DESIGN OF A LIGHTCRAFT MODEL FOR EXPERIMENTATION ON LASER PROPULSION

Felipe Trizzini, felipetrizzini@hotmail.com
Hélcio Francisco Villa Nova, helcio.villa@ufabc.edu.br.com.br
Israel da Silveira Rêgo, israel.rego@ufabc.edu.br
Universidade Federal do ABC, Rua Santa Adélia 166, Bairro Bangu, Santo André - SP, Brazil

Marco Antonio Sala Minucci, sala@ieav.cta.br
Paulo Gilberto de Paula Toro, toro@ieav.cta.br
José Brosler Chanes Junior, brosler@ieav.cta.br
Antônio Carlos de Oliveira, acoc@ieav.cta.br
Laboratório de Aerotermodinâmica e Hipersônica Prof. Henry T. Nagamatsu, Instituto de Estudos Avançados, Rod. dos Tamoios, Putim km 5,5, São José dos Campos – SP, Brazil

Abstract. *Instead of powering a rocket with explosive chemical reactions, a innovative concept, called laser propulsion, involves propelling a rocket by beaming energy to it from outside laser sources. Such a technology would make possible much easier and cheaper access to space. This paper concerns the optical and aerodynamics design of an aerospace vehicle, named lightcraft, which has being currently projected at Universidade Federal do ABC for future hypersonic wind tunnel experiments on laser propulsion in collaboration with the Institute for Advanced Studies of the Brazilian Air Force.*

Keywords: Laser propulsion, Lightcraft, Prototype, Optics, Aerodynamics

1. INTRODUCTION

Lightcraft is a revolutionary vehicle whose flight principles, structure, and propulsion systems are radical departures from conventional launch vehicles and whose unique performance will bring affordable, easy and mainly safe access to space (Myrabo and Lewis, 2009). Conventional rockets must carry combustible material and oxidizers to provide the energy, and therefore must be very large and heavy. On the other hand, a ligthcraft vehicle carries much less or no propellants, since it derives its working fluid from the atmosphere, and receives the power needed for its propulsion from an outside source such as beamed laser or microwave power (see Fig. 1). Thus a major saving in the launch cost or price is possible with ligthcraft technology because of the good-sized and lightweight hardware.

Figure 1. Artistic view of a lightcraft in atmospheric flight under laser power beam (from LTI, 2009).

To be realistic about lightcraft technology, extensive studies of the design of lightcraft vehicle and complex experiments on laser propulsion physics have been pursued by various scientists and engineers around the World. Laser propulsion physics are now much more understood, as laser-induced air breakdown experiments are underway at the Henry T. Nagamatsu Laboratory of Aerothermodynamics and hypersonic at the Institute for Advanced Studies (IEAv) of the Brazilian Air Force in São José dos Campos, Brazil – in cooperation with U.S. Air Force and the Rensselaer Polytechnic Institute (Salvador, 2010). Recently, the Federal University of ABC (UFABC) in Santo André, Brazil has begun the studies on the design of a lightcraft vehicle in partnership with IEAv for future experimentation on laser propulsion physics. This paper concerns a 3D CAD lightcraft model preliminarily designed at UFABC.

2. LIGTHCRAFT CONFIGURATION AND OPERATION

The lightcraft vehicle is an innovative combined-cycle engine (air-breathing and rocket) whose main structures are a forebody, a shroud (inlet) and an afterbody as shown in Fig. 2. The forebody acts as an airbreathing engine inlet which slows down and compresses the air prior to admission into the ignition chamber of the lightcraft. The afterbody has a dual function: It is the primary receptive optic (parabolic mirror) for the laser beam which provides power to the engine, and it is also a plug nozzle for expansion of the exhaust gas. The primary thrust structure is the annular shroud. The shroud serves as both air inlet (along with the forebody) and impulsive thrust surface.

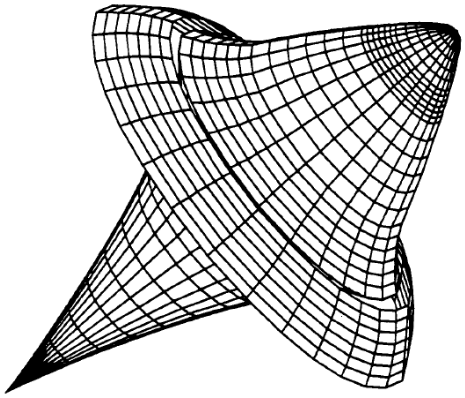


Figure 2. Lightcraft vehicle configuration (Adapted from Myrabo, 1988).

