Nuclear and future flight propulsion

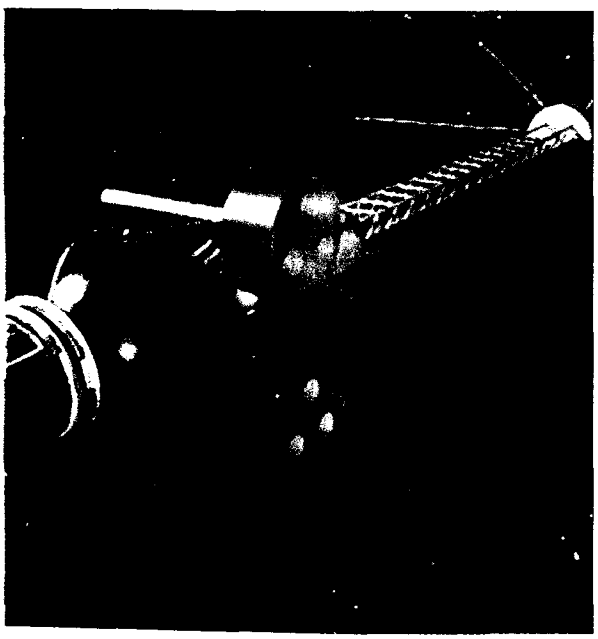
NASA-Glenn continued research on use of atomic species as high-energy-density propellants, which could increase the specific impulse of hydrogen/oxygen rockets by 50-150%. Experiments characterized the efficiency of solid hydrogen particle formation in liquid helium. These data will support design of processes for trapping atomic hydrogen, boron, or carbon within solid hydrogen. ORBITEC developed a propellant based on gelled ultrafine aluminum powder and LH_2 fuel. This could increase the performance, density impulse, and combustion efficiency of rockets and combined-cycle engines using LH_2/LOX propellants.

Nuclear fission propulsion

NASA-Marshall and Los Alamos National Lab continued development of reactors for near-term nuclear electric propulsion (NEP) applications. A simulated 30-kW thermal core was tested using high-performance electric heaters, and was integrated with a Stirling cycle engine and ion thruster for an end-to-end demonstration of NEP. Focusing on refractory metal cores for flight applications in the 300-400-kW thermal power range, Marshall is testing a stainless steel 100-kW thermal core that is geometrically identical to a flight unit. Marshall is also investigating special resistance heaters for full-power tests of refractory flight units.

The University of Florida's Innovative Nuclear Space Power and Propulsion Institute (INSPPI) and NASA-Marshall are evaluating multimegawatt NEP systems based on vapor core reactors and magnetohydrodynamic power conversion. Recent experiments have demonstrated materials compatibility with the high-temperature UF4-KF working fluid. Results show that such systems could supply over 50 MW at power system specific masses lower than 0.5 kg/kW.

Nuclear electric propulsion spacecraft for near-term outer planetary missions use nuclear-powered ion engines.



INSPPI investigated uranium tricarbide fuels for compact nuclear thermal propulsion (NTP) systems. Experiments with (U, Zr, Nb)C tricarbide solid solutions have proven the feasibility of low-porosity fuel elements with high melting points, high power densities, and superior corrosion resistance to hydrogen. Recent efforts have focused on fabrication techniques and processing of tantalum, hafnium, and tungsten uranium-zirconium ternary carbide fuels. Square-lattice honeycomb fuel elements assembled from simple wafers of tricarbide fuel promise substantial thrust-to-weight and specific impulse improvements over conventional NTP.

The Italian space agency supported research on a high-performance NTP concept conceived by Carlo Rubbia. Reactor flow passages lined with 1-μm-thick layers of fissile fuel deposit energy into the propellant directly via fission fragments. Radial injection of propellant along each passage maintains the liner at low temperatures while allowing bulk propellant temperatures much greater than conventional NTP. Analysis of hydrogen with a 3D coupled Navier-Stokes/Montecarlo code have indicated specific impulse and thrust ranging from 2,000 sec to 4,000 sec and 10^3-10^4 N, respectively. Experiments have shown the coating to be chemically stable at about 1,000 C for durations exceeding those of fast human Mars missions.

ESA recently patented a nuclear concept that applies thermal and electric propulsion modes to the same exhaust stream. The bimodal reactor heats propellant to the core's temperature limits. A thermodynamic loop extracts additional heat and produces electrical energy, which is applied to the exhaust via inductive acceleration or heating.

High-energy plasma propulsion

NASA-Glenn evaluated new magnetoplasmadynamic thrusters using a high-power capacitor bank capable of delivering a 2-millisec pulse at over 30 MW. With TRW and NASA-Marshall, Glenn is developing the pulsed inductive thruster, an electrodeless concept that promises high efficiency over a wide range of specific impulse and less material erosion than conventional thrusters. Computational analyses of plasma formation and acceleration mechanisms are under way. Other research includes assessing plasma detachment from magnetic nozzles, and helicon wave plasma generation.

