Balloons Don't Lift

By Andrew K. Baird

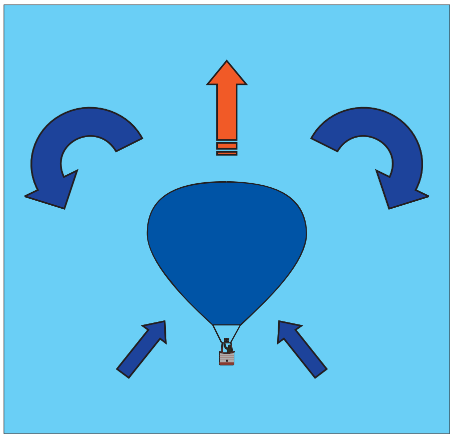
Despite the simplicity of our sport, some of the obvious "facts" we thought we knew – like hot air rising – aren't quite as straightforward as they appear.

For example, balloons really don't lift. To explain, let's go back to third grade physics to discuss three important and long forgotten principles: (1) the pull of gravity, (2) the weight of air and (3) the belief that Archimedes must have been a balloonist.

Principle 1: The Pull of Gravity

Gravity pulls us – and everything around us – as close to the center of the earth as possible. It does this until something gets in our way, preventing us from moving closer to the center of the earth.

Let's use the example of a glass of water. If we pour water from a pitcher into an empty glass, the water falls into the glass (pulled by gravity) until it hits the bottom of the glass (something got in its way) and then it pools up, raising the level of the liquid until we stop pouring.



The same is true of any substance – milk, beer, even solids like sand. In fact, if we then pour sand into that same glass of water, we observe the same thing happening. The sand falls from the pitcher by gravity until the bottom of the glass gets in its way, and then it piles up on itself. The sand falls through the water because the effect of gravity is greatest on the heaviest or most dense objects.

In the process the water level rises as the heavier sand displaces it. Probably none of us would say that the water lifted, or that water is a good lifting medium, or that we should all be flying water balloons. But what just happened in our imaginary glass is exactly what happens to our balloons every time we fly.

Take a balloon in level flight. When we bring the balloon to 'equilibrium', which is a great way to describe it, everything is in balance.

In level flight, the effect of gravity is exactly the same on the balloon as it is on the surrounding air. The balloon and the surrounding air are in a constant battle – pushing against each other as they are both acted on by gravity.

Adding heat to the balloon makes the balloon as a whole less dense. Now the balloon and the surrounding air are no longer in balance – the surrounding air is being affected by gravity more than the balloon. In its rush to get as close to the ground as possible, the surrounding air pushes the balloon out of its way…up. So the balloon doesn't actually lift up, it is pushed up!

Principle 2: Air is heavy

On an average day at sea level 1,000 cubic feet of air weighs about 76 pounds. It's really that mass that's important. Mass is the measure of how much 'stuff' (matter) an object contains. Weight is the effect of gravity on this mass.

Let's take a large ride balloon of 250,000 cu. ft. and set it on an oversized bathroom scale in the middle of the launch field. As we hot inflate, the reading on the scale gradually gets lower and lower, until the exact moment of take-off when it reaches zero. However, if we could measure the mass of the balloon, we would see that it remained relatively constant. Taking into consideration the air inside the envelope, the balloon still has a mass of roughly 19,000 pounds, even thought it is technically 'weightless'.

Considering mass, it is easy to see why balloons make drag landings in the wind – slowing down a 19,000-pound object takes some time. It also explains why tether ropes need to be so strong. An AX-7 actually has a mass of nearly three tons (compared to its free lift of perhaps only a few hundred pounds).

It also explains why 'racing' balloons tend to be as small as possible. You can imagine how much more effort and time it takes to maneuver an object with a mass of nine tons versus one that that's only two tons.

Principle 3: Archimedes Must Have Been a Balloonist

Amongst other things, the Greek physicist Archimedes first described the principle of buoyancy. He said that an object (balloon) would sink into a fluid (air) until it displaces an amount of that fluid equal to its own weight. So if we take a balloon and drop it from a great height, it will fall until it finally reaches the point of equilibrium where its own weight is exactly equal to the weight of air it is displacing (pushing out of the way).

