

## COB-2019-0746

# PROPOSAL OF A RACING WHEELCHAIR PARTIALLY BUILT IN ADDITIVE MANUFACTURE

**DONEGA, Thiago Jose**  
**ALVES, Diego Augusto Costa**  
**SOUZA, Márcio Peres de**  
**ARAUJO, Cleudmar Amaral de**

Federal University of Uberlandia, Mechanical Engineering College, Laboratory of Mechanical Projects, Technological Innovations Center in Paralympic Sports (CInTEsP), Uberlandia, Brazil

thdonega@yahoo.com.br, diegoaugusto@ufu.br, marcioperes@ufu.br, cleudmar.araujo@ufu.br

**FREITAS, Deny Gomes de**

Pitágoras College, Course in Physiotherapy, Uberlandia, Brazil

denyfreitas@hotmail.com

**Abstract.** *Among the advances evidenced over time in race wheelchairs, the use of new materials and the reduction of the mass of the equipment stand out. Thus, the objective of the present work is to evaluate the use of a structural profile partially constructed with the use of additive manufacturing. Computational simulation of the structure was done by the finite element method, considering part manufactured by additive manufacture and part made of aluminum alloy. The results showed that the structure supports the applied static loads and the weight of new structure is lower than other commercial racing wheelchairs. We conclude that it is possible to build equipment that partially uses manufacturing by the additive manufacturing method and that other materials must be tested to evaluate the most suitable material.*

**Keywords:** *Racing Wheelchairs, Finit Elements, Paralympics, Additive Manufacturing*

## 1. INTRODUCTION

Since the begin of the wheelchair race in the Paralympics, there have been a lot of changes in the designs of these equipment. The changes have brought about extraordinary improvements in athlete performance (Masse *et al.*, 1992).

According to Masse *et al.* (1992) In the 1980s there were the development of new racing wheelchairs that can be responsible for extraordinary improvements in the wheelchair racing performance. Among these improvements can be mentioned changes in the structure that gave improvement in the aerodynamics of the chairs and decrease in structure mass.

Most racing wheelchairs structures are made of aluminum, steel, or titanium, and some carbon fiber composite (Cooper, 1991).

According to Järveläinen (2008), the racing wheelchairs are comonly made of an aluminum structure that is fairly lightweight. Figure 1 shows an example of a currently used racing wheelchair.



Figure 1. Tatyana McFadden on a racing wheelchair at a Paralympic Games. Available from: [http://mediad.publicbroadcasting.net/p/shared/npr/styles/x\\_large/nprshared/201805/160392341.jpg](http://mediad.publicbroadcasting.net/p/shared/npr/styles/x_large/nprshared/201805/160392341.jpg). Accessed in: 03/27/2019

The current racing wheelchair uses the most diverse materials for the fabrication of the main structure. Among the materials currently used are the 6061 T6 aluminum alloy (INVACARE™ show in the Fig. 2, MOTIVATION™ and SPEED RACING™), 7020 aluminum alloy (WOLTURNUS™) and carbon fiber (OX™, BMW™ show in the Fig. 3, KIWAMI™ and IDOMI™ show in the Fig. 4).



Figure 2. The structure of this racing wheelchair manufactured by TOP END/INVACARE is made of 6061 T6 aluminum alloy. Available from: [https://topendwheelchair.invacare.com/file/v4536626461701872225/general/TopEndHeroBannerHigh%20D\\_Roman\\_03.jpg](https://topendwheelchair.invacare.com/file/v4536626461701872225/general/TopEndHeroBannerHigh%20D_Roman_03.jpg). Accessed in: 06/02/2019.

The BMW Designworks development studio, located in California, USA, has developed a carbon fiber racing wheelchair for the United States Paralympics athletics team to use at the Rio 2016 Paralympics, shown at Fig. 3 (Newcomb, 2016). According to a report by Newcomb (2016), BMW used carbon fiber instead of traditional aluminum structures to increase the strength/weight ratio and to improve aerodynamics, since with carbon fiber the possibilities of redesigning the shape of the equipment are greater (Newcomb, 2016).



Figure 3. Racing wheelchair developed by BMW. Available from: (Newcomb, 2016).

