STRUCTURAL ANALYSIS OF A THREE WHEELED FRAME FOR RACE RUNNING (PETRA) USING FINITE ELEMENT METHOD

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Abstract. Race Running (PETRA) is a para-athletics modality predominantly suited to those with Cerebral Palsy but also suitable for those with other disabilities that affect mobility and balance. The device used for its practice is called Race Runner and consist of a three wheeled frame, with handlebars, a saddle and a trunk support, similar to a tricycle. Rather than using a pedaling system, the athletes propel themselves along the racetrack by stepping their feet on the ground. This adapted sport was invented in Denmark in 1989 and is under analysis for inclusion in the 2024 Paralympic games. PETRA was taken to Brazil in 2009 as an initiative of the Associação Nacional de Desportos para Deficientes (ANDE), the organization responsible for holding the events and championships at the country. In this context of promoting this sport and provide support to athletes, the Comitê Paralímpico Brasileiro (CPB) approached the authors proposing the design of an affordable and reliable Race Runner. One of the models that is being currently used presents constant cases of breakage and instability during the race, as reported by them. This initial study aims to identify the existing limitations in the frame to better understand the points to be improved in a new design. Therefore, a CAD model of the evaluated frame was made, and a structural simulation was carried out using the finite element method. Two load conditions were simulated: the first being the application of the user's weight and the second a torsional analysis of the frame as a consequence of the athlete's gait. The results of the analysis revealed that the frame is in fact not well designed, and the critical points found coincided with the most common reports of breakage cases. Such results will serve as a basis for an optimization of the frame aiming to improve the athlete's performance and safety.

Keywords: Race Running, PETRA, Adapted Sports, Finite Element Method

1. INTRODUCTION

Race Running, also known as PETRA, is a para-athletics modality predominantly suited to those with Cerebral Palsy, although it is also suitable for those with Parkinson's disease, Muscular dystrophy and other disabilities that affect mobility and balance, who are not able to functionally run (van der Linden et at., 2018). This adapted sport was invented in Denmark in 1989 by Mansoor Siddiqi and Connie Hansen who both were wheelchair racers and wanted to develop a more appropriate way for people with Cerebral Palsy to practice athletics (Sidiqqi, 2016). Since then, the sport grow around the world and is being proposed to be included as an official Paralympics sport. PETRA only came to Brazil in 2009 through the Associação Nacional de Desportos para Deficientes (ANDE) and, currently, still in implementation phase in the country (Marçal et al., 2020).

The equipment used basically consists of a tubular frame, a front wheel, two rear wheels, a bicycle seat, and a trunk support in which the user can support himself in an inclined forward position while controlling the steering by means of a handlebar. The tubular frame has the geometry of an arch with an opening at the rear so that the user has space to move the lower limbs freely (Calve et al., 2018). A good frame design must reconcile stability with low weight (Domínguez, 2017) so the athlete can reach higher speeds safely during races. The general construction must follow a series of restrictions imposed by the regulation of this modality. Figure 1 shows an example of an imported commercial race runner model used by athletes today.

Figure 1. By ConnieHansen PETRA Race Runner™. Source: https://by-conniehansen.com/product/racerunner-petra-racerunner/ Accessed 07 April 2021

One of the main problems faced by coaches and athletes in Brazil at this stage of implementation, and which has hindered the spread of the sport in the country, is precisely the access to the equipment. The European imported models are expensive for the Latin-American population (Domínguez, 2017), and, even if they present some variations of size, for a better performance in the sport it is essential that the tricycle is adjusted accordingly to the dimensions and characteristics of each athlete. This adjustment is extremely challenging because it involves several factors such as strength in the muscles of the arm, trunk, neck, and the individual resistance of the athlete. Similar positions can result in different forms of movement (Hutzler, 2007).

The most viable solution has been the manufacture of their own equipment adapting parts of bicycles and a welded frame however these are not always well designed and present problems of resistance and instability, putting the safety and performance of the athletes at risk. As for the material of the frame, steel or aluminum is generally used. The first option, although presenting better resistance, impairs the performance on the track due to the greater weight. The second material, although much lighter, results in a structure that is not very rigid and consequently with high instability during the race.

In this context of promoting this sport and provide support to athletes, the Comitê Paralímpico Brasileiro (CPB) approached the authors proposing the design of an affordable and reliable Race Runner. One of the models currently being used for sport initiation presents constant cases of breakage and instability during the races., as reported by them.

