Comment on "Jet propulsion by microwave air plasma in the atmosphere" [AIP Adv. 10, 055002 (2020)]

Randell Lee Mills
Brilliant Light Power, Inc.
105 Terry Drive, Suite 103
Newtown, PA 18940

The nature of absolute space for the proper time and mass/energy of a fundamental particle such as a free electron and the constant maximum speed of light give rise to a reactionless means of propulsion involving conservation of photon energy absorbed by a free lepton such as a free electron. Conservation laws of a fundamental particle such as a free electron during photon absorption results in the directional increase in the inertial parameters of inertial momentum and mass/energy corresponding to kinetic energy with no reaction of a massive third body reaction partner in the exchange. Specifically, an incident photon increases the kinetic energy of a free electron in the direction of it motion relative to its absolute space by ½ of the photon energy given by $\hbar\omega$ wherein $\hbar$ is Planck's constant bar and ω is the photon angular frequency. All electromagnetic waves comprise a superposition of photons [1]. Transfer of photon energy must instantaneously obey causality, locality, continuity with conservation of photon energy of $\hbar\omega$ and the electron and photon angular momentum $\hbar$, wherein conservation of linear momentum is not obeyed. The classical theory regarding the nature of the photon and free electron that give rise to the reactionless force exploited as the mechanism a novel means of propulsion called "space drive" is given in by Mills [1]. A simulation of this phenomenon is given by Mills [2].

Directional kinetic energy may be manifest as a directional lift force by directing the kinetic energized electrons toward a transducer such as a piston. In two patent applications Mills [3-4] discloses space drive, a system that exploits conversion of photon energy to reactionless free electron kinetic energy to provide reactionless lift and propulsion. Specially, space drive comprises (i) a source of microwave power such as microwave generator and a matching network, (ii) a plasma torch with a directional plasma gas flow along the axis of a plasma chamber tube that is powered by the microwave power to maintain a plasma comprising a flow of free electrons along the axis of the plasma tube, (iii) a source of microwave photons such as the plasma torch to apply microwave power to the directional electron flow to create (a) an increase in kinetic energy in the directional electron flow due to the free electrons absorbing the microwave photons in a directional manner and gaining reactionless kinetic energy in a directional manner and (b) directional plasma gas flow with increased kinetic energy since the electrons drag positive ions such as H_3^+ ions with an extraordinary long lifetime [5] that are easily formed and maintained in high concentration in a plasma environment [6] and further accelerate the collisionally-coupled plasma gas, and (v) a transducer such as piston to convert the directional increased kinetic energy flow into a lift force.

In general, the plasma may be formed by a plasma generator such as a surfaguide plasma generator such as exemplary one by Sairem [7]. Alternatively, the plasma generator may comprise a microwave plasma system such as an atmospheric-pressure microwave plasma generator. An exemplary atmospheric-pressure microwave plasma generator is one by Leins et al. [8]. A commercial version is available by Muegge Gerling [9]. Microwave plasma systems that function on the principle of reactive momentum conservation between and object to be propelled and a kinetic energized stream of gas and ions have been studied extensively. The reactive propulsion force and thrust and corresponding efficiency produced by flowing and expanding a pressurized plasma gas energized by microwave power through a typical converging-diverging nozzle such as de Laval nozzle has been shown to be poor.

Motivated by the desire to replace jet engines based on fossil fuels Ye et al. at Wuhan University [9] tested an atmospheric-pressure microwave plasma torch for the ability to heat an ambient air stream and create a pressure and corresponding lifting force on a weight comprising a metal ball of adjustable mass that occluded microwave heated plasma torch gas flow at the top of the torch plasma tube when the gravitational force on the ball or weight matched the lifting force of the microwave heated flowing gas. The lift force and corresponding pressure that lifted the ball was significant compared to atmospheric pressure. Ye et al. [10] erroneously equated the lift force that was comparable to that of a jet engine to the thrust force. Unfortunately, the upward force of the of pressurized gas on the ball and the force of the ball's weight are equal and in opposite directions. The pressure forces on the plasma tube also balance. There was no net propulsion force on the plasma tube, ball, and plasma tube. A net propulsion force in the opposite direction of the ball-restricted plasma tube is given by the nozzle trust equation wherein any net thrust was due to the gases escaping through the small aperture between the ball surface at the top surface of the plasma tube. This thrust is orders of magnitude less than the lift force due to the pressure and flow of the plasma torch plasma gas as reported in an analysis of the Ye at al. experiment [10] by a Wright et al. at the University of California Los Angeles [11].