Honda-Yachiyo company is developing a fully carbon fiber structure (Cooper *et al.*, 2018). Honda-Yachiyo offers two models of carbon fiber racing wheelchair, KIWAMI™ and IDOMI™, shown at Fig. 4.



Figure 4. Racing Wheelchair models IDOMI (left) and KIWAMI (right) developed by Honda-Yachiyo. Available from: <https://www.yachiyo-ind.co.jp/lib/2018/03/kiwamiidomi1.jpg>. Accessed in: 29/05/2018

Several authors affirm that the mass of the race wheelchair is one of the most influence variables on the performance of the athlete. Thus, the more it is possible to decrease the mass, the less time the athlete will spend to reach the finish line

(Fuss, 2009; Mason, 2011; Barbosa and Coelho, 2017). By this way, a product made from plastic materials by means of additive manufacture has the possibility of reducing the mass of the equipment due to the low densities of materials used in 3D printing, such as PLA (Polylactic acid), ABS (acrylonitrile butadiene styrene) and Tritan™.

According to Volpato and Carvalho (2017) it is possible to construct parts and prototypes through the additive manufacture from a 3D (three-dimensional) representation of an object made in a Computer-aided Design (CAD) system. According to the authors it is possible to construct complex geometries by means of the successive addition of layers of the material used (Volpato and Carvalho, 2017).

Thus, due to the importance of the mass decrease in the structure of the racing wheelchair, and in view of the possibilities that the additive manufacture has presented the objective of the present work is to evaluate the use of a structural profile partially constructed with the use of additive manufacturing.

## 2. COMPUTATIONAL PROCEDURE

The model was designed based on measures found in the user manual and parts catalogs of the TOP END™, INVACARE racing wheelchair. In addition, measurements were taken of SPEED RACING™ racing wheelchair made available by a wheelchair athletics team from SESI, Uberlândia. The cage of the racing wheelchair was designed based on commercial profiles available in manufacturer's catalogs, such as the examples shown in Fig. 5, such as round tubes, round bars and flat bars. These are profiles commonly used in the construction of equipment and are commercially found with certain ease. These profiles can be seen on racing wheelchair cage in Fig. 6.

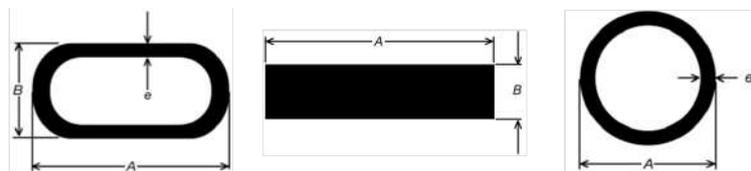


Figure 5. Structural profiles used in the model with comercial profiles. Font: (ALCOA, 2015)

The front of the model, consisting of the fork, steering and T-frame, was designed in an aerodynamic format and for manufacturing using additive manufacture (Fig. 6).

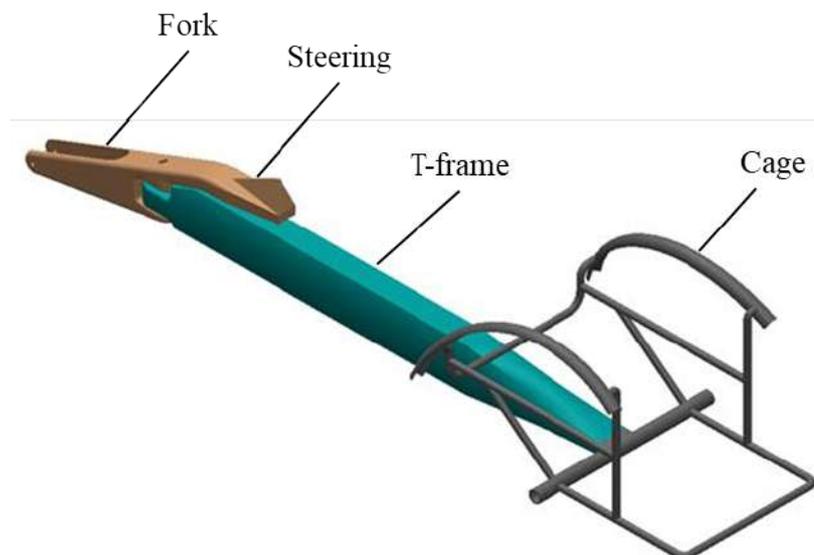


Figure 6. New model of racing wheelchair designed with parts to built by additive manufacturing.

