"Secret Life of a Tyre"

by Tony Cripps

Have you ever wondered how a tyre on a wheel supports the weight of your car? Not given it a thought? Well, things are not as simple as you might think. We all know when the air pressure is low, the tyre appears flat, and the weight of the car makes the whole thing sag so the air pressure does have something to do with it. But how is the weight of the car supported by this air pressure if the pressure is the same all the way around the rim? Surely the air pressure pushing down on the top half of the rim surface will be balanced out by the pressure pushing upwards from the bottom half, right? So exactly how is the weight supported?

Consider Fig 1. Here we have the weight of the car W and the reaction force R from the road. The two forces are in balance (otherwise the wheel and tyre would move in the vertical direction). The question is, how is the force W at the wheel hub transmitted down to the surface of the road so that the road can support it?

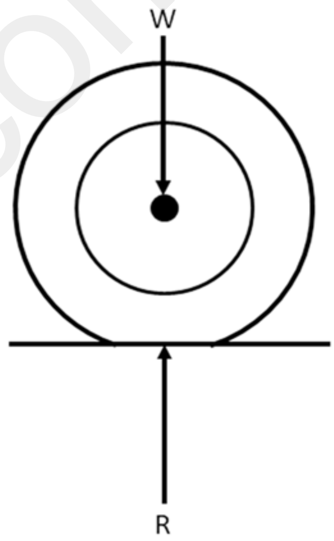

Fig. 1. *Weight W of car is balanced by reaction R from road*.

You might remember from physics lessons that a pressure in a gas is distributed evenly throughout the volume. That is, if we have a balloon full of compressed air, we don't find that the pressure in the balloon is greater at one place compared to another, the pressure is uniform throughout. Now, when pressure acts over a surface, the force applied is found by multiplying the pressure times the area over which the pressure acts. What this means for a tyre and wheel is that the pressure inside the tyre is distributed uniformly throughout the volume of the tyre. So, for every square centimetre of wheel rim surface, we have the same force acting. Further, this force acts at right angles to the surface upon which it acts. But, if the pressure is the same at the top and the bottom of, and all the way around, the rim, then all these forces will balance out. So, the question is, if the forces due to the air pressure balance out, just what is supporting the weight W of the car?

To appreciate what is happening, we need to look at a cross-section of the wheel. We must draw the wheel as a free-body diagram. This is a diagram where we just draw the object in complete isolation except that we show each and every force acting on the object. In this case, the forces acting directly on the wheel are:

(1) The weight W of the car
(2) The forces P due to the pressure of the compressed air
(3) The forces B acting on the rim where the tyre bead is in contact with the rim

Since the forces due to the air pressure completely balance out, we can forget about these for the moment. What is left are the forces acting at the bead. What are these forces? Well, it is easy to imagine that when the tyre has pressure in it, the fabric of the tyre is placed under tension, just like the surface of a balloon is under tension when it is inflated. That is, the air pressure pushes outwards on the tyre walls and the side walls are placed in tension in the radial direction (we will forget about tensile forces around the circumference at the moment).

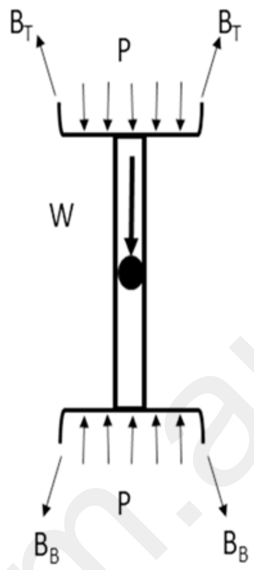

Fig. 2. *Free-body diagram of the wheel showing all forces acting on it. B_T is the force due to the bead at the top, and B_B is the force due to the bead at the bottom of the tyre.*

Now let's look at a free body diagram of the *tyre* in cross section, Fig. 3.

The tension in the side walls depends on the air pressure inside the tyre. But, and here is the crucial point, the downwards pressure from within the tyre over the contact patch is balanced by the upwards pressure over the contact patch from reaction force from the road. That is, the pressure over the contact patch is not contributing to the tension in the radial plies in the side walls because the tyre material is sandwiched between the inside pressure and the road surface. You can see this yourself if you put the palm of your hand flat against the side of a party balloon. You will feel the balloon material relax under your palm as the tension in that part of the balloon surface is relieved. This means that for a tyre, the tension in the side walls at the bottom is less than the tension force in the side walls at the top. What this then means is that there is a greater tensile force in the ply at the top of the tyre than there is at the bottom. It is this difference in tensile force that supports the weight of the car.

Does this make sense? Let's try a couple of different cases:

1. The tyre pressure is reduced: In this case, the tyre would go slightly flat and the contact patch area would increase. But, the difference between the tension in the top and bottom of the radial plys would remain the same, even though the absolute value of these tensile forces would be less. It is the *difference* in tension that is important.
2. The tyre pressure is increased: In this case, the contact patch area would decrease, and less of the radial ply would be sandwiched between the road and the air pressure force. In other words, more of the radial ply of the tyre at the bottom would be under tension, but the *difference* in tension between the top and the bottom would remain the same.
3. The weight of the car is increased: the contact patch increases in size and so the *difference* in tension between the top and the bottom plies is increased by the same amount.

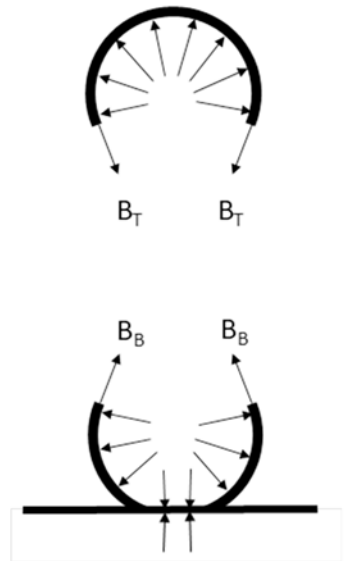

Fig. 3 *Free body diagram of tyre*.

So, contrary to expectations, when you look at your wheel and tyre, the wheel is actually hanging inside the tyre bead from the extra tensile force in the radial plies at the top! When you consider how think these sidewalls are, and how much force they are called upon to withstand (suspension shocks as well as the static mass of the car), you can appreciate what a fine job they do.

The author thanks Mr Brian Le Grice, of Sydney Technical College, for the remarkable explanation of this commonplace event.

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