= Mechanics of Oscar Pistorius ' running blades =

The mechanics of the running blades used by Oscar Pistorius depend on special carbon @-@ fiber @-@ reinforced polymer prosthetics . Pistorius has double below @-@ the @-@ knee amputations and competes in both able @-@ bodied and T44 amputee athletics events . Pistorius ' eligibility to run in international able @-@ bodied events is sanctioned by the International Association of Athletics Federations (IAAF) .

Pistorius began running in 2004 after a rugby knee injury led to rehabilitation at the University of Pretoria 's High Performance Centre with coach Ampie Louw . His first racing blades were fitted by South African prosthetist Francois Vanderwatt . Because he was unable to find suitable running blades in Pretoria , Vanderwatt ordered some to be made by a local engineer at Hanger Orthopedic Group . These quickly broke , and Vanderwatt referred Pistorius to American prosthetist and Paralympic sprinter Brian Frasure to be fitted for carbon @-@ fibre blades by Icelandic company Össur .

Pistorius ' participation in able @-@ bodied international sprinting competitions in 2007 raised questions about his use of running blades , and the IAAF amended their rules to ban the use of " any technical device that incorporates springs , wheels or any other element that provides a user with an advantage over another athlete not using such a device . " After initial studies , Pistorius was ruled ineligible for competitions under these IAAF rules . After further research was presented , the Court of Arbitration (CAS) ruled that his running prostheses were not shown to provide a net competitive advantage over biological legs . In 2012 Pistorius qualified for and competed in both the 2012 Olympic Games and the 2012 Paralympic Games using his running blades , becoming the first amputee sprinter to run in the Olympic Games .

= = Pistorius ' athletics prostheses = =

The blades are transtibial prostheses , meaning they replace legs and feet that are amputated below the knee (BK) . They were developed by medical engineer Van Phillips who incorporated Flex @-@ Foot , Inc . , in 1984 , and in 2000 sold the company to Össur which now (in 2012) manufactures the blades . They are designed to store kinetic energy like a spring , allowing the wearer to jump and run effectively .

Carbon fibre is actually a carbon @-@ fiber @-@ reinforced polymer , and is a strong , light @-@ weight material used in a number of applications , including sporting goods like baseball bats , car parts , helmets , sailboats , bicycles and other equipment where rigidity and high strength @-@ to @-@ weight ratio is important . The polymer used for this equipment is normally epoxy , but other polymers are also used , depending on the application , and other reinforcing fibres may also be included . In the blade manufacturing process , sheets of impregnated material are cut into square sheets and pressed onto a form to produce the final shape . From 30 to 90 sheets may be layered , depending on the expected weight of the athlete , and the mold is then autoclaved to fuse the sheets into a solid plate . This method reduces air bubbles that can cause breaks . Once the result is cooled , it is cut into the shape of the blades . The finished blade is bolted to a carbon fibre socket that is an intimate fit to each of Pistorius ' legs . These are custom made and make up the bulk of the total cost , along with the assessment and setting up of the finished prostheses . Each limb costs between $ 15 ? 18 @,@ 000 USD .

Pistorius has been using the same Össur blades since 2004 . He was born without fibulae and with malformed feet , and his legs were amputated about halfway between knee and ankle so he could wear prosthetic legs . He wears socks and pads which are visible above the sockets to reduce chafing and to prevent blisters , and the sockets have straps in the front that can be tightened to make the prosthesis fit more snugly .

Pistorius uses custom @-@ made spike pads on the blades . Before development of the pads , his spikes were changed by roughing up the surface and applying over @-@ the @-@ counter spikes by hand , but the results using this method were inconsistent . Research was conducted in Össur ? s Iceland lab using a pressure @-@ sensitive treadmill and film at 500 fps to measure the blade

strike , and produced a spike pad which includes a midsole of two machine @-@ molded pieces of foam of different densities to cushion impact , with a carbon fibre plate on the bottom . The developers attached the pad with contact cement , which can be quickly removed with the application of heat when the spike pad needs to be changed .

Because of the curved design , the blades have to be slightly longer than a runner 's biological leg and foot would be . The blades replace the hinge of an ankle with elastic compression that bends and releases the blade with every stride , so the uncompressed blade leaves the user standing on tiptoe . They are designed to move forward , so have no heel support in the back . According to Josh McHugh of Wired Magazine , " The Cheetahs seem to bounce of their own accord . It ? s impossible to stand still on them , and difficult to move slowly . Once they get going , Cheetahs are extremely hard to control . "

= = How the blades work = =

In 2007 Pistorius applied to run in able @-@ bodied track meets . He was at first accepted , but questions quickly arose about whether the blades give him an unfair advantage . After initial research showed the blades did provide an advantage , the International Association of Athletics Federations (IAAF) changed their rules to ban the use of technical devices that provide an advantage and ruled him ineligible to compete . Pistorius challenged the ruling with additional research and was reinstated by the Court of Arbitration for Sport (CAS) in 2008 , meaning that he can continue to run in able @-@ bodied meets as long as he uses the equipment that was studied in the research .