After the modeling of the racing wheelchair was completed, the structural static analysis was carried out by the finite element method (MEF), aiming to investigate the mechanical strength of the structure and the critical points likely to fail due to static loads.

In the analysis was used the ANSYS™ software. The material assigned to the cage for analysis was the 6061 T6 aluminum alloy. Its mechanical properties are: Young's Modulus 71 GPa, coefficient of poisson 0,33, Yield Strength 280 MPa. Already in the Fork, Steering and T-frame was assigned the material PLA. Its mechanical properties are: Young's Modulus 3.5 GPa, coefficient of Poisson 0,36 and Yield Strength 59 MPa.

According to Callister (2008), one of the main characteristics of aluminum and its alloys is its relatively low specific

mass ( $2.7 \text{ g/cm}^3$  compared to  $7.9 \text{ g/cm}^3$  of steel). PLA also has a relatively low specific mass ( $1.25 \text{ g/cm}^3$  compared to aluminum  $2.7 \text{ g/cm}^3$ ).

As we can be seen from Figure 7, the locked made on the tested structure are indicated by the red arrows. The lock of the structure were made at all points where the racing wheelchair wheels are located. Thus, were locked the supports (axle holes) of the two rear wheels and the front wheel support (axle hole).

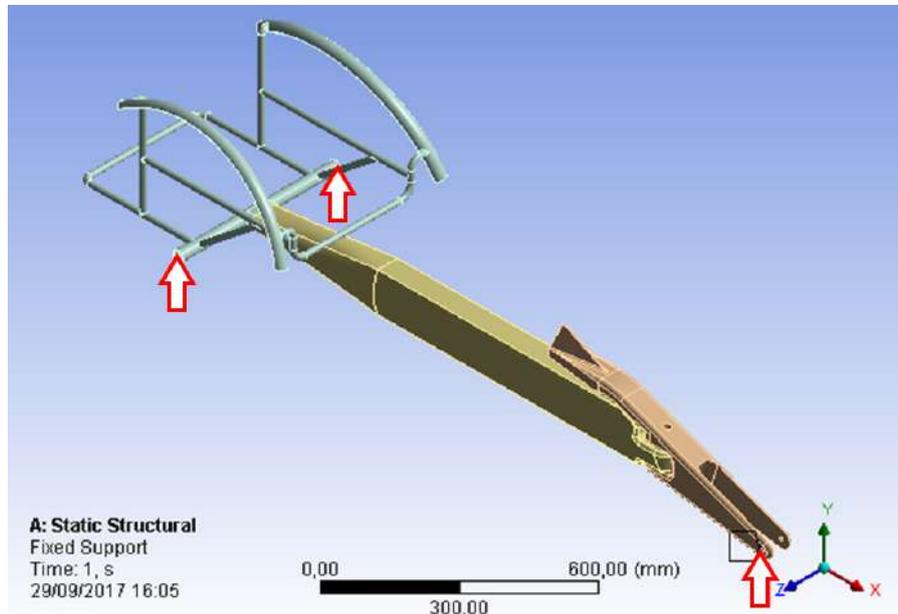


Figure 7. Points were the structure was locked.

In the preliminary tests using finite element modeling a vertical load of 1800 N was defined, essentially, on the two tubes that support the load of the athlete in the seat cage. This load was applied to the center of gravity of the two tubes located in the center of the seat cage, showed in the Figure 8.

