12 AEROSPACE AMERICA DECEMBER 2008

December 2008

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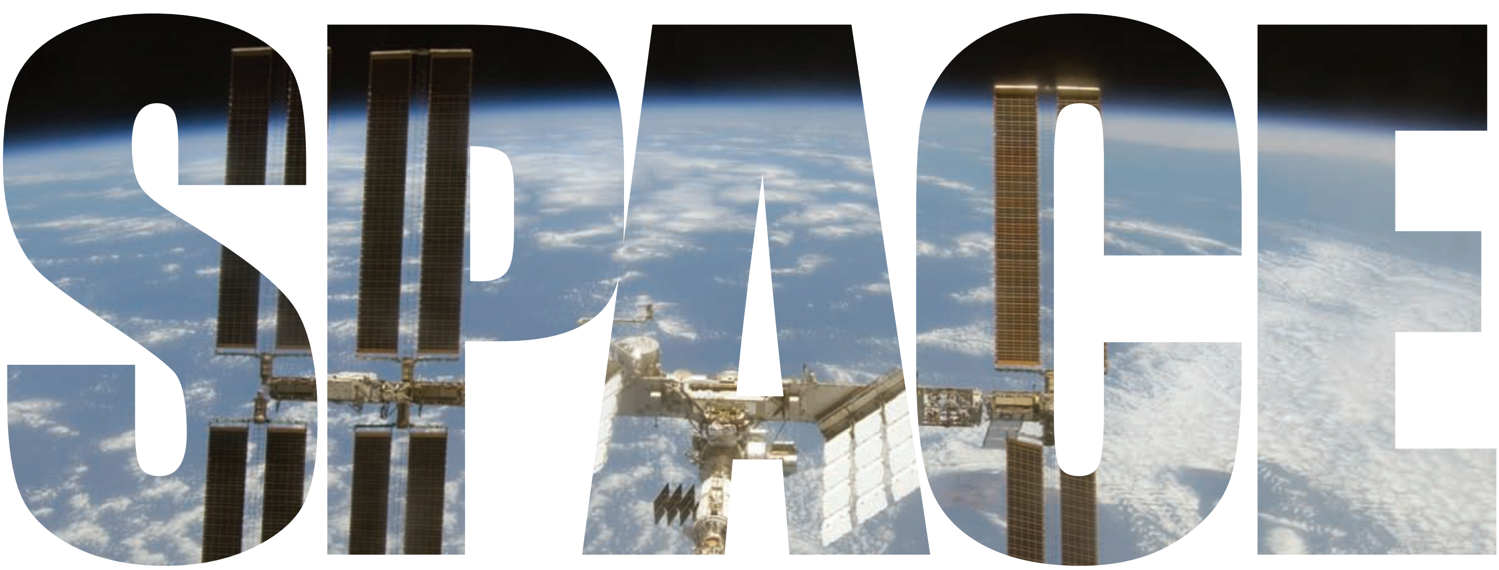
2008 The year in review



A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

Nuclear and future flight propulsion

This year brought tremendous progress in nuclear and future flight propulsion, with advanced research in outer planetary mining and breakthrough propulsion physics.

Mining the outer solar system

In the development of atmospheric mining of the outer solar system, supporting vehicles were investigated and their masses and trip times assessed. Overall, nuclear electric propulsion (NEP) and nuclear thermal propulsion (NTP) vehicles can deliver the needed payload masses to outer planet moon bases. However, the added masses required for the vehicles, the in-situ propellant manufacturing facilities, the landing vehicles, and other infrastructure impose a large added mass penalty for the smaller atmospheric mining missions.

Supporting vehicles for moon base activities will cause significant growth in the mass delivered to the outer planets to support the atmospheric mining operations. The moon base lander masses required for varying levels of rocket specific impulse were estimated. Even with a 480-sec I_{sp}, the lander masses for delivering a large payload to the surface will not be modest: approximately 144 metric tons (MT).

To support the moon base transportation, NEP transfer vehicles were investigated. The initial mass for the NEP orbital transfer vehicles was estimated for a range of payload masses and propulsion system dry masses. The total of the payload and the propulsion system dry mass was 21, 51, and 101 MT. This range was selected based on past studies and the potential variations in mass to accommodate long-lived NEP vehicles in outer planet environments (the need for additional thrusters to allow for thruster lifetime limits, and so on).

