PHYSICS IN DAILY LIFE:

WHY PLANES FLY

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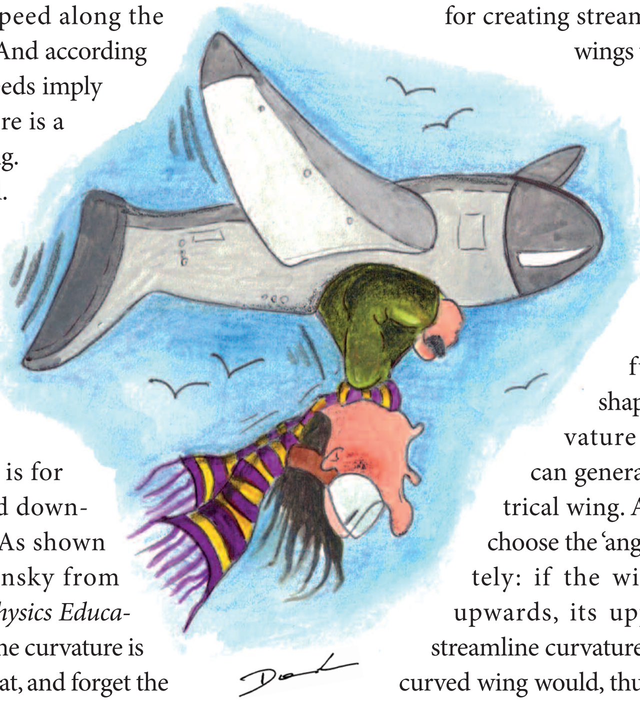
Ask any physicist how the wings of an aircraft work, and most probably he or she will come up with the popular explanation based on Bernoulli's law. The idea is that the cross section of a wing is curved along the upper side, and more or less flat at the bottom. Air hitting the front of the wing, the 'leading edge', is split in two, and the two air masses meet up again at the rear of the wing, the 'trailing edge'. Since the distance along the upper surface is longer, the air speed along the upper side must be greater. And according to Bernoulli's law, larger speeds imply lower pressures, and so there is a net upward force on the wing.

It sounds simple and logical. But it's wrong. We *know* it must be wrong. If this were the correct explanation, how on earth would planes be able to fly upside down?

So what *is* it that produces lift on a wing? It turns out that all we need is for the air flow to be deflected downward by the wing profile. As shown elegantly by Holger Babinsky from Cambridge back in 2003 (*Physics Education* **38**, p. 497-503), streamline curvature is the key. Think of a sailing boat, and forget the mast for a second. The sail can be seen as a vertical wing. It works beautifully propelling the boat, but its shape is nowhere near that of a traditional wing. There is no difference in path length along the two sides of the sail, so the Bernoulli explanation invoking different path lengths fails. Yet the sail is very efficient, simply because it creates curvature in the air flow. If we work it out, we find a simple relation between the curvature of the flow and the pressure gradient perpendicular to the streamlines: $dp/dn = \rho v^2/R$, with coordinate n normal to the streamlines, ρ the air density, v the speed and R the radius of curvature. The sign is such that the pressure decreases toward the center of curvature. This yields a pressure decrease at the convex side of the sail, and a pressure increase at the hollow side.



Indeed, thin curved wings like those of a sail are ideal for creating streamline curvature. Birds' wings tend to be like that. For aircraft, this is not an attractive option: thin curved wings would not meet structural demands and, in addition, would have no useful volume for storing fuel. Fortunately, *any* shape that introduces curvature into the flow profile can generate lift, even a symmetrical wing. All we have to do is to choose the 'angle of attack' appropriately: if the wing is slightly tilted upwards, its upper side will create streamline curvature as effectively as a thin curved wing would, thus giving by far the largest contribution to the lift. Below the wing there are regions of different senses of curvature, creating a net effect which is close to zero.

So, for a symmetrical wing the amount of lift – positive or negative – is purely a matter of adjusting the angle of attack, obviously within certain limits. And flying upside down is now a piece of cake. If you feel like it, of course. ■