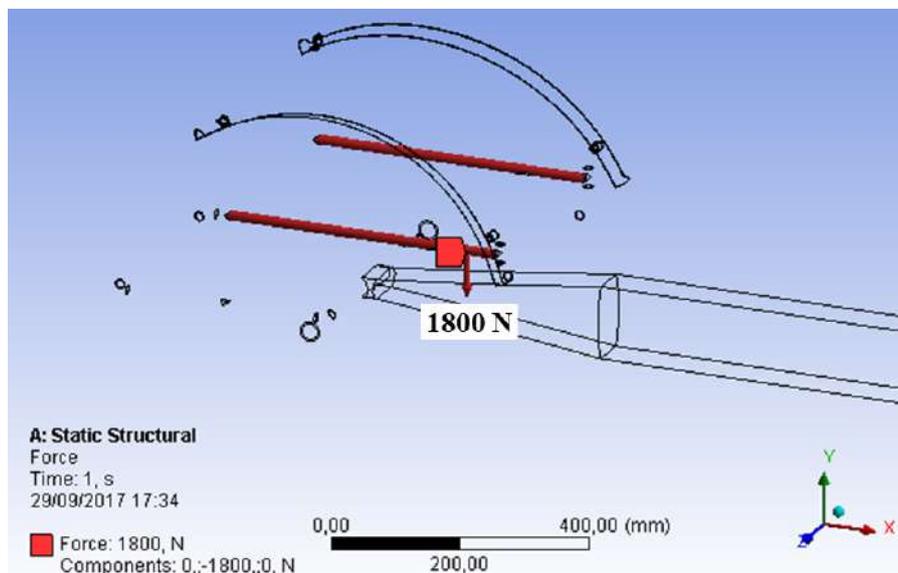


Figure 8. Position of vertical load in the seat cage.

### 3. RESULTS AND DISCUSSION

Figure 9 shows results of the structural millimetric displacement in the racing wheelchair's frame. Note that the maximum displacement is approximately 9.26 mm. This displacement is justified by the fact that it is in the part of the structure that was designed using aluminum alloy. In this area the dimensions are same as a lot of equipment already used by many athletes. Therefore, this issue is not of concern, since there is no such problem in current equipment used on the athletics.

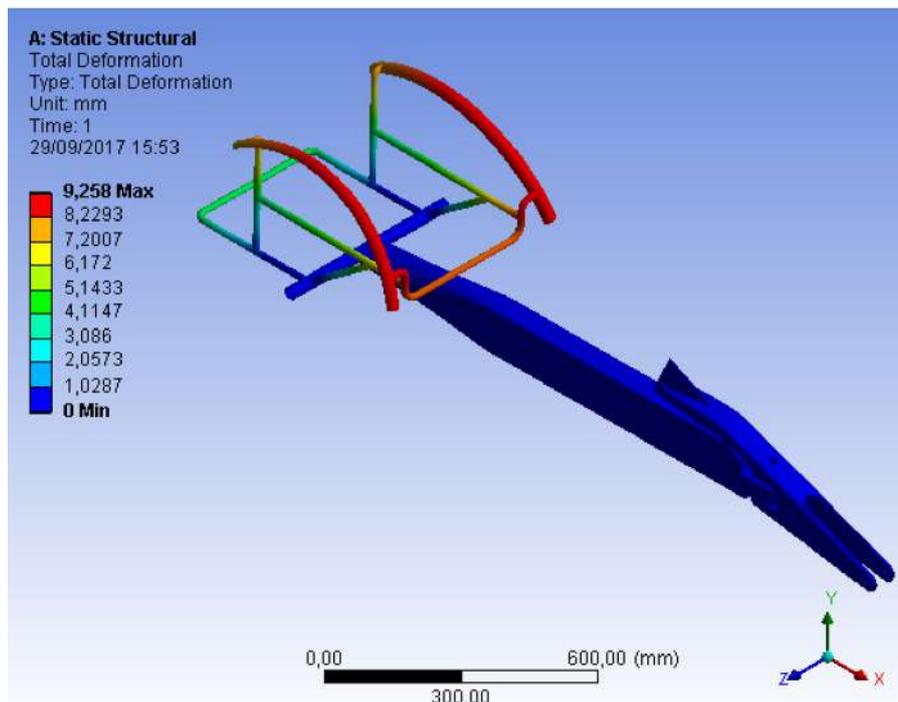


Figure 9. Illustration of the result obtained with the deformation in the racing wheelchair structure.