With the 21-MT dry mass class NEP vehicles with a 5,000-sec I_{sp}, the initial mass for the alpha of 10 kg/kW ranges from 49.4 MT for the 0.5-MWe (megawatts of electrical power) vehicle, 135 MT for the 5-MWe vehicle, and 230 MT for the 10-MWe vehicle. Thus the lower power NEP (with power levels of less than 5 MWe at 10 kg/kW) can deliver a lower initial mass than the 145-MT initial mass NTP vehicle option.

A moon base is an additional complexity that will increase maintenance requirements and add higher cost to the mining scenario. By using only orbital resources, such as orbital transfer vehicles, and the interplanetary transfer vehicle for Earth return, the mass that must be transferred to the outer planets is reduced. Therefore reducing the moon base's complexity will be a great benefit for any mining plan.

Because of the added mass and complexity associated with the outer planet moon base options, these options do not appear attractive. Space-based assets seem superior in terms of reducing mission mass and complexity. The added maneuvers for lifting the propellant from the moon's surface, rendezvous and transfer to the transfer vehicle, and then conducting the relatively long trip from the moon's orbit to the rendezvous and pickup point all add many hundreds of metric tons to the overall system.

However, building small way stations or storage points on small moons may have potential advantages. Their cold surfaces would be attractive for cryogenic caches of fuels or other in-situ resources that require long-term storage. Future interstellar exploration will be fostered and fueled by the in-situ resources of the ice giant planets Uranus and Neptune. Humankind's first tentative steps out of the solar system will likely use the powerful energies of the outer planet atmospheric gases.