Currently all such propulsion systems are based on production of equal and opposite reactive momentum transfer that requires system mass loss in addition to highly inefficient power loss. In contrast, space drive lift or thrust is in the direction of mass flow, requires no mass loss, and can be at least 50% power efficient of microwave power to propulsion kinetic power, wherein the efficiency can be boosted by energy recovery in a closed system. Thus, it is worth revisiting the analysis of the Ye at al. [10] experiment in these terms since some of the basic components of space drive are present assuming that the flattened microwave waveguide was capable of supplying microwave photons corresponding to a far field effect in addition to free electrons via gas ionization which may be predominantly via near electric field coupling, ohmic power transfer.

In addition, Wright et al. [11] reported the results of a restricted heated plasma flow model of the Ye at al. [10] experiments wherein the effect on the plasma chamber pressure as a function of microwave heating power and gas flow rate were analyzed. In addition to losses to escaping, heated flowing gas, microwave power was lost to atmosphere from the walls of the plasma tube of 27 mm OD and 600 mm length and from the surface of the weighted metal ball of 75.5 mm OD. The gas jet at the aperture between the gas tube caused forced convection cooling of the ball and caused moderate forced air flow over the surface of the plasma tube cylinder. Typical air heat transfer coefficients for moderate air flow and forced air convection cooling are 100 $W/m^2{}^\circ C$ and 200 $W/m^2{}^\circ C$, respectively [12]. Using these values in Wright's Eqs. (3-6) results in an immaterial increase in pressure due to the restricted heated stream flow. The Wright et al. analysis [11] shows larger pressure increases for the test parameters. But, over the ranges of the experimental conditions of flow and power, there are large discrepancies between the model and the data wherein the corresponding curves obviously have different slopes and intercepts. Wright used a value of 15 $W/m^2{}^\circ C$ for the air heat transfer coefficient applied to the tube-wall area only. To be very conservative, the pressure rises according to Eq. (3-6) were calculated using 30 $W/m^2{}^\circ C$ for the area of the tube and 200 $W/m^2{}^\circ C$ for the area of the metal ball, and the hydraulic resistance value derived from the Ye et al. [10] data ($R_{hyd} = 2.20 \text{ X } 10^7$ Pa s/m^3) was used rather than the mistyped reported value [11]. The potentially significant loss contribution by heat conduction to the waveguide and coupler was not included in the analysis. The results as a function of gas flow rate and microwave power compared to the experimental values of Ye et al. [10] are given in Table 1. The results clearly indicate that there is an unexplained source of excess force.

Table 1. Comparison of the experimental forces lifting the ball (green) and the modeled force (black) due to flowing the heated plasma gas through the tube-ball channel as a function of the microwave input power and the gas flow rate. There is a source of excess force that is dependent on the plasma gas flow rate and the microwave power.

Force (N) at flow rate (m^3/h)

Microwave Power (W)	0.7	0.65	1	1.15	0.3	1.45
0	1.77	2.14	2.49	2.85	3.19	3.54
	1.50	2.00	2.75	3.50	3.80	4.00
100	1.89	2.27	2.65	3.02	3.39	3.75
200	2.00	2.41	2.81	3.20	3.59	3.97
300	2.12	2.55	2.97	3.38	3.78	4.18
400	2.24	2.68	3.12	3.55	3.97	4.39
	3.00	5.30	6.25	7.70	9.30	10.90
500	2.35	2.82	3.28	3.73	4.17	4.60
600	2.46	2.95	3.43	3.90	4.36	4.80
	5.50	7.80	9.30	10.70		
700	2.58	3.09	3.59	4.07	4.54	5.01
800	2.69	3.22	3.74	4.24	4.73	5.21

The experimental excess force increased with increasing flow rate and applied microwave power as shown by the experimental data reported in Ye et al. [10] in Figures 4a and 4b. Both dependencies support the presence of a space drive effect. Increasing microwave power increases the number of free electrons and the number of microwave photons to be absorbed by the directional flowing electrons. The increased flow increases the directionality of electron flow which increases the direction absorption of the microwave photon. The plasma gas used by Ye et al. [10] was ambient atmosphere that may comprise up to 4% water vapor which serves as a source of H_3^+ ions. Ye at al. [13] discuss the positive water effect on their results which is consistent with the enhancement of the space drive ion and plasma gas dragging effect due to the presence of these long-lived ions.

