Laser Power for UAVs

A White Paper
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Summary: Lasers can transmit power to UAVs in flight, giving them potentially unlimited endurance aloft. Silent, refueling-free laser-electric UAVs are practical with current technology and could be developed and deployed quickly.

Background

Unmanned aerial vehicles (UAVs) are seeing increasing use as demand for them explodes[1], but their range and sortie duration are limited by their on-board energy storage (either in the form of batteries or fuel). Landing UAVs to refuel them not only takes them off-station, but requires skilled manpower and adds risk: even more than manned aircraft, UAVs are most likely to crash when taking off or landing.

The longest-endurance fuel-powered UAVs have stayed aloft is only 80 hours.[2] Electrically-powered UAVs have many advantages, including quiet operation and low maintenance requirements, but have much more limited range and endurance, even with the best foreseeable batteries. Even a solar-electric UAV has to date only remained aloft for 82.5 hours.[3] Solar-powered "eternal" UAVs and lighter-than-air (LTA) platforms are bulky, fragile, and expensive, and so far have very limited payloads and operational envelopes.

<u>WHAT IF</u> we could have robust, high-performance UAVs that never needed to land?

System Concept and Technology

A laser power link for UAVs is shown in schematic in Figure 1. The laser transmitter converts power from a primary source (battery, generator, or AC line power) into a monochromatic (single-wavelength) beam of light.

[1] "Defense Secretary Robert Gates has described ground commanders' appetite for UAVs as insatiable." http://www.airforcetimes.com/news/2008/09/airforce_army_uav_092908w/
[2] Boeing Condor. http://en.wikipedia.org/wiki/Boeing_Condor
[3] QinetiQ Zephyr. http://en.wikipedia.org/wiki/Unmanned_aerial_vehicle

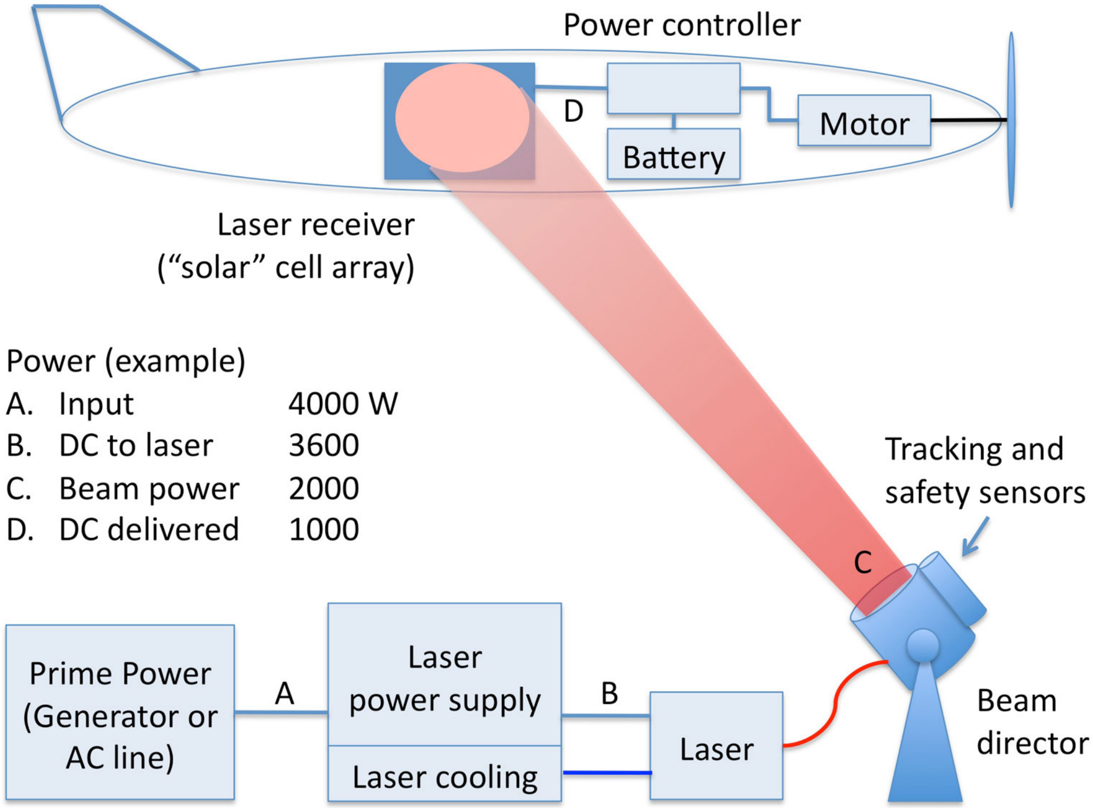

Figure 1. Schematic diagram of power beaming to UAV.