Basically, the operation of the lightcraft vehicle can be described as follows. A pulsed laser light is beamed to the parabolic optic at the rear of the engine, then is reflected and concentrated into the ignition chamber, causing explosion of the air with production of a high temperature and high pressure air plasma. Such plasma soon expands accompanied by a shockwave that interacts directly with the shroud and the plug nozzle, creating momentary elevated pressures which result in impulse. In this way, laser energy is converted into a detonation shockwave which transfer momentum to the vehicle as shown in Fig. 3.

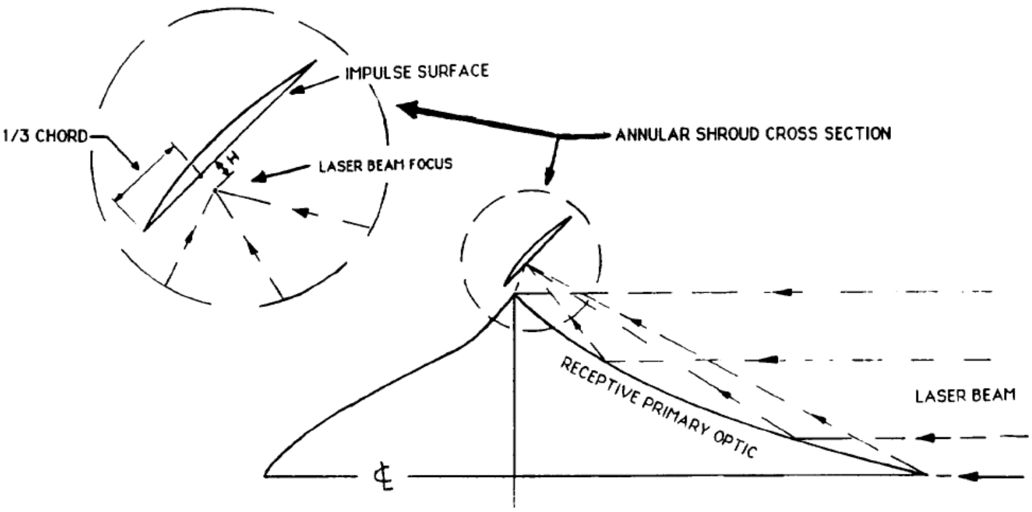


Figure 3. Side view of the lightcraft vehicle showing its principle of operation (Adapted from Myrabo, 1988).

3. RESULTS AND DISCUSSIONS

3.1 Nose cone design

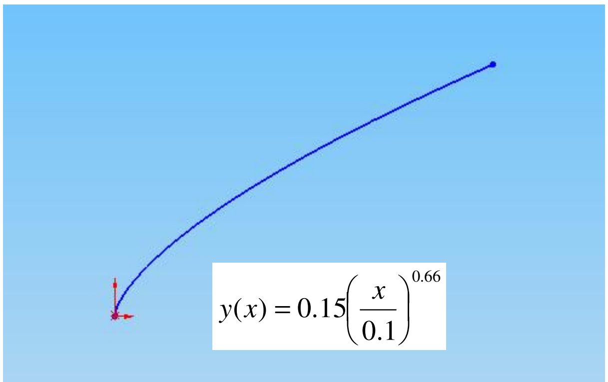
The nose cone is the fowardmost structure of the lightcraft and should be design to withstand head load and to lower aerodynamics resistance. The best geometry for nose cones during supersonic and hypersonic phases of flight is given by power series such as:

$$y(x) = a\left(\frac{x}{b}\right)^n \tag{1}$$

, where a is the nose cone length, b is the nose cone radius and n is a power factor. Values of n within 0.5 and 0.75 leads to nose cone shapes whose total drag coefficient decreases with increasing Mach numbers (above Mach 1). A power factor of 0.66 was then arbitrarily chosen. The quantities a = 0.15 and b = 0.1 m were selected to satisfy experimental constrains such as laser spot size (18 cm in diameter) and test section dimension of the IEAv hypersonic wind tunnel (1 m in width × 1 m in height × 1.4 m in length). The nose caliber is around 0.75 which is good to dissipate aerodynamic heat at high speeds. A tentative contour of the lightcraft nose cone is given by the following power series:

$$y(x) = 0.15\left(\frac{x}{0.1}\right)^{0.66} \tag{2}$$

Figure 4 shows the lightcraft nose created by the rotation of Equation (2) around its symmetry axis and the internal configuration of the nose for instrumentation and assembly to the compression ramp (next sub-section).