Pistorius ' performance in the early able @-@ bodied races raised questions because of two major concerns : his pattern of running the races and his leg @-@ swing times . Most sprinters spring out of the blocks with their fastest time and slow down as the race progresses , but Pistorius ran a " negative split , " starting slowly and building up speed in the last half of the race (though he no longer uses this pattern) . His average time was also less in the 400m race when compared to other runners than in the 200m . Controversy about the use of the blades persists , but the research provided considerable information on how they work in application , and other research is expected to follow .

Able @-@ bodied sprinters have calves and ankles that return and amplify the energy supplied by their hips and knees , while Pistorius compensates with additional work because he does not have calves and ankles with their associated tendons and muscles . An analysis published by Engineering & Technology magazine estimates that in using the blades , Pistorius must generate twice the power from his gluteal and quadriceps muscles that a normal sprinter would . Other sources also credit core abdominal muscles and a faster arm swing . His trainer estimates that about 85 percent of his power comes from his hips and the rest from his knees . This results in a gait that waddles slightly , as Pistorius swings his upper body to balance the springing action of the blades . The blades compress under his weight , then release as he moves forward , providing forward thrust from the tips as they return to their molded shape . As they spring off , he swings them slightly out to the side and throws them forward for the next stride .

Pistorius is always slow in starting a race because the flexible blades do not provide thrust out of the blocks . Pistorius must begin from an awkward position , swing his leg to the outside and pop straight up from the blocks to begin running , when the preferred method is to push off with horizontal force . For the first 30 meters of a race , he keeps his head down and takes short , quick strides . As he establishes a rhythm , he can raise his head and increase his speed . While some runners jog up and down , losing energy , Pistorius directs energy forward , looking somewhat like he is rolling on wheels . He also compensates for the adjustments ankles make on the turns , breaking the curves into short , straight lines . According to his coach Ampie Louw , Pistorius may be able to use the inward lean to generate force and come out of a turn going faster .

= = Research = =

= = = Brüggemann study = = =

To resolve questions about the blades , Pistorius was asked to take part in a series of scientific tests in November 2007 at the German Sport University Cologne with Professor of Biomechanics Peter Brüggemann and IAAF technical expert Elio Locatelli . After two days of tests , Brüggemann reported that Pistorius used about 25 percent less energy expenditure than able @-@ bodied athletes once he achieved a given speed . The study also found that he showed major differences in sprint mechanics , with significantly different maximum vertical ground return forces , and that the positive work or returned energy was close to three times higher than that of a human ankle . The energy loss in the blade during stance phase when the foot was on the ground was measured as 9 @.@ 3 percent , while that of normal ankle joint was measured at 42 @.@ 4 percent , showing a difference of more than 30 percent . Brüggemann 's analysis stated that the blades allowed lower energy consumption at the same speed , and that the energy loss in the blade is significantly less than in a human ankle at maximum speed . In December of that year , Brüggemann stated to Die Welt newspaper that Pistorius " has considerable advantages over athletes without prosthetic limbs who were tested by us . It was more than just a few percentage points . I did not expect it to be so clear . " The study was published in 2008 in Sports Technology , but later researchers stated that the analysis " did not take enough variables into consideration " . Commentators have also argued that the IAAF study did not accurately determine whether Cheetahs confer a net advantage because measuring the net advantage or disadvantage conferred on an athlete using Cheetahs is not possible given current scientific knowledge . Second , the IAAF study may not have measured Pistorius ? s performance against appropriate controls . IAAF used five able @-@ bodied athletes , who run 400 @-@ meter races in similar times to Pistorius , as controls . However , because Pistorius was relatively new to the sport of running , he may not have trained enough to maximize his physical potential and reach his peak performance when the IAAF study was conducted . In March 2007 , approximately 9 months before the IAAF study was conducted , Pistorius ? s coach commented that Pistorius had not trained enough to achieve an upper body commensurate with the upper bodies of most elite sprinters . To obtain the most accurate understanding of how the prostheses affect Pistorius ? s performance , he should be compared to athletes with similar physical potential . Consequently , the IAAF study may have been flawed because it compared Pistorius , who might have the physical potential to run faster than his current times , against athletes at their peak .