The preferred laser technology for most near-term applications is arrays ("stacks") of near-infrared laser diodes (see Figure 2). Laser diode arrays are efficient (>50% DC power in to light out[4]), compact, and relatively inexpensive, and are now sufficiently robust and reliable (>20,000 hour operating life) for field use. For some low-power or long-range applications, other lasers, notably diode-pumped fiber lasers, can provide a brighter (lower divergence) beam, which permits the transmitter optics to be much smaller, at the expense of higher laser cost and lower efficiency.

A beam director or beam-steering mirror directs the laser beam at the UAV receiver, under control of a pointing and tracking system. A UAV is a cooperative target, so optical tracking is straightforward, but can be supplemented with RF or GPS-based methods for acquisition and tracking through clouds or past obstacles.

[4] The DARPA SHEDS program (Super High Efficiency Diode Sources) has a goal of developing 80% efficient diode arrays; efficiencies over 70% have been demonstrated.

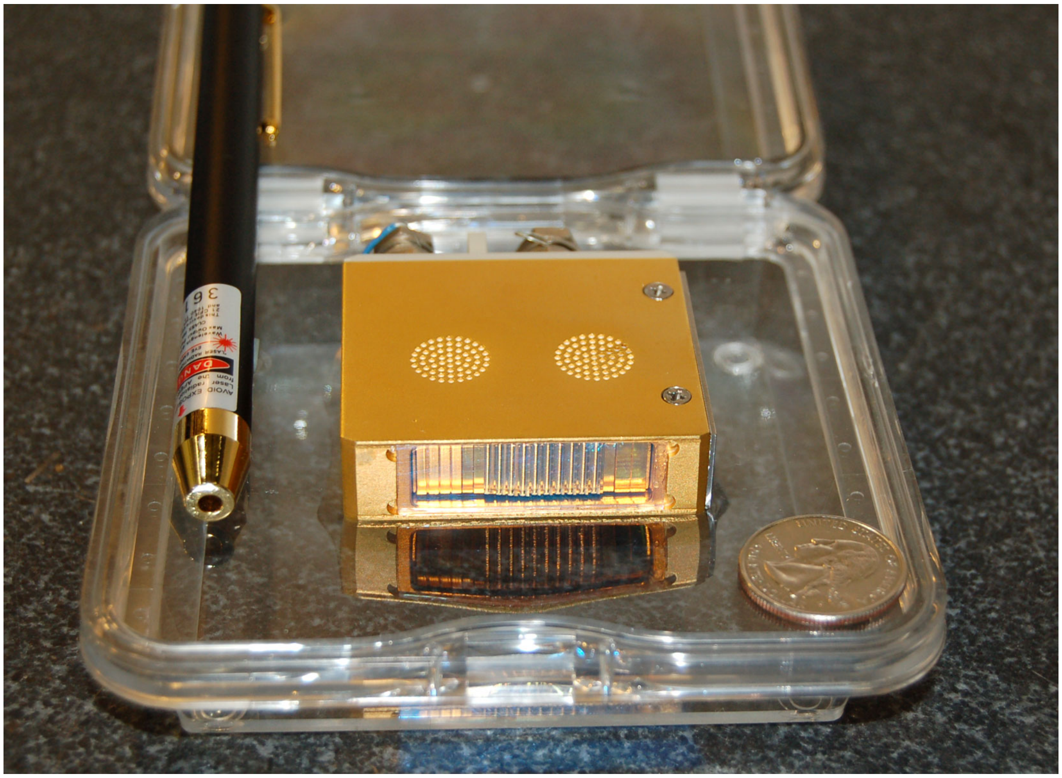

Figure 2. Sample near-infrared 1,000W (1.3 HP) laser diode array, less than 3 inches across.

