

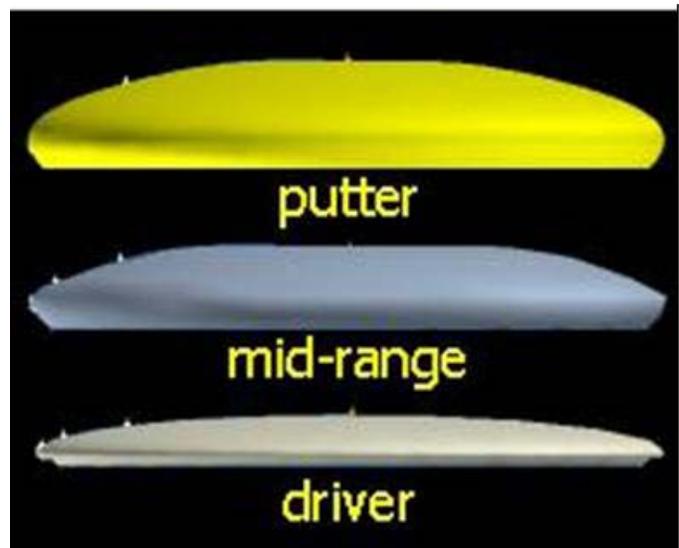
## The physics relating to different golf disc models.

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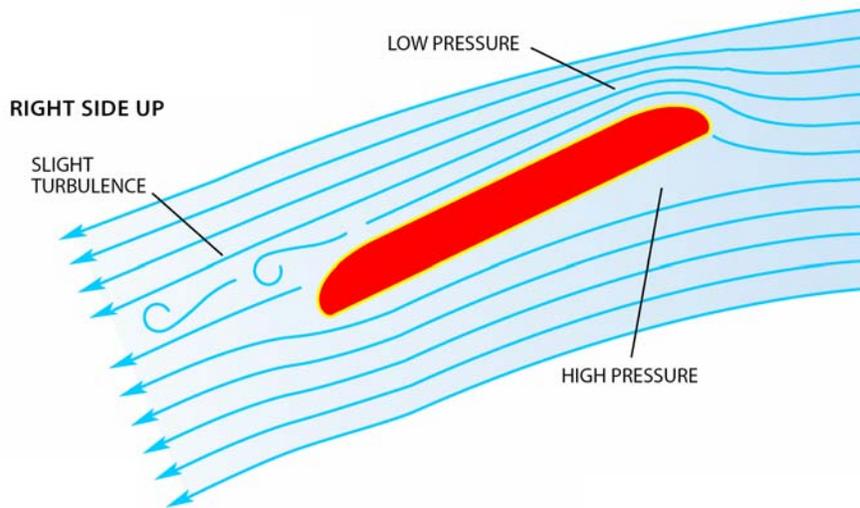
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As you become more familiar with the discs in your bag, you will notice how their trajectories result from the collective details of each throw. This document is meant to serve as a means to explain the physics behind these results that you witness. With an understanding of the physical mechanisms simultaneously at work in disc flight, you should be better able to decide with a greater comprehension, the combination of elements, which essentially also includes choice of disc model, to impart to each throw faced with any possible set of circumstances. At first, what is explained here may seem to have little or no connection with your experiences. If this is the case, I would suggest re-visiting this article again in a few months after having gained and catalogued some more throwing experience.

Let's begin by reviewing a basic, but essentially distinguishing feature of golf discs, which is their cross-sectional profile. Figure 1 to the right shows a schematic of a putter, a mid-range disc and a generic driver. As we move from putter through to driver, the edge profile goes from rounded to sharply angled. The dome height becomes less pronounced as well. These two features are essential details that give rise to the flight characteristic of these different discs.



**Figure 1: generic cross section profiles for different disc types.**



**Figure 2: The disc as an airfoil, causing flow separation and its associated lift.**

Let us now refer to Figure 2 above, showing the air streamlines around a moving disc. What is relevant here is the relative motion between the air and the disc. The forces acting on a disc would be the same for a disc flying through still air, or a stationary disc positioned in a wind tunnel. Through pressure considerations, the air being separated by the disc will be induced to fill the pressure void created at the trailing edge of the disc. Owing to the shape of the disc, the path over the top surface is longer, thereby requiring air taking the top path to move more quickly in order to meet up with air going underneath. The pressure of the moving air against the surface is inversely proportional to its speed, so that the net result is that there is a lower pressure on the top of the disc than on the bottom, thereby imparting the aerodynamic lift that helps the disc fly. A golf disc in this sense is a kind of an airfoil.

