17th Brazilian Congress of Thermal Sciences and Engineering
November 25th-28th, 2018, Águas de Lindóia, SP, Brazil

ENCIT-2018-0416
OPTICAL DESIGN FOR LASER PROPULSION SYSTEM

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Abstract. *Rockets engines based on chemical propulsion are the most commonly used to launch objects into Earth's orbit; they have considered high cost chemical components that require high dexterity, careful transportation and storage. However, the laser propulsion will become the space access cheaper, and promote further improvements in safety and environmental problems. The purpose of this work is to develop the optical design for this technology, applying this concept to the DVPL (Laser Propulsion Technology Demonstrator) in development at the Prof. Henry T. Nagamatsu Aerothermodynamics and Hypersonic Laboratory of the Institute for Advanced Studies (IEAv).*

Keywords: *Optical design, laser propulsion, DVPL.*

1. INTRODUCTION

Space access has currently carried out through the chemical propulsion of the rocket engines, which has a high operational cost, making it difficult to space access and consequently the launching of payloads into Earth's orbit. In this sense, aiming for easy space access, laser propulsion is an advanced and attractive proposal to launch payloads in Earth's orbit, because is capable of generating high momentum for the vehicle (Feikema, 2000). The functional principle of the system is resort the force of a high-powered laser pulse to generate propulsion, using an external laser source to provide the necessary energy for the launching. The laser pulse will focusing on the rear of the DVPL (Fig. 1), where it will be reflected by the parabolic mirror and concentrated at the ionization's region, where this concentration causes the air at the focal point to ignite, creating plasma, and this plasma expands and generates the necessary thrust to the launching (Pinto, 2009).

While the vehicle has been in the atmosphere, the air will be used as a propellant material. It allows a reduction in the vehicle size by up to ten times and a reduction in weight up to a thousand times because the fuel on board the vehicle is no longer needed, due the outside laser source.

From the economic point of view, to put in Low Earth Orbit (LEO) a micro or nano-satellite in the order from 10 e 100 kg, the cost is approximately US $ 20.000,00 according to current propulsive systems (rocket engines); however, with the laser propulsion cost can be reduced to US $ 200/kg (Myrabo, 1989).

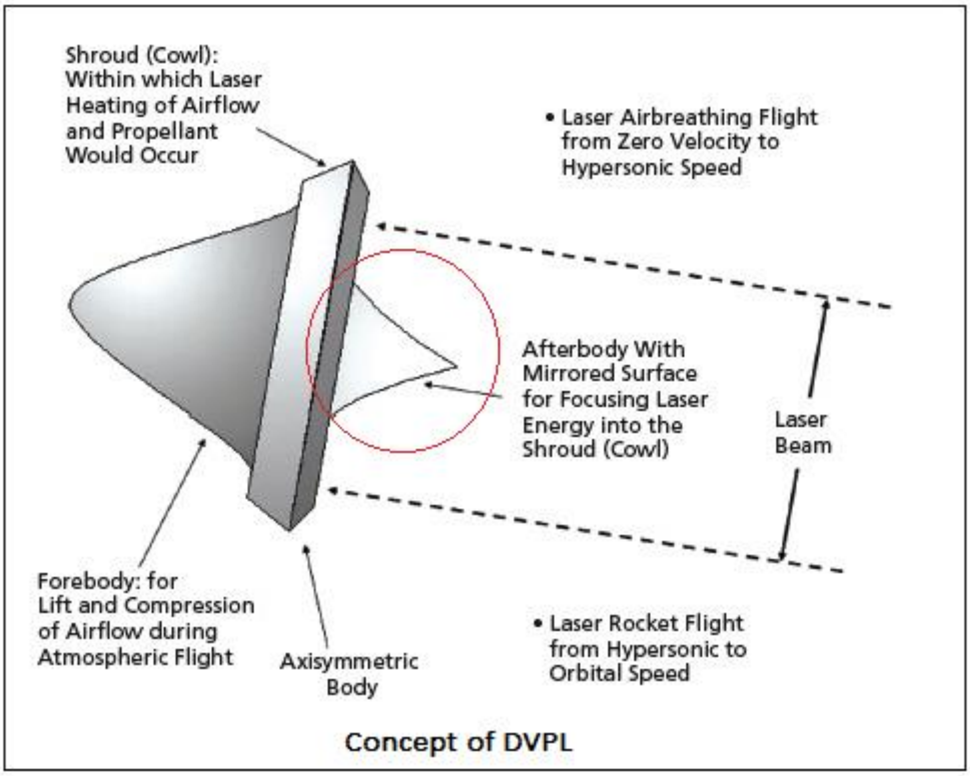

Figure 1. Concept of DVPL, and the Optical Design for Laser Propulsion System (Air Force Research Laboratory, 2010).

