# Plasmadynamics and lasers

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The numerous research and technology efforts under way in the U.S., in both civilian and military programs, reflect continuing high interest in the potential aerospace applications of plasmadynamics and lasers.

## Plasmadynamics

The announcement of NASA's new space exploration vision early last year has reinvigorated efforts to develop high-power plasma thrusters for anticipated deep space transportation needs. A notable example is the VASIMR (Variable Specific Impulse Magnetoplasma Rocket) engine research team, which continues to make rapid progress in key technical areas.

For example, a recent threefold increase in the power of the helicon plasma source (to 10 kW) has yielded important physics results supporting high-power scaling of the concept. The higher helicon power levels increased ionization efficiency and yielded denser plasma with complete propellant burn-up. In turn, the higher plasma density increased the antenna loading and hence the efficiency of the second-stage RF booster.

Recent deuterium experiments reaffirmed a strong single-pass ion acceleration effect as predicted by theory and experimentally demonstrated with helium in 2003. Average measured ion exhaust velocities routinely exceed 100 km/sec, and the current focus on high-power physics scaling aims to achieve 30-kW steady-state operation early this year. Experiments using a new translatable force sensor developed by NASA Marshall clearly show the importance of the RF booster in achieving good system performance and indicate that 1/10 of the total power vectored to the booster contributes to a threefold increase in the total force of the jet. This scaling effect is being examined at higher booster power.

The important issue of plasma detachment from the magnetic nozzle is also being investigated. A magnetohydrodynamic (MHD) theory developed by the University of Texas at Austin predicts a well-behaved transition from sub-Alfvenic to super-Alfvenic flow inside a paraxial nozzle with efficient plasma detachment for VASIMR-relevant parameters.

Other major technology issues include thermal management and high-temperature superconducting magnet development. These are being addressed through three competitive Small Business Innovative Research contracts to develop advanced bismuth-strontium-calcium-copper oxide superconducting magnets as well as to demonstrate cryocooler technologies suitable for this application.

As an alternative approach, researchers at NASA Marshall are investigating a pulsed plasma accelerator that may lead to an efficient plasmoid thruster. The Plasmoid Thruster Experiment utilizes a gas-fed conical theta pinch coil ringing at 500 kHz to produce as many as six spheromaks during a single high-voltage discharge event, and high-speed imaging has shown that the resulting spheromaks exit the pinch coil with velocities exceeding 30 km/sec. Current research focuses on performance and efficiency optimization studies and the development of highly reliable solid-state components suitable for operation at multikilowatt average power levels.

MHD hypersonic flow manipulation has been further explored this year with some notable accomplishments. For example, LyTec, in collaboration with the Institute of High Temperatures of the Russian Academy of Sciences, continued an experimental program jointly sponsored by DOD and NASA in which small-scale models of basic geometric shapes were tested in an MHD accelerator-driven hypersonic wind tunnel. This work is directed at determining the viability of MHD interaction techniques for influencing flow distributions around aerodynamic bodies and reducing drag and leading-edge heat loads.

The most significant outcome of these experiments was the first definitive demonstration of shock structure control in a hypersonic inlet using MHD interaction. In related work, researchers at the Air Force Research Laboratory have continued exploratory studies on various aspects of magnetogasdynamics-assisted scramjet operation.

An event underscoring the practical importance of understanding solar behavior was the sudden and unexpected series of solar eruptions during late October. These solar flares ranged from M-class to X-class in intensity and generated intense geomagnetic storms that risked damage to space facilities, communication networks, and power grids on a worldwide scale.

Recently, scientists at the University of Alabama in Huntsville have developed solar simulation tools that yield deep insight into the physical processes associated with the initiation of coronal mass ejections and show tremendous potential as a science-based predictive tool for space weather forecasting.

## Lasers

Development of electrically powered laser technology has accelerated this year, particularly in the area of high-power fiber laser technology. Electrically powered lasers offer many advantages relevant to the aerospace community, not the least of which involves logistics. The gas and chemical lasers that have traditionally dominated high-power application require the delivery, handling, and disposal of fuels that are often hazardous. Electric lasers, on the other hand, can use existing power supply systems on board a platform, minimizing the logistical trail to the fuel for the power generation system.

This facilitates electric laser use in remote sensing, industrial cutting and welding, communications, planetary science missions, and military weapons systems, all key applications in aerospace technology.