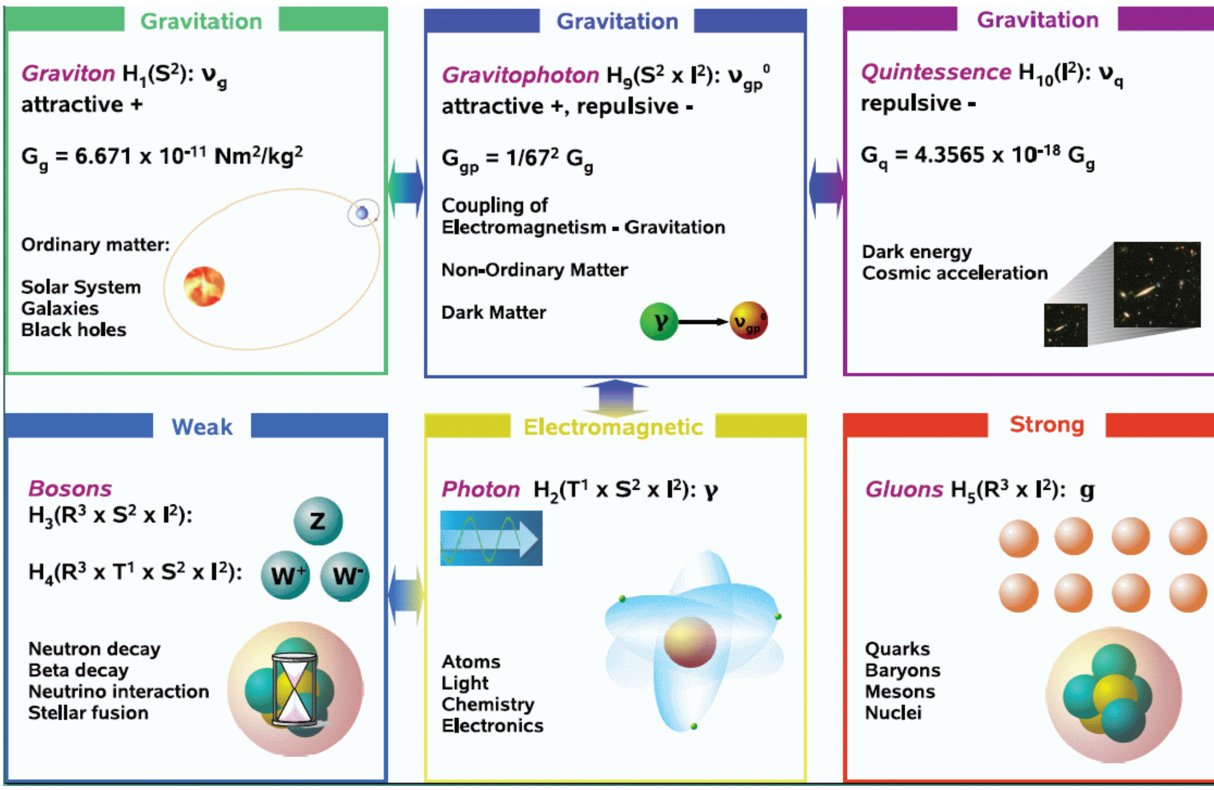
Stepping-stones to the stars

An initial survey of locations and resources in the outer solar system was conducted. Propulsion options from many studies were summarized and other likely sources of propellants and other in-situ resources identified.

Atmospheric mining of the outer solar system is one of the options for creating nuclear fuels, such as 3He, for future fusion-powered exploration vehicles or powering reactors for Earth's planetary energy. The atmospheres of Uranus and Neptune would be the primary mining sites, and robotic vehicles would wrest these gases from the hydrogen-helium gases of those planets. While preliminary estimates of the masses of the mining vehicles have been created, additional supporting vehicles may enhance the mining scenarios. Storing the mined gases at automated bases on outer planet moons or orbital transfer vehicles was an idea conceived to ease the storage requirements on interplanetary transfer vehicles (that would return the cryogenic gases to Earth).

In addition, Kuiper Belt objects and bodies in the Oort Cloud may provide havens for human and robotic explorers. Caches of propellant ices and gases on these primordial objects may be excellent way stations on the path to interstellar space. Bodies such as Plutinos may provide attractive cryogenic construction sites for large fusion- or antimatter-powered vehicles.

by **Benjamin Donahue, Tryshanda Moton-Nkhata** and the **AIAA Nuclear and Future Flight Propulsion Technical Committee**



Research involves the possible relations among gravitational, electromagnetic, and nuclear strong and weak forces.

This research is conducted by the NASA Glenn Small Business Innovative Research (SBIR) Program. More information can be found at the SBIR Fuels and Space Propellants website: http://sbir.grc.nasa.gov/launch/foctopsb.htm.

Advances in breakthrough propulsion physics

Much research was conducted this year on the investigation of the experimental basis of the existence of gravity-like fields that cannot be described by conventional gravitation; that is, by the accumulation of mass. Investigations emphasized a geometrized approach termed Extended Heim Theory, which extends Einstein's idea of the geometrization of physics by employing the additional concepts of Heim.

Work principally involved investigating recent experimental data and propulsion implications of gravitation field variations. Specifically, the existence of gravity-like fields (gravitational acceleration fields) that might be generated by producing a time-dependent gravitomagnetic field were studied. The ensuing gravitational force sought is more in the range of the electromagnetic force. In other words, the coupling constant of the gravity-like field must be completely different from common gravitational coupling.

General relativity (GR) predicts that any rotating massive body (such as Earth) drags its local spacetime around, called the frame dragging effect, generating the so-called gravitomagnetic field. Since spacetime itself gets twisted, a gyro whose axis of rotation remains invariant should exhibit a misalignment, since our local coordinate system is no longer inertial. This effect, predicted by Lense-Thirring in 1918, however, is far too small to be seen in a laboratory on Earth. For this reason the Gravity Probe-B experiment was launched in 2004 after more than 40 years of preparation.

Recent experimental data may indicate the production of gravimagnetic field forces of higher orders of magnitude than predicted by GR, and perhaps are therefore outside GR. They cannot be explained by the classical frame dragging effect of GR and may represent a new kind of physical phenomenon.

The first technical book to detail the science behind the notions of gravity-control propulsion and faster-than-light travel will be published as part of AIAA's Progress in Astronautics and Aeronautics series. *Frontiers of Propulsion Science* connects relevant physics to the unsolved goals of breakthrough interstellar flight.