The results of the structural analysis show that the maximum von-Mises equivalent stresses reached 262.5 MPa at the cage which was designed with aluminum profiles (Fig. 10). Thus, it is considered that the maximum stress that the structure can reach is equal to the material Yield Strength (the aluminum Yield Strength is 280 MPa). Therefore, it is possible to verify that the structure meets the requirement of mechanical strength.

It is important to clear that in the parts where additive manufacture was used, the maximum von Mises tensions were below 59 MPa (PLA Yield Strength).

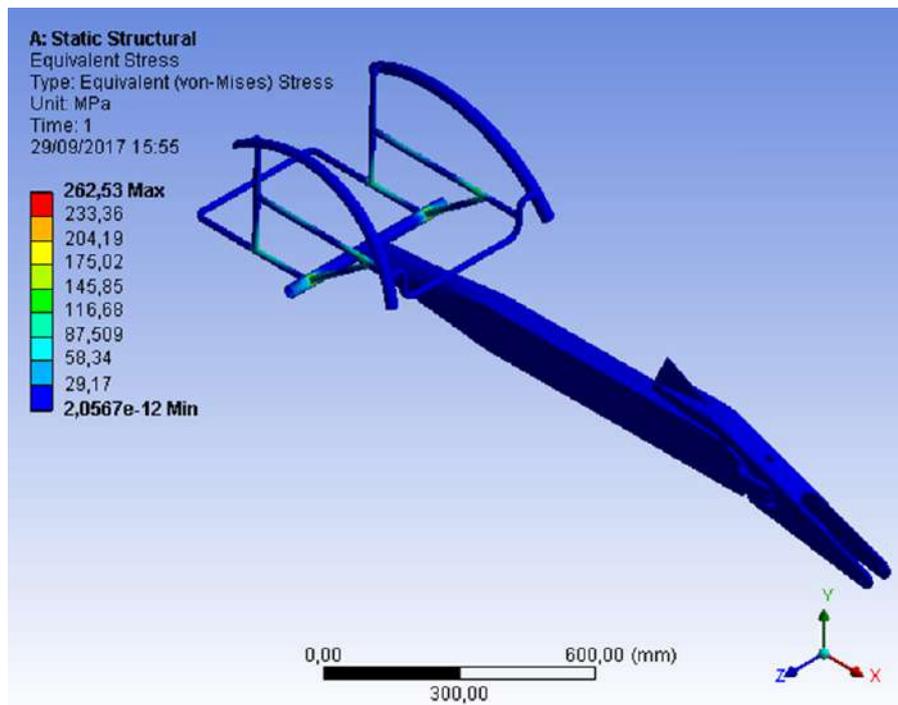


Figure 10. Illustration of the result obtained with the von-Mises equivalent stress in the racing wheelchair structure.

The mass of the model also deserves attention. In this case, the simulation presented a theoretical mass of 3.15 kg. This is lighter than the 4.5 kg of the racing wheelchair with commercial profiles, and made entirely of aluminum,

presented by Donegá (2015). This information is important because the weight of the racing wheelchair is significant to the performance of the athlete.

#### 4. CONCLUSIONS

This preliminary analysis shows that it is possible to build parts of a racing wheelchair using additive manufacture. However, it is noted that it is necessary to do other types of tests and analyzes to validate the use of this type of manufacturing in these equipments. In this work, PLA was used for 3D printing, which is an interesting material for making prototypes, but it is not suitable for the construction of final products. As a suggestion of future work, it is indicated to test other 3D printing materials, such as Tritan™, which is a lightweight plastic and has better mechanical properties than PLA and ABS. Figure 11 shows the racing wheelchair partially built in additive manufacture, assembled with rear and front wheels.