Lawrence Livermore National Laboratory (LLNL) and the University of Michigan continued work on laser accelerated plasma propulsion systems (LAPPS), in which lasers with ultrashort pulse lengths accelerate charged particles to relativistic energies. Experiments have produced proton beams containing 10^{11} particles at mean energies of 10-15 MeV, while those at LLNL have produced beams containing five times as many protons at an energy of about 60 MeV. LAPPS could feasibly produce specific impulse of 10 million sec at very modest thrust.

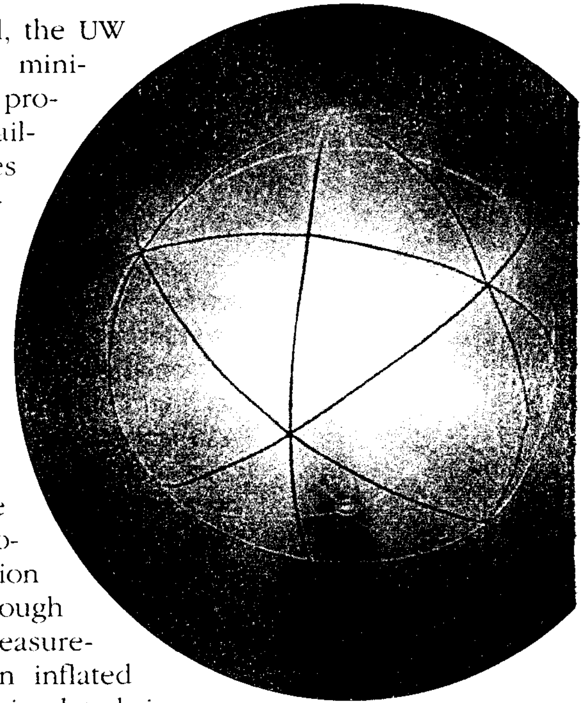
The University of Washington (UW) pursued development of the inductive magnetized plasma accelerator (IMPAC), in which conically shaped coils form and accelerate a self-confined plasmoid to high velocity. Preliminary single-pulse tests of the IMPAC source have produced 5,300-sec I_{sp} at overall electrical efficiency of 50%. Both specific impulse and efficiency are predicted to increase, to 14,400 sec and 90%, respectively, with a new accelerator coil.

Experiments by NASA-Marshall evaluated magnetized target fusion propulsion, which combines aspects of inertial and magnetic confinement to achieve efficient plasma heating and ignition with a relatively lightweight system. Using a derivative pulsed plasma thruster, experiments successfully demonstrated launch of 0.2-mg toroidal plasmas to velocities up to 108 km/sec.

With the University of Illinois and NPL Associates, NASA-Marshall continued research on inertial electrostatic confinement fusion using a recently completed 2-ft-diam reaction chamber. Precise measurements of density and neutron production in a deuterium plasma confirmed fusion rates of 10^5 reactions per second. Future tests will increase power levels and attempt to achieve energy gains of 10^3.

The University of Alabama in Huntsville has developed an ablative laser propulsion method that uses intense, nanosecond-scale (less than or equal to 10^{-10} sec) pulses to ablate a solid propellant and produce thrust. This method leads to more efficient energy coupling than other schemes based on microsecond-scale pulses and heating of a gaseous propellant. Results from direct force measurements of graphite and aluminum suggest 2×10^4-sec I_{sp}, with energy coupling coefficients ranging from 50 N/MW to 100 N/MW. Time-of-flight data indicate ion velocities of 200 km/sec and roughly 10^4-sec I_{sp}.

With NASA-Marshall, the UW continued work on its mini-magnetospheric plasma propulsion concept. This sail-type approach involves inflation of a magnetically confined plasma bubble that achieves thrust through interaction with flowing charged particles in the solar wind. Experiments by Southwest Research Institute on a laboratory prototype have demonstrated efficient production of plasma, inflation of the magnetic field through optical and in-situ measurements, deflection of an inflated magnetosphere by a simulated ion wind source, and stability of the artificial magnetosphere for several seconds.



Steady-state fusion plasma takes place within an inertial electrostatic confinement reaction chamber.

Advanced concepts and architectures

Plus Ultra Technologies is studying missions involving use of its innovative MITEE (miniature reactor engine) nuclear thermal rocket concept. One is for a five-year Europa sample/return mission with a small nuclear-heated submarine probe that would melt through the ice and explore a possible subsurface ocean. Another is for a nuclear-powered ramjet flyer that would operate in the upper Jovian atmosphere and perform extended measurements of temperature, pressure, and other atmospheric properties.

The Johns Hopkins University Applied Physics Lab is investigating near-term interstellar precursor mission concepts using Delta III-class or smaller launch vehicles. A promising but thermally demanding approach is to bring a probe close to the Sun and execute a Delta-V maneuver of roughly 10 km/sec-15 km/sec at a perihelion of about three solar radii. High-thrust techniques being studied include solar-heated thermal rockets and scaled-down nuclear pulse propulsion systems.

Kare Technical Consulting is evaluating a concept for an interstellar probe that is accelerated by a particle beam consisting of small, laser-pushed sails. Because a series of small sails can be accelerated more easily than a single sail of the same total mass, a larger vehicle and payload can be boosted over months or years by a comparatively modest laser. ▲

by **George Schmidt**