Flying saucers

For most of us frisbees are just a bit of fun, so why is planetary scientist **Ralph Lorenz** taking them so seriously?

THROW a frisbee just right and it can skim straight for dozens of metres, arc across the sky, or zoom up before gliding gently to the ground. Misjudge the flick of your wrist and the spinning plastic disc will wobble precariously before flipping over and falling to earth. Why is it so easy to go wrong?

Embarrassingly, no one really knows why it is so hard to throw a frisbee straight, and why such a simple piece of plastic can fly in so many different ways. It's a problem that also bedevils our understanding of other flying objects, including space probes hurtling through the atmospheres of alien planets. Which is why, as part of my work as a planetary scientist, I have been out in the fresh air, studying the dynamics of frisbee flight.

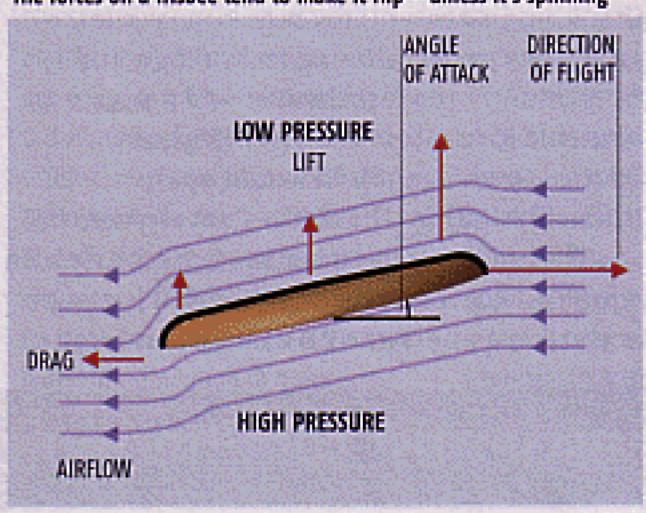
Frisbees in one form or other have been around for more than 130 years. The name comes from William Frisbie, a 19th-century Connecticut baker whose pie tins, turned upside down, were renowned fliers.

What makes frisbees such good fliers is their shape: a flat disc with a deep, downward-curving lip all round. As the frisbee flies forwards, the flow of air around the lip makes it behave as a short, stubby wing. Air passing over the top of the disc moves faster than the air below it, and this lowers the pressure on the top of the disc, creating the aerodynamic lift needed to keep the disc afloat.

But there are complications. The front of the disc experiences more lift than the back, and this tends to make a frisbee's flight unstable. Unlike aeroplanes, which have a tail to keep them steady, frisbees have no extra surfaces to control the uneven distribution of forces across the disc, so they tend to flip. But they do something aircraft can't do: they spin around their vertical axis. It only takes a minute or two playing with a frisbee to realise that spin is the key to a successful throw. It's the same principle that keeps gyroscopes and spinning tops upright: nudge a rotating gyroscope and you find that it doesn't fall to the ground; only its spin axis is knocked off-course. In the same way, when a frisbee is spinning, the uneven lift causes it to veer off to one side rather than flip completely.

FLIGHT OF A FRISBEE

The forces on a frisbee tend to make it flip – unless it's spinning



Another plus for the frisbee is the rim, because most of a frisbee's mass is concentrated there, making it more stable than a flat spinning plate. Because the rim is quite thick, though, a frisbee experiences more aerodynamic drag than a flat disc flying through the air. Aeronautical engineers tend to view drag as a bad thing, because it slows aircraft down, but in a frisbee the drag-producing rim helps to distribute the forces more evenly around the surface. The air flowing underneath the disc tends to get caught under the rim at the back the disc. This increases the lift at the rear of the frisbee somewhat, limiting its tendency to veer or flip. Finally, frisbees have grooves on the top surface that help to reduce the drag force that slows a smooth disc down.

It turns out that the lift and drag forces on a frisbee depend on a parameter called the angle of attack – its back-to-front tilt relative to its direction of flight (see Diagram). For a frisbee to fly straight, and without flipping, the optimum angle of attack is 10 degrees.

But these basic features of frisbee flight do

GETTY IMAGES

A frisbee may be a simple plastic disc but its flight pattern is a lot more complex than you imagine

> **"Going out in the sunshine to test-fly a frisbee is rather fun. But these tests are a cheap way of refining the way signals from spacecraft are analysed"**

not explain the subtle turns that it can make, especially towards the end of its flight. This is where the latest research comes in. Two years ago, aerospace engineers Jon Potts and Bill Crowther at the University of Manchester in the UK began exhaustive studies with frisbees as part of their work into unmanned aerial vehicles. They wanted to know what factors affected the sideways tilt of the disc. To find out, they stuck a frisbee on a motorised rod to spin it and placed the whole set-up in a wind tunnel. They showed that the tilt rate depends on both the angle of attack and a quantity called the advance ratio, which measures how fast the disc spins relative to its speed through the air.

When a frisbee leaves the thrower's hand, it typically spins at about eight revolutions per second. It keeps spinning at this rate, even as its forward motion slows, which means that the advance ratio increases over the course of the flight. As a result, its tilt rate also changes as the flight progresses.

Potts and Crowther's measurements could eventually help to reveal the secret of a good throw. In principle if you know how fast you fling a frisbee, you could use their wind-tunnel measurements to work out at what angle you should throw it to make it go as far as possible or to keep it in the air for as long as possible.

Such insights could help teach us rather more than the best way to hurl a plastic disc around the park. I got involved in frisbee research because engineers sending probes to other planets deliberately put their craft into a spin as a way of stabilising them during their descent. This is far easier than the alternative: monitoring every aspect of their motion, and firing an array of thrusters to correct the slightest wobble. For the Mars Pathfinder mission, NASA spin-stabilised the probe as it plunged through the Martian atmosphere.

To work out the aerodynamics of their probes, engineers spend weeks testing scale models in a wind tunnel. From the density of air and the area of the model, they can calculate the probe's so-called aerodynamic coefficients, using fluid dynamics equations. When the full-sized probe reaches its destination, researchers use the same equations in reverse to work out the density of the alien atmosphere from force measurements gathered by sensors on the craft.

At least that's the theory. The trouble with space probes is that it is all too easy to misinterpret the measurements they beam back. For instance, a spinning probe entering a dense atmosphere will experience far greater drag than in a thin one. Yet drag can also be down to the flight conditions, rather than an alien environment. So how do you figure out what is really going on?

Knowledge of a frisbee's flight can help, so to find out more, I equipped a frisbee with a miniature equivalent of an aircraft's black box flight recorder. It includes an accelerometer to measure the forces on the disc, and a magnetometer and light sensor to measure the orientation of the frisbee relative to the Earth's magnetic field and the sun. Calculator batteries provide the power, and a computer chip stores the measurements for each flight.

One of the things these test flights have revealed is that wobble causes a lot of extra drag. What's more, the drag increases with the square of the angle of attack, which means that the average angle of attack alone does not tell you enough to work out the average drag on the disc. You have to know the extent of the wobble as well. Only by characterising exactly how the drag depends on flight conditions – and figuring out ways to measure and model how much wobble occurs – will we be able to profile alien atmospheres accurately.

I can't deny that going out in the sunshine to test-fly a frisbee is rather fun. But these tests do provide a cheap way of getting real flight measurements that can be used to refine the way signals from spacecraft are analysed. They are also a way of exploring techniques for integrating sensors and electronics with structures – which is vital in making space probes more compact. Rather than building the parts into separate boxes – the usual spacecraft assembly approach – they can be attached flat onto the body of the frisbee itself without disturbing the airflow.

The next step will be to go beyond just the overall aerodynamic coefficients and to measure and understand the distribution of pressure over the spinning disc. This is much easier to do with a disc smothered with sensors than in a wind tunnel. Knowing the pressure distribution is vital to understanding how the aerodynamic forces might be controlled in future, for instance with small flaps. By directing airflow away from the surface of the disc, and so altering the pressure distribution on it, a flap could be used to steer the disc.

So far, my experiments haven't improved my frisbee throwing. But knowing the aerodynamic coefficients accurately, I could always construct a frisbee simulator to predict the flight path. But rather than sit at the computer, I'm off out into the sunshine to fling the real thing. ●

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