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Light Craft Powered by Laser Propulsion

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Abstract: This paper emphasis on an experimental structure of LIGHTCRAFT- A LASER POWERED LAUNCH VEHICLE. The goal is to analyze the structure and study the principle behind the use of laser. The main constraints are reduction of laser energy required and mass of vehicle. The three segments of the craft-forebody, afterbody and cowl are manufactured within the limitations of availability of material and manufacturing process. This light weight body houses micro-satellite/nano-satellite in its forebody. The afterbody is beamed with high power laser to impart the thrust to propel it. The power of the laser ionizes the air molecules, increasing the temperature. This results in a shock wave that propels the craft.

The scaled down model made of SS304 is tested using a low power laser. To increase the propelling capacity and decrease the power required for laser, a thin layer of paraffin wax is also coated on the afterbody while propelling. This proved to be more efficient

1. INTRODUCTION

The idea of Laser Propelled Lightcraft Vehicles was first conceptualized in the early 1970's as a means of achieving low cost earth to orbit payload launches. Since 1986 the U.S Security Defense Initiative Organization has supported research programs in Laser Propulsion systems. Laser Propelled Lightcraft Vehicles have also been investigated by the Air Force Research Laboratory (AFRL). Power is transmitted to the Lightcraft from a ground based laser, and air is utilized during flight in the sensible atmosphere. When the Lightcraft exits this region of usable atmosphere, the laser is then used to heat an ablative fuel source

A Lightcraft is a 1kg launch vehicle, made from high temperature ceramic materials, that flies into space on a megawatt laser beam. This ultra lightweight vehicle is powered by repetitively-pulsed detonations induced by a ground-based laser.

2. LITERATURE SURVEY

Arthur Kantrowitz (1972), in "Propulsion to Orbit by Ground based Lasers" calls attention to a propulsion system based on the high power laser. It is well known that a laser can evaporate a substance at a distance. At higher fluxes the vapor can be ionized, yielding very high specific impulse. He reported that he had produced 30kW in a well collimated beam from a gas-dynamic laser that could be designed for indefinite duration. Transformed into kinetic energy of a jet, the energy of this laser would produce about a kg of thrust.

3. WORKING PRINCIPLE

A ground based laser is the power source that propels the Lightcraft into orbit. Lightcraft can deliver payloads into space while most of the engine stays on the ground.

The back side of the craft is a large, highly polished parabolic mirror that is designed to capture the laser beam projected at it from the ground. The mirror focuses the beam, rapidly heating the air to 5 times the temperature of the sun, creating a blast wave out the back that pushes the vehicle upward.

The air in the rear region becomes heated and expands violently in a laser-supported detonation, producing thrust. As the beam is rapidly pulsed, the vehicle is continuously propelled forward, on its way to orbit. When a lightcraft is in the atmosphere, air is used as the propellant material (reaction mass).

A lightcraft's propulsion is dependent on the external laser's power and so propulsive power is not limited to that generated by on-board machinery.

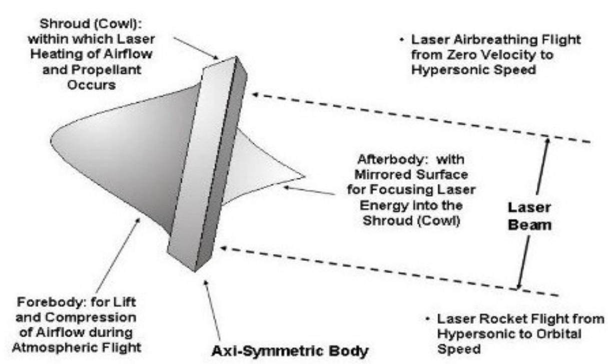

Fig. 3.1. Working principle of lightcraft

The basic components of lightcraft:

- **Parabolic mirror** - The bottom of the spacecraft is a mirror that focuses the laser beam into the engine air.
- **Cowl** - The inlet air is directed into this chamber where it is heated by the beam, expands and propels the lightcraft.