In terms of disc models, the putter has a more pronounced dome, and as such gets more of this kind of airfoil lift, and produces what we observe as its “floaty” behaviour when we throw it. The blunt edge however, creates more drag (having to deflect air), so that the putter has a lot of its forward momentum diffused. The driver with its much sharper edge profile, generates less lift from its flatter profile,

but at the same time induces much less drag, so that it holds its speed better and the result is a flight that is more ballistic than lift-driven. The mid-range disc logically, has properties somewhere in between.

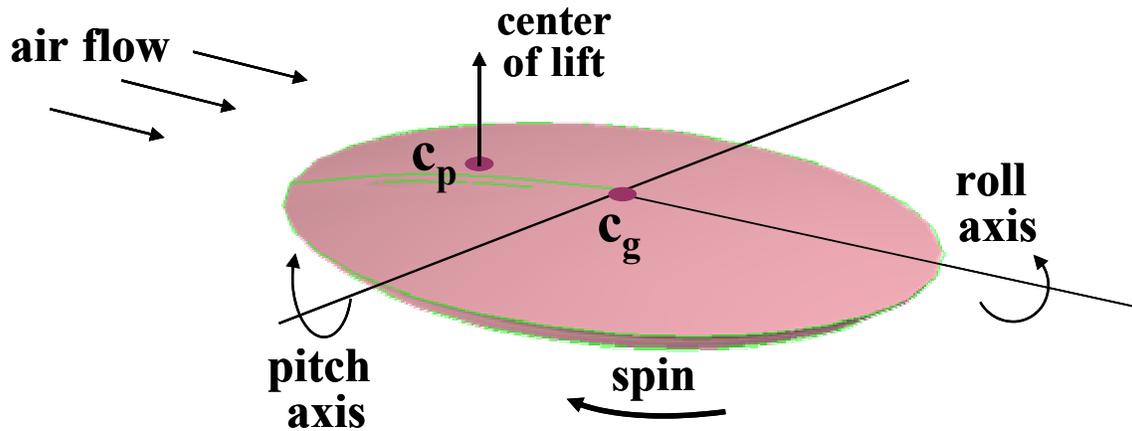


Figure 3: Free body diagram showing gyroscopic forces involved in a flying disc.

A real disc, of course, rotates as well, and its flight is fully three dimensional. Above, Figure 3 is a free-body diagram of the elements involved in accounting for the rotational behaviour of a disc. A disc can be considered as a free floating gyroscope. When in flight, the leading half of the disc contains the center of pressure, so that an upwards pitching force exists, shown as the arrow labeled L. Since this is a rotating body, angular momentum is conserved. The net result is that the positive pitching force is manifested in a roll rate, that is, the left side of the disc banks downward. (ie; on a moving bicycle, leaning to one side will cause the free-pivoting front tire to actually TURN to that same side). This upward force on the leading edge of the rotating disc which causes it to bank to the left is known technically as gyroscopic precession.

As mentioned earlier, more drag is produced by a blunt edged disc. From experimental studies with various discs, models producing higher the drag will exhibit less of a pitching moment. For sharp edged discs, the drag is minimized, so a larger precessional roll occurs, thereby imparting what we recognize as

overstable properties to discs. The pitching moment is also varies directly with the angle of attack of the disc, that is the angle that the underside of the disc makes with the ground. At high angles of attack, with the leading edge tilted upwards, a very large precessional roll is generated, and this is the physical reason why discs thrown too high will “stall”, namely banking dramatically to the left at the sacrifice of forward speed and distance.