Who should care about all this?

You should. These principles explain why balloons do the things they do. Understanding how balloons really work is key to being an effective instructor and a better pilot (not to mention being able to predict performance for that record flight).

A close look at balloon performance reveals that the thing really driving balloon performance is not temperature, or altitude, or pressure, or humidity, or anything else except … air density. These other measurements are just an indicator of what the local air density might be.

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Why Do We Need a Burner?

When we heat air it expands, but our envelopes have a fixed volume, so what happens to the expanding air?

It gets forced out. The amount of air forced out is exactly equal to the gross lift of the balloon at any given moment. One could say that the job of the burner is to 'throw out' air molecules.

Air molecules are a lot like balloonists.

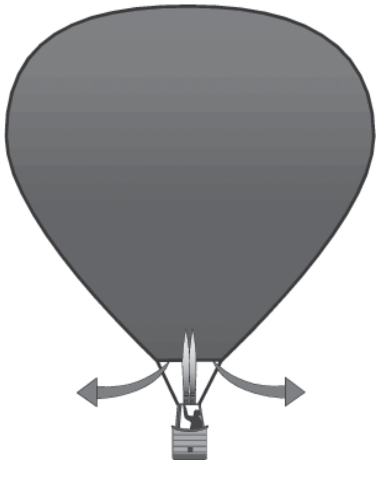
In winter, we balloonists tend to huddle together, not moving much or taking up much space. In summer we tend to move around more, taking up a lot more space.

The same is true of air molecules. The colder the weather, the closer they stay together. In winter, our envelopes have a lot more air molecules trapped inside.

When we increase envelope temperature by 200F, we expel about 24% of the air molecules we started with. The more molecules we start with (i.e. in winter) the more 'performance' we'll have.

The Hotter I fly the more sluggish my balloon becomes

We just described why performance is better on a cold day versus a hot day, but the same is true of temperature inside the balloon.



The higher your level-flight temperature, the harder it will be to generate a rate of climb. This has nothing to do with temperature limits or burner performance.

Remember that to create lift we take air molecules from inside the envelope and throw them outside – without changing the volume of the balloon.

If we've already thrown out most of the air molecules (by flying at let's say 250F instead of 200F) it will be harder to throw out many more molecules in order to generate lift.

Why Does My Envelope Temperature 'Jump' 15 Degrees Right After Takeoff?

There's another phenomenon related to everything we've discussed so far. This one bugged me for years as a ride operator so let me describe the scenario.

Your passengers arrive at the launch site and to your surprise they each weigh some 30 to 40 pounds more than it says on the reservation card. It's a hot night and you're going to be close to the temperature limit of the balloon.

Rather than scare your passengers by thumbing through the flight manual immediately before take-off, you decide to get them on board, heat the balloon to equilibrium and check your temperature.

Doing so, you find that the balloon is just below your balloon's limit so you take off. You get to the treetops in level flight, and check the temperature again – a few degrees below the limit—perfect. Five minutes later, at the same altitude and still in level flight you look down at the instruments and find that you are now 10 F *above* the limit. What happened?

The answer is quite straightforward. During the inflation and heating to buoyancy you add a lot of heat in a short space of time. This creates turbulence inside the envelope – thoroughly mixing the air. The result is that all the air in the envelope is roughly the same temperature. After take-off you continue to add heat, but this time in small less-frequent blasts. Consequently the air has a chance to stratify, settling into temperature layers – the coolest layers near the mouth and the hottest layers at the top, which is where we measure the temperature. Although the average or effective temperature of the envelope remains constant, the temperature of the air in the top of the envelope near the sensor has risen. Same net lift – higher measured temperature – and perhaps higher blood pressure of the pilot in command.

Now you see why I said that things we thought we learned in flight training aren't quite as they appear.

ANDREW BAIRD is general manager of Cameron Balloons USA. His responsibilities include flight-testing new special shape and standard balloons, and the general testing and implementation of new designs and equipment.