

WHAT IS THE FASTEST HUMANLY POSSIBLE TIME FOR THE OLYMPIC 100M FREESTYLE EVENT

TEAM 1046

NZ's Next Top Engineering Scientist

Introduction

SUMMARY

Olympic 100m freestyle event takes place in a 50m pool, consisting of a diving entry and glide, up to the distance of 15m, where upon the swimmer must surface and begin swimming the stroke. It also consists of one turn, at the end of the first length, where they may propel themselves against the pool end. Freestyle is defined as any stroke that is not another official stroke, but we have used the assumption that it is the conventional front crawl style as this is believed to be the most efficient swimming style. Our calculated fastest possible time was 40.7 seconds, which was feasible when considering that the current world record for the 100m freestyle is 46.91 seconds.

OUR QUESTION

Over the past generation, the scientific analysis of certain sporting techniques has allowed humans to push physical boundaries and achieve record breaking feats. In particular, research around the biomechanics and physical analysis of competitive swimming events, has sparked a plethora of research around the maximum capabilities of an athlete in this code. The current world record for the 100m freestyle event is held by Brazilian, Cesar Cielo, who completed the event in a time of 46.91 seconds (Wikipedia, 2016). As the Rio Olympic Games fast approaches, Cielo's 2009 performance will be scrutinized by swimming experts worldwide, and all facets of his world record breaking race are likely to be replicated by aspiring medalists from across the globe.

However, in analyzing Cielo's record breaking performance, we must question to what extent his abilities are limited – be this by his physiology/biomechanics, by the inevitable psychological restraints of the human mind, by his swimming techniques and a number of other environmental factors which surround his endeavors to push human limits. This research aims to take into consideration the restrictions which limit our performance in a 100m freestyle event. Upon reducing these restrictions to the minimum level, we can find the fastest possible time for the 100m Olympic freestyle event.

OUR DEFINITION OF THE QUESTION

- 100m swimming events can take place in 2 lengths of pool – 25m (short course events) and 50m (long course events). In this investigation we have made the assumption that the event is a 'long course', as this is the category of 100m freestyle which is completed at the Olympic Games. This assumption is necessary as it defines how many turns the swimmer will have to make when completed in the race – the 'short course' is comprised of 3 turns (4 lengths of the pool), whereas the 'long course' comprises of only 1 turn (2 lengths of the pool). Upon turning at the end of the pool, the swimmer creates extra propulsive forces which contribute to a higher average velocity – hence the 'short course' and 'long course' 100m events need to be separated.

- According the Federation Internationale De Natation, (FINA All Rights Reserved., 2015-16), “Freestyle means that in an event so designated the swimmer may swim any style, except that in individual medley or medley relay events, freestyle means any style other than backstroke, breaststroke or butterfly.” Due to this definition, we have had to clarify ‘freestyle’ as the generally accepted ‘front crawl’ stroke, which “involves alternating arms that make windmill arc motions forward while the head is underwater, and the swimmer breathes at the side.” (Wikihow, 2015)
- The competition is run under the rules of the Olympic Governing Body – specifically to this question, the diving board is at a maximum height of 0.75m, with a maximum angle of 10 degrees (we have selected the maximum height to generate maximum velocity upon water contact – greater flight time means a greater maximum height is reached, and therefore acceleration due to gravity in maximized, whilst horizontal velocity remains constant).

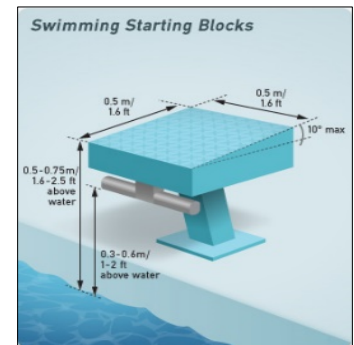


Figure 1: Regulation starting block

- We have assumed that the fastest humanly possible time to complete a 100m Olympic event will be achieved by a male swimmer – this has been deduced by taking into account that males are biologically and biomechanically stronger and more physically capable than females. This is supported by the current records for 100m long course swimming event, in which the male record is a time of 46.91 seconds, compared to the female record of 52.06 seconds (World record progression 100 metres freestyle, 2016). A study regarding “Gender differences in strength and muscle fibre characteristics” has also proven that “women are approximately 52% and 66% as strong as the men in the upper and lower body respectively” (Department of Physical Education, McMaster University, Hamilton, Ontario, Canada, n.d.).

Method of calculation

The process we will use to calculate the fastest humanly possible time for the Olympic 100m freestyle event, is by breaking the race into sections. These sections can be modelled by the following diagram.

The sections which are critical in maximizing velocity, and hence minimizing swim time are:

- 1) Beginning – dive. This comprises of reaction time and take-off (explosive power/angle)
- 2) Gliding (1) and (2) – The time that the swimmer spends underwater. This underwater phase is crucial as “it is how the swimmer converts the speed he or she gets from the dive into the breakout, and carries it into the stroke” (Caldas, n.d.) Two gliding phases exist in the race – the first is after the initial dive, and the second is after the flip turn. According to the Federation Internationale De Natation, “Some part of the swimmer must break the surface of the water throughout the race, except it shall be permissible for the swimmer to be completely submerged during the turn and for a distance of not more than 15 meters after the start and each turn. By that point, the head must have broken the surface.” (FINA All Rights Reserved., 2015-16). The most successful breakout distance has been proven to be 10.5m, so this is the value will use for calculations (Take your marks ... the science behind the perfect swimming dive, 2014).

- 3) Swimming sections (1) and (2). These are the periods in which the swimmer is (assumed to be) traveling at a constant speed – performing regular strokes and continuously flutter kicking. Section 1 of the swimming is after the initial dive/glide, section 2 is on the second length, after the turn.
- 4) The flip turn – the change of direction of the swimmer- transitioning between the first and second laps.

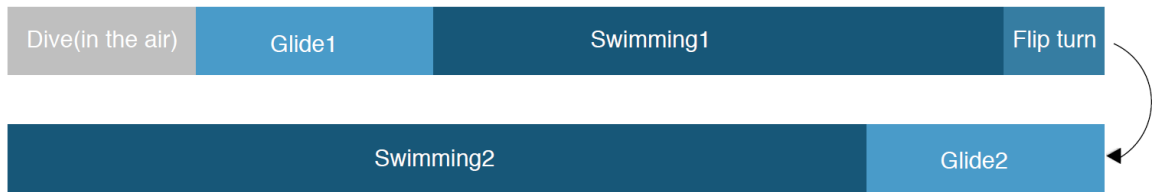


Figure 2: Diagram of optimum 100m race – distances broken down

By calculating the most efficient, fastest methods of performing each of these sections of the race and adding these values together, this theoretically gives us the fastest humanly possible time to complete the 100m Olympic freestyle event. Each section’s fastest value will be calculated using known values for the maximum of human capabilities, and the techniques which are proven to provide the fastest times – for example, explosive power in the block start, and a 45-degree angle to maximize velocity when the swimmer hits the water.

PHASE 1: THE START

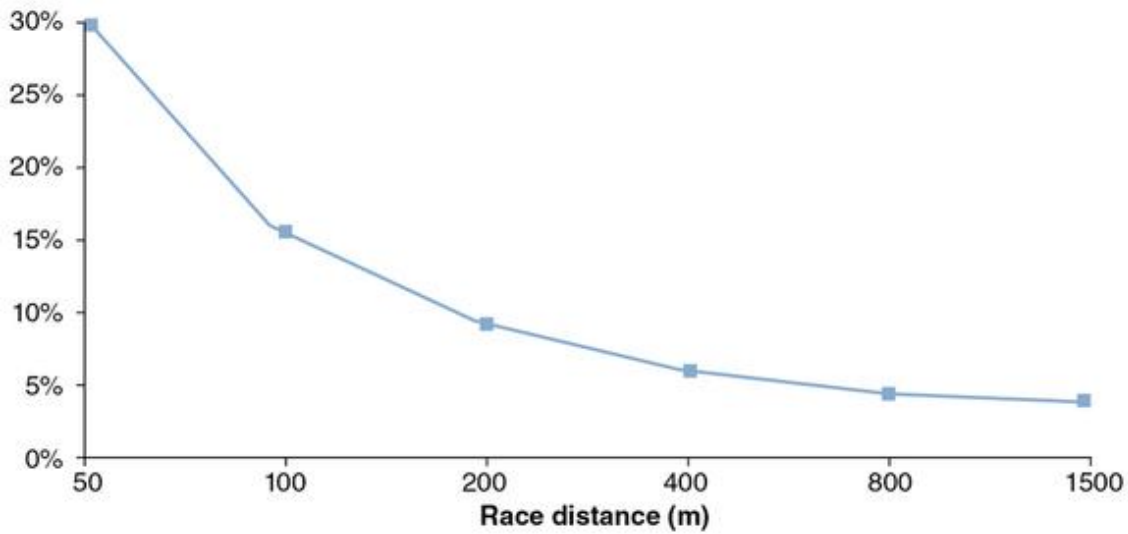


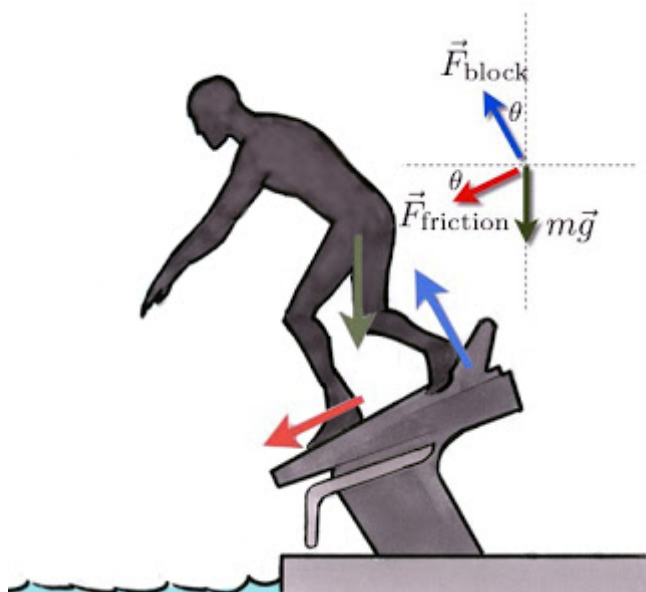
Figure 3: Graph showing the proportion of swimming race taken up by the “start” (definition given below) – data from Olympic swimming results from 1972 to 2004 (Science of Swimming Faster, 2015)

The swimming dive start is defined as the time from the starting signal (the gun or beep) to when the center of the swimmer’s head reaches 15m down the pool. (Take your marks ... the science behind the perfect swimming dive, 2014). The start of a race is significant in achieving a record breaking time – as,

especially in short sprint races such as the 100m, it accounts for a large proportion of the overall race, as shown in the diagram above.

The first phase of the race which needs to be considered is the dive. To maximize the velocity of the dive, the athlete must find a balance between the initial vertical velocity and the initial horizontal velocity.

To calculate the fastest time for an Olympic dive in a 100m freestyle event we must first take into



consideration the reaction time of an individual. The range of values for elite swimmers reaction times using a track start block (the type of block used in Olympic events) is 0.80 ± 0.01 s. Using the lower limit for this value (0.79s) will give an accurate representation of the fastest humanly possible reaction time in this scenario.

Next, we must consider the “flight/take off” portion of the swimmer’s dive – this is crucial, as it will provide the swimmer’s maximum period of velocity in the whole race. The take-off can be viewed using physics principles.

When the swimmer jumps off the starting block, there are 3 forces acting on him: his weight force as a result of his mass, the friction force acting in the direction to oppose his acceleration, and the

force of the diving board pushing upwards on him. These forces are shown in the diagram above. The assumption is made that the swimmer only jumps horizontally, with no vertical acceleration. Due to this assumption, the forces acting on the swimmer in a vertical direction must equal zero $F_{\text{NET(Vert)}}=0$.

$$F_{\text{block}} - mg = 0$$

$$F_{\text{block}} = mg$$

This equation represents that the sum of the vertical forces acting on the swimmer equal zero (force upwards equal force downwards).

The only force acting in the horizontal direction is friction – opposing the horizontal movement of the swimmer. The value of this frictional force must be less than or equal to the force of the block, multiplied by a constant value, called “the coefficient of friction”. This coefficient value is a representation of the frictional interaction between two surfaces (the foot of the swimmer and the block). The below equation represents that the frictional force will only work as hard as to represent the two surfaces from sliding across each other.

$$F_{\text{friction}} \leq \mu_s F_{\text{block}}$$

The following equation can be utilised to represent the unbalanced force acting in the horizontal direction

$$F_{\text{friction}} = ma_x$$

The most efficient dive which is humanly possible will maximise the frictional force (above this maximum will cause the diver to slip). Therefore, the maximum frictional force is equal to the unbalanced horizontal force. This gives the relationship, that acceleration is equal to the coefficient of friction multiplied by the force of gravity.

$$\mu_s F_{\text{block}} = ma_x$$

$$\mu_s mg = ma_x$$

$$a_x = \mu_s g$$

We now consider the net forces in the x and y directions – the y direction is zero due to the balanced vertical forces. The x direction is equal to the value of the unbalanced horizontal force, caused by the physical exertion of the swimmer, minus the frictional force of the block.

$$F_{\text{net-x}} = -(F_{\text{block}}) \sin \theta - (F_{\text{friction}}) \cos \theta = -ma_x$$

$$F_{\text{net-y}} = (F_{\text{block}}) \cos \theta - mg = 0$$

When these equations are put together, we can achieve the final relationship for the maximum horizontal acceleration of the swimmer as he leaves the block.

$$F_{\text{block}} = \frac{mg}{\cos \theta}$$

$$ma_x = (F_{\text{block}}) \sin \theta + \mu_s (F_{\text{block}}) \cos \theta$$

$$ma_x = \left(\frac{mg}{\cos \theta} \right) (\sin \theta + \mu_s \cos \theta)$$

$$a_x = g(\tan \theta + \mu_s)$$

We can now calculate the acceleration. Gravity is constant at 9.8ms^{-2} , and theta is 10 degrees from the angle of the block. Using this formula, and the given coefficient of friction of 0.8, we can calculate the maximum acceleration as 9.57ms^{-2} .

To calculate the initial horizontal velocity, we use the equation $a = \frac{\Delta v}{\Delta t}$

The value for the horizontal acceleration is 9.57ms^{-2} , so we rearrange the equation and multiply this value by the swimmer's reaction time of 0.79s to find the initial horizontal velocity. This gives a value of 7.56ms^{-1} .

Now we must find out the time taken for the swimmer's hands to enter the water from the height of 0.75m of the diving board (assuming the swimmer is crouched low so his height is negligible). The angle of his dive will be parallel to the water, due to research that elite swimmers dive at an angle of -5 to 10 degrees (we have taken an angle of 0 degrees). We can use projectile motion to find the time taken for the swimmer's hands to reach the water's surface, using the equation:

$$d = v_i * t + \frac{1}{2} * a * t^2$$

Initial vertical velocity is zero. Vertical acceleration is constant at -9.8ms^{-2} , and vertical distance is 0.75m . Upon calculation, we found the time for the hands to reach the water to be 0.39 seconds. We then used the equation for horizontal velocity to find the horizontal distance travelled from the dive. Time was 0.39 seconds; initial horizontal velocity was 7.56ms^{-1} .

$$v = \frac{d}{t}$$

This gave a horizontal distance of 2.96m .

To find the swimmer's overall velocity as they hit the water before the glide, we need to calculate the final vertical velocity. We use: where initial velocity is 0ms^{-1} , acceleration is -9.8ms^{-1} and distance is 0.75m .

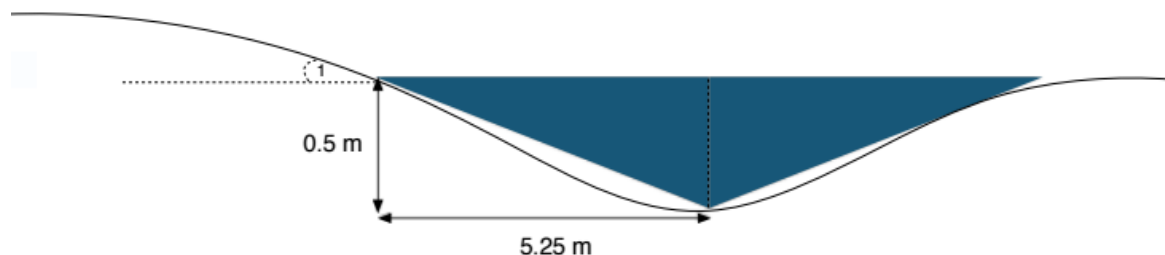
$$V_f^2 = V_i^2 + 2a\Delta x$$

Final velocity returns an answer of 3.83ms^{-1} .

Using Pythagoras, we can use the horizontal constant velocity of 7.56ms^{-1} and the calculated vertical velocity of 3.83ms^{-1} to find the overall velocity before the swimmer hits the water. $\sqrt{(7.56^2+3.83^2)} = 8.47\text{ms}^{-1}$.

PHASE 2: GLIDING

To find the fastest possible gliding time for the athlete, we must consider the total distance he will travel underwater. International swimming guidelines state that the swimmer must not travel a greater distance than 15m without breaking the surface of the water, with the most successful breakout distance having



been proven to be 10.5m. However, we must consider the fact the athlete, in fact, will travel a GREATER distance than 10.5 m underwater, due to the depth they reach after the dive. We assume this depth to be 0.5m, which has been proven as a successful maximum depth. (Take your marks ... the science behind the perfect swimming dive, 2014). If we model the underwater path of the swimmer on two right angled triangles (making the assumption the path is symmetrical) we receive the following diagram. Therefore, the total underwater gliding distance is shown to be $5.27 \times 2 = 10.55$ m (using **Pythagoras**).

According to statistics, the optimum distance to travel underwater whilst strictly gliding is 6.5m. After this, the swimmer will use the 'dolphin kick' technique until they break the surface of the water. It has been found that the maximum speed elite swimmers can attain whilst using the dolphin kick is 2.5ms^{-1} . At the end of the 10.55m underwater glide period, we have assumed that the athlete will have reached the 2.5ms^{-1} optimal dolphin kick speed. Therefore, we have calculated the time taken in the whole 'gliding phase' by dividing the distance by the change in velocity (where initial velocity is 8.47ms^{-1} , final velocity is 2.5ms^{-1} and distance is 10.55m.)

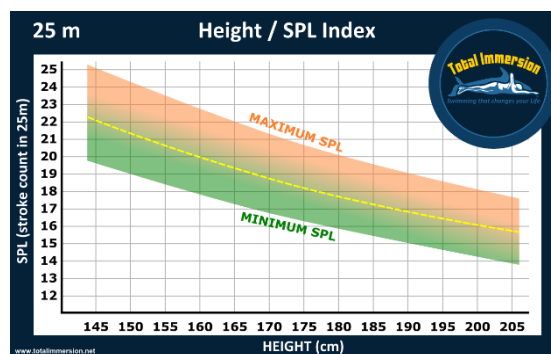
$$v = \frac{d}{t}$$

From this calculation, we received a time for the fastest possible gliding phase of 1.77s.

PHASE 3: SWIMMING

We need to find the maximum speed that the swimmer could possibly attain, we must take into consideration his dimensions. We are assuming that this swimmer as an 'ideal' physique, which will allow him to perform to an optimum ability. From research, we have found that the arm span of the swimmer, to provide a long lever and maximum propulsion force, must be 222cm, equaling 2.22m. His height is 198cm.

This graph has been used to calculate the strokes per meter of the swimmer. Using a height of 198cm, we can see from the graph that the maximum value for stroke count in 25m will be 18.3 strokes per 25m, which gives a value of 0.73 strokes per meter. From our research, we have approximated that the swimmer will be actively swimming/stroking from a distance of 81.2m – this accounts for the distance for the horizontal travel from the dive, the initial glide and the second glide after the flip turn (which is approximately half the distance of the first turn). Therefore, over the course of the swim, the athlete will take a total of 81.2×0.73 strokes = 59.2 strokes.



Considering the optimum angle for a freestyle stroke for elite swimmers, of between 100 and 130 degrees, with an average of 120 degrees, we have found that the athlete's stroke length will be 2.2m. (Ford, 2015).

From the following graph, it can be seen that a swimmer with a stroke length of 2.2m would have a stroke frequency of approximately 1 s^{-1} (based on the 'forecast' – prediction off the graph). If the swimmer is taking 1 stroke per second and has a stroke length of 2.2m, his velocity during the swimming phase must be 2.2ms^{-1} . This is 0.07ms^{-1} faster than the world record, which is feasible value.

Using the equation: $v = \frac{d}{t}$

we can calculate the total swimming time. The velocity is 2.2ms^{-1} and the distance is 81.2m. Therefore, the time spent in the swimming phase will be 36.9 seconds.

PHASE 4: FLIP TURN

The final component we must calculate is the time taken for the flip turn. We calculated the by using a circular motion equation of

$$v = \frac{2\pi R}{T} \quad 2\pi r$$

The velocity used is 2.2ms^{-1} , which was the swim speed of the athlete. The radius used was 0.31m which was calculated from the equation where circumference is equal to the height of the athlete which was 1.98m. Therefore, by substituting these values into the first equation, the period of the flip was 0.88s.

TOTAL TIME

Total time is equal to swim time + glide time (1) + glide time (2) + flip time + dive time

So... $36.9\text{s} + 1.77\text{s} + 0.885 + 0.88\text{s} + 1.185\text{s}$

TIME = 40.74s

Conclusion

In conclusion we found that our results were very close to the world record of 46.91 s, the time was minimized by our assumptions of them using the perfect conditions of a 100m swim, with a perfect horizontal dive, fastest underwater travelling and surface travelling, optimum flotation, long stroke length combined with efficient breath control, and a perfect turn. Our swimmer is in the best possible physique for the swim. The speeds he has reached are very possible as they have been recorded in the past by swimmers, however he has maintained them longer than any human has before. The final time we attained was 40.74s, which was feasible when considering that the world record for the 100m swim was 46.91 seconds.

To further our investigation, it would be interesting to go further into the physiological capabilities of humans, such as lung capacity and lactic acid levels which accumulate when anaerobic exercise is held for an extended period of time.

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