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Development of a new wheelchair for wheelchair basketball players in the Netherlands

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Abstract

The aim of the development of a new basketball wheelchair was to reduce the weight of the frame, to develop a program to fit anthropometric measurements to design a custom made wheelchair and to develop high-end wheels to increase propulsion efficiency by reducing rolling resistance. The redesigning process resulted in a frame which is 30% lighter than current aluminium wheelchair frames, a program that links anthropometric data to a CAD model of wheelchairs and a new wheel. Several tests were performed to evaluate the new wheelchair. The tests showed promising results with respect to improving both technical performance combined with the athlete's performance.

Key words: Wheelchair basketball; development of frame and wheel

1. Introduction

In wheelchair sports, athletes require a wheelchair design that best meets the demands of a specific sports discipline. After the Paralympic games of Beijing observations were made for the Dutch wheelchair basketball team. Main problems noticed were that chairs often broke and chairs were not optimal designed for every individual athlete. Therefore the development of a new basketball wheelchair started after the 2008 Paralympics. The strength of this project is that the research and development is done in close collaboration of the *sport*, (the Dutch Basketball Federation [Wheelchair basketball athletes]), *companies* (inMarket [Product development], Harting Bank [Supplier rehabilitation products]), *universities* (the Technical University Delft [Biomechanical Engineering], the Hague University [Human Kinetic Technology]) and InnoSportNL.

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In wheelchair basketball, manoeuvrability and high accelerations from standstill are the most important features [1], and chairs must be optimal designed for this performance. The main purpose of the project "Development of a new individualized basketball wheelchair for London 2012" is to take the performance of the Dutch National Wheelchair Basketball to a higher level. Besides regular training and focus on sports, technical improvements of the basketball wheelchair will also lead to ergonomic improvements such as: better play performance and improved power efficiency and handling. The project focuses on:

Reduction of the frame weight while increasing strength;

Development of a program to fit anthropometric measurements into a customized wheelchair design, for optimal performance and comfort;

Development of high-end wheels to increase propulsion efficiency by reducing rolling resistance.

2. Design process

2.1. Frame

The purpose of designing a new frame is to reduce the weight while increasing strength.

2.1.1 Weight reduction

These days, high end wheelchairs are made of aluminium or titanium. Taking the average manufactured high-end wheelchair into account, aluminium basketball wheelchair frames weigh 10 kg on average excluding rear wheels, while titanium frames weigh 9 kg. The weight of the chair influences the rolling resistance: reducing the weight of the frame by about 30% will reduce rolling resistance with about 10 % [2].Weight reduction in the new design of the wheelchair frame is achieved by using the optimum moment of inertia in tubes by increasing the outer diameter of the aluminium tubes. This makes it possible to reduce wall-thickness and results in weight reduction. The wheelchair frame is built as a solid welded frame, only the footrest is adjustable with fasteners. Preferably the wheelchair is built with only one anti-tip castor to reduce further weight. In total a weight reduction of 23% is achieved compared to titanium frames, and 30% compared to the aluminium frames.

2.1.2 Increasing strength

An increase in strength is achieved by the positioning of the tubes for a better distribution of forces. The base for the wheelchair is a so called 'box frame': diagonal tubes support the main points of the wheelchair frame; the four points that create the seating surface and the points which form the wheelbase (two front castors, two rear wheels and one or two anti-tip castors) (see fig 1a and 1b). The supporting tubes also result in a greater stiffness of the wheelchair frame which has a positive effect on the propulsion. The choice of heat treatable aluminium alloy in this design increases the strength of the material whilst avoiding heat stress risks in the welded area. The design of the new frame is presented in Figure 1.

2.2 Customization

Configuration of the wheelchair frame depends on anthropometry, field position and handicap of the basketball player. So, in the most ideal situation a frame must be individually configured. A computer based model was developed to apply the individual requirements of the player into the wheelchair model.

All variables to configure the wheelchair (e.g. seat height, wheel size, distance from backrest to wheel axle) must be filled in an Excel sheet. These variables, including the rules for wheelchair configuration according to the IWBF (International Wheelchair Basketball Federation), are converted into a coordinate system, which is the input for the CAD (Computer Aided Design) model of the wheelchair. This results in a customized wheelchair model (with a tolerance of 1 mm), for every individual basketball player.

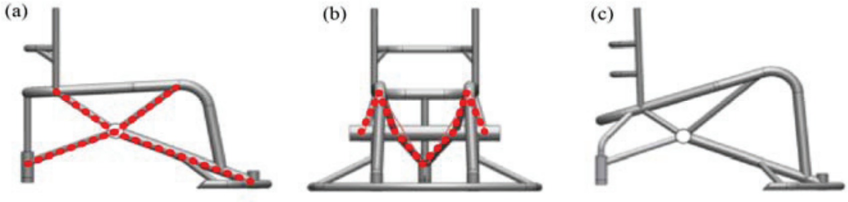

Fig. 1. The design of the frame; (a) Side view of the frame, box frame is indicated with dots; (b) Front view with box frame (indicated with dots) (c) example of a variation of the customized frame

2.3 Wheels

The criteria on wheel positioning and selection are very broad. Especially, wheel diameter and camber have a large effect on the performance of the chair [3]. In the redesign of the wheel the aim was to combine the positive aspects of a cambered wheel without having the negative aspects of increasing rolling resistance. In general, a cambered wheel increases the stability and manoeuvrability, which is absolute necessarily in wheelchair basketball. Camber angles up to 20° are often used, however this increases the rolling resistance, caused by the deformation of the tires.