In the receiver, specialized photovoltaic cells matched to the laser wavelength and beam intensity ("laser cells," by analogy to "solar cells") convert the laser light back to electric power. [5] Because the laser beam can be interrupted by obstacles, including clouds, most applications will require some on-board storage or auxiliary power source; such storage can also support operations out of range of the laser, and can supply power for peak demands from the UAV itself or from its payload.

A safety subsystem ensures that the beam is unobstructed and directed at a proper receiver before high powers are transmitted, and switches off power if anything moves into the beam path.

While not shown in Figure 1, in most systems the laser power link can readily support a parallel optical communications link with high bandwidth in one or both directions, sharing the ground optical aperture and pointing/tracking system.

The actual UAV platform can be of almost any type, including conventional winged aircraft, helicopter-type platforms, or LTA vehicles, subject only to the need for a reasonable downward- or side-facing surface for the laser receiver.[6] Smaller systems could use lightly-modified versions of existing battery-powered UAV designs, with

[5] Other types of receivers are possible, such as laser turbojets which use laser power instead of combustion to heat air and produce thrust, but photovoltaic receivers are the best developed.
[6] With current laser cells, the deliverable power is limited mainly by cell cooling, and can easily exceed 6 kW/m^2, or about 1 HP per square foot.

fractional-HP to ~20 HP (15 kW) motors; in some cases, existing airframes can probably be retrofitted with laser receivers (and smaller batteries). Larger UAV classes, currently fuel-powered, would need more substantial modifications or new designs, but there is no obvious obstacle to supplying up to several hundred kW to a suitable airframe.

Concept of Operation

Laser power links enable two types of operation. One is near-continual powering of the UAV, which would therefore need only a very small energy storage device on-board. The other is intermittent recharging when the UAV returns to a designated area within reach of the base station; in this case the UAV would need larger on-board energy storage. In both cases, the laser power link improves on-station time and reduces personnel requirements during UAV mission cycles.

We envision three general applications for laser-powered UAVs feasible with current technology:

1. A stationary observing platform for long-duration ISR (Intelligence, Surveillance, and Reconnaissance). The UAV can be a quadricopter, airplane, or aerostat.
2. Extended or multi-mission operations. An electric UAV is launched and flies to a target beyond laser range where it can loiter for some time. Once the on-board energy storage goes below a predetermined level, the UAV flies to a location within line of sight of a recharging laser and recharges in the air.
3. Unlimited patrol. Missions that can be conducted within line-of-sight (~10 miles for an altitude of 1 mile) of a laser station (which may itself be moving) can be continuously powered, enabling a UAV to patrol or shadow a target indefinitely.

Case 1: Stationary Observing Platform

Situational awareness can be vastly improved through elevated observing platforms, and UAVs are well-suited to providing high-altitude surveillance. Downtime due to the need for refueling reduces coverage and adds logistical loads to personnel. Power beaming to electric UAVs would enable 'eternal' UAVs which could operate 24/7, providing continuous surveillance without the risks and personnel requirements of repetitive take-offs, landings, and refuelings.

The UAVs could operate at any practical altitude, from 1,000' (or lower) to over 70,000' under constant laser power. Military bases would find micro-UAVs, such as quadricopters, of use for base patrol, or more traditional airplane UAVs for higher-altitude area observations. Naval vessels would deploy an airplane UAV or perhaps an aerostat or similar lighter-than-air (LTA) ship for extreme long-distance observations and communications. See Figure 3 for a schematic diagram of these possibilities.