On the underside of a disc’s rim, there is usually a concave surface between the external rim of the disc and the inner vertical edge that we grip with our fingertips. This edge is highlighted in yellow in the accompanying figure, so you can identify what I’m referring to. I’m not aware of a formal name for this part of the disc, so for our

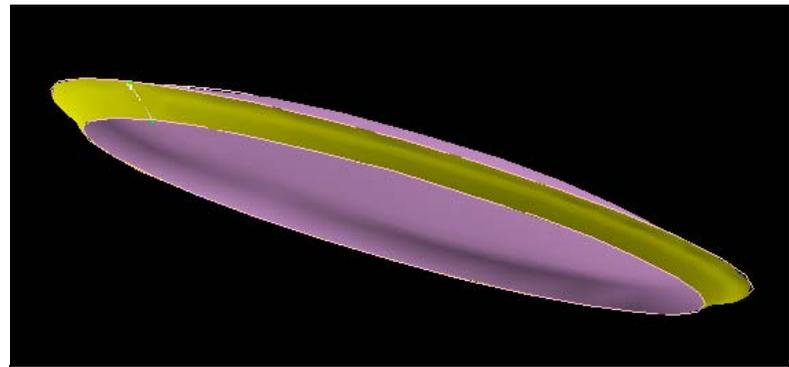


Figure 4: The "under-rim" is highlighted in yellow on this disc.

discussion’s sake, let’s call it the “under-rim”. The precise details of how the under-rim is contoured can have significant effects on the stability of a mid-range or driver disc, as this a key region where air streamlines are deflected and separated. Small variations can produce a whole range of results. For example, compare a Stratus to a Cyclone. The under-rim on the Stratus has a far more vertical slope where it joins the inner rim, causing comparatively more flow separation, and consequently a more understable flight. So to extend the logic, keeping an identical driver-style under-rim, but making one disc with a fairly flat dome and a second with a higher, more rounded dome, will result in two models of discs which may be both high-speed overstable drivers with slightly different properties making them suitable for situations with subtle differences. As we complete our discussion, we’ll revisit these hypothetical discs and deduce what they both might be best suited for. A point here being, the more a player

understands and appreciates the nature of these subtleties, the more ready they are to expand the selection of discs carried in their bag.

At this point we have introduced a gyroscopic force which occurs with a flying disc, inducing a leftward bank for a right-handed throw, suggesting that the flying disc will nosedive down to the left. Clearly, this is not what we observe. Golf discs also produce a second kind of steering force, which happily is to the right side, the net consequence of which is to counteract the leftward precessional roll, and allow for a stable, level flight. Consider Figure 5 here showing a top view

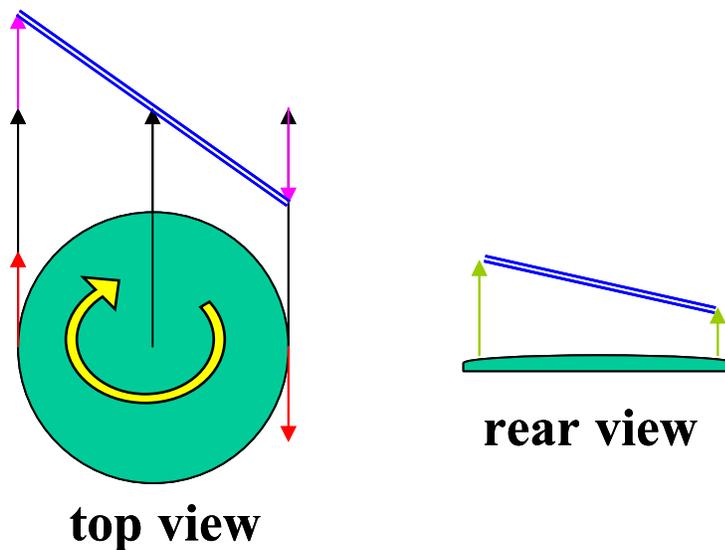


Figure 5: Schematic of how airspeed generates asymmetric lift.