2. OBJETCTIVES

This work presents the results of an initial phase of the research that aims to structurally evaluate the frame of one of the tricycle models used for the practice of PETRA by Brazilian athletes. ANSYS® software was used for simulation, by the Finite Element Method, of the mechanical resistance of the frame and identification of critical points that should be optimized in order to improve the safety and performance of the runners.

3. FINITE ELEMENT MODEL PREPARATION

The tricycle model used in the study was provided by the Comitê Paralímpico Brasileiro (CPB). It is a model manufactured in Brazil at the request of the CPB to meet the limitations of the competition regulations and aiming at a low production cost and is the most commonly used in the country. This model is mainly used to serve the sport initiation program, not being a specific competition model. Thus, it has standardized dimensions and adjustments in the seat and trunk support to adjust to different athletes.

The athletes and coaches who use this model alleged constant cases of breakage in the structure and instability during races. As it was noticed the appearance of cracks or great deflection in the tubes, new reinforcements were added to the structure in an attempt to make the equipment safer. However, these reinforcements were given as preventive measures and subjectively without any form of structural analysis. Therefore, the first stage of the work consists of performing analysis using finite elements to identify the critical points of the structure

3.1. CAD modeling

All dimensions of tubes present in the structure were measured so that a model identical to the original was recreated in CAD using the SolidWorks® software. Figure 2 shows the PETRA model used.

Figure 2. Race Runner CAD model

For the simulation, the CAD model was modified by adding a plate to represent the trunk support in a simplified way and facilitate the correct application of efforts during the simulation. The handlebar support tube has been extended to represent the attachment point of the front wheel. This simplified model can be seen in Figure 3 below.

Figure 3. Simplified CAD model for the simulation

The geometry was exported to ANSYS Workbench® for structural simulation. The specified material was the same as the original frame, the 6061 T6 aluminum alloy with a yield strength of 276 MPa (Callister, 2008). The total mass obtained in the model was 3.70 kg (8.16 lbs).

3.2. Mesh preparation

The mesh used was the tetrahedral type and its size was defined by convergence analysis, using the skewness parameter as a factor to evaluate the mesh quality. Tetrahedral elements are easy to fit to the contours of the geometry and are computationally inexpensive (Wang et Al., 2004). According to the user guide of the ANSYS® software, values

less than 0.5 indicate a good mesh. Refining of the weld regions of the tubes was also used, due to the greater probability of critical points occurring in these contacts. The final mesh can be seen in detail in Figure 3.
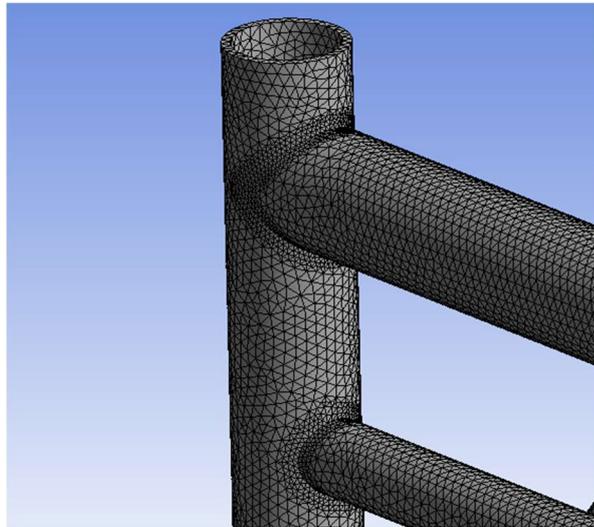

Figure 3. Detail of the final mesh used for the simulations.

3.3. Boundary conditions for athlete weight load on the frame

Two load conditions were simulated. The first being the application of the user's weight on the frame. As the analyzed model has the maximum indication of user weight of up to 70 kg (154.32 lbs), this was the load applied to evaluate the structural performance of the geometry. The simulation of this case was done with the fixation of the three wheels and the application of a load of 700 N distributed between the trunk support and the seat with a proportion of 30% and 70% respectively, as shown in Figure 4. These values were estimated based on what was found in the manual of one of the imported models as what is a good posture to have during the practice of the sport (Hansen, 2015).
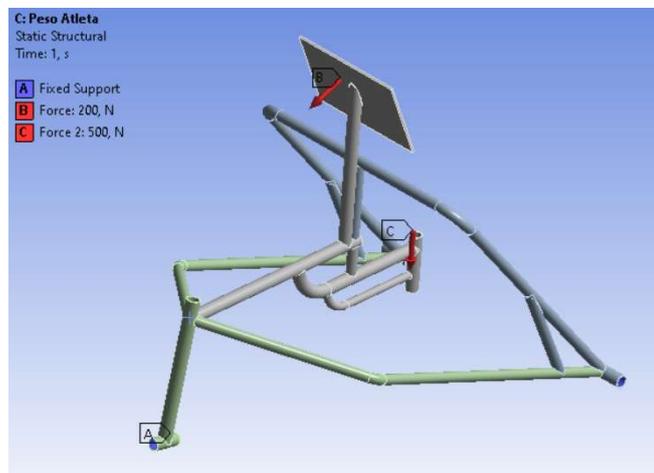