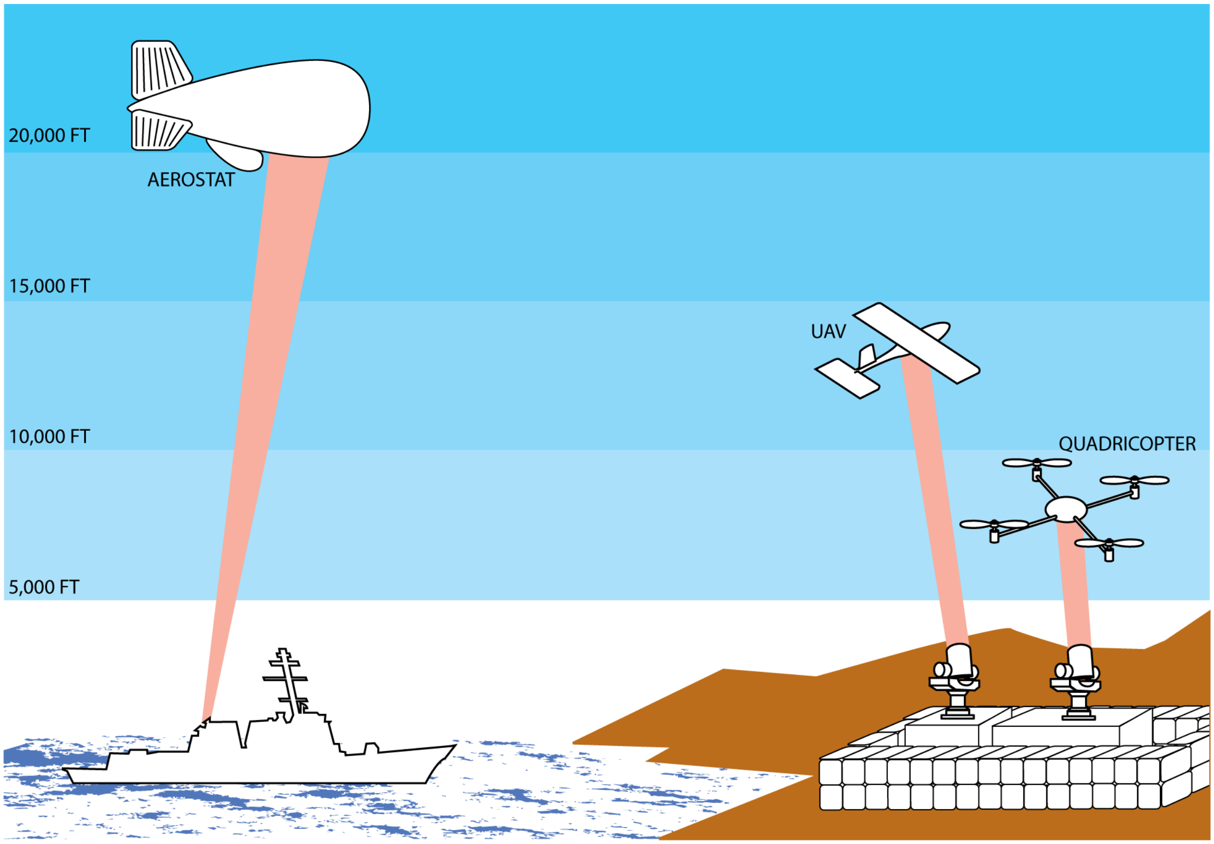

Figure 3. Stationary observing platforms.

A permanently-stationed, high-altitude UAV would behave, in many ways, like a low-cost high-performance geostationary satellite, except that it would be located only a few miles above ground. Such an eternal UAV would be able to provide surveillance and communications across a region continuously.

Case 2: Extended / Multi-Mission Operations

Beam-powered UAVs can also operate far away from the beaming station through use of on-board energy storage (e.g., batteries). UAVs can remain airborne indefinitely by regularly returning to the area near a beaming station to recharge its batteries. In the example shown in Figure 4. Extended/multi-mission ops., a mobile beaming station serves as the "refueling" point for an observation UAV which loiters over the beaming station until its on-board storage is full, then it flies to its target (which could be 100 miles or more away). It loiters over the target, sending back imagery and sensor data, until its power level is low enough that it needs to return to the beaming station to recharge.

The beaming station does not have to be at the same location that the UAV is launched from, and in fact there can be many beaming stations strategically located along a path of interest for the UAV, to vastly extend its range and/or to enable it to alternate between targets.

There does not need to be a one-to-one ratio between beaming stations and UAVs. One beaming station support multiple UAVs which rotate in and out of recharging mode. A network of beaming stations can support a large number of UAVs with flexible flight paths.