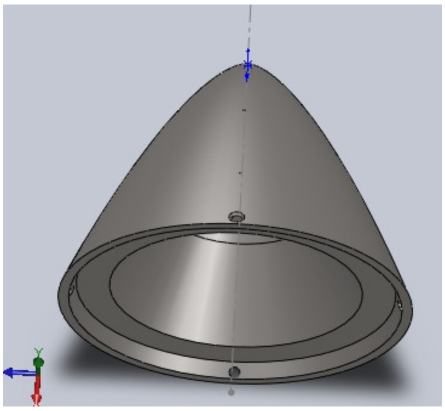


Figure 4. Lightcraft nose contour (left) and 3D CAD configuration (right).

3.2. Compression ramp design

The compression ramp should be design to compress the air isentropically by means of compression waves and slow-down the velocity of the air flow prior to enter to the ignition region of the lightcraft. Figure 5 shows the forebody contour of the lightcraft which consists basically of the nose cone followed by the compression ramp.

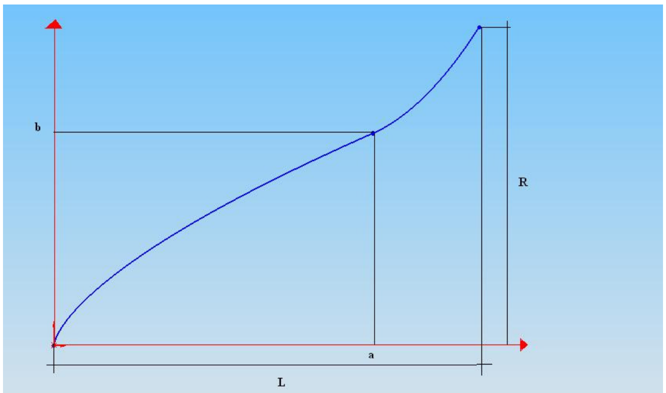


Figure 5. Contour of the lightcraft foreboby.

As shown in Fig. 5 the quantities L and R are the forebody length and radius, respectively. For the sake of simplicity, the compression ramp contour was chosen to have the shape of a parabola such as:

$$y(x) = Ax^2 + Bx + C \tag{3}$$

, where A, B and C are unknown coefficients that should be found analytically. The continuity of both contours at $x = a$ along with the boundary conditions at their ends allow A, B and C to be written as a function of the quantities a, b, n, L and R as follows:

$$A = \frac{bn}{2a^2} - \left[\frac{2Ra^2 - bnL^2 - 2ba^2 + bna^2}{2a^2(-L^2 + 2aL + a^2)}\right] \tag{4}$$

$$B = \left[\frac{2Ra^2 - bnL^2 - 2ba^2 + bna^2}{-L^2 a + 2La^2 - a^3}\right] \tag{5}$$

$$C = b - \frac{bn}{2} + \left[\frac{-2Ra^2 - bnL^2 + 2ba^2 - bna^2}{-L^2 + 4aL - 2a^2}\right] \tag{6}$$

The quantities L = 0.2 and R = 0.15 m were chosen to satisfy the experimental constrains mentioned previously. A tentative contour for the compression ramp is the following parabola:

$$y(x) = 11.2x^2 - 2.9x + 0.3 \tag{7}$$

Figure 6 shows the lightcraft forebody created by the rotation of Equations (2) and (7) around their symmetry axis and a prediction of the flow around the lightcraft forebody with CFX code at Mach 6. Note that the air flow around the forebody for supersonic flight behaves like a conical flow with a weaker oblique shock emanating from the tip and streamlines deflected not exactly parallel to the forebody surface (in contrast with supersonic flow over a wedge).