Figure 4. Boundary conditions for the static simulation of the athlete's weight on the frame.

3.3. Boundary conditions for torsional analysis of the frame

In the second case, a static analysis was performed to simulate the effect of the user's trunk movement during the run and the frame torsional resistance. It was found that the weight distribution in similar models of this tricycle is in the order of 25% on each rear wheel. Therefore, only the fixation point of the front wheel was limited, keeping the rear wheels free to move, and to represent the alternation of efforts between the sides, it was applied a load of ±175 N as shown in Figure 5.
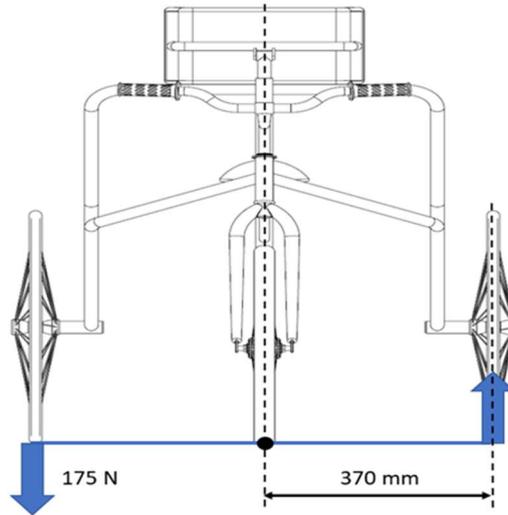
Figure 5. Representation of the applied load to simulate the torsion of the frame.

Considering the distance from the rear wheel of 370 mm to the symmetry plane, the moment applied to the seat tube was ±65000 N.mm. In addition, the 200 N load applied to the trunk support was maintained. The boundary condition settings for this case in ANSYS® are shown in Figure 6.
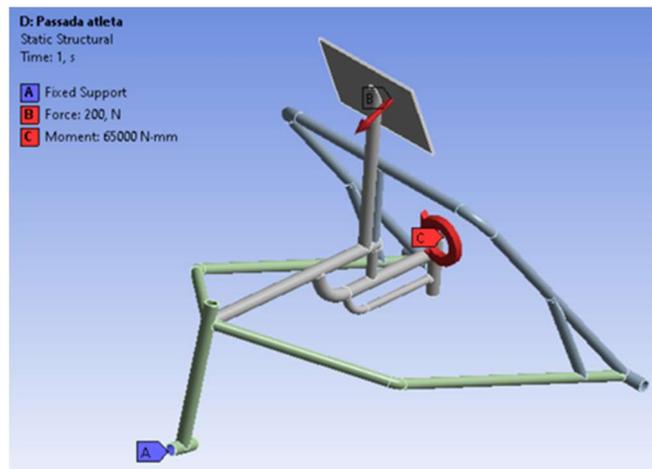

Figure 6. Boundary conditions to simulate the effect of the athlete's gait on the frame.

4. RESULTS AND DISCUSSION

Once all boundary conditions were defined, the simulations were performed. The result of the convergence study for the simulation is shown in Table 1.

Table 1. Mesh quality evaluation and simulations convergence study results

Mesh Element Size [mm]	Skewness	Athlete's Weight		Athlete's Gait	
		Total Deformation [mm]	Equivalent von-Mises Stress [MPa]	Total Deformation [mm]	Equivalent von-Mises Stress [MPa]
10	0,8269 ± 0,1376	6,6039	176,32	7,8122	212,31
5	0,6736 ± 0,1559	7,3953	259,12	9,3598	278,79
4	0,5673 ± 0,1592	7,4635	294,93	10,3932	335,70
3	0,4428 ± 0,1535	7,5523	312,99	10,5169	356,25
2,5	0,3640 ± 0,1526	7,5696	319,89	10,5513	361,56

