta p = \left( p - p_0 \right) = \sigma_{1v} \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \]

where: \( \Delta p \) = pressure difference across the surface,
\( p \) = pressure outside the surface,
\( p_0 \) = pressure exerted by the liquid inside,
\( \sigma_{1v} \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \) = pressure exerted by the surface “skin” of the liquid,
\( R_1, R_2 \) = the radii of curvature for any two orthogonal curves in the surface at their point of intersection,
\( \sigma_{1v} \) = the interfacial surface tension between the liquid and the vapor above it.

Figures 6, 7, 8 and 9 illustrate application of Young-Laplace capillary physics principles to establishing liquid space optics techniques and estimating surface quality.

Foundations of LSO: Ta Li’s 1960 “Hydrostatics in Various Gravitational Fields

Ta Li (Ref. 26, Fig. 10) considered a closed container with axial symmetry, partly filled with a liquid and the remainder with the vapor of that liquid—as stabilized in zero-gravity by the combination of (fixed) surface tension and (fixed) liquid-solid contact angle. He then applied the variational calculus to ascertain the cross-section curve of that liquid for arbitrary axial force (nominally a degree of earth sea-level gravity, but as well one of course can substitute any other applicable force,
such as gravity gradient, solar/stellar light pressure, self-gravitation, arbitrary perturbation, propulsion, etc.)

Casting solution to Li's resulting differential equation in appropriate optical and physico-chemical parameters, one finds (Ref. 4):

\[ e^2 \approx \left( \frac{1}{2} \right) n g_0 C D^3 \left( \frac{D}{V} \right)^2 \]  

(2)

where:  
- \( e \) = error (from circularity), as defined in Fig. 10,  
- \( n \) = load in g's,  
- \( g_0 = 980.665 \text{ cm/sec}^2 \)  
- \( C = C_{\text{liquid}} - C_{\text{vapor}} \)  
- \( C_{\text{liquid}} = \frac{\sigma_{lv}}{g_0} \)  
- \( C_{\text{vapor}} = \frac{\sigma_{lv}}{g_0} \)  
- \( D \) = diameter of optical element, cm  
- \( V = f/\# \) or focal ratio of optical element  
- \( \sigma_{lv} \) = surface tension of liquid, dyne/cm

For example, application of equation (2) to the case of a liquid-gallium-plated, liquid-Dow Corning 200-surfaced, one-mile-diameter, plastic mirror in zero-gravity (orbit), requires that no greater (axial--deemed worst-case) acceleration than 7.16x10^{-15} sea-level earth gravities operate, if liquid mirror is to remain diffraction-limited (i.e., correct to \( \lambda/4 \) over-all) in greenlight.

9. C.H. Townes on "Beam-Tightening"

C.H. Townes & R.N. Schwartz (Ref.27), laser (or "optical maser") co-inventors, consider "directivity of the beam from an optical maser. If a maser produces a wave of wavelength \( \lambda \) with constant phase over a surface of diameter \( d \), the angular width of the radiating beam is approximately \( \lambda/d \). However... its angular width can be still further reduced if it is operated in conjunction with an auxiliary optical system... Imagine that an ideal lens of focal length \( d \) and diameter \( d \) is put in the beam. Then, at the focal point the entire beam has a diameter approximately \( \lambda \). If this focal point is made to coincide with that for a much larger ideal lens or reflecting mirror of diameter \( D \) and focal length \( D \) or larger, the beam emerges from the latter with an angular width determined by its aperture, of \( \lambda/D \)... it is not necessary actually to focus the beam to a small spot..."

The above is the kernel principle of the "send" application of liquid space (laser) optics. "Receive" applications of the latter of course correspond just to the conventional science of construction and operation of large astronomical telescopes, particularly as exhibited in orbital (or unpowered-trajectory) spacecraft, i.e., "zero-g".