Ye et al. [13] published a response to the Wright analysis [11] that calculated the gas temperature rise with 100% of the microwave power heating the flowing gas and the corresponding maximum static gas pressure from the ideal gas law while not addressing the physics of the restricted hydraulic flow or any analysis of the conversion of the plasma chamber pressure into a feeble thrust from the gas expansion through the nozzle created by the ball restriction. It is noteworthy in the Ye et al. response [13] that further details and parameters of the system to supply the plasma gas flow, test parameters, and corresponding experimental results are reported. The gas source was an air compressor that provided gas at a constant pressure set to achieve the desired flow rate as measured by a flow meter. For flow to occur, the input air plasma gas pressure must exceed the plasma chamber pressure even in the case that the flow is restricted, and the plasma is heated by the applied 2.45 GHz microwave power. The microwave power heating and flow restriction must be compensated by a reduced gas flow for continuous flow to occur which is consistent with the reported 20% error in the flow meter reading [13]. In this case, space drive can account for any increase in plasma chamber pressure above the gas inlet pressure. Ye at al. [13] report that with the experimental parameters of an input power of W_m = 0.4 kW, air flow rate I_{air}

= 5.0 × 10^{-4} m^3/s (1.8 m^3/h), and a pressure of the inflowing compressed air in the experiment of P_{air} = 1.07 × 10^5 N/m^2, the measured thrust pressure was 2.4 × 10^4 N/m^2. Subtracting the maximum net chamber pressure being the inflowing pressure P_{air} minus the ambient atmospheric pressure of P_{atm} = 1.01 X 10^5 N/m^2, gives a net lift pressure of 1.8 X 10^4 N/m^2.

Consider the reanalysis of the Ye et al. [10] data with the condition of fixed input pressure set by the air compressor to maintain a desire flow rate measure by its flow meter. The input pressure for each flow rate may be obtained from Ye et al. [10] with the condition of zero microwave input power. Then, the lift data may be corrected for the input gas pressure. Ye et al. [10] provide exactly this data. Specifically, the net space drive lift pressure as a function of microwave power and flow rate at a fixed microwave power are given in Ye et al. [10] Figures 5 and 5b, respectively. For exemplary conditions of 400 W microwave power at a plasma gas flow rate of 1.45 m^3/h, the space drive lift pressure in the direction of plasma flow is 1.5 X 10^4 N/m^2 or about 15% of atmospheric pressure and comparable to the area thrust density of a jet engine.

Next, consider the theoretical space drive force possible under the experimental conditions of the Ye et al. [10] as an explanation of the results. At a plasma gas flow rate F_l through a volume V, the resulting transit time T is

$$T = \frac{V}{F_l}$$

At a microwave power of P_w, the maximum increase in directional kinetic energy K of the plasma electrons is

$$K = P_w T$$

According to the kinetic theory of gases, the kinetic energy is related to the pressure P (force/area) per volume V by

$$P = \frac{2}{3}\frac{K}{V} = \frac{2}{3}\frac{P_w T}{V} = \frac{2}{3}\frac{P_w \frac{V}{F_l}}{V} = \frac{2}{3}\frac{P_w}{F_l}$$

For

$$P_w = 400\ W$$

$$F_l = 1.45\ m^3/h = 4.03\ X 10^{-4} m^3/s$$

$$V = \frac{\pi\left(\frac{24\ mm}{2}\right)^2 (600\ mm)}{1 X 10^9 mm^3/m^3} = 2.71 X 10^{-4} m^3$$

The transit time T is

$$T = \frac{V}{F_l} = \frac{2.71\ X\ 10^{-4} m^3}{4.04\ X 10^{-4} m^3/s} = 0.672\ s$$

The increase in directional kinetic energy K is

$$K = P_w T = 400\ W\ X\ 0.672\ s = 269\ J$$

The directional space drive pressure differential P is

$$P = \frac{2P_w}{3F_l} = \frac{2}{3}\frac{400\ W}{4.03\ X\ 10^{-4} m^3/s} = 6.62\ X\ 10^5 N/m^2$$

The lift or thrust force F_z on a piston of cross-sectional area A is

$$F_z = PA$$

For

$$V = \frac{\pi\left(\frac{24\ mm}{2}\right)^2}{1X10^6 mm^2 / m^2} = 4.52X10^{-4} m^2$$

$$F_z = PA = \left(6.62\ X\ 10^5 N/m^2\right)\left(4.52\ X\ 10^{-4} m^2\right) = 300\ N$$

