Spring, Soar and Spin?

The Science and Engineering behind Springboard Diving

The sport of diving has always captured the imagination. At elite level grace, power and precision are brought together for a few moments of freedom from the normal constraints of gravity, making it fascinating to watch. And all this is possible because the diver is an expert at using the mechanical properties of the springboard and his or her own body, to initiate and control somersaults and twists that seem impossible to most of us.

The first divers (as we know the sport today) were actually gymnasts who wanted to practice complicated somersaults and twists without landing on a hard floor. Competitive diving has only been around for about a hundred years, and the early springboards were just wooden planks covered with matting to prevent divers slipping. Today, the technology has moved on considerably and there are now standard springboard types so that wherever a diver is in the world, they are assured of a familiar board.

The standard springboard today is 16 feet long, with an adjustable pivot to increase or decrease the effective length of the board. They are made of an aluminium aircraft alloy which can bear very large loads before it breaks, and so is capable of storing large quantities of elastic energy. As the board is tightened (the pivot is moved forwards, making the board shorter and so effectively stiffer - see figure 1), it takes less time for the board to reach its lowest point and begin to rebound. The diver adjusts the pivot to suit his or her size and style of diving to gain the greatest height, since the diver's movements must be perfectly synchronised with those of the board.

There are two basic take-off positions - forwards and backwards. For a forwards take-off, the diver starts near the back of the board and walks forward, finishing with a jump to land on the end of the board ready for take-off. This first jump store elastic energy in the board before the diver jumps off the end of the board, so that when they do leave the board, they are benefiting from the energy from two separate jumps. This is why a diver can reach heights of about 1.5m above the board, even though no human can perform a standing jump to that height.

A backwards take-off is performed starting with the diver's heels over the edge of the board. This allows the ankles to flex beyond 90 degrees so that even more force can be exerted on the board as they straighten.

The power for take-off comes from contraction of the quadriceps muscles (the big muscles on the front of the thigh) and also the calf muscles (which are used to point your toes). During the take-off action, the diver uses his or her arms to generate lift and to start the rotation. The diver pushes down on the board to store some elastic energy, bends his/her legs, and brings his/her arms down so that they reach their lowest point as the same time that the board reaches its lowest point. As the board rebounds, the diver straightens his legs and throws his arms upwards, pushing against the board. The board pushes up on the diver (that's Newton's third law!) and sends him into the air. Much of the skill involved in take-off is in the timing - mistakes mean that the diver does not take all the energy with him, leaving the board bouncing too much and so wasting energy that could have been used in the dive.

The laws of physics state that once a body is not touching anything else, its angular momentum must be conserved, so in order to somersault, divers must generate angular momentum before they leave the board. This is done by swinging the arms round from the hips, forward and upwards (in a back take-off) or from above the head forwards and downwards (for a forwards somersault). Angular momentum depends both on the speed of rotation and the distance of the rotating object from the centre, and it must remain constant throughout the dive. By changing their body shape to change their moment of inertia, the diver can control how fast he is rotating. A diver can straighten out his whole body to slow the rotation or tuck up tightly in a ball so the all his mass is very close to the centre of rotation to somersault as fast as possible. However, once he has left the board the diver cannot stop rotating completely. In competition, a diver must demonstrate as many controlled somersaults and twists as possible, in order to gain maximum points. The best divers can achieve four and a half forward somersaults from a three metre springboard or one and a half somersaults with as many as four twists!

To twist, a diver needs to start rotating about a different axis. To somersault, he is rotating about an imaginary line that passes from his left to his right through the centre of his body. Twisting is rotating about an axis that goes from the head to the toes, down the length of the body. But the twist doesn't start until the diver has left the board and we've just said that once a diver is off the board they cannot change the total amount of angular momentum that they have. So how do they do it? The secret is in using the arms to tilt the body so that it's not perfectly vertical at the top of the somersault. In order to rotate like this, the body needs to turn about the twisting axis, and to counterbalance this turning, the whole body twists in the opposite direction. The twist can then be stopped by bringing the body back into vertical alignment.

Divers only use two of their possible axes of rotation - the third one is an axis passing from the front to the back of the body. It's not used for two reasons. One is that your knee joints can only bend in one direction, making it difficult to initiate turning about this third axis. The other is that rotation about this axis is not stable and would be very wobbly and difficult to control.

At the end of the dive comes the bit that most people are worried about when they learn to dive - hitting the water! Most dives finish with a hands-first entry position and the divers hands are together one on top of the other, so that the palms hit the water first. This breaks the surface tension of the water and the rest of the divers body will pass through the "hole" made by their hands. It's important that the diver has a straight body as the enter the water - a splashy entry means that the body wasn't straight and that other parts of the body hit untouched water and so have to break the surface tension again.

How fast is a diver going when they reach the water? If they jump from a 3m springboard, they are likely to be travelling at about 10 metres per second when they hit the water (about 21mph). The total time in the air will be about a second and a half. Diving from a higher board doesn't actually add that much time in the air because the diver is continually being accelerated by gravity. They are falling fastest as they reach the last part of the dive and so they fall through the extra distance much more quickly.

So when you watch the Olympic divers this summer, spare a thought for the amount of science that's going into the dives. And they make it look so easy!

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