The redesigned rim is designed to support the tire in a specific camber angle. This results in a wheel that is manoeuvrable through its camber and has the low rolling resistance of a wheel without a camber, see Figure 2. The redesign of the rim and the use of tubular tires allow a deformation of the tires in a cambered wheel to be comparable to a wheel without a camber (0° angle).

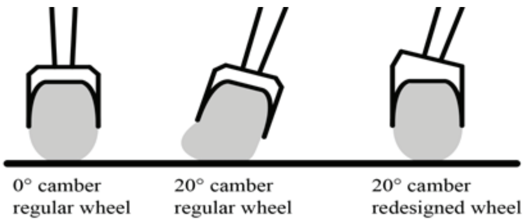

Fig 2. A schematic overview of the redesigned wheel compared with a regular one

2.4 Results design process

The different design aspects resulted in:

- A redesigned frame which is 25% lighter than the current aluminium wheelchair frames;
- A program to link anthropometric data to a CAD model of wheelchair;
- A new rim with the pros of a cambered wheel without its main disadvantage: increased rolling resistance.

3. Evaluation of the products

The first prototype of the frame and rims were tested in three different ways:

- Fatigue and impact tests on the frame
- Drag tests in the lab (towing tests on a treadmill) with 3 different wheels at different pressure circumstances of the wheel.
- Performance tests

3.1 Fatigue and impact tests

Impact tests: The maximum velocity a basketball player can reach during a game is about 5 m/s [4,5]. Maximum impact forces of 10.000 N are used for evaluation of the wheelchair. Three points of impact were evaluated on the frame based on most common contact points with other wheelchairs during a game (see arrows in fig. 3a). The impact was also applied in a CAD model using the Finite Element Method (see fig. 3b) during the design process.

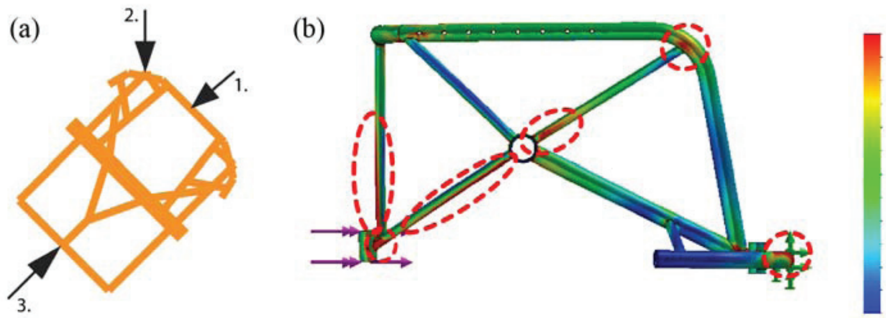

Fig 3. (a) top view of the frame , the three vectors indicate the points of impact; (b) stress overview in a CAD model with a finite element analysis. The wheelchair model was fixed at the front wing, with a load horizontally placed on the anti-tip castor. Encircled (red) areas show a maximum stress of 150 MPa

After the first prototype was completed, an impact test was performed using a pendulum, load was added to create an impulse of 140 kg ms^{-1} , 280 kg ms^{-1} and 392 kg ms^{-1}. The wheelchair was fixed to the ground and a mould placed opposite the direction of the pendulum. The first deformation (dent) was detected during 392 kg ms^{-1} at the frontwing of the wheelchair and the seating tubes were torn apart.

Fatigue tests: Fatigue was tested in a drop test. During a drop test the wheelchair (including wheels) is supported as though it stands on a horizontal plane and then dropped freely 50 mm ± 5 mm on to a rigid horizontal plane. The load was placed on the seat of the wheelchair, first 80 kg was tested followed by 100kg. A complete drop test runs for 6666 cycles. The results of the tests showed no deformation, fracture or visible cracks after 1 drop test with 80 kg. Deformation of side guards, caused by the shifting weight on the wheelchair seat was detected after 3000 cycles with 100kg. The tubes were not deformed.

