The Open University

The Science Behind the Bike
Forces

Presenter
When a cyclist rides a bike around a track or along a road the rider applies forces that propel the bike forwards. There are other forces acting on the bike that tend to slow it down. Identifying these forces and understanding their effect enables bike designers, sports scientists and elite athletes to work to minimise the negative effects of these forces and increase the positive in order to maximise performance.

Simon Smart
Bike Aerodynamicist and Designer
There's really only two key forces that are acting on you and slowing you down and those are the two forces that require you to produce three hundred watts to move at say thirty mile an hour and those two forces are the frictional force through the tyres and then the drag force, which is coming from the rider and the equipment. Particularly the frictional force from the tyres could be around fifteen per cent of the total power output and the rest comes from drag.

Dr Calum MacCormick
Physicist
The cyclist applies force to the pedals, which turns the pedals and then in turn turns the wheels eventually. And the wheels apply frictional force against the road, which pushes the drivers of the bike and the cyclist forwards. They also encounter forces, which act against them pushing forwards primarily aerodynamic drag but also gravitational force in some situations and also frictional force. The most important of these is usually aerodynamic drag but in certain events such as climbing mountains in the Tour de France or in the Classics it's gravitational effort which is of primary importance as well.

Chris Boardman MBE
Olympic Champion and Bicycle Designer
Aerodynamics is the biggest influence on performance for most cyclists – I mean in mountain biking it becomes more about ground friction speed to low and the ground friction's much higher. So it's a different pair of events but if blanket cycling aerodynamics is everything and then of that the biggest thing – the biggest impact you can have is rider position.

Graham Obree
Twice World Hour Record Holder
The physics is this. Your energy output mass of your body increases cubically while the frontal area increases to the square. So the bigger you are then the less surface area you have per kilogram. Put it this way. If there's two riders they both produce the same mortgage output per kilogram the big guy will go quicker. It's the laws of physics.

Dr Calum MacCormick
The drag force on the cyclist depends on the square of the cyclists speed through the wind which means that in fact the power required to go at that speed depends on the cube of the velocity which means for instance if you want to double the speed of yourself you need to multiply your power by a factor of 8. At twenty miles an hour it takes someone of moderate aerodynamics about 200 watts to travel at that speed. If he wants to increase his speed to about 25 or 26 miles an hour he almost has to double the power. So you'd be putting about 400 watts and the break down of the power is very different in the two cases. In the first case at 20 miles an hour about 30 per cent of his effort goes against friction on a flat road and 70 per cent would be about against aerodynamic drag. At 26 miles an hour, when he's making twice as much power so really much working much, much harder about 20 per cent of his effort is against friction and about 80 per cent of his effort is against the aerodynamic drag. So he's really increased a lot.

Presenter
Tests on the effects of these forces and how to improve the performance of bike and rider as a single unit have in recent years been performed in the controlled environment of a wind tunnel.

Gerard Vroomen
Innovator and Cervélo Bicycle Designer
In the wind tunnel basically you put your bike and the rider and the rider can be a real rider, it can be a mannequin, you put it in a wind tunnel so you have wind flowing and basically you put that whole thing on a – on a scale but instead of the scale where normally you stand on a scale bathroom scale and you have your weight .. this scale flips 90 degrees and so as the wind pushes against the rider it pushes into the scale and you have a reading. And that force is your drag. So the less drag you have the less force is pushing on to that scale and so there you can see what's more or less affected.

Simon Smart
Bike Aerodynamicist and Designer
The wind tunnel is used to obviously simulate the airflow over the rider in the system in a controlled manner in which we can then do some experimentation and draw conclusions, make good base lines and then make improvements. The wind tunnel needs to have consistent airflow, which doesn't change throughout the experimentation that you can rely on. So a clean air flow of which you can vary the speed. Generally when you cycle you don't necessarily cycle into a head on wind. The wind angle is always changing. So we also we look at how the component or the body position responds to different wind angles.

Gerard Vroomen
You can change out frames. You can change out ..frames. You see how that affects that drag reading and that's how you can find better – better shapes and better designs for products.

Presenter
As a result of these wind tunnel tests … riders can then alter clothing, equipment and positioning on the bike and on the track or road to change the impact of these forces.

Slipstreaming for example reduces drag thus saving energy for endurance and acceleration later in the race.

Simon Smart
You can obviously change your tyre compound, tyre stiffness and your mass and that affects friction forces. There's only so much that you can do there but then there's a much bigger amount of things you can do a wider range of things you can do with your position and your equipment to reduce the overall drag.

If we consider how much energy or power you have to produce to propel yourself at 30 mile an hour you could say that as much as 85 per cent of that is due to aerodynamic drag. And of that 85 per cent you could then split that down and say that around 75 per cent of that comes from the body as you can imagine because it's a you know a very large frontal area. So in terms of improving performance rider positioning, helmets, clothing comes very high up over and above the equipment.

Gerard Vroomen
The biggest change you can make is to your position which is about two thirds of that drag and to the bike which is about one third. So the bike you're looking at the wheels and the frame predominantly and of course on the position you're looking at changing your frontal area because the drag is nothing else than your shape multiplied by the frontal area, the size of the hole that you push through the wind. So if you can make that smaller you go faster. That's also why on a race bike obviously you're hunched forward so you're trying to reduce the frontal area or on a recumbent bike you know when you lie backwards you can make that hole even smaller. And that's why all records are held by recumbent bikes because you can

make that frontal area really small and then if you put a whole fairing around it that makes that shape factor better then you have a winning combination to go you know 120 kilometres an hour on a flat road instead of maybe 70 that Cavendish can do.

Presenter
And of course the design of the bicycle cannot be underestimated. Determining the influences of these forces on the bicycle and understanding their effects is now an extremely scientific process.

Chris Boardman
First of all we say what shape do we want? Well, this is the shape that we want no matter how wacky it is. Say right – well how do we get to keep that shape? And then we will computer simulate so in a computer computational fluid dynamics and finite element analysis first and foremost. We use the computer model to give us the shape that we want so aerodynamics on a computer. And then we'll make a rapid prototype of that and put it in a wind tunnel. and we'll confirm because computers aren't always right that that is the case. And then when we've decided what the shape is - finite element analysis, which is types of carbon fibre and resins amounts of it in different areas – put it into a computer programme. The computer programme bends and twists it and says you need a bit more here, you can get away with less there. And then we go and make a prototype.