Solar and Drag Sail Propulsion: From Theory to Mission Implementation

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Solar and drag sail technology is entering the mainstream for space propulsion applications within NASA and around the world. Solar sails derive propulsion by reflecting sunlight from a large, mirror- like sail made of a lightweight, reflective material. The continuous sunlight pressure provides efficient primary propulsion without the expenditure of propellant or any other consumable, allowing for very high $\Delta V$ maneuvers and long-duration deep space exploration. Drag sails increase the aerodynamic drag on Low Earth Orbit (LEO) spacecraft, providing a lightweight and relatively inexpensive approach for end-of-life deorbit and reentry.

Since NASA began investing in the technology in the late 1990's, significant progress has been made toward their demonstration and implementation in space. NASA's Marshall Space Flight Center (MSFC) managed the development and testing of two different 20-m solar sail systems and rigorously tested them under simulated space conditions in the Glenn Research Center's Space Power Facility at Plum Brook Station, Ohio. One of these systems, developed by L'Garde, Inc., is planned for flight in 2015. Called *Sunjammer*, the 38m sailcraft will unfurl in deep space and demonstrate solar sail propulsion and navigation as it flies to Earth-Sun L1. In the interim, NASA MSFC funded the *NanoSail-D*, a subscale drag sail system designed for small spacecraft applications. The *NanoSail-D* flew aboard the Fast Affordable Science and Technology SATellite (FASTSAT) in 2010, also developed by MSFC, and began its mission after it was was ejected from the FASTSAT into Earth orbit, where it remained for several weeks before deorbiting as planned.

NASA recently selected two small satellite missions as part of the Advanced Exploration Systems (AES) Program, both of which will use solar sails to enable their scientific objectives. Lunar Flashlight, managed by JPL, will search for and map volatiles in permanently shadowed Lunar craters using a solar sail as a gigantic mirror to steer sunlight into the shaded craters. The Near Earth Asteroid (NEA) Scout mission will use the sail as primary propulsion allowing it to survey and image one or more NEA's of interest for possible future human exploration. Both are planned for launch in 2017.

As the technology matures, solar sails will increasingly be used to enable science and exploration missions that are currently impossible or prohibitively expensive using traditional chemical and electric rockets. For example, the NASA Heliophysics Decadal Survey identifies no less than three such missions for possible flight before the mid-2020's. Solar sail propulsion technology is no longer an intesting theoretical possibility; it has been demonstrated in space and is now a critical technology for science and solar system exploration.