3.2 Drag tests in the lab

In order to measure the rolling resistance of the wheels, drag tests with the wheelchair were performed [6] with 3 different wheels at different pressure levels of the tires. The experiment consisted of a wheelchair drag test on a motor-driven treadmill (length 4.80 m, width 3.00 m custom built by Force Link). Wheel alignment was kept as constant as possible. The velocity of the treadmill was 5 km/h, the slope of the treadmill varied from 0.5° to 5° with steps of 0.5°. The tests were performed with 3 different wheels (the new designed wheel compared to a Schmicking wheel and a Mavic wheel) with a pressure of the tubes of 15 bar. Two wheels were also tested at 12 and 7 bar. The friction coefficient (f) was calculated for every wheel according to:

$$f = F_t mgsin(\alpha)/mgcos(\alpha) \quad (1)$$

Where F_t = towing force as is measured with a force transducer; m = the mass of a buddy and the chair (in this experiment 62 kg), g = 9.81 m^2 and α = the slope angle of the treadmill.

Friction coefficients of the wheels at different pressure conditions are presented in Table 1. As can be seen in this table the Mavic wheel has the lowest rolling resistant coefficient (0.0067) versus the new design (0.0078) and the Schmicking wheel (0.0080) at 15 bar. The low resistance of the Mavic wheel might be caused by the fact that the wheel had no push rims. Therefore the measurements at lower pressure were performed only for the two other wheels.

Table 1. Friction coefficients (f) of the wheels at different pressure conditions

Wheel type	f at 15 bar	f at 12 bar	f at 7 bar
Schmicking	0.0080	0.0081	0.0092
Mavic	0.0067	-	-
New design	0.0078	0.0080	0.0087

It can be concluded that the differences were very low but the new designed wheel showed better performance especially at lower pressure.

3.3 Performance tests

In order to measure the performance of the wheelchair in standardized conditions 4 tests out of a test battery [6] were carried out with 4 elite wheelchair basketball players of the Dutch national team. The tests were chosen with respect to manoeuvrability and acceleration. All tests were done twice. Mean of the two tests was calculated. All subjects had no training experience with the new chair.

The tests performed are:

- A 5 meter sprint at 3 starting positions of the wheelchair: straight, turned 90° left and 90° right;
- A 20 m sprint;
- A stop and turn test;
- A slalom track.

Three male players performed all tests in 2 different chairs, their own (Quickie All-Court for player 1 & 2 and Performax for player 3) and the new prototype. One female player performed all test in her own chair with two different wheels, her own Schmicking wheels with tubes and the new wheels with new rim also with tubes. The results of the performance tests are presented in Table 2 and 3. All time differences in performance were very small.

Performance of the new chair is presented in Table 2. In this table it can be seen that for 2 subjects the performance in the 5 m sprint sessions was better in the new chair than in their own chair. For 2 subjects the slalom trail was performed faster in the new chair then in their own chair.

Table 2. Performance test with the new prototype. Time differences between the new and old chair are presented in seconds and as a percentage. A positive difference means that the new chair is faster than the old chair and this field is coloured grey

	Subject 1		Subject 2		Subject 3	
	Δ Time (s)	%	Δ Time (s)	%	Δ Time (s)	%
5 m sprint straight	-0,29	-15,3	0,05	2,29	0,04	1,98
5 m sprint turn 90° left	-0,02	-0,7	0,17	7,33	0,04	1,82
5 m sprint turn 90° left	-0,16	-7,6	0,06	2,83	0,11	5,44
20 m sprint	-0,25	-4,3	-0,32	-5,45	0,26	4,52
Slalom	0,22	1,8	0,14	0,96	-0,06	-0,54
Stop and turn	-0,37	-2,2	-0,77	-4,61	-0,55	-3,99

The results show some differences in performance. The new wheelchair seems to be better for subject 2 (classed 1.5) and 3 (classed 4.5) and seems not as good for subject 1 (classed 1).

Performance of the new wheel is presented in Table 3. The new wheel seems to be better in the short sprint tests, but in other tests didn't perform better. All subjects in the tests stated that they needed more training to get used to the chair or wheel. They believed they might perform better with the new chair or wheel after training. Especially with respect to manoeuvrability.

Table 3. Performance test with the new wheel. Time differences between the new and old wheel are presented in seconds and as a percentage. A positive difference means that the new chair is faster than the old wheel and this field is coloured grey

	Subject 4	
	Δ	
	Time (s)	%
5 m sprint straight	-0,11	-5,38
5 m sprint turn 90° left	0,06	2,87
5 m sprint turn 90° left	0,05	2,31
20 m sprint	-0,24	-4,17
Slalom	-0,08	-0,73
Stop and turn	-0,11	-0,77

4. Discussion

The tests showed promising results with respect to improving both technical performance combined with the performance of the athlete. Although the subjects did not have any training with the new frame and wheels, already some improvements in performance could be seen in the performance tests.

The tests resulted in some design improvements of both frame and wheel. Most improvements were done on the wheel: the position of the rim with respect to the wheel and the height of the rim is changed. The new frames and wheels will be produced in the beginning of January 2012 for the female athletes of the Dutch national wheelchair basketball team. Performance tests and drag tests in the lab will be repeated and compared with the prototype tests. Additional field tests will be performed during competition and training events in the preparation of the team for the Paralympics in London 2012.

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