2. DESIGN METHODOLOGY

The objective is to investigate computationally the characteristics and optical aspects of the DVPL, performing numerical analysis with the application of TracePRO software, and then compare the obtained results.

The points of incidence of the laser pulse will also be calculated in the sense to evaluate the parabolic function of the mirror and thus decide which will be the best focal point that will develop momentum to the DVPL.

To give development in the studies of the parabolic mirror, it will be necessary to analyze the trajectory of light propagation, so that we can verify the correct points for the incidence of the laser pulse. The equation that describe the parabolic mirror of the rear of the DVPL was previously studied and generated the function, Eq. 1 (simple parabolic function), calculated with the Microsoft Office Excel software, forming a second-order parabolic function, with the coefficient of determination equal to R^2 which indicates how much the trend line passes exactly through the points of incidence (R^2 varies between 0 and 1, indicating in percentage how much the model can explain the observed values, when the R^2 approaches 1, more loyal is the model) (Trizzini, 2009).

$$y = 0{,}599x^2 - 1{,}089x + 0{,}340 \qquad (1)$$

The parabolic function was formed based on the size of the forebody of the DVPL, and with dimensions of the hypersonic wind tunnel T3 test section, which will be used later for the experimental tests, so that the total length of the DVPL corresponds to 400 mm and the body circumference at 300 mm (150 mm radius) (Fig. 2).

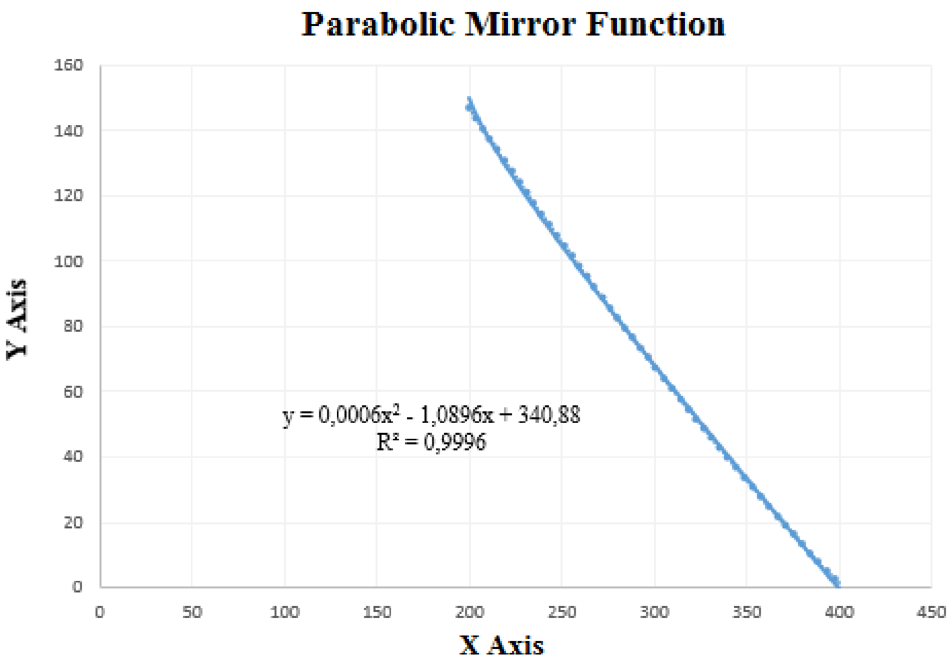

Figure 2. Concept of the parabolic mirror of the DVPL.

With the aid of a scatter graphic will obtain the propagation of the points of incidence, as shown in the (Fig. 2), and with Microsoft Office Excel program we able to find the coordinates of each point.

2.1 Laser

The laser used for the research will be a pulsed CO_2 laser, called TEA-622. This TEA laser was provided by the United States to the Prof. Henry T. Nagamatsu Aerothermodynamics and Hypersonic Laboratory of the Institute for Advanced Studies in Brazil.

Pulsed infrared laser energy was supplied by one of the two Lumonics TEA-620 CO_2 lasers available, which share the same resonator cavity. An attractive feature of these TEA-620 lasers is their ability to deliver a very short (~1 μs), high energy pulse, up to 500 joules each, while operating in the stable resonator mode with peak powers of 2.2 GW, according to the manufacturer. Although the TEA-622 can deliver up to 1000 joules (i.e., 500 J per 620 module in the stable resonator mode) (Fig. 3) (Salvador, 2010).

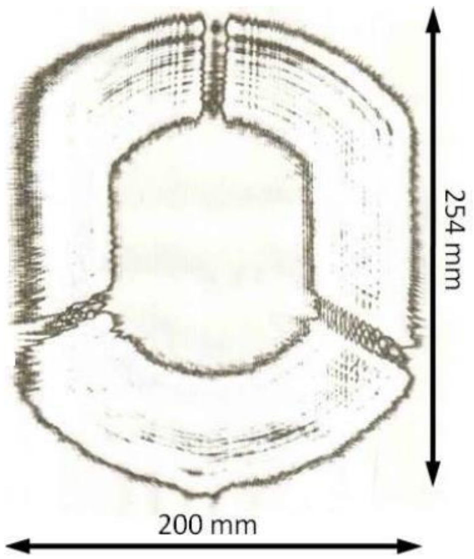

Figure 3. The beam footprint of TEA 622 laser (Salvador, 2010).

The laser pulse characteristics achieved with this high gain (HG) mixture are displayed in Tab. 1 (Patel, 1968).

Table 1. Lumonics TEA-620 laser pulse characteristics with high gain gas mixture.

Parameter (units)	Value
Energy per pulse, (J)	150-230
Wavelength, (μm)	10.6
Peak pulse duration (FWHM), (ns)	90-100
Maximum peak power, (MW)	≈1800
Total pulse duration, (μs)	≈1.0
HG gas mixture flow, (ft^3/hr)	16.0 He/ 6.5 CO_2/ 3.2 N_2
Power supply voltage, (kV)	65-70

2.2 Geometric Design

Through the parabolic function created above (Fig. 2), and using the Autodesk Inventor Software was designed a 3D model of the parabolic mirror, where can be estimate the incidence points of the laser pulse on it, to be performed later a numerical analysis in the TracePRO software, remembering that each pulse of light focused on the parabolic mirror is reflected to a single focal point (Fig. 4).

To create the geometry of the rear of the DVPL, the parabolic function will be revolutionized along the horizontal line in the axis of the abscissa (x axis), giving rise to a solid of revolution in 3D shape, which will allow a better understanding (Fig. 5).

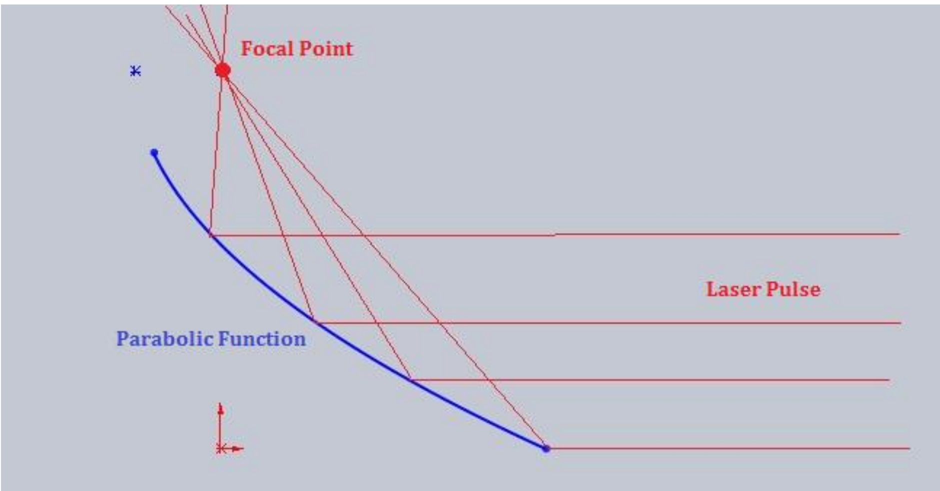

Figure 4. The parabola representing the trailing edge of the DVPL (2D), and the incidence of the laser on it.

Figure 5. The 3D format of the rear of the DVPL.

Remembering that the parabolic function was formed based on the size of the forebody of the DVPL and due to the hypersonic T3 wind tunnel dimensions, which will be used later for the experimental investigation. Thus, the (Fig. 6) shows the dimensions of the DVPL, and indicates where the focal point should be located.

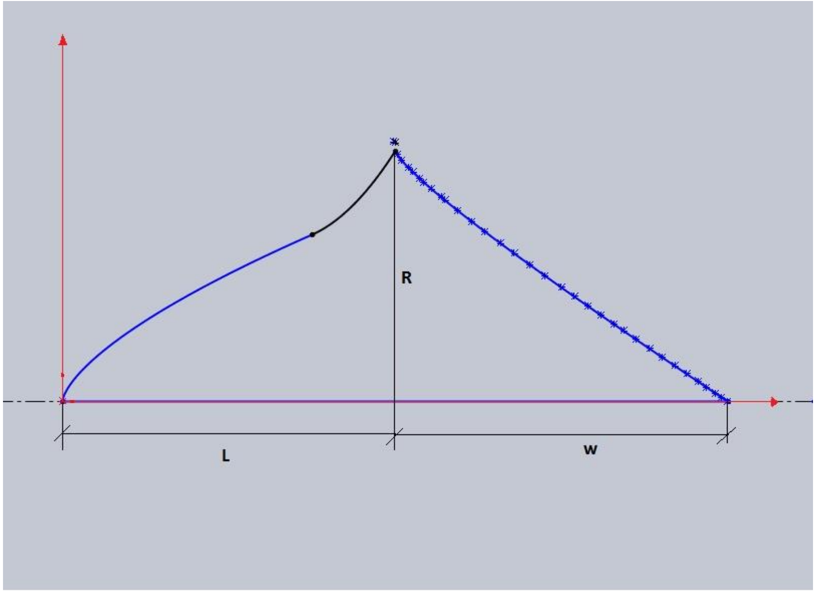

Figure 6. DVPL length representation.

The coordinate L corresponds to the length of the forebody (200 mm), R is the radius of the circumference of the body (150 mm), W is the length of the rearbody (200 mm), and the focal point needs to be locate between 5 to 10 mm above of the circumference of the body, to produce the necessary propulsion system.

2.3 TracePro

TracePro is an optical engineering software for designing, analysis and optimization of optical and lighting systems. It has an intuitive CAD interface and powerful interactive optimizers. TracePro is the first optical analysis software with the industry standard engine, ACIS®, at its core. Can be used to create a virtual prototyping environment to perform software simulation before manufacture.

TracePro has been used in many projects for designing and analyzing all types of optical/ illumination systems ranging from stray light suppression in telescopes and cameras to biomedical applications, to LED modeling and solar collector modeling. In the aerospace market, TracePro is best known for its stray light analysis capabilities.

For this work will be inserted in the software a CAD model of the rearbody of the DVPL and a model of the laser TEA 622, as shown below (Fig. 7).

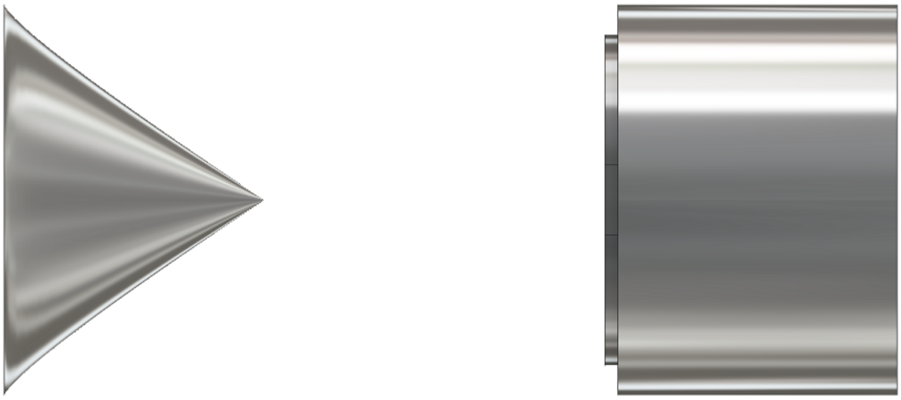

Figure 7. DVPL rearbody and laser.

The frontal image of the laser in a CAD model (Fig. 8) is similar to the format obtained in Fig. 3, and the laser configuration data follow according to table 1, wavelength 10.6 μm, maximum peak power 1800 MW, and absorptance of 0.05.

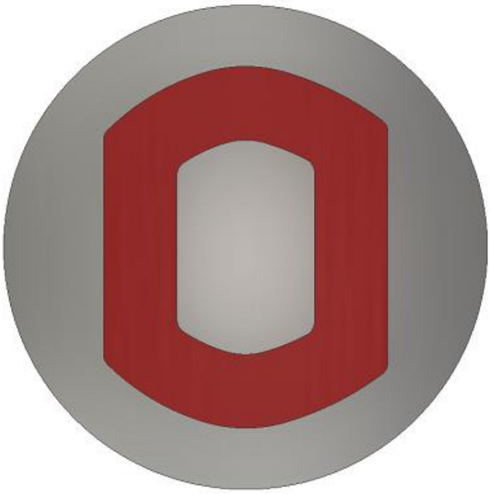

Figure 8. 3D CAD model of TEA 622 laser.

To simulate the interaction of optical physics with matter, the laser pulses will be focused on the rear of the DVPL and then reflected by the parabolic mirror and thus generating the focal point (Fig. 9).

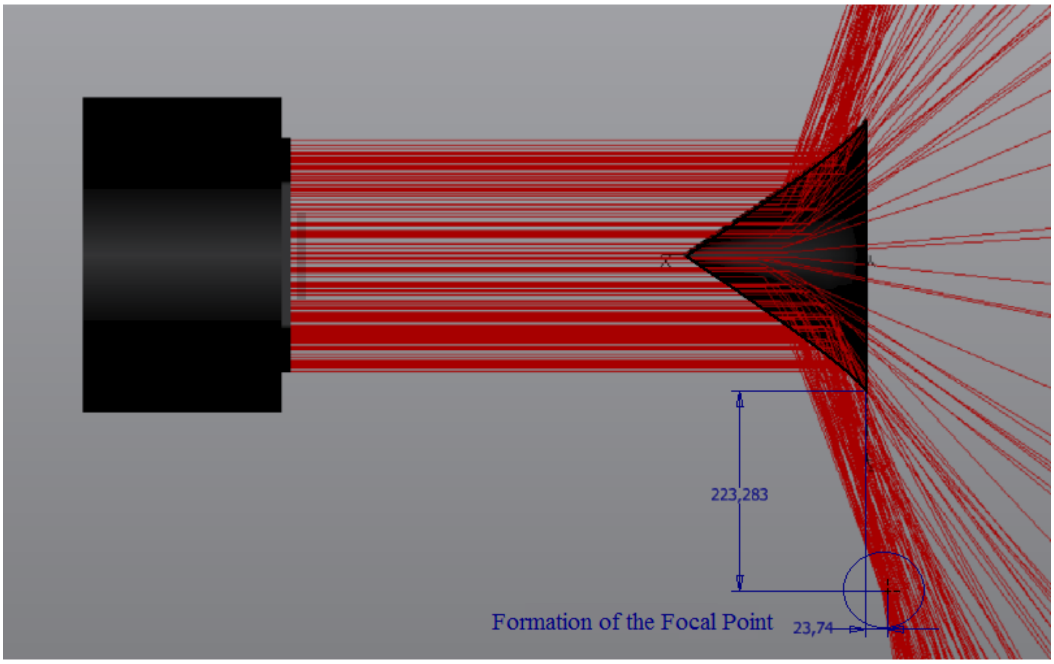

Figure 9. Interaction of the laser with the rearbody of the DVPL resulting in the formation of the focal point.