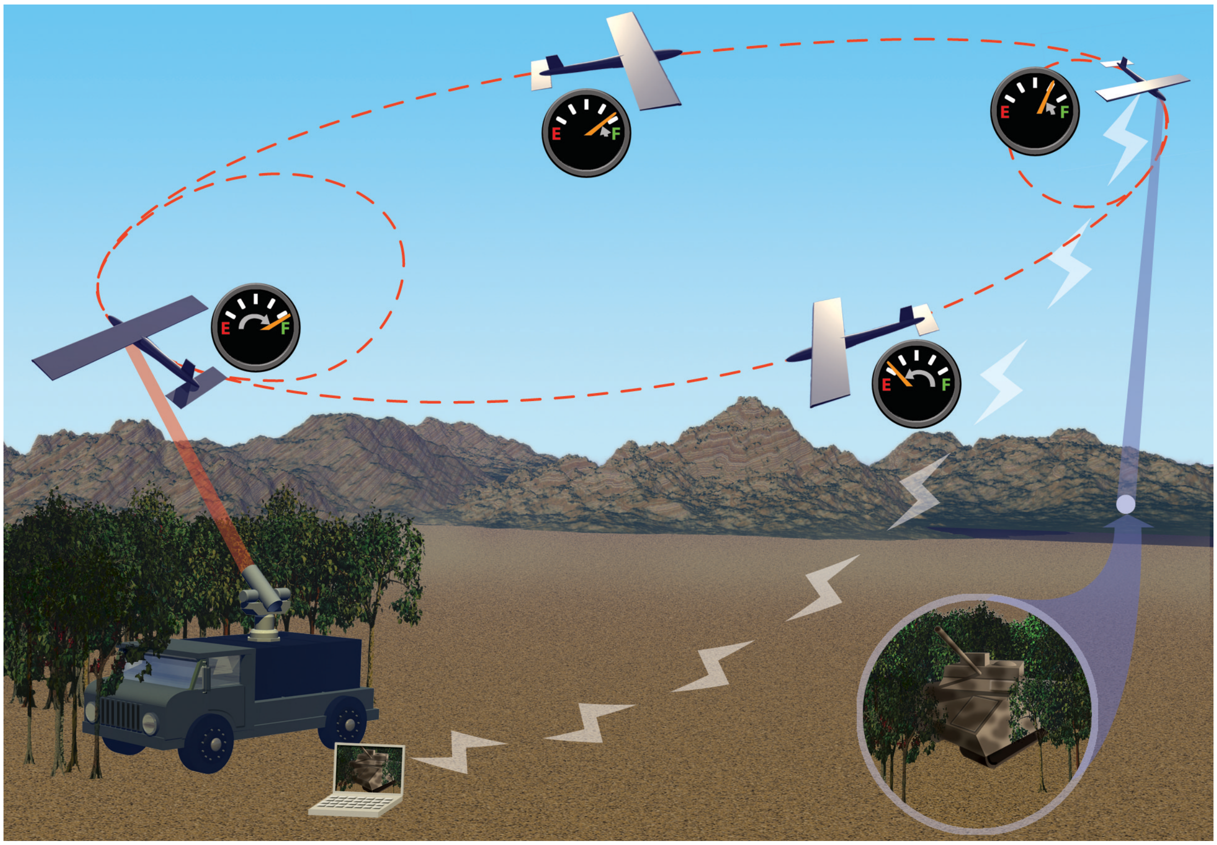

Figure 4. Extended/multi-mission ops.

Another example of recharging for extended missions is relatively small UAVs flying within a few kilometers of a base, e.g., for perimeter patrol. Many UAVs could be rotated between recharging near a beaming station and out to near-base missions.

Because in-flight recharging can be done at relatively short range, optics requirements are modest, and the impact of clouds and other beam obstacles is reduced. However, both transmitter and receiver must handle much more than the mission-average power.

Case 3: Unlimited Patrol

A UAV can be continuously powered at long horizontal ranges, assuming it remains within line of sight of a beaming station. For a ground-based transmitter, a UAV would typically need to stay a few degrees above the horizon (Figure 5). The beaming station could be mobile, which would allow the UAV to operate miles ahead of the path of a fleet of vehicles, providing advance surveillance and other functions for the mobile group.

For even longer ranges, as well as operation past hills or other obstacles, either the transmitter itself, or a relay mirror, could be mounted on an airborne platform – an airplane, aerostat, or UAV.