10. LREM Interplanetary and Interstellar Spaceships

Note in Fig.11, (1) is payload (stoppable or unstoppable); (2) is interplanetary Laserpowered Remote Electricrocket (ion) Motor (LREM) disc ("metallic" or frozen, hydrogen, or tungsten); (3) is insulator "spike-bed" to fix separation between disc and electrode mesh; (4) is electrode mesh; (5) is envelope of exhaust plume; (6) is direction of impinging laser beam from distant SEHS; (7) is direction of rocket exhaust.

"Practical" interstellar rocket exhaust speed presupposed by the present writer, is \( v = c/4 \) corresponding to \( I_p = 7,500,000 \) sec. It is presumed such an \( I_p \) (=7,500,000 sec) is feasible by suitable development of the particle accelerator principle.

Rocket principle contemplated thereto is application of energy at the orbital macrolaser moving focus in space vacuum, to achieve the highest possible specific impulse. For the interplanetary case only, solar/stellar energy is considered somewhat expendable.

Finally, U. Brauch et al of "DLR," Stuttgart, Federal Republic of German (Ref.29), notes a sunpumped, thermally excited CO\(_2\) (gas) laser operating at 10.6 \( \mu \)m, may have efficiencies from 0.2 to 15%. But they warn the possible high value "is...theoretical... and up to now, not confirmed experimentally." M. Toussaint of Eurospace, Paris, France (Ref.3) further notes "...solar pumped lasers, which convert directly into a laser beam the solar energy absorbed by an amplified medium... (feature)... a relatively high global efficiency (probably on the order of 10%)... In principle, the Solar Power Satellite preference would be given to laser transmission."
Fig. 6. Space-Built Precision Boundary Rings
(By permission of AAS - Ref. 1)

Fig. 7. Why Fluids Cannot "Leak" Out of Boundaries
(By permission of SPIE - Ref. 2)

Fig. 8. Minimization of Boundary Errors Via Liquid Ring
(By permission of AAS - Ref. 1)
Fig. 9. Impossibility of Short-period Errors in Liquid Surfaces
(By permission of AAS - Ref. 1)

\[
\begin{align*}
\text{GIVEN: A DEPRESSION IN THE} \\
\text{BOUNDARY SURFACE} \\
\text{ASSUME: THAT THIS RESULTS IN A} \\
\text{Dimple in Liquid Surface} \\
\text{BOUNDARY RING} \\
\end{align*}
\]

\[
\begin{align*}
&= \sigma \left( R + \frac{R}{n} \right) = \sigma \left( R + \frac{1}{n} \right) \\
&\text{BUT:} \quad \sigma \left( R + \frac{R}{n} \right) > \sigma \left( R + \frac{1}{n} \right) \quad \text{(CONTRADICTION)}
\end{align*}
\]

\[\text{Then: Normal Pressure due to Surface Tension}\]

\[\text{Fig. 10. Error} \delta \text{ Due to a Finite Axial Load} N_g\]
(By permission of AAS - Ref. 1)

\[\text{C = Characteristic} = \Delta \rho / \rho_g\]

\[\text{R} = \text{Radius of Mirror} = \rho (2.107)^{d_{\text{in}}}\]

\[\text{F = Focal Length} = R / 2\]

\[\text{D = Aperture} = F / D\]

\[\text{N = Load} = N_g\]

\[\text{\[\delta = 2C \Delta \rho \Delta \rho / \rho_g\] Error} = \delta_g + \delta_0 \text{ gives } N_0 = \rho_0 \text{ and} \rho \approx \rho_0 \]

\[\text{Surface under zero load}\]

\[\text{Surface under finite load}\]

\[\text{Fig. 11. Electromagnetic Non-Self-Contained Rocket Motor Used to Power Interstellar Missions:}\]

(1) Payload (stoppable or unstoppable); (2) High-temperature ionizable (ablatable) disc; (3) Insulator "Spike-Bed" to fix separation between disc and electrode mesh; (4) Electrode mesh; (5) Envelope of exhaust plume; (6) Direction of impinging laser beam from distant orbital laser beampower source; (7) Direction of rocket exhaust.

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Fig. 12. Interstellar Ship in Acceleration Phase

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