The advances in high-power fiber laser technology have been the most remarkable. Since the early 1990s, diffraction-limited high-power fiber lasers have increased in power from only a few watts to 300 W in 2003 to 1 kW this year. Given this rapid increase, single-mode, diffraction-limited fiber lasers with powers in the range of several kilowatts could reasonably be expected in the near future. Combined with efficient phasing techniques, bundled arrays of fiber lasers could potentially reach much higher powers and offer competitive solutions to other laser systems in high-power applications.

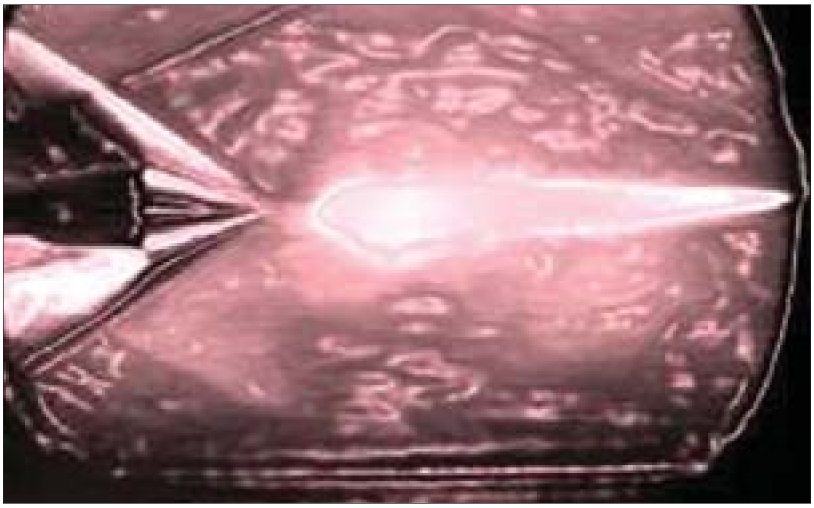
Oxygen-iodine laser technology saw the first success in efforts to convert this laser from the chemical reactions that have traditionally powered it to electric discharge powering. Researchers at the University of Illinois Urbana-Champaign and CU Aerospace demonstrated the first measurement of laser gain in the electric discharge-powered oxygen-iodine laser.

The goal of this and the various other electric oxygen-iodine laser development efforts is to alleviate logistical dependence on potentially hazardous fuels, a factor that hampers chemically powered lasers, and further enable the application of oxygen-iodine laser technology in logistically constrained applications. However, advances in chemical oxygen-iodine laser technology continue. Research teams continue to improve chemical efficiency and performance with an eye toward weapons application and minimized logistics. Theoretical examinations of these devices using computational fluid dynamics and more basic one-dimensional theory are closely coupled to these experimental programs.

Aerooptics-related research and testing have increased recently, as laser directed-energy weapons and free-space communication have advanced toward field testing and application. Projects include direct measurements of time-resolved aerooptic distortions in both low-speed and transonic flows, further research on closed-loop control corrective optics, reduced order modeling of the aerooptic distortions, high-fidelity LES simulations of the aerooptic phenomena, and the development of high-frequency wavefront sensors for aerooptic measurements.

This year such projects examined the role of secondary gas injection and active flow control as a means of mitigating some of the deleterious effects of turbulent airflows that occur naturally over the exit pupils of beam directors on airborne platforms. Aerooptics research and testing is expected to remain an important research area in the coming years.

In the area of laser application, the use of laser energy deposition in the air ahead of a supersonic vehicle to reduce drag is being investigated. High-intensity laser pulses are used to heat the gas ahead of the bow shock wave, creating an area of low-density air. The energy deposition can be enhanced by propagating electric discharges into the ionized air in the heated region. The consequent heating and expansion pushes the air out from a region ahead of the bow shock wave. The vehicle then travels through the low-density region, experiencing greatly reduced air resistance. Experimental and theoretical efforts are focused on examining the underlying physics of this process to characterize the potential for real-world application.



*A laser-induced blast wave was induced near a test article in supersonic flow.*

Researchers from NASA Marshall and Dryden and the University of Alabama demonstrated the first flight of a laser-powered aircraft. The aircraft converts coherent photons from a ground-based laser to electric current through solar cells on the underside of the aircraft; these cells in turn power the engine. The potential applications of this newly developed technology are widespread.