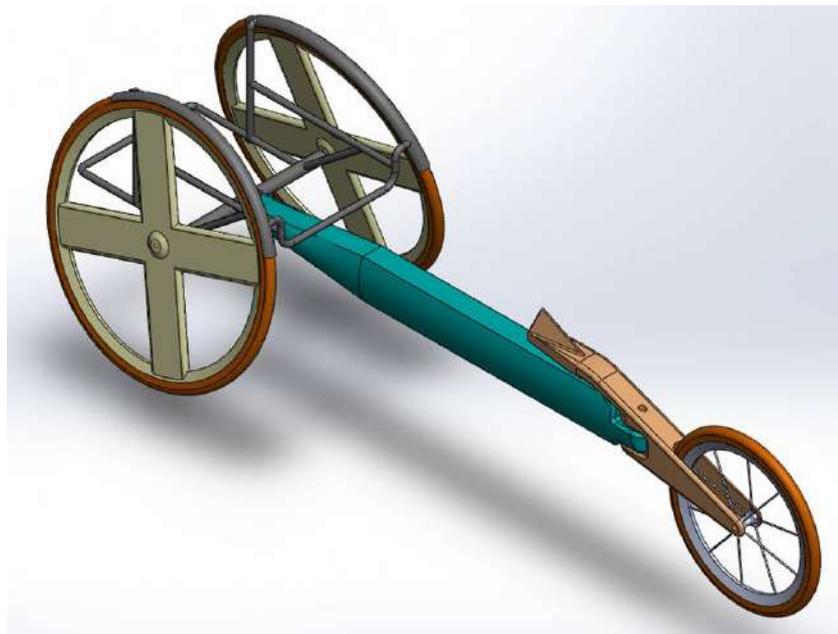


Figure 11. Racing wheelchair assembled

#### 5. ACKNOWLEDGEMENTS

The authors would like to acknowledge CNPq, CAPES, FAPEMIG, for the financial support to this research work, and to allow the participation on this event.

#### 6. REFERENCES

- Barbosa, T.M. and Coelho, E., 2017. "Monitoring the biomechanics of a wheelchair sprinter racing the 100 m final at the 2016 paralympic games". *European Journal of Physics*, Vol. 38, No. 4, p. 044001. URL <http://dx.doi.org/10.1088/1361-6404/aa6905>.
- Callister, J.W.D., 2008. *Ciência e engenharia de materiais: uma introdução*. Livros Técnicos e Científicos.
- Cooper, R.A., 1991. "High-tech wheelchairs gain the competitive edge." *IEEE engineering in medicine and biology magazine: the quarterly magazine of the Engineering in Medicine & Biology Society*, Vol. 10, No. 4, pp. 49–55.
- Cooper, R.A., Tuakli-Wosornu, Y.A., Henderson, G.V., Quinby, E., Dicianno, B.E., Tsang, K., Ding, D., Cooper, R., Crytzer, T.M., Koontz, A.M., Rice, I. and Bleakney, A.W., 2018. "Engineering and technology in wheelchair sport". *Physical Medicine and Rehabilitation Clinics*, Vol. 29, No. 2, pp. 347–369. URL <http://dx.doi.org/https://doi.org/10.1016/j.pmr.2018.01.013>.
- Donegá, T.J., 2015. "Equipamento para personalização de cadeiras de rodas de corrida". Universidade Federal de Uberlândia.
- Fuss, F.K., 2009. "Influence of mass on the speed of wheelchair racing". *Sports Engineering*, Vol. 12, No. 1, pp. 41–53.
- Järveläinen, K., 2008. "Kinematic differences between three wheelchair racers (t54) in sprint start". University of Jyväskylä.
- Mason, B., 2011. "The ergonomics of wheelchair configuration for optimal sport performance".

- Masse, L., Lamontagne, M. and O'riain, M., 1992. "Biomechanical analysis of wheelchair propulsion for various seating positions." *Journal of rehabilitation research and development*, Vol. 29, No. 3, pp. 12–28.
- Newcomb, T., 2016. "Bmw made a carbon fiber racing wheelchair for team usa". Disponível em: <http://www.popularmechanics.com/adventure/sports/a20566/bmw-made-a-carbon-fiber-racing-wheelchair/>. Acessado em: 02 de Julho de 2016.
- Volpato, N. and Carvalho, J.d., 2017. "Introdução à manufatura aditiva ou impressão 3d". In N. Volpato, ed., *Manufatura Aditiva*, Blucher, chapter 1, pp. 15–30. ISBN 978-85-212-1150-1.

## **7. RESPONSIBILITY NOTICE**

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