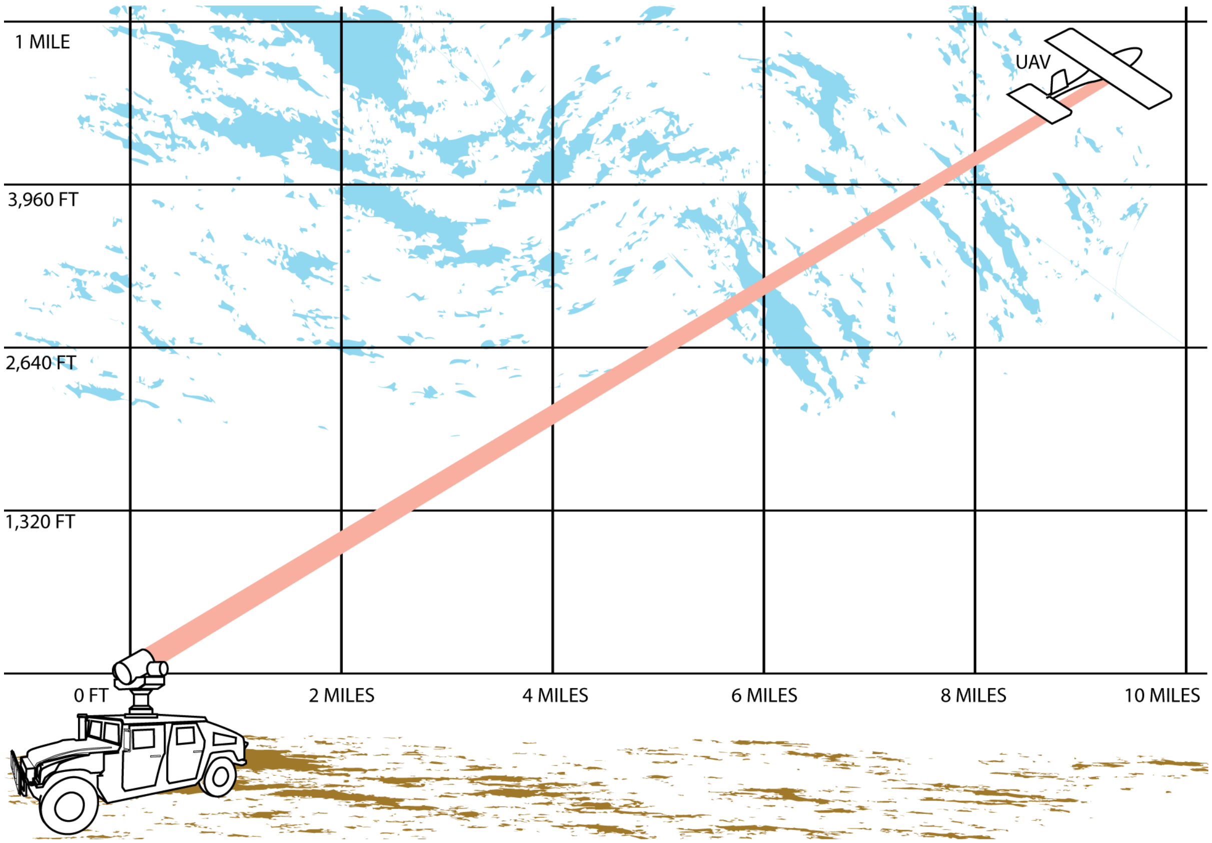

Figure 5. Long-duration ISR.

Technology Readiness

LaserMotive, using internal funds, has built and operated a complete transportable power beaming system which delivered several hundred watts to a moving vehicle over a range of 1 km, and in excess of 1,000 watts at slightly shorter range. The system was operated repeatedly at NASA Dryden Flight Research Center (Edwards AFB) in November 2009, winning the 2009 NASA Centennial Challenge for Beamed Power. [7]

With this demonstration, laser power beaming has reached Technology Readiness Level (TRL) 5. Comparatively minor upgrades in packaging and integration, using LaserMotive's existing technology, would allow power beaming to be classed as TRL 6.

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[7] See http://www.nasa.gov/home/hqnews/2009/nov/HQ_09-261_power_beam.html for details, and http://www.nasa.gov/offices/ipp/innovation_incubator/centennial_challenges/index.html and http://www.spaceward.org for general information on the competition.