of a disc, whose rotation is indicated by the yellow arrow. The black arrow from the center of the disc represents the airspeed of the disc, that is, how fast it is moving as a body relative to the air. The red arrows on the left and right sides of the disc represent the rotational speed of the disc at these outside positions. The total airspeed at any point on the disc is the sum of the translational speed (ie; how fast the disc is covering ground) plus the rotational speed. On the left side, the rotational speed is aligned with the translational speed, but on the right side, it is against it. In the center of the disc, there is zero rotational speed. We add

the rotational speed to the translational speed with the pink arrows. The net airspeed is represented by the blue line. Clearly, the airspeed is not uniform across the disc; it increases from the right side to its maximum value on the left side. Recall from our previous discussion that lift is proportional to airspeed. The blue line above the profile view of the disc in the diagram shows how the lift force is distributed over a disc. Consequently, because the disc is spinning, more lift is generated on the left side of the disc than on the right side, producing a force that will tend to tilt the left edge upwards. Should a left-side-higher orientation arise, the disc will bank to the right. Simultaneously, the gyroscopic roll force is applied. If the precessional roll and the asymmetric lift force are more or less in balance, the flight will be essentially level and straight. If one of these forces dominates, the flight will be in a curving trajectory in the direction of the dominant force.

At this point, we have established enough of a technical foundation to move on to illustrating how these mechanisms apply themselves when different throws with different disc models are considered. To do this, let's consult the first field chart diagram, Figure 6. Here we consider a basic throw. To isolate the effects of the different disc models, we'll consider that the only thing different about any of the throws on the first chart is simply the speed of release. Everything else is the same, a flat launch angle, initial flight direction, no tilt, and equivalent amounts of "snap" or spin imparted to the disc. It should be noted however, that the rotation imparted to a disc must be in proportion to its release speed, as this is inherently part of the act of throwing. The throws are assumed to be right-handed backhands. Left-handed backhands, or right-handed forehand throws, which impart spin in the opposite direction, will produce left-to-right mirror images of the trajectories illustrated

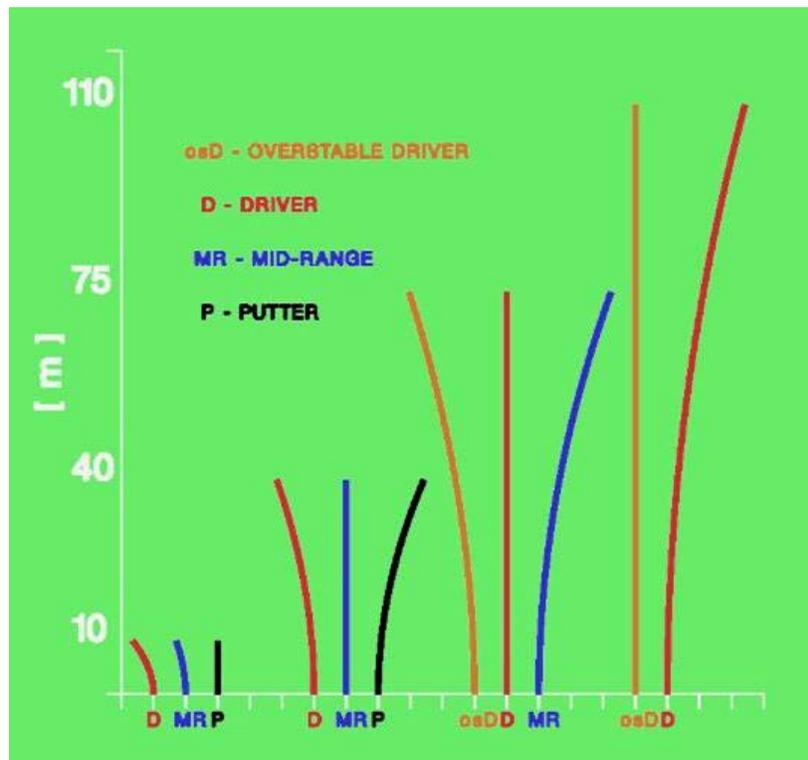


Figure 6: Schematic trajectories for throws with various model types at various release speeds.

The first set of throws, which is shown at the left of Figure 6, is thrown with enough speed for the discs to fly a distance of 10 meters. At this comparatively low speed, with low spin, the mid-range and the driver generate a weak lift force and consequently veer to the left. The lift and precessional roll generated by the putter are in good balance and it flies straight. Of course, this is what the putter is designed to do!