4. STRUCTURE AND DESIGN

4.1. Conceptual Model

- Cowl diameter = 10cm
- Fore body diameter = 6.5cm
- After body diameter = 4cm
- Cowl height = 0.8cm
- Fore body height = 5.8cm
- After body height = 3.8cm
- Thickness = 0.5mm
- Weight approximated = 15g

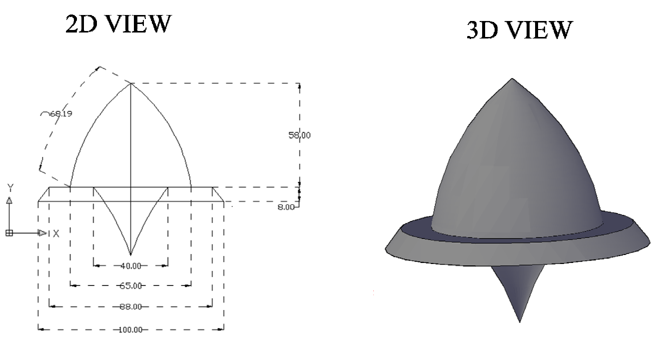

Fig. 4.1.1. Conceptual model.

4.2. Experimental Model

- Cowl diameter = 6.1cm
- After body diameter = 4cm
- Cowl height = 0.8cm
- After body height = 3.8cm
- Thickness = 0.5mm
- Weight approximated = 7g

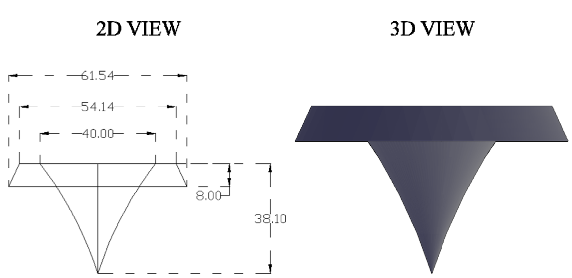

Fig. 4.2.1. Experimental model.

5. MANUFACTURING PROCESS

The manufacturing was done in two steps:

- Making of mould.
- Making of part.

5.1. Making of Mould

The mould was made using OHNS(Oil Hardened Non Shrunken Steel). The metal is lathed to form the moulds of desirable shape and size to make the models. A total of 7 moulds were made, including the male and female part.

5.2. Making of Part

The forebody and afterbody is made of stainless steel 304, whereas the cowl/shroud of mild steel. SS304 was used because of its deep drawing ability and reflective property. Mild steel was used in order to weld together the different segments.

6. MATERIAL USED

6.1. Stainless Steel

Type 304 stainless steel is a T 300 Series Stainless Steel austenitic. It has a minimum of 18% chromium and 8% nickel, combined with a maximum of 0.08% carbon. It is defined as a Chromium-Nickel austenitic alloy.

Grade 304 is the standard "18/8" stainless that you will probably see in your pans and cookery tools.

6.1.1. Material Properties

Physical Properties

Density = 8.03 g/cc

Mechanical Properties

Hardness, Rockwell B = 82

Electrical Properties

Electrical Resistivity = 0.000116 ohm-cm

Magnetic permeability = Max 1.02

6.2. Mild Steel

It is a carbon steel typically with a maximum of 0.25% Carbon and 0.4%-0.7% manganese, 0.1%-0.5% Silicon and some traces of other elements such as phosphorous, it may also contain lead (free cutting mild steel) or sulphur (again free cutting steel called re-sulphurised mild steel).

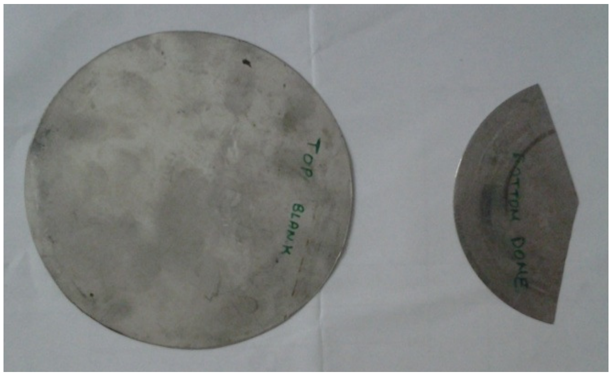

Fig. 6.1. SS304 used for forebody and afterbody.

Fig. 6.2 Mild steel used for cowl.