3. RESULTS AND DISCUSSIONS

As we can see in Fig. 9, it is possible to see the focal point very far from where it should be (5-10 mm above the body radius), so the model needs some changes (by iteration process), due to this, the first modification will be in the designed model, starting with the new shape of the rear of the DVPL, increasing its length. The new concept has a total length of 580 mm. The forebody will keep the original size, which corresponds to 200 mm in length and 300 mm in circumference, so the rearbody increased 180 mm, in search for a better position for the focal point. So, the rearbody stays with 380 mm in length (Fig. 10).

Figure 10. The new concept of the rear of the DVPL.

Now, with a new CAD model, we imported to Excel the points used for create this new design and thus generate a new scatter graphic which shows a new parabolic curve (Fig. 11).

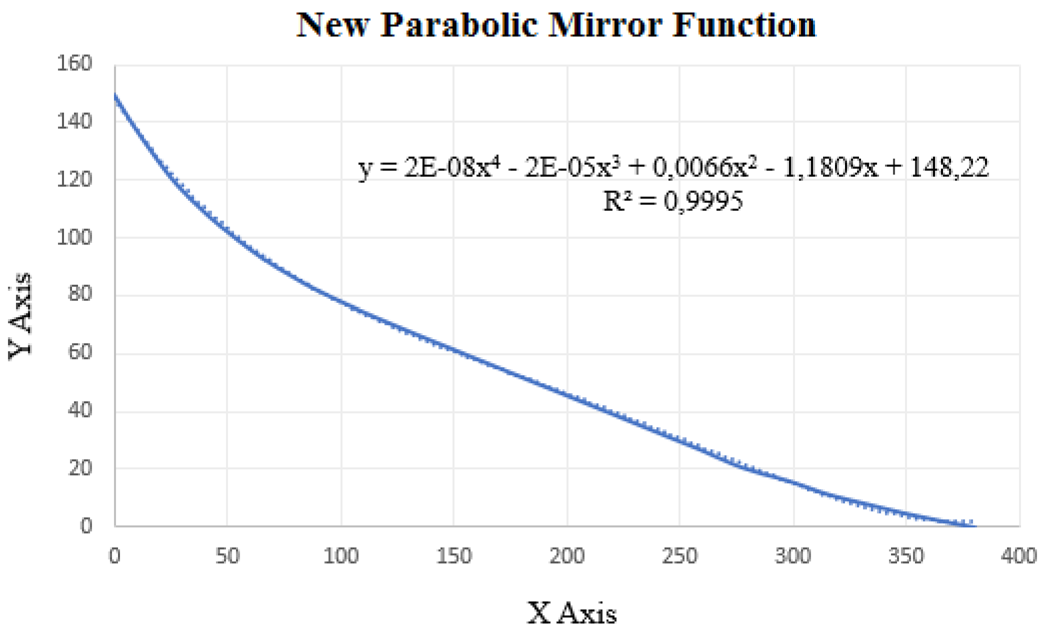

Figure 11. New concept of the parabolic mirror of the DVPL.

A fourth-order polynomial equation was generated (Eq. 2), with determination of the R^2 coefficient.

$$y = 2E\text{-}08x^4 - 2E\text{-}05x^3 + 0{,}0066x^2 - 1{,}1809x + 148{,}22 \tag{2}$$

Finally, was performed the analysis in TracePro software (Fig. 12), and thus the focal point focusing on the rearbody between 5-10 mm above of the body circumference was obtained.