The next set of throws was thrown with a release speed to fly 40 m. At this higher speed, where a greater lift force is generated, it dominates in the case of the putter, so the net result is a trajectory that curves to the right. The driver is still not given enough speed to be in balance, so its precessional roll still dominates and it curves left. The mid-range is in proper balance at this speed and flies straight. It might appear odd on the chart that a putter is shown to reach the same distance as a driver. You can try this experiment yourself with different

models. Gliding and edge-drag properties aside, discs with a similar initial speed will all go similar distances, albeit on different trajectories. It would be more correct to have the arc lengths of the throws equal on the chart, so that some forward distance in the cases of non-straight trajectories would be sacrificed to sideways motion. In plainer language, the straighter the flight, the greater the distance.

We move on to throws with a release speed to reach a distance of 75 m. We replace the putter in this set with an overstable driver, that is, a driver with a very sharp edge shape and flat dome profile that gives it an extreme degree of left-veering tendency. The familiar pattern from the 40 m case reemerges, with the speed now being excessive for the mid-range, insufficient for the overstable driver and in balance for the driver. For any of these cases, there is nothing inherently right or wrong about any of these throws. A situation on the golf course requiring a right bend over 75 m simply calls for the mid-range disc, and this is fairly common practice at Jacques Cartier for tee shots on Holes 11 and 17.

Finally, to fly a disc 110 m requires a tremendous amount of release speed. Not every player will have this ability. A standard driver thrown at this speed will generate such a great lift force that it will overpower the precessional roll resulting in a trajectory that curves to the right. Players will refer to this action as “turning-over”. In the case of an overstable driver, it requires an extreme amount of release speed to generate the necessary lift force to balance its large precessional roll and keep its trajectory straight. Examples of overstable drivers would be the Banshee, the Xtra, X2 or Firebird. It is rare indeed to see one of these discs on a low, level, near dead-straight trajectory, as few players possess the required power. If a putter were thrown at this speed, the lift force would be so excessive that the disc would turn-over out of control and nosedive to the right.

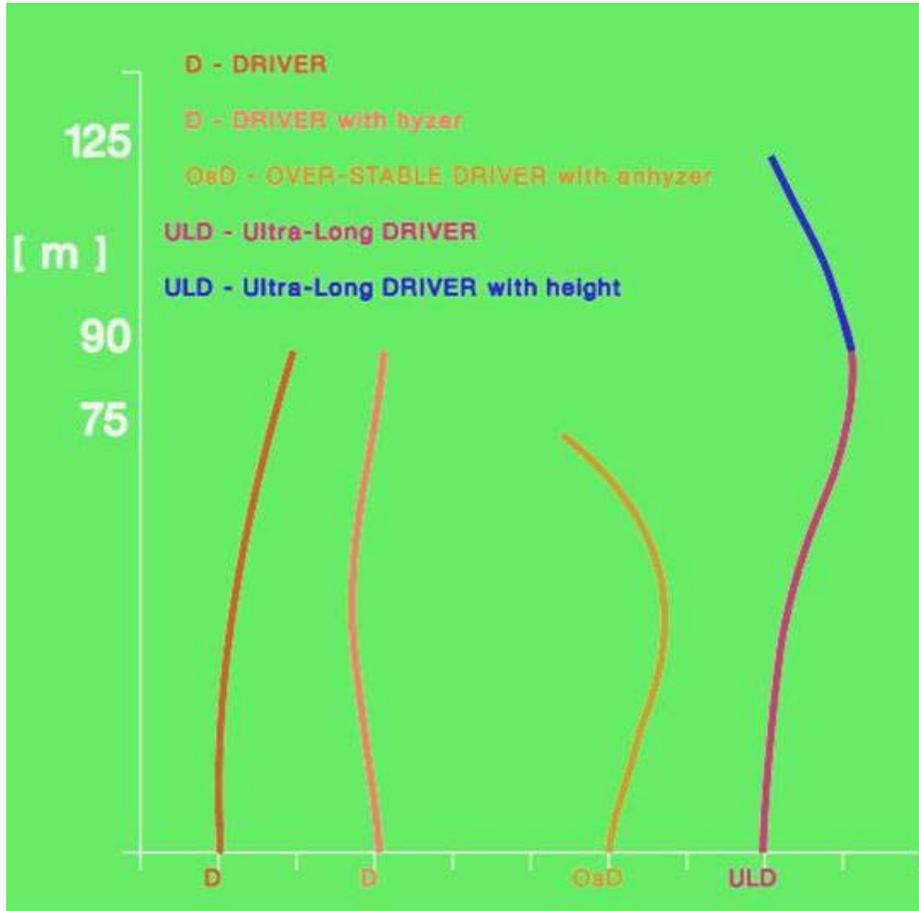


Figure 7: Schematic trajectories with more advanced throw features.

