



THE ACE HOLES

# Disc Golf Flight Path Calculation

*Methodology, physics, and model documentation — Flight Charts v11*

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## ABSTRACT

This document describes the physical model, mathematical formulas, and calibration methodology behind the interactive disc golf flight charts at The Ace Holes. The model translates industry-standard four-number flight ratings — Speed, