Laser Ignition for Hybrid Rockets

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Introduction

Given the success that CubeSats have had performing valuable research at a reasonable cost in Earth orbit, NASA is beginning to consider the concept of an interplanetary CubeSat. The goal with these interplanetary CubeSats is to develop a technology that can enable a large range of affordable science missions targeted at planets other than Earth. One of the main challenges faced in this type of mission is designing a propulsion system that can provide the large (>1km/s) delta-V requirements needed to place the CubeSat in orbit around another planet and provide necessary orbit adjustment burns. Hybrid rockets, which feature a solid fuel and therefore a larger energy density than liquid or cold gas thrusters, could provide sufficient delta-V, but currently lack a lightweight ignition system that can provide numerous motor restarts. This work aims to address this gap in hybrid rocket ignition technology and focuses on the development of a lightweight, restart capable laser ignition system.

Objectives

Motivation: Hybrid rocket motors lack a compact, lightweight ignition system that can provide numerous motor restarts

Research Objective: Develop a laser ignition system that utilizes one or more laser diodes and demonstrate ignition and restart of a laboratory scale hybrid rocket motor

Laser Diodes

A laser diode is a semiconductor laser. As a result, this type of laser is compact and lightweight, while also being able to produce several watts of optical power from a single laser. One of the challenges of working with small lasers is keeping the laser cool. Significant heat is generated through the lasing process and as the laser gets hotter, the power it produces decreases. Heat removed from the laser could potentially be put to use in a laser ignition system to preheat the oxidizer that is injected into the combustion chamber.

Experimental Components

An 8 watt laser system is being designed and assembled to sit atop an existing laboratory scale hybrid rocket motor:

- The hybrid rocket motor is specially designed with two quartz windows allowing optical access into the combustion chamber, enabling visualization of the ignition/combustion process
- The primary fuel to be studied is paraffin wax, with the goal of eventually broadening the study to include PMMA
- The initial iteration of the laser system will consist of one 8W laser diode (808nm) and two lenses for focusing the beam onto the fuel grain surface
- The top face of the combustion chamber is being modified to include a laser window which can be placed at several locations along the length of the fuel grain
- When running experiments the laser power, laser pulse width, laser focal spot size and location, chamber pressure and oxidizer flow rate are all variables that can explored to determine the range of parameters that will result in motor ignition
- The laser ignition process will be studied visually using high speed and Schlieren imaging techniques
- The goal is to determine if it is possible, with a single laser, to pyrolyze the paraffin fuel (turn it into vapor) and heat the surface of the fuel grain sufficiently high that the fuel vapor and oxidizer locally ignite and then spread from the source of ignition

Fuel Additives for Laser Ignition

Most (if not all) hybrid rocket fuels are either partly or mostly transparent to light over a broad range of the spectrum. Paraffin wax is translucent, while PMMA is almost fully transparent. This property of hybrid rocket fuels makes them poor absorbers of optical energy from lasers, and so a highly absorbing additive must be added to these fuels. For this experimental work, carbon black powder is added to the paraffin fuel in order to more effectively absorb optical energy at the fuel grain surface. At carbon black concentrations of 1% by mass, the absorption of a paraffin fuel sample is increased by enough to enable rapid fuel pyrolysis using as little as 0.5 watts of optical power.

Next Steps

1. Demonstrate a single ignition of the visualization hybrid rocket motor using the single laser diode ignition system
2. Study the operating range over which ignition can be achieved with this laser system
3. Demonstrate one or more restarts of the visualization hybrid rocket motor using the single laser diode ignition system

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References


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