Let us now consider the second field chart above, Figure 7. Here we introduce some additional elements of throwing. First let us consider changing the angle of release. Figure 8 shows a rear view of a disc in three different orientations. For a right-handed backhand throw, when the outside edge is tilted downwards, the throw is said to be made with “hyzer”. When the outside edge is tilted upwards, the throw is made with “anhyzer”. Releasing a disc on an angle initially overrides some of its natural flight



Figure 8: Depictions of release angles for hyzer and anhyzer.

tendencies and is a way to modify a trajectory as a situation may dictate. From left to right, the first throw is a driver thrown with speed to reach 90 m. This is enough speed for a disc like an XL, Cheetah, Eagle or Cyclone to turn-over somewhat, so we see a right bending trajectory. If the same throw is made with some hyzer on release, the hyzer orientation will begin moving the disc to the left, but as the flight proceeds, the lift force is operating and tilting up the left edge of the disc until it begins to dominate and steers the disc to the right. Comparing the second throw to the first, the distance is the same but the paths taken were different. This is often essential for avoiding obstacles en route to a basket. The third example shows an overstable driver thrown with anhyzer at a speed for 75 m. The anhyzer steers the disc right at first, but the asymmetric lift is insufficient to prevent precessional roll, which at low speeds (for an overstable driver) dominates and eventually steers the throw to a net leftwards trajectory. For many throws, the target landing point is as equally important as the path taken to get there.

The fourth (and fifth) throw depicted features a class of drivers known as ultra-long drivers. These tend to be sharp edged drivers with higher rounded domes in their centers. Models include, the Valkyrie, the Archangel and the XS. These models are more physically complex than others, so here a good grasp of disc aerodynamics is most relevant for gaining their maximum potential. Throwing an ultra-long driver with as high a release speed as possible may result in a trajectory shown in pink on the chart. The higher dome on these models contributes to an enhanced airfoil lift force and the disc does not require excessive speed to make it turn-over. At high speed, the turn-over phase of the flight may be extended and with a flat release, the disc may lose enough altitude on its rightward turn that it will hit the ground. In this example, the disc may still have had a fair amount of forward speed even when landing after a 90 m flight. Drag (air resistance) on a disc causes it to slow down as it flies. Drag also decelerates the rotational rate of a disc over the course of its flight. As it slows

down, the lift force is reduced and the precessional roll can begin to dominate. The higher dome on an ultra-long driver allows the disc to glide better at low speeds, based on the original airfoil effect first discussed in this article. In order to take advantage of the forward speed still remaining when the driver hit the ground, the disc could be thrown in a slightly upwards release direction, but still with a zero angle of attack. (The angle of attack is the angle between the plane of the bottom of the disc and the ground, see figure. Thus here, a difference is that the thrower's wrist is slightly turned down to compensate for the upward angle of launch.) Since the disc is higher in the sky, its turn-over phase with accompanying altitude loss can be accommodated, so that when the precessional roll takes over with speed remaining, the trajectory can begin steering back leftwards through what is known as the glide phase of the flight. A release speed that might get 110 m of distance from a flat, level throw with an overstable driver, could very well reach 125 m with a properly executed high throw with an ultra-long driver. This additional portion of a flight that could lengthen a throw with height is shown in blue in the chart. Using such techniques local players have managed to achieve distances of 140 to 150 m with tailwinds. What was just explained above, the differences between overstable drivers and ultra-long drivers, is a response to the hypothetical disc design problem posed earlier in the article.

To round out the discussion, a few related topics will be touched upon.