As part of its own development efforts, LaserMotive is planning at least a small-scale demonstration of laser power beaming to an electric UAV by the end of 2010; the actual scale and degree of integration demonstrated will be dependent on available funding.

Programmatic Recommendations

Evaluation

Designing a beam-power system for a specific near-term application requires system analysis and design to understand actual requirements and implications for power delivered, safety, reliability, etc. and to estimate the size, weight, power requirements, and efficiency of fieldable links.

Initial analysis and conceptual design for one or two selected vehicles and missions can be completed by LaserMotive in 3-6 months, with a small ($100K) effort.

Component and Subsystem Development

The primary area for component R&D is photovoltaic cells. The vast bulk of PV cell development has been aimed at improving efficiency and/or lowering costs for solar cells, which must convert broad-spectrum light from a thermal source. Efforts to optimize "laser" cells suitable for power beaming have been limited. At least a basic review of PV technology is urgently needed, ideally leading to a "laser cell" development effort similar to the recent DARPA SHEDS program which succeeded in radically improving the efficiency of high-power semiconductor diode lasers.

The primary area for subsystem development is safety. Extremely reliable safety systems will clearly be needed if kilowatt- and higher-power laser beams are to be used routinely for power beaming. Operational and regulatory issues will also have to be addressed, a process which should begin in earnest as soon as possible.

System Development and Demonstrations

If laser power beaming is to contribute to near-term operations, or to be incorporated in next-generation UAV system development, a demonstration of one or more laser power links in a relevant environment should be pursued at the earliest opportunity. Of course, such a demonstration can be tailored to a specific near-term mission or requirement set if such exists. In the absence of a pre-existing need, however, the following suggestions illustrate interesting systems which we believe could be demonstrated in prototype form in ~18–24 months, using existing technology:

- Small- or Micro-UAV recharging with multiple UAVs, maintaining one or more vehicles "on station" while others are in transit or recharging
- High-altitude (near-vertical) loitering: power > 10 kWe, at a range of >5 km (10,000 ft).
- Long-range, low-angle beaming: > 10 kWe, horizontal range > 5 km, vertical range > 1.5 km.

Conclusions

Laser power beaming has the potential to expand the capabilities of UAVs enormously, in both civilian and military applications. Power beaming at kilowatt power levels and kilometer range has been demonstrated in the field. The next steps include adding subsystems, such as safety and fully-automated tracking, needed for actual use, and integrating power beaming with real UAV systems. Operational and regulatory issues for high-power lasers need to be addressed.

LaserMotive is eager to take the next steps, and we look forward to working with manufacturers and users of UAVs.

About the Authors

Dr. Jordin Kare is a leading physicist, aerospace engineer and one of the industry's top experts on laser propulsion and laser power beaming. Dr. Kare has been involved in the development of laser and space technology for more than 20 years. As a physicist in Lawrence Livermore National Laboratory's Special Projects group, he was the project leader for Mockingbird, a conceptual design for an extremely small reusable launch vehicle, and mission planner and science team liaison for the Clementine lunar mapping mission. Prior to co-founding LaserMotive, Dr. Kare spent 10 years as an independent consultant to the aerospace industry and government agencies, developing and analyzing new concepts for remote sensing, space systems, and energy technology; during this time he twice received grants from the NASA Institute for Advanced Concepts. Dr. Kare holds dual undergraduate degrees, in Electrical Engineering and Physics, from MIT, and a Ph.D. in Astrophysics from the University of California, Berkeley.

Before assuming the presidency of LaserMotive, Thomas Nugent was a project scientist at Intellectual Ventures Labs, a multidisciplinary early-stage R&D laboratory in Bellevue, WA. Mr. Nugent has also served as Research Director for LiftPort Inc., a pioneer in the development of the modern space elevator concept. While at LiftPort, he led the research team that outlined a realistic path to space elevator development, as well as working on a variety of milestone tests of robotic lifters. He has been involved in liquid-fueled rocket engine development and testing through the MIT Rocket Team, and advanced fusion propulsion research at the Jet Propulsion Laboratory. Mr. Nugent holds a B.S. in Physics from University of Illinois at Urbana-Champaign, and M.S. in Materials Science and Engineering from MIT.

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