The results of the static simulation for the athlete's weight indicated a maximum displacement of 7.57mm (Figure 7) with a maximum equivalent von-Mises stress of 319.89 MPa (15% higher than the value of the aluminum alloy yield stress). The critical point was found at the union of the support tube of the trunk support with the seat fixation tube, as can be seen in Figure 8. The reports of athletes and coaches, indicate exactly this region as a common point of breakages in this frame, indicating that the results of the model are consistent with the reality of the equipment.
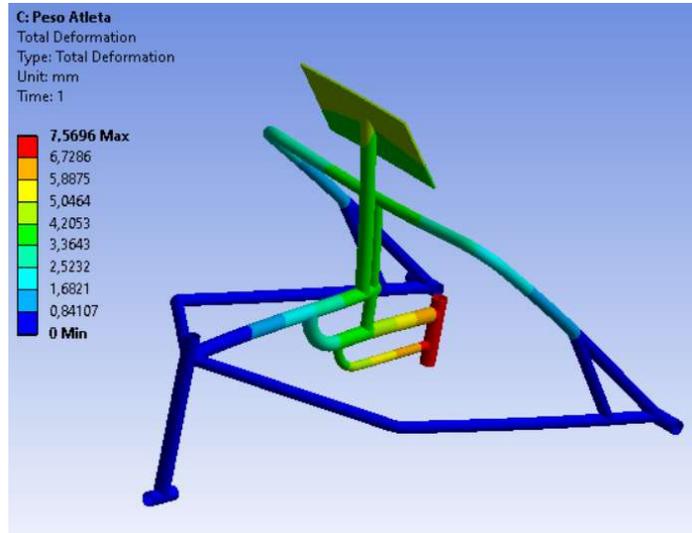
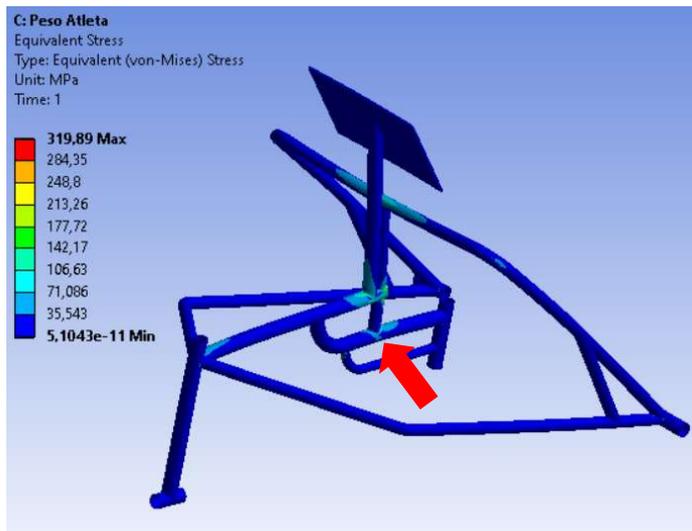Figure 7. Total deformation simulation results for the athlete's weight load condition.

Figure 8. Equivalent von-Mises stress simulation results for the athlete's weight load condition.

