JBIS, Vol. 65, pp.112-113, 2012

INVITED COMMENTARY BY DOCTOR JAMES BENFORD

1041 Los Arabis Lane, Lafayette, CA 94549 USA.

James Benford is the founder and Director of Microwave Sciences, Inc. He has published many technical papers on fusion and microwaves, particularly pertaining to space propulsion. He is the author of the seminal book "High Power Microwaves". He is the Leader of Project Forward and a designer on Project Icarus.

We Should Develop Beamed Power Sailships

I have been concentrating on beam-powered propulsion, especially in beam-driven sails, for 18 years, because it has such clear advantages. The fundamental attraction of beamed power for space is simple: electromagnetic waves can carry energy and momentum (both linear and angular) over great distances with little loss. For the microwave frequency region total vertical attenuation through the atmosphere is 0.1-1 dB, meaning loss of only 2-20%. Photons also lose a negligible energy when radiated out of a potential well such as Earth's, due to a very small gravitational redshift. Compared to the cost of orbiting chemical fuels, beaming energy from the ground is four orders of magnitude cheaper [1].

I led the team that in 2000 demonstrated first flight of microwave-driven carbon sails using microwave beams to produce several gee accelerations (see Fig. 1). Further experiments demonstrated *beam-riding*, stable flight of a sail propelled by a beam. Beam photon pressure will keep a concave shape sail in tension, and gives a sidewise restoring force. The beam can also carry angular momentum and communicate it to a sail to help control it in flight. This effect can stabilize the sail against the drift and yaw, and this has been shown in our experiments [2].

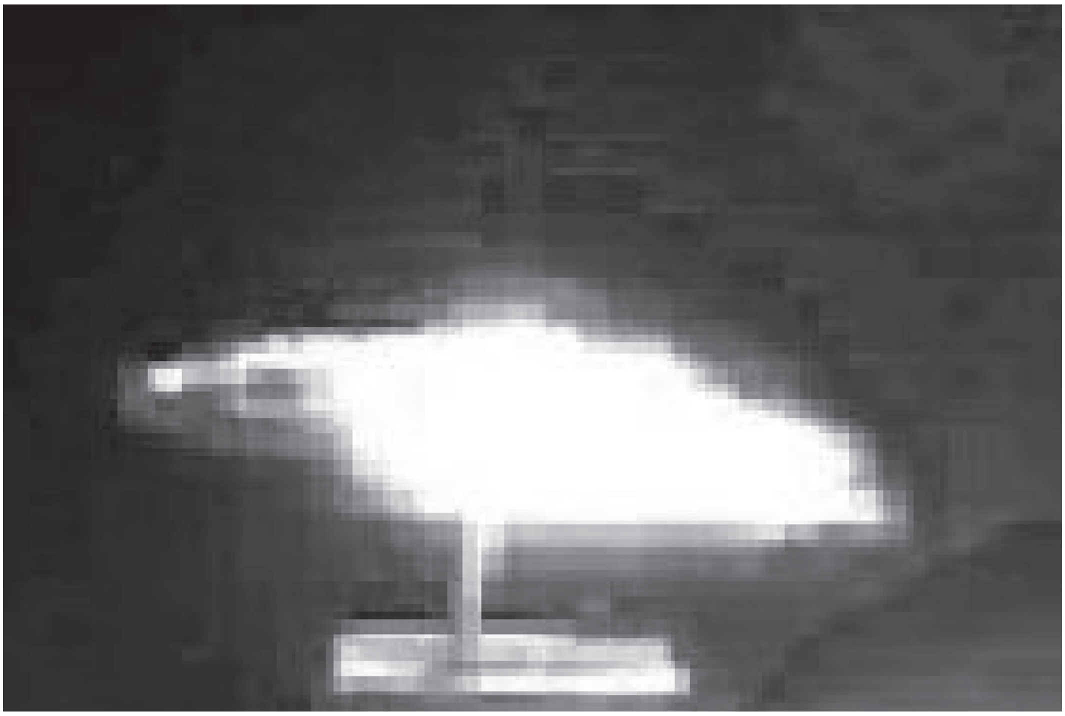

Fig. 1 Carbon sail lifts off end of waveguide at two gravities acceleration, April, 2000 [2].