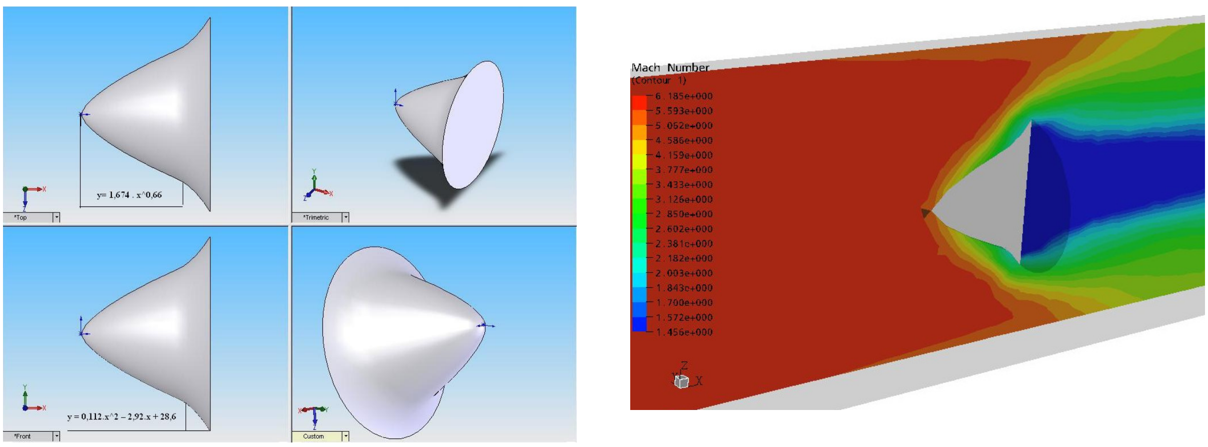
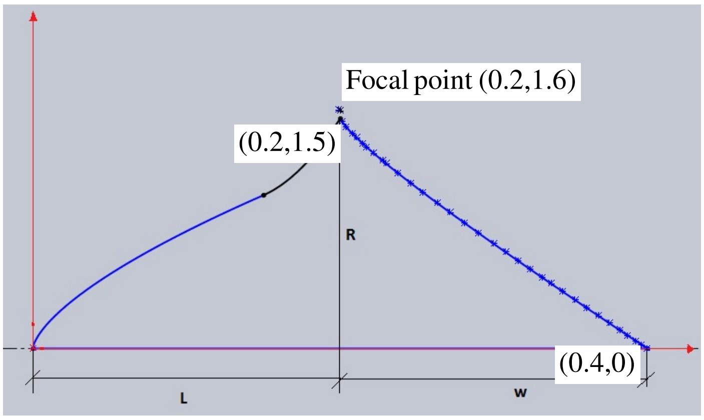


Figure 6. Lightcraft forebody configuration (left) and CFX velocity contours at Mach 6 (right).

3.3 Afterbody design

The lightcraft afterbody should be design to be a parabolic reflector and at the same time a plug nozzle. Thus, the afterbody is the heart of the lightcraft. The criteria for designing the afterbody are both optical and aerodynamic. Only the optical criterion of the reflector is discussed herein.

For the sake of simplicity, the afterbody contour was chosen to be a parabola. A tentative parabola with focus at x = 0.2 and y = 0.16 was then obtained by interpolation between the following points on the parabola: (0.2, 0.15) and (0.4, 0). An afterbody length of 0.2 m was chosen to satisfy the test section dimension of the IEAv hypersonic wind tunnel. The parabola equation can be easily modified by altering its focal point as shown in Fig. 5. The aerodynamic characteristics of the present afterbody contour will be better analyzed by means of numerical flow experiments with CFX software.



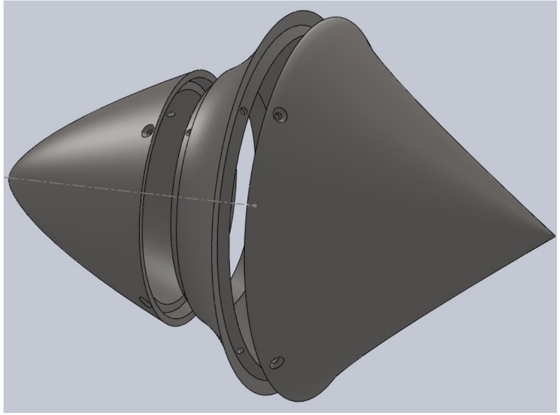


Figure 5. Contours of both forebody and afterbody (left) and 3D CAD forebody plus plug nozzle (right).

3.4 Shroud design

The shroud serves as primary structure for delivering impulse to the lightcraft. Such a structure should withstand strong shock waves generated by the laser-induced air explosion. The presenting design is based on the previous studies of Myrabo, 1998. The design and location of the shroud should be such that its weight and drag are reduced and the impulse maximized. Initially, the shroud contour was chosen to be triangular with its lower base as a plate as shown in Fig. 6. In order to save weight and become the shroud more aerodynamic during the atmospheric flight, the triangular contour was altered as sketched in Fig. 6. In spite of all the considerations mentioned above numerical flow analyzes with CFX software will be performed for better design the present shroud contour.