The simulation for the gait load resulted in the maximum total deformation found of 10.5513 mm located in the rear wheel hub (Figure 9). As the feedback from athletes pointed out that the tricycle has a lot of instability during races, a way to improve this aspect would be to aim to reduce this displacement result and propose a frame design with greater torsional rigidity. The maximum equivalent von-Mises stress was 361.56 MPa (30% above the yield strength of aluminum). The critical point of stress was found in the same region of the static analysis, as shown in Figure 10.
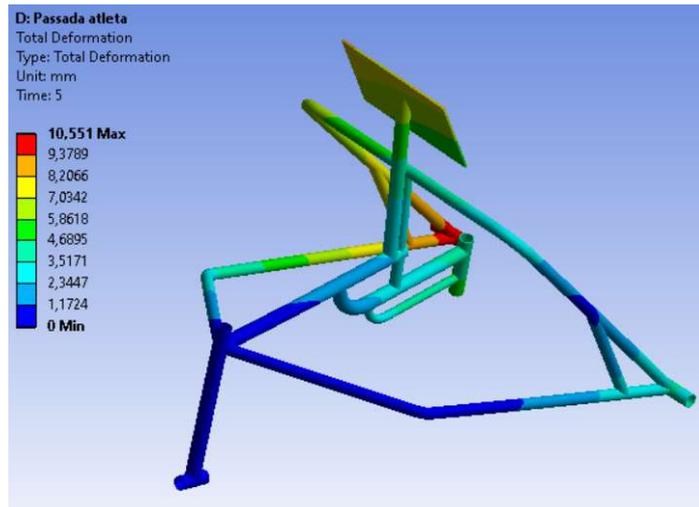
Figure 9. Total deformation simulation results for the athlete's gait load condition.
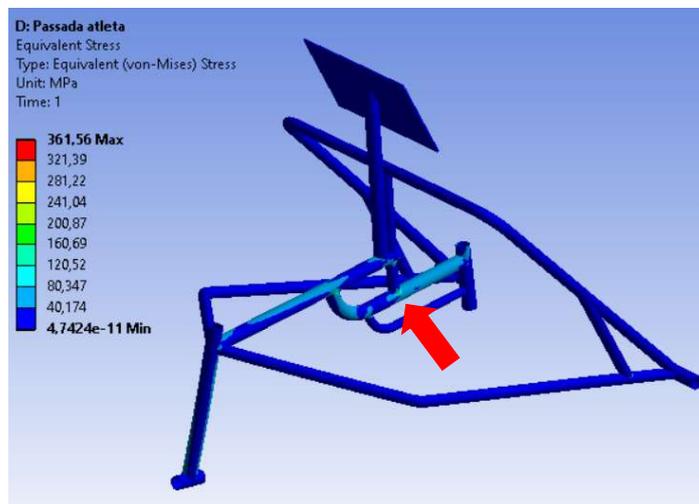

Figure 10. Equivalent von-Mises stress simulation results for the athlete's gait load condition.

5. CONCLUSIONS

The results of this study indicate that the Race Runner used is not really well designed. In addition, the fact that the critical points of the simulation models coincide with the points reported as being the main incidences of failure corroborates the validity of the results found. For the total deformation results, the maximum displacement found on the gait simulation justifies the instability faced by athletes while racing. However, in the literature, no clear loading conditions in the frame were found, and the values used in this study were estimates developed by the authors themselves based on the average weight of the athletes. Another phase of this study, that is already being done, consists of obtaining the real loads condition experimentally in the frame during its use and its results will be used for the final validation of the model and optimization of the structure, in order to guarantee an improvement in the performance and safety of the athletes.

6. ACKNOWLEDGEMENTS

7. REFERENCES

ANSYS®, "ANSYS® Workbench User's Guide", 2020.

CALLISTER, W. D, 2008. *Materials Science and engineering: An introduction* (in Portuguese). 7. ed. Rio de Janeiro: LTC, 2008. 705 p.

CALVE, T., RUSSO JÚNIOR, D.V., BARELA, A.M.F. "Strategies adopted by younger and older adults while operating a non-pedal tricycle". *Brazilian Journal of Physical Therapy*, Vol. 22, p. 64-69, 2018.

CPISRA "Race Running rules and regulations", 2015. Source: <https://www.sports.org.au/racerunning>. Accessed: 07 April 2021.

DOMÍNGUEZ, B. M. S. "Papalani, Tricycle for sport and rehabilitation development of people with Cerebral Palsy". *RESNA Annual Conference*, 2017.

HANSEN C. "PETRA RaceRunner™"; 2015. Source: <https://by-conniehansen.com/product/racerunner-petra-racerunner>. Accessed: 07 April 2021.

HUTZLER, Y. "A systematic ecological model for adapting physical activities: Theoretical foundations and practical examples". *Adapted Physical Activity Quaterly*, Vol 24, p. 287-304, 2007.

MARÇAL, L. C. B., DA SILVA, F. G., CALEGARI, D. R., FILHO, J. F., VIEIRA, I. B. "Ranking brasileiro de Petra Race Running – 2015 a 2019". Brazilian Journal of Development, Vol 6, No 12, 2020.

SIDDIQI, M. "The History of Race Running"; 2016. Source : <https://www.racerunning.org/document/default.asp?documentID=499&id=832>. Accessed: 07 April 2021.

VAN DER LINDEN, M. L., JAHED, S., NICOLA, T., VERHEUL, M. "The influence of lower limb impairments on RaceRunning performance in athletes with hypertonia, ataxia or athetosis". *Gait & Posture*, Vol. 61, p. 362-367, 2018.

WANG, E., NELSON, T., RAUCH, R. "Back to Elements – Tetrahedra vs. Hexahedra", *ANSYS International Conference*, 2004.

8. RESPONSIBILITY NOTICE

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