December 2007

AEROSPACE AMERICA

air & SPACE

YEAR IN REVIEW 2007

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

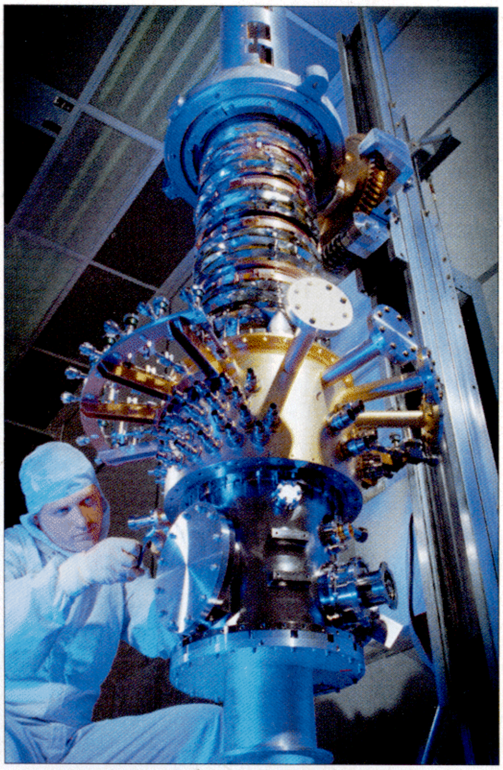
Nuclear and future flight propulsion

This year saw several achievements in nuclear and advanced propulsion technologies, including new developments in outer solar system mining research, advances in nuclear fusion propulsion technology, and new discoveries in breakthrough propulsion physics.

Outer planet atmospheric mining

New research insights regarding atmospheric mining of the outer solar system were developed at NASA Glenn. Four major options for the mining of Uranus and Neptune for helium 3 and hydrogen fuels were assessed, and the masses of the required vehicle were estimated. Balloons, hypersonic scoopers, and two types of atmospheric cruisers (or aerospacecraft) were investigated.

The cruiser options were found to be most successful. While balloons may be a viable option for short-lived mining, cruisers will likely have a considerably longer lifetime and afford a lower total mass for the overall mining system. Using a combination of a cruiser, an orbital transfer vehicle, and a fuel storage facility integrated into an interplanetary transfer vehicle, the fuels could be wrested from the gas giant planets. Understanding the lifetime issues of a cruiser aerospacecraft in the 70-K temperature environment of Uranus and Neptune will require much additional research.



Gravity Probe B collected data on the rotation of the Earth.

In all cases, atmospheric mining of the outer planets will require a number of spacecraft and many complex maneuvers to wrest fuels from their powerful gravity wells. Cruisers, balloons, and scoopers each entail different mining scenarios. Cruisers have the advantage of operating in the atmosphere at subsonic speeds, which would ease the liquefaction requirements for mining. Also, the stresses on the vehicle seem the most benign of all of the mining vehicles. The cruiser may be most attractive for the longer term missions. It will likely use the planetary atmosphere for fuel (for a nuclear "air-breathing" engine), capturing and liquefying the needed gases from the atmosphere as well. The cruiser may exit the atmosphere and be refitted or resupplied (with delivery capsules, other consumables, replacement units, and so on) from orbital assets.

Balloons have been proposed in the past as viable mining platforms. However, the lifetime of these systems, especially higher temperature balloons, would be a limiting factor in a balloon-borne mining scenario. Balloons are better suited to shorter life missions. Typical balloon lifetime for Earth exploration is usually in the 10-100-hr range. The scooper miners, although a fascinating option, will likely be used for short and limited forays into the atmosphere. Given the complexity of the missions and the delta-V required for mining, the cruiser- and balloon-borne approaches are the most likely to be acceptable for future study.

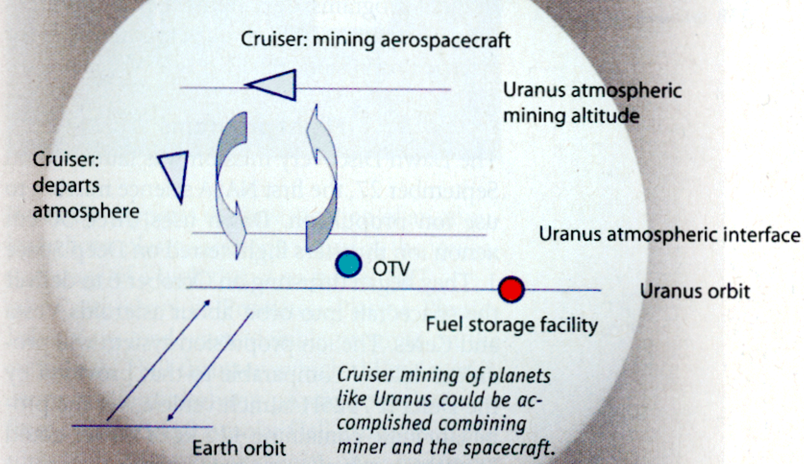
Vehicle and mission complexities associated with atmospheric mining make it a daunting task. Based on analyses of the masses of the vehicles, only very high specific impulse, high thrust, and lightweight vehicles can possibly allow an effective strategy for such mining. Additional research is needed in lightweight cryogenic gas separation technologies and the likely lifetime of aerospace vehicles in the cryogenic environments of the outer planet atmospheres.