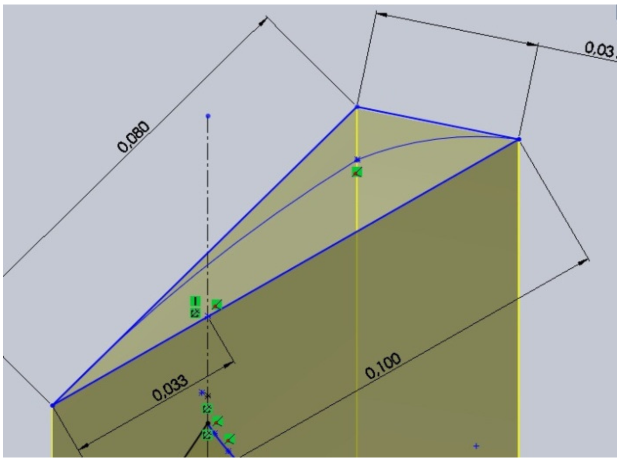


Figure 6. Comparison between the triangular and smoothed shroud contours (in meter).

The shroud position should be chosen in order to interact with as many shock wave fronts as possible. Figure 7 shows two tentative positions of the shroud with respect to focal point. Note that when the shroud tip is placed above the focal point a few number of shock fronts interact with the lower plate. On the other hand, when the shroud tip is displaced horizontally towards nose more shock fronts are then blocked by the lower plate, thereby increasing somehow the thrust. The vertical position of shroud should be chosen based on thrust and heat transfer criteria. The annular shroud should be supported by struts fitted on the lightcraft body. Both shroud and its support struts should be able to withstand stresses caused by successive detonation waves induced by the repetitive laser beams. Figure 8 shows the preliminary drawings of the support struts. Nonetheless numerical flow analyzes with CFX software will be performed for better design and place the shroud as well as stress and deformation analysis better design the support struts.

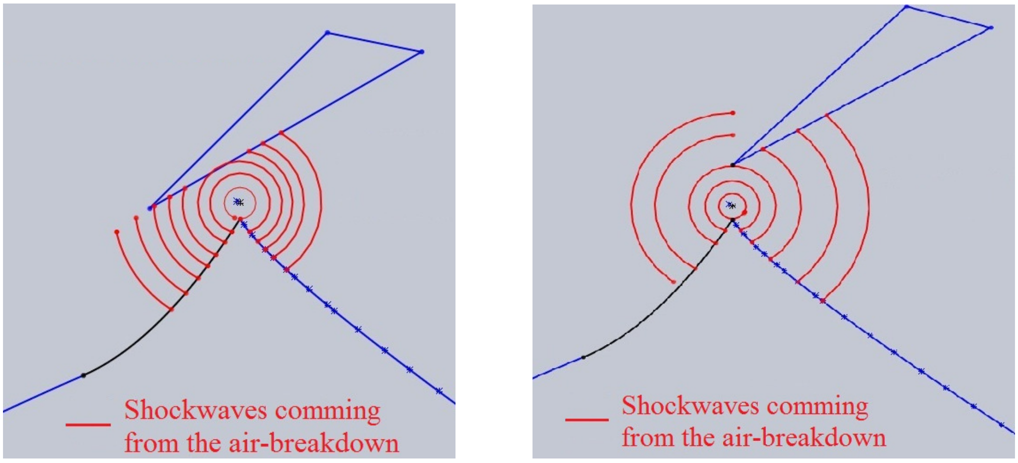


Figure 7. Shroud tip in position forward (left) and rearward (right) of the focal point.

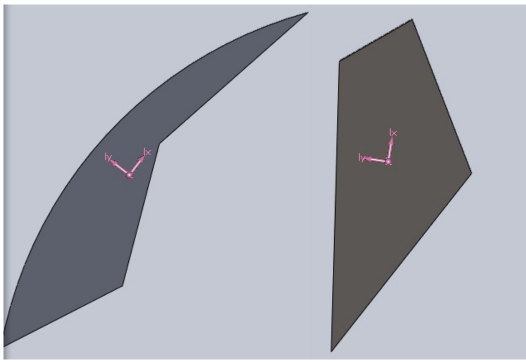


Figure 8. Shroud strut designs: Left strut is almost 80 % lighter than right one.

Figure 9 shows a 2D view along with 3D drawings of the lightcraft (shroud struts not shown) created from rotation of each tentative contour around the center line. The 3D CAD lightcraft forebody and afterboby can be conveniently changed altering each contour obtained previously, i.e., changing the quantities a, b, n, L, R and the parabola focal point. Numerical flow analyzes with CFX software will serve as a guideline for the aerodynamic design of the lightcraft as it becomes more elaborated.

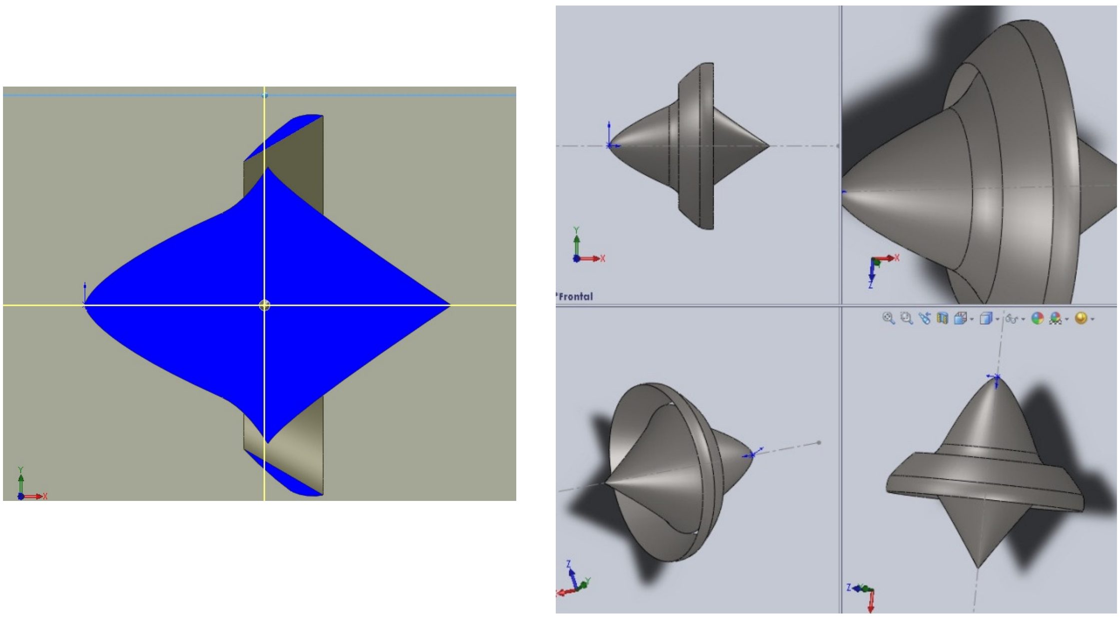


Figure 9. 2D view of the lightcraft (left) and 3D CAD lightcraft (right).

4. CONCLUSIONS

Lightcraft is a revolutionary air and space vehicle driven by remote sources of laser power. Such a technology will be available in next two decades. Recently, UFABC began study of lightcraft technologies. Based on aerodynamics and optical criteria, the forebody, afterbody and annular shroud of the lightcraft were preliminarily designed herein. As the design of the UFABC lightcraft become more elaborated, it will be constructed and then tested in the IEAv hypersonic wind tunnel, under a collaborative research between both institutions. Future works include performing numerical flow simulations and stress and deformation analysis that will all serve as design baseline and completing the internal configuration of the lightcraft.

5. ACKNOWLEDGEMENTS

The first author thanks the Conselho Nacional de Desenvolvimento Cientifico e Tecnológico (CNPq) for providing his scholarship.

6. REFERENCES

LTI, 2009, “Lightcraft Technologies, Inc.” 22 Feb. 2011 < http://www.lightcrafttechnologies.com/technology.html>.

Myrabo, L. N, 1988, “Apollo Ligthcraft Project”, NASA/USRA Advanced Design Program, Florida, USA, pp. 16.

Myrabo, L. N and Lewis J. S., 2009, “Lightcraft Flight Handbook”, Ed. Apogee Books, Ontario, Canada, pp. 15.

Salvador I. I., Myrabo L. N., Minucci M. A. S., Oliveira A. C., Rêgo I. S., Toro P. G. P., Channes Jr. J. B., 2010. “Experimental Analysis of a 2-D Lightcraft in Static and Hypersonic Conditions”. AIP Conference Proceedings, Vol. 1230, pp. 61-76.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.