Plasmadynamics and lasers

Interest in potential aerospace applications for plasmadynamics and laser technologies remains high, as reflected in the numerous research and technology efforts under way both in the U.S. and abroad.

**Nonequilibrium plasmas**

Utilization of nonequilibrium plasmas for low-temperature ignition and flame-holding in high-speed flows has been demonstrated in several laboratories using a variety of gas discharge mechanisms. This approach is of special interest for high-speed air-breathing propulsion, because a nonthermal mechanism of active radical production offers a possible means of inducing ignition using low levels of electrical power while also stabilizing and holding the flame without the use of physical obstacles.

Ohio State University’s Nonequilibrium Thermodynamics Laboratories, for example, used a diffuse low-temperature radio frequency (RF) discharge to ignite and stabilize premixed methane-air, ethylene-air, and CO-air subsonic flows at static pressures of 0.1-0.2 atm. In these cases, large-volume ignition was achieved at temperatures as low as 250-300 C, whereas the autoignition temperature at these pressures is in the range of 700-800 C. This result strongly suggests the influence of a nonthermal ignition mechanism, with participation of active radical species generated in the plasma. Further support for this conclusion may be derived from the observation that localized ignition methods, such as spark discharge and a high-temperature arc discharge, failed to produce ignition and flame-holding under identical conditions.

Motivated by these promising results, the group has initiated further studies to explore the phenomena at higher flow speeds and pressures. To improve efficiency, the team is using a high-voltage (25-30 kV), short pulse duration (10-15 nsec full width at half maximum), high rep rate (100 kHz) pulsed plasma generator.

Several scientific laboratories in Russia have obtained similar results using techniques such as subcritical microwave discharges, pulsed streamer discharges, and fast ionization waves, primarily through pioneering efforts at the Institute of High Temperatures, the Moscow Radio Technical Institute, and the Moscow Institute of Physics and Technology.

This year the Ohio State group revealed a new method for controlling UV/visible radiation in nonequilibrium plasmas, which occur in high-altitude rocket plumes. Experiments in their laboratory demonstrated that the emission intensity of CO-laser-pumped, low-temperature (300-700 K) plasmas can be dramatically reduced through the removal of free electrons. The electrons were removed from the plasma by applying a weak electric field to a pair of electrodes near the discharge region. This resulted in a nearly complete extinguishing of the UV/visible glow at very low ionization fractions. Further experiments are seeking to elucidate the kinetic mechanism responsible for this unexpected behavior and to explore the feasibility of various applications.

**MHD**

Interest in crossed-field magnetohydrodynamics (MHD) accelerators for propulsion applications has been gradually reemerging. NASA-Ames attained a very important milestone this year with the demonstration of an experimental MHD accelerator in its electric arc shock tube facility. Only a few experiments have been conducted using this particular gas acceleration technique, and the recent ARC experiments have significantly enlarged the existing technical knowledge base. In these initial tests, the ARC device, which was operated in a segmented Faraday mode with a mean applied magnet field of 0.92 tesla, demonstrated a maximum velocity increase of ~40%. If the magnetic field can be upgraded to 3 tesla, the device is expected to achieve a velocity increase of ~120%. At present, the ARC device is the only operational MHD accelerator in the U.S. and presents a unique opportunity for further technological development.

The use of MHD for aerodynamic flow control applications is also of much contemporary interest, and researchers at Princeton have attained a critical milestone with the first lab demonstration of MHD power extraction from an externally ionized, cold, supersonic air flow. Their device uses high-voltage, high repetition rate, nanosecond-duration pulses to produce a nonequilibrium ionization condition in a channel having a 5-tesla applied magnetic field. This approach achieved sufficient ionization and electrical conductivity to allow extraction of power from the cold, high-speed air stream.

LyTec LLC, in collaboration with the Institute of High Temperatures, has continued exploratory experiments on MHD interaction for hypersonic flow control. This work is directed at exploring the potential of MHD interaction to influence flow distributions around aerodynamic bodies and to reduce drag and leading-edge heat loads. Multiple experiments have been performed on small-scale models of basic geo-
metric shapes at hypervelocity flow conditions, and the results clearly show potential for redistributing the flow and shock structure to control airflow into hypersonic engine inlets. Follow-on work will pursue larger scale demonstrations of these effects.

**Lasers**

The past 12 months have seen significant advances in high-power weapons-class lasers. The Missile Defense Agency/USAF Airborne Laser (ABL) program is rapidly approaching first light of the six-module chemical oxygen-iodine laser (COIL) at the heart of the weapon. Preparations are under way at the System Integration Laboratory, a moth-balled 747-200 converted into a ground test platform, for first light testing of the megawatt-class COIL flight hardware.

Other key pieces of the ABL weapon system have passed significant technical milestones that facilitate demonstration of the system. Laser Power completed application of a very low absorption optical coating to the primary beam director mirror, the first coating at the 1.315-µm wavelength on a mirror larger than 1.5 m in diameter. Raytheon completed testing of the track illuminator laser, a configuration of several solid-state Yb:YAG lasers used for target tracking. In addition, the air-to-air refueling of the YAL-1A, a converted Boeing 747-400 freighter, was successfully demonstrated.

The Mobile Theater High-Energy Laser (MTHEL) program, a joint effort by the Army, the Israeli Ministry of Defense, and Northrop Grumman Space Technologies, provided a stunning demonstration of the potential capabilities of tactical high-power lasers as battlefield weapons. At the White Sands Missile Range, the Army MTHEL Testbed (formerly known as the THEL Advanced Concept Technology Demonstration) successfully destroyed five artillery projectiles in flight. The MTHEL Testbed had previously succeeded in destroying 28 Katyusha rockets in midflight, both in salvos of multiple launches and in single launches.

The Air Force Research Laboratory (AFRL) Directed-Energy Directorate awarded separate contracts to Northrop Grumman Space Technologies and Raytheon to develop high-power solid-state laser technology. The 25-kW solid-state laser demonstration program is representative of an increasing trend in the development of high-power laser technology, shifting away from chemical lasers and toward electrically powered lasers. An explicit goal of this program is to achieve adequate power levels for effective weapon systems while avoiding the logistical difficulties associated with chemical lasers. The Army Space and Missile Defense Command is pursuing a similar technical path for next-generation MTHEL. A test device recently demonstrated 11-kW operation, with 20-kW operation scheduled for 2005.

Chemical laser technology, while being challenged by solid-state lasers in moderate power applications, continues to be advanced with an eye toward addressing logistical concerns. The Dept. of Physics at Ben-Gurion University of the Negev, for example, attained a record 33% chemical efficiency in a COIL using nitrogen diluent. Previously, chemical efficiencies this high had only been attained with the use of helium diluents. High-efficiency COIL operation using nitrogen diluent opens a new pathway for substantially reducing operational costs.

Researchers at the German Aerospace Center set a new record for laser power through silica fiber. In their experiments, silica fiber was used to transmit 11-kW continuous-wave power output from a COIL to a laser cutting experiment, paving the way for consideration of COIL-based industrial lasers. Also, the AFRL Directed-Energy Directorate significantly increased the power level of the all-gas-phase iodine laser (AGIL) to 33-W continuous-wave power, a substantial increase from the hundredths of a watt measured during the original lasing demonstration. AGIL holds promise as a future alternative to COIL on the ABL platform and HF/DF in the space-based laser because of its lower weight and short wavelength.

Experiments at the Ohio State University Nonequilibrium Thermodynamics Laboratory demonstrate ignition and stabilization of a fuel-air flame using a diffuse low-temperature RF discharge (top) and a new method for controlling UV-visible radiation from nonequilibrium plasmas.