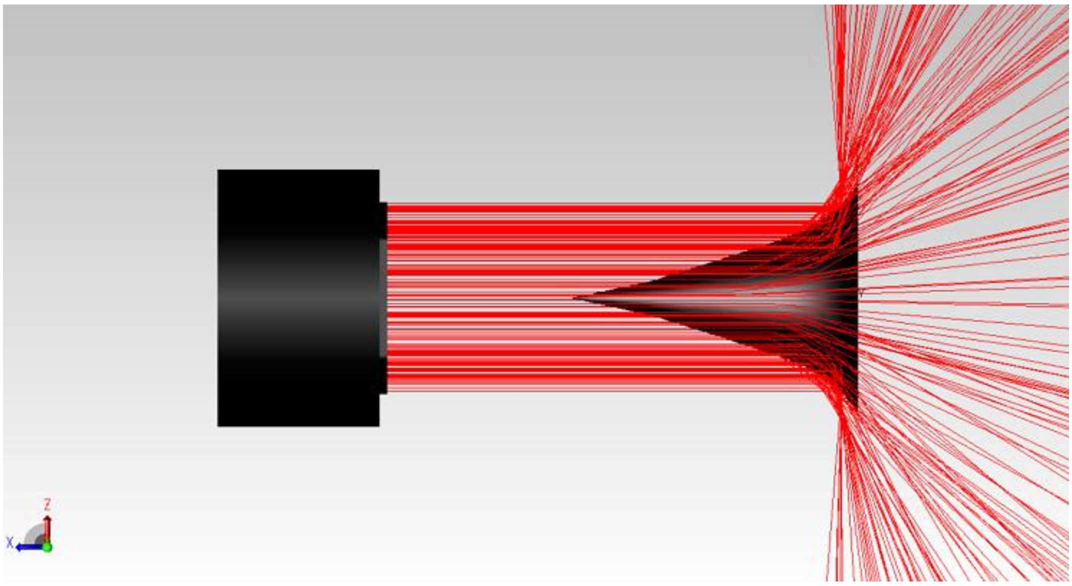

Figure 12. The new concept of the parabolic mirror, and the interaction with the laser pulse.

As now we can see, the focal point is placed at 7.75 mm above the body circumference, below of the shroud, which results the ideal condition to plasma and thrust generation for the vehicle. The Figure below shows the distance of the new focal point (Fig. 13).

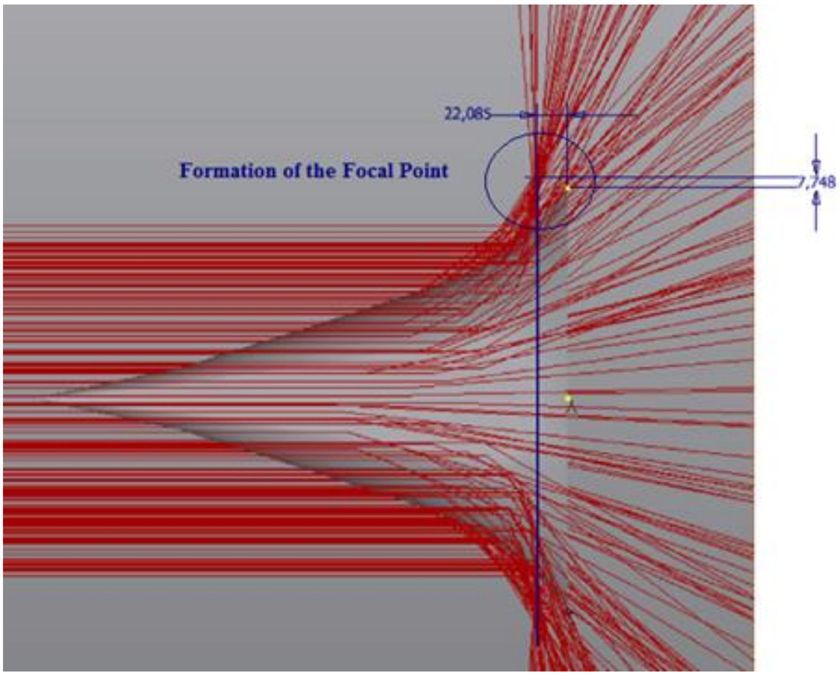

Figure 13. Focal point formation in the new DVPL design.

4. CONCLUSION

The study on the rearbody of DVPL was initially carried out based on previous research. But only with the numerical analysis, it was possible to see the formation of the focal point did not occur exactly as predicted. Therefore, a new numerical analysis and several attempts of 3D models were necessary to establish the correct positioning of the focal point.

The correct positioning of the focal point it is very important to this study, because the laser is the main source of energy for the studied propulsion system, and it is not placed on board of vehicle, allowing an increase in the ratio between the driving force (thrust) and the total weight of the launch vehicle. Such factors, when combined, would revolutionize the traditional space transportation through safe, economical, fast, and ecological access to outer space.

5. REFERENCES

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