The lift reported by Ye et al. [10] requires only $\frac{11\ N}{300\ N}\ X\ 100 = 3.7\%$ coupling of microwave power to a corresponding increase in directional kinetic energy K of the plasma electrons compared to the maximum of 50% wherein ½ of the energy of each microwave photon absorbed by a free electron is manifest as directional increased electron kinetic energy. Space drive has the potential of being orders of magnitude more powerful and is a closed system that can provide thrust indefinitely with electrical power provided to the drive by a SunCell wherein water can serve as the source of hydrogen fuel. For example, increasing the microwave power from 400 W to 1 MW electric and scaling the geometric parameters in the thrust equations demonstrate that the corresponding omnidirectional, reactionless space drive thrust easily increases to over 1,000,000 lbs. compared to the 40,000 lbs. of axial jet exhaust thrust of the F35. Moreover, the corresponding space drive craft is anticipated to be much smaller and lighter that the 70,000 lb. F35 [14].

Consider a craft that produces a space drive thrust of two times the acceleration of gravity ($g = 9.8\ m/s^2$). The distance X to Mars is $305.18\ billion\ m$. The time t to arrive at Mars for a constant acceleration a of $2g$ and the corresponding final velocity v are

$$t = \sqrt{\frac{2X}{2g}} = \sqrt{\frac{2\left(305\ X\ 10^9 m\right)}{19.6\ m/s^2}} = 1.76\ X\ 10^5 s = 2\ days$$

$$v = 2gt = 19.6\ m/s^2 X\ 1.76\ X\ 10^5 s = 3.5\ X\ 10^6 m/s = 7.7\ X\ 10^6 miles/h$$

compared to 10,000 miles/h and three years for rocketry that at the current state of the art requires a 394 ft tall 11 million lb. rocket and scores of launches for in-space fueling just to reach the moon alone with no fuel infrastructure on Mars to make the trip back.

In further experiments, additional system improvements given by Mills [3-4] may be tested. The space drive may further comprise an addition source of photons such as microwave photon transmitter such as a microwave generator and a horn antenna. The photons made incident the plasma free electron flow are absorbed by the electrons to increase the electron kinetic energy of the electrons in their initial direction of travel as well as that of dragged ions such as long-lived H_3^+ ions of a plasma comprising hydrogen. The absorption efficiency and conversion to directional kinetic energy can be made very high by recirculating unabsorbed photons resulting multi-pass through the plasma using microwave reflectors. To reduce power loss in piston heating by the lift-flow power and to boost the efficiency by energy recovery, the kinetic energy of the plasma may alternatively be transduced into propulsion energy by a magnetohydrodynamic (MHD) converter wherein plasma flow is arrested within a short distance in an MHD channel, and the piston or MHD converter are rigidly attached to a craft to which the lift is imparted. Specifically, for sufficiently high plasma flow velocity and magnetic field, plasma will be electrostatically arrested in the MHD channel, and the plasma flow stops and transfers its kinetic energy and linear momentum to the MHD system [15] as directional lift.

Typically, there is no directional flow in microwave plasmas. The vector acceleration and gained electron kinetic energy caused by absorption of microwave power averages out to zero net flow due to the random motion of the plasma electrons. Only heating occurs which is average kinetic energy. Space drive requires first the creation of a directional electron flow such that microwave absorption increases the directional electron kinetic energy and plasma flow. The gained kinetic energy is relative to the electron's absolute space frame, the rest frame of the creation of the electron at its particle production event. It is not relative/arbitrary which does not conserve the mass-energy inventory of the universe [16]. Since the lift or propulsion force is reactionless, the plasma gas formed by recombination at the piston or MHD converter may be recirculated by a blower in a closed gas system wherein the blower may maintain a constant inlet gas jet to establish plasma flow and lift directionality.

Free electrons can also directionally and reactionlessly absorb laser light. This is the mechanism of laser electron accelerators wherein photons are absorbed by the free electrons of highly ionized plasmas such as hydrogen plasmas of a hydrogen gas jet [17]. The electrons are reactionlessly and directionally accelerated to relativistic energies. The propagation direction of a high-power laser pulse (e.g. 0.5TW) in the gas establishes the vector of directionality of the reactionless electron acceleration. Relativistic protons beams may also be created by ion dragging [18]. Some limitations of a laser reactionless space drive are the high power required, large scale of the laser system, laser power inefficiency, small cross sectional beam size, and cost. Compact gyrotrons of megawatt scale are used to directionally and reactionlessly accelerate fusion plasmas to increase the toroidal plasma flow current. This is a very efficient and large-scale continuous system with a cost of about $1/W microwave power. Components [3-4] to propel trans-medium, omnidirectional craft of megawatt pound-scale lift are commercially available.

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