Mining the planets will likely unlock new capabilities for exploring and exploiting the solar system. The initial steps in pursuing in-situ resource utilization will allow new visions of energy sources for Earth, solar system spacecraft, and perhaps humankind's first step into interstellar space.

Fusion propulsion

Researchers from the University of Illinois Fusion Studies Lab described a path for the expeditious development of D-^{3}He fusion for space power at the AIAA IECEC meeting in St. Louis

by
Tryshanda Moton-Nkhata
Benjamin Donahue
Jochem Hauser



Cruiser mining of planets like Uranus could be accomplished combining miner and the spacecraft.

in June. The availability of lunar ^3He resources makes this a key goal for future space exploration. A relatively rapid development path appears feasible based on progress in alternate fusion concepts combined with the less demanding engineering requirements and improved environmental and safety features of a D-^3He fueled fusion reactor (compared to a D-T fueled fusion reactor). A high beta-type fusion confinement system is essential to burn D-^3He. Various candidates include field reversed configurations, dense plasma focus, and inertial electrostatic confinement (IEC).

To illustrate the potential for such propulsion systems, researchers at the university have updated their prior conceptual design, Fusion Ship I, based on an IEC fusion rocket. The IEC power unit simplifies confinement structure, giving a very high power-to-weight ratio and a high efficiency due to direct conversion of the D-^3He fusion 14.7-MeV proton energy to thrust. The power unit was sized to give trip times of several months to the outer planets. The updated design incorporates a unique magnetic channel coupled array of eight IEC units to improve plasma confinement and efficiency.

Field propulsion

Experiments performed at ARC Seibersdorf Research in Austria indicate that a gravitational-like field of 10^{-4} g is induced near a niobium superconducting ring when the ring's rotation rate changes (http://arxiv.org/pdf/0707.3806). If genuine, this would be the first-ever gravitational-like field induced by controllable means. The field is circular and is located inside the ring. Its direction and magnitude oppose the ring's angular acceleration. Since the field is transient and circular, it is not immediately applicable as a propulsion effect, but such a physics discovery would dramatically expand new options for the future.

The observed effect is somewhat similar to the "frame-dragging" effect predicted by the theory of general relativity, a phenomenon that is also describable as a "gravitomagnetic field." This effect occurs when an inertial frame is dragged along slightly in the vicinity of moving matter, such as near the surface of a rotating star. While similar, the experimental observations do not match any theoretical predictions. In fact, the noted effect is roughly 30 orders of magnitude larger than what is predicted by frame-dragging, but it must be emphasized that extending general relativity theory down to the scale of these experiments and to include superconducting effects requires simplifications and assumptions that may skew their applicability. Present emphasis is on ensuring that the measurements are not due to spurious causes.

A second set of experiments conducted at the University of Canterbury, New Zealand, used the world's most accurate ring laser gyro to search for the noted effects, but using a rotating superconducting *lead* mass and a different orientation of their laser gyro than the ARC laser gyro configuration (http://www2.phys.canterbury.ac.nz/~physrin/papers/SuperFrameDragging2007.pdf). Their data show a possible gravitational-like field effect on the ring laser gyro from the rotation of the lead mass. These data and the ARC experiments have enough similarities to suggest corroborating evidence, yet are different enough that no firm conclusions should yet be reached.

Yet another experiment to scrutinize for corroborating effects is the Gravity Probe B mission. This satellite collected data in 2004 and 2005 to search for frame-dragging effects from the rotation of the Earth as well as other predicted effects from general relativity. Since the probe uses two superconducting gyroscopic spheres that are coated with niobium, it may have conditions similar to the ARC Seibersdorf Research experiment. The data from this mission are still being analyzed. Again, it is too soon to reach any definitive conclusions.

In short, a new gravitational effect may have been discovered, one that would open new options for seeking breakthrough space propulsion. However, the effect in its present form is not directly applicable, and further experiments are needed to confirm the validity of these initial observations.