= = = Weyand , et al. study = = =

In 2008 a team of seven researchers conducted tests at Rice University , including Peter Weyand , Hugh Herr , Rodger Kram , Matthew Bundle and Alena Grabowski . The team collected metabolic and mechanical data by indirect calorimetry and ground reaction force measurements on Pistorius ' performance during constant @-@ speed , level treadmill running , and found that the energy usage was 3 @.@ 8 percent lower than average values for elite able @-@ bodied distance runners , 6 @.@ 7 percent lower than for average distance runners and 17 percent lower than for able @-@ bodied 400m sprint runners . At sprinting speeds of 8 @.@ 0 , 9 @.@ 0 and 10 @.@ 0 m / s , Pistorius produced longer foot to ground contact times , shorter leg swing times , and lower average vertical forces than able bodied sprinters . The team concluded that running on the blades appears to be physiologically similar but mechanically different from running with biological legs . The study was published several months later in the Journal of Applied Physiology . The inconsistencies between the finding of this study and the Brüggemann study were attributed to differences in study methodology .

In the study , the blades were found to have an elastic energy return of about 92 percent , whereas biological legs provide between a 93 and 95 percent return . Grabowski also stated that the prostheses reduce the amount of force Pistorius can apply to the ground when he runs , reducing his ability to propel himself forward . The shape of the blade foot is a longer lever than the human

foot , providing a contact point further away from the axis of rotation than a real foot . This would allow greater torque generation when an identical amount of force is applied , but because of the springy quality of the blades , Pistorius is unable to exert the same force as an able @-@ bodied runner during push off from the ground . Kram also stated that Pistorius ' " rate of energy consumption was lower than an average person but comparable to other high @-@ caliber athletes . "

The lightness and rigidity of the blade compared to muscle and bone may allow blade runners to swing their legs faster than able @-@ bodied runners . In comments on the article , Peter Weyand and biomechanist Matthew Bundle noted that the study found that Pistorius re @-@ positioned his legs 15 @.@ 7 percent faster than most world record sprinters , allowing for a 15 to 30 percent increase in sprint speed .

= = = Grabowski , et al. study = = =

In 2008 a research team including Alena Grabowski , Rodger Kram and Hugh Herr conducted a follow @-@ up study of single amputees with running blades which was published in Biology Letters . Each of six amputees ' affected leg performance was compared against that of their biological leg . The team measured leg swing times and force applied to the running surface on a high @-@ speed treadmill at the Biomechanics Laboratory of the Orthopedic Specialty Hospital , and also studied video of sprint runners from the Olympics and Paralympics . They found no difference in leg swing times at different speeds , and recorded leg swing times similar to that of able @-@ bodied sprinters . They also found that single running blades reduced the foot to ground force production of the tested runners by an average of 9 percent . Because force production is generally considered the most significant factor in running speed , the researchers concluded that this reduction in force limited the sprinters ' top speed . Grabowski also found that amputees typically increased their leg swing times to compensate for the lack of force .

= = = Other discussion = = =

Discussion continues about the relative advantage or disadvantage of using the blades . Researchers and analysts also point out that the research studies are done on level , stationary treadmills , and do not measure performance from starting blocks or on actual curved tracks . They also do not take into account differences in physiology between amputees and non @-@ amputees , who have such factors as musculature , blade height and weight and differences in blood circulation patterns due to the history of their limb loss .

= = 2012 Paralympics = =

A controversy over the effects of running blade length arose at the 2012 Paralympic Games , as Brazilian runner Alan Oliveira and USA runner Blake Leeper changed to longer running blades within a few months before the 2012 Paralympic Games . This led to marked improvement in their running times . Pistorius complained after the 200m race that the blades provided artificially lengthened running strides , which would be an infringement of the IPC rules , regardless of that the blades were within the allowable height limits for the athletes concerned . His complaint was supported by single @-@ leg runners including Jerome Singleton and Jack Swift , who called for the T43 double blade and T44 single blade classes to be separated in future events , as single blade runners were unable to adjust the height of the prostheses , and must always match the length of their biological leg with a running blade .

The improvement in running time and the wide broadcast of the race results provided a public demonstration of how the blade length affects performance . Pistorius ' stride length was actually 9 percent longer (2.2m vs 2.0m) , but Oliveira took more strides (99 vs 92) . The combination of stride length and stride rate led to a clearly unusual performance with the longer blades . Pistorius ' management issued a statement saying that Pistorius is always 1 @.@ 84 meters tall , regardless of

what prostheses he wears , and that the decision to maintain this height for his running blades was an issue of fairness .