Chapter 18

LASER PROPULSION

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1. INTRODUCTION

This chapter is devoted to the description of laser propulsion. The technologies dealt with in this chapter use thermal energy or pressure of propellant fluids powered by laser radiation to generate impulse. The propellants are not necessarily in a plasma state and can be a hot fluid. In fact, this flexibility leads to the wide range of applicability of laser propulsion. Therefore, laser irradiation and propellant feeding conditions have to be optimized depending on the field of application or mission of the technology.

The concept of the laser propulsion was conceived back in the early 70's by Kantrowitz (1971). It was estimated that a one-megawatt laser system can launch a one-kilogram payload to the low earth orbits (500 to 1500 km altitude). Since then, the study of laser propulsion has evolved into a laboratory fundamental investigation on basic characterization of laser-plasma interactions in conjunction with the study of laser plasma interactions of inertial confinement fusion research (Reilly, 1979; Phipps, 1988). One typical example of these investigations was done by Phipps, where universal scaling on impulse generation in terms of laser parameters over many orders of magnitude was found. The optimization introduced above can be viewed on this scaling in terms of laser parameters such as intensity, wavelength, and pulse width.

From the early 90's, advancements of high power laser facilities, such as for materials science, accelerate the thrust measurements (Pirri, 1974) and demonstrations of so-called "Light Craft" devices (Myrabo, 2002; Sasoh,
Various applications have been proposed including biomedical devices (Yabe, et al., 2002b, 2003b), air plane (Yabe, et al. 2002a), satellite posture control (Phipps and Luke, 2000), orbital transfer vehicle (Uchida and Bato, 2003) as well as space debris mitigation (Phipps, 1998; Schall, 1998). Among them, laser orbital transfer vehicle (LOTV) or “laser tugboat” seems to be realized by the combination of currently available technologies and yet has significant impacts over current technology. Its feasibility will be examined in this section.

Unparalleled uniqueness of laser propulsion is that it can generate thrust remotely by beaming necessary power from distance. This characteristic leads to an advantage of eliminating the necessity of carrying a power source onboard the vehicle. However, this is not the limit of the technology when it is applied to so-called “space debris problem” (Johnson, 1991). The space debris will prohibit us from going into space if no countermeasures are taken since it will eventually cover up the near earth orbits. In principle, only laser propulsion with remote power beaming seems effective in the mitigation of a countless amount of space debris. The most effective way of using laser propulsion to mitigate space debris is to generate ablation on the surface and change its orbit so that it eventually falls to the upper atmosphere. An example of laser system for space debris removal will be described.

The first part of this chapter describes the basic elements of laser propulsion which makes the technology unique compared to others such as chemical and electrical propulsion. The uniqueness of laser propulsion technology comes from the fact that mass of propellant and laser intensity can be controlled independently and therefore, power density carried by propellant can be controlled over many orders of magnitude. Basic elements of impulse are of course mass and velocity (energy). The performance of a propulsion system can be evaluated in terms of the mass efficiency or energy efficiency, depending on the purpose of a specific application.

2. SCALING LAW IN LASER PROPULSION

2.1 Basic Concept

The most significant concept for laser propulsion is a parameter called momentum coupling coefficient, $C_m$, a measure of energy usage. It is defined as a ratio of impulse (momentum) generated to laser power. Different expressions are possible between pulsed and cw laser wave formats. In the case of pulsed lasers the expression becomes