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DESIGN CONSIDERATIONS FOR SPACE TRANSFER VEHICLES USING SOLAR THERMAL PROPULSION

William J. Emrich, Jr
NASA - Marshall Space Flight Center
Bldg. 4200, Room 350
Huntsville, AL. 35812
(205) 544-7504

Abstract

The economical deployment of satellites to high energy earth orbits is crucial to the ultimate success of this nation's commercial space ventures and is highly desirable for deep space planetary missions requiring earth escape trajectories. Upper stage space transfer vehicles needed to accomplish this task should ideally be simple, robust, and highly efficient. In this regard, solar thermal propulsion is particularly well suited to those missions where high thrust is not a requirement. The Marshall Space Flight Center is, therefore, currently engaged in defining a transfer vehicle employing solar thermal propulsion capable of transferring a 1000 lb payload from Low Earth Orbit (LEO) to Geostationary Earth Orbit (GEO) using a Lockheed Launch Vehicle (LLV3) with three Castors and a large shroud. The current design uses liquid hydrogen as the propellant and employs two inflatable 16'x24' elliptical off-axis parabolic solar collectors to focus sunlight onto a tungsten/rhenium windowless black body type absorber. The concentration factor on this design is projected to be approximately 1800:1 for the primary collector and 2.42:1 for the secondary collector for an overall concentration factor of nearly 4400:1. The engine, which is about twice as efficient as the best currently available chemical engines, produces 2 pounds of thrust with a specific impulse (Isp) of 860 sec. Transfer times to GEO are projected to be on the order of one month. The launch and deployed configurations of the STUS are shown below.

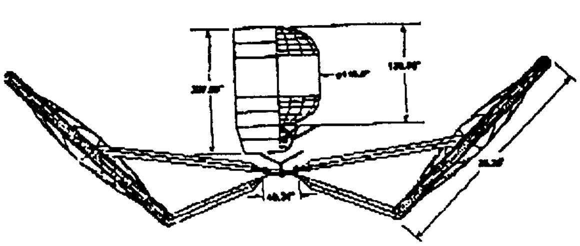
All aspects of the stage were studied for technical feasibility. The results indicate that the design, development, and operation of the solar thermal upper stage is feasible; however, it was found that there are several components which will need advanced technology development. In particular, tungsten material fabrication methodologies will need to be developed in order to produce an absorber which will be able to withstand the thermal cycling resulting from the numerous startups and shutdowns required of the engine. Tungsten is a notoriously difficult material to work with and the successful production of an STUS absorber will require that innovative fabrication techniques be mastered along with the possible use of various tungsten/rhenium alloys. Optical calculations performed to date on the absorber indicate that it is quite important to maintain good pointing accuracy (< 0.4°) to prevent hot spots from appearing on the absorber cavity's walls. The absorber nominal operating conditions have the outlet hydrogen gas temperature set at 2540°K at a pressure of 172 kPa. Maximum wall temperature are calculated to be ????°K.

The solar collectors, which are used to concentrate the sun's diffuse solar energy onto the absorber, will also require an advanced technology development effort. In particular, the manufacturing and testing for controllability of large, inflatable, ultraviolet (UV) rigidized structures will be required. It is crucial that the focused sunlight be directed both stably and accurately at the solar absorber to achieve the required hydrogen gas temperatures. In order to reduce the weight of the collector and to package it in a small volume, the entire collector assembly is inflatable. It is deployed pneumatically and rigidized after exposure to the solar UV radiation. The parabolic off-axis reflector consists of an aluminized polyamide film and a clear polyamide canopy held in place by a low pressure gas.

Also necessary for the operational upper stage development are the developments of composite tank and fluid management technologies for cryogenic propellants. Because of the relatively long transfer times required by the STUS, long term storage of liquid hydrogen is required. The number of engine burns and the weight sensitive nature of the entire vehicle are all major drivers for the fluid management system and affect its interaction with the thermal control and feed systems. In addition, the propellant management system must provide the absorber with a range of precise flow rates since the absorber will be operating close to its creep stress rupture limits and will be undergoing continual thermal cycling as the spacecraft moves in and out of earth's shadow. The feed system as currently envisioned is a single fault tolerant pressure fed system using the tank pressure form the cryogenic hydrogen tank. Two absorbers feed a single nozzle to minimize boundary layer losses.

Based on this point design, the total development cost for the STUS is estimated to be approximately $100M dollars. The first unit cost is estimated to be $15M dollars with $11M and $9M for the 10th and 25th unit respectively. These unit costs reflect savings of 14% to 26% over current systems.

Solar Thermal Upper Stage
Flight Configuration



Solar Thermal Upper Stage
Launch Configuration