I've come to feel increasingly that the context of the interstellar propulsion challenge should be seen the same way we've always thought of fusion: first get the physics solved, then the engineering, and finally address the economic feasibility. For beam-driven sails, the physics is done. We have demonstrated flight, beam-riding and beam-induced (& controlled) spin. The engineering requirement is for large assemblies of modular sources of the photons, be they microwave, millimetre wave or laser, and large antenna/optic arrays. We have vast experience in such areas and progress is steady. These are clear advantages. I favour microwave and mileometer waves over lasers for near-term research, because they have ready practical advantages:

- Large microwave apertures are much easier and much cheaper to fabricate than large laser apertures.
- Microwave and millimetre wave sources, waveguide and supporting equipment, such as power supplies, are a developed industry. That means it is cheaper and faster to build systems. In fact, we can use the spare microwave and millimetre wave equipment in labs.
- Microwaves can be produced with higher efficiency than laser beams, leading to lower cost of electrical power and reduced waste heat. Millimetre wave generation technologies now make it possible to generate wavelengths as short as 0.1 cm with relatively high efficiency (~40%).
- Phased arrays of microwave transmitters are relatively easily done, while phased arrays of laser beams, although

possible in principle, are thus far difficult to achieve in practice.

- Microwave sails made of carbon- carbon (C-C) material are lighter than laser-driven sails. And they can be perforated to reduce the weight, resulting in grids. C-C circuits are under development, so a sail could in the future have embedded computational ability and be "smart."

Note the difference between beam-driven sails and the Nuclear Option, as I call it. Nuclear fission we know well enough that physics and engineering are understood well enough, but I have seen no estimated cost of a nuclear thermal rocket. Fission-fusion hybrids are hypothetical until fusion gets out of the physics stage it's in now. Pure fusion, especially the aneutronic reactions that should be more desirable for rockets, is struggling with physics and engineering issues (the First Wall problem, for example). And we know that nuclear is much more expensive to research and develop compared with beam-driven sails. What would a nuclear rocket cost? That's beyond this horizon at present.

So my feeling is that we should put more of our effort into beam-driven sails in this era of little funding. We'll make more progress that way. And the way to do that is beam-driven sail experiments and simulations, combined with the on-going parallel development of solar sails, which will tell us how to deploy and control larger sails. To eventually have a power beaming capability, space infrastructure must exist to build upon. How do we get from where we are now to a future when directed energy can be used for fast missions, including interstellar? By developing other applications of directed energy and solar sails in parallel.

I feel beam-driven propulsion is more firmly grounded, more thought through and quantified than nuclear propulsion methods at present. In today's funding environment, that's not likely to change. We should choose to develop beamed power. To pursue this opportunity, I have established Project Forward, named for Robert Forward, who pioneered this subject, as part of Icarus Interstellar. The goal is to build the technical foundation required for eventual successful interstellar flight by beamed propulsion of a sail, to make credible such an interstellar probe. Project Forward will be a parallel study performed by members of Icarus Interstellar and affiliated organizations. We can quickly move on to laboratory experiments on beam-driven sail propulsion experiments, leading to demonstrations in space itself. Let's get on with it!

References

1. J. Benford, "Space Applications of High Power Microwaves", *IEEE Trans. on Plasma Sci.*, **36,** pp.569-581, 2008.
2. J. Benford, "Flight and Spin of Microwave-driven Sails: First Experiments", *Proc. Pulsed Power Plasma Science 2001*, IEEE 01CH37251, pp.548-552, 2001.

* * *