7. NUMERICAL ANALYSIS

Performance parameters for thrust generation:

Specific impulse, $I_{sp} = F/g\dot{m}$

Where, $F = \dot{m} \times V_E$

$\dot{m} = 4.99\times10^{-8}$g/s eq.7.1

$V_E = 9800$m/s (velocity of detonation wave)

Therefore, $I_{sp} = 1000$s

Propulsion efficiency, η = propellant kinetic energy/laser power

$= \frac{1}{2}\dot{m} \times (V_E)^2 / P_L$ eq.7.2

Where, P_L = laser power = 3W

Therefore, $\eta = 0.7987 \approx 80\%$

Thrust, $T = (2 \times \eta \times P_L)/(I_{sp} \times g_o)$ eq.7.3

$= (2 \times 0.8 \times 3)/(1000 \times 9.8)$

$= 4.897\times10^{-4}$N

8. APPLICATION OF LIGHTCRAFT

- Micro/Nano-satellite launch services
- Nano-satellites: 1-10kg (current target)
- Micro-satellites: 10-100kg (future target)
  - Global positioning
  - On-orbit inspection
  - Entertainment
  - Telecommunications
  - Environmental monitoring

Table 8.1 Comparison between conventional launch and lightcraft

Conventional Launch	The Lightcraft
\$175, 000, 000 • Chemical Rockets: • carry massive propulsion source on board • are expendable • extremely costly • prone to explosion due to fuel on board	\$46, 000 • Laser Propulsion: • propulsion energy source remains on the ground • Lightcraft are inexpensive to manufacture and extremely light weight • highly reusable power source is never subjected to the risks of flight

9. RESULT

9.1. Material

- The initial idea was to use silicon carbide as the material, because of its elevated temperature performance. But the required quantity of SiC (<60gm) were only available in powdered form. The sintering process required to solidify it takes long time. Also, sintering facilities are not preset in South India.
- The material later considered was Aluminium, owing to its less density 2.7g/cc. The forebody was drawn from Al. But when drawn for afterbody, the structure failed.
- Thus, SS304 and mild steel were selected for the purpose. SS304 blank was easily pressed to form the afterbody and forebody. Mild steel cowl was made and through gas welding, the structure was joined.

9.2. Laser

- We approached national and foreign companies for procuring a high power laser (>1W). But in most of the countries, selling of lasers higher than 5mW for purposes other than industry is illegal. In India, the Government order is required to purchase a laser.

- So numerical analysis was made to find the specifications of laser. According to those calculations, a laser of at least 3W laser with pulse energy 255J can be used for the purpose. Paraffin wax, when coated in the afterbody increases the efficiency of the system.
- A 3W laser with pulse energy 255J ionizes 25% of Nitrogen in the cowl area of the experimental model.

9.3. Testing

- Testing was done using a Q Switched Nd-YAG laser of 835mJ pulse energy and frequency 10Hz.
- Theoretical distance moved = 2.43cm
- Experimental distance moved = 1.9cm
- Deviation = 21.8%

10. FUTURE ENHANCEMENTS

- The study of various efficiency coefficients that are the important parameters in the overall energy equation are highly recommended.
- Overall energy conversion, $E_f = \eta \times \alpha \times \beta \times \gamma \times E_L$

Where,

η = propulsion efficiency
α = expansion efficiency
β = absorption efficiency
γ = transmission efficiency
E_L = laser energy

- We recommend the use of variable power of lasers with varying pulse rates to obtain a detailed study of the equations of motion of the lightcraft and to get the generalized relation between power and distance.

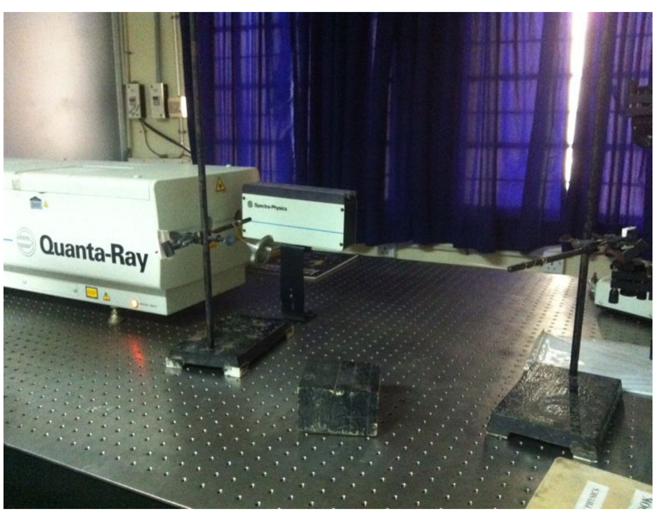

Fig. 9.3.1

Fig. 9.3.2

Fig. 9.3.1 & 9.3.2. Experimental testing of lightcraft using Nd-YAG laser.

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