Wind: The simplest cases are headwinds and tailwinds. Both of these operate in the same way in the sense that they directly contribute to (positively or negatively) the net airspeed of a disc. With a tailwind, when a disc is released at 75 kpm with 25 kph of wind, the disc-air interaction is at 50 kph. This is tantamount to throwing for shorter distances, so that the amount of disc stability needed for a desired trajectory is lessened. To give a concrete example, a Cyclone with a strong tailwind is liable to fly quite straight over 90 m. With a

headwind, the opposite occurs, a 75 kph release into a 25 kph wind, produces a 100 kph airspeed. The disc thinks it has been shot out of a cannon on a calm day. An example would be a Banshee holding a straight line over 75 m. For this exact reason, with dramatically increased lift, putts are liable to fly over the basket when sent into a strong headwind.

Crosswinds are far trickier and after more than ten years of highly contemplative disc golf, I still don't think I have mastered my comprehension of all the nuances they can bring to disc flight. In general they tend to amplify the curve already underway if the wind is pushing on the bottom surface of the disc. Crosswinds can also delay and/or negate expected tilt changes if they manage to start pushing on the underside of the disc during the early part of a flight. If the wind pushes on the top surface of a disc it tends to suppress the entire flight and push the disc to the ground. In most real cases however, the wind direction is some intermediate angle between purely a headwind, tailwind or crosswind, with localized swirling patterns over the landscape. In these real cases you can only estimate some kind of crude weighted average of the various effects at play and hope for the best. Again, mindful of the fluid no-slip condition, the wind is weakest near the ground, so on extremely windy days, it is often advisable to keep throws low.

**Weight:** You will notice that among a selection of discs, even among discs of the same model, that they are available in different weights, typically from about 165 g up to 176 g.

First, let me explain why we have this particular narrow range of weights available. As it turns out, for the diameters of the discs that are used (around 21 cm) this narrow weight range is about the limit of what can be made to fly in a stable fashion at the speeds players throw. The gyroscopic roll and asymmetric lift generated by the disc as it is spinning exist in balanced opposition. If the

weight of a disc is outside of the 165-176 g range, the pressure and lift forces generated by the throw go too easily out of balance, and the disc flies out of control. The asymmetric lift forces that can be generated would be insufficient to steady discs much heavier than this, and they would violently turn over discs much lighter than this. Try driving a 150 g class driver, it will turn-over more readily than a putter. They have to be thrown more slowly and with considerably more snap than normal. This is why children's discs are lighter; they simply don't throw with the same release speed.

In general, the main effect of adding weight to a disc is to delay the onset of turn-over. More lift force is needed to tilt a heavier disc. The precessional roll is more insensitive to disc weight as the pitching moment and its coupled roll will both decrease and remain in proportion as weight is added.

Thus, into a headwind, heavier discs perform better since the headwind will produce more lift force that has less effect on the greater mass. Conversely, lighter discs perform better downwind since at lower net airspeeds where discs are more apt to fade left, less force is needed to generate the lift to counteract this. By the same token, a lightweight overstable driver may add distance to a throw since it will resist the precessional roll a little longer. For these reasons, many players will carry different weights of the same disc model in their bag.

**Wear:** Players notice that the stability of discs diminish over time. This effect increases as the surface of the disc becomes rougher, dirty and scratched, as well as from the steady accumulation of nicks and gouges in the rim. The aerodynamic consequence of all this is that air passing around such a flying disc is subject to increased friction and hence the drag force becomes greater. This extra friction increases the lift effect so that while the precessional roll may remain essentially constant, over time, the rightward lift force consistently becomes greater. Further, damage to the rim of the disc will serve to increase

flow separation, thereby reducing the precessional roll tendency, accelerating a disc's descent into instability. After a long enough time, the disc is considered "beat-up" or even worn out. I have discarded some mid-weight Banshees over the years simply because they were so worn that their flight characteristics became too unreliable. On the other hand, a disc like a beat-up Cyclone2 can fill a superb niche in a golf bag as an 85 m turn-over disc. Some new types of extra-durable, ultra-smooth plastic, such as used in the Innova Champion Edition models, can dramatically extend the service life of a disc.

It is hoped that the player making the effort to read through this document, will be able to digest and appreciate these basic physics whose component factors determine the net aerodynamic behaviour of a golf disc. Adjusting and coordinating every element of a throw with an understanding of their collective effects should offer the player an improved range of options for achieving any possible desired trajectory.

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