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Author: Mr. Jasper Preijde
The Netherlands

Dr. Angelo Cervone
Delft University of Technology (TU Delft), The Netherlands

DESIGN AND MODELLING OF A NEW CONCEPT OF SOLAR THERMAL COMBINED PROPULSION & POWER SYSTEM FOR SMALL SATELLITES: FEASIBILITY AND PERSPECTIVES

Abstract

In the past, little research has been conducted in solar thermal propulsion for spacecraft, in spite of the growing interest in solar thermal power for terrestrial applications. This paper will present the results from a feasibility study of a solar thermal hybrid system for small spacecraft in the range of 100 to 350 kg, in which space and terrestrial technology are combined for both power and propulsion functions of the spacecraft, both relying on the same energy source. A miniaturized assembly based on an Organic Rankine Cycle generates power and includes an evaporator, micro-turbine, condenser and micro-pump. For propulsion, a cryogenically stored liquid propellant is heated by part of the input solar thermal energy and then expelled to generate thrust. The solar radiation is focused by a primary and secondary solar concentrator into an insulated absorber which stores the thermal energy. A conductive interface with a heating gas conduit transfers the thermal energy via a heating gas to the evaporator.

The complete system is numerically modelled based on the fundamentals of thermal energy transfer, thermodynamic processes and nozzle flow. The system model is subsequently run for various system concepts with different design variables. A total of six concepts were analysed, based on three different absorber shapes (conical, cylindrical and spherical) and two propellants (hydrogen and ammonia).

The six concepts were evaluated which resulted in a preferred concept with a cylindrical absorber and liquid ammonia. It generates a thrust of 1.27 N, a specific impulse of 181 s and a power of 114 W. The hybrid system, including propellant, takes up a mass fraction of 0.62 of the total spacecraft wet mass of 230 kg. The resulting hybrid system efficiency has been shown to be 36%. This performance is typical of small spacecraft of the size considered for this study, such as ESA's Proba satellite series.

A detailed design of this concept, including all components and interfaces, will be presented in the paper and compared to representative conventional systems with equal thrust and power generation capabilities. It can be concluded that for small spacecraft in the aforementioned range the hybrid system is relatively not advantageous due to the large system mass involved, even though it can constantly provide power. However, for larger spacecraft beyond Earth orbit (or in orbits with short eclipse periods), the system is extremely promising due to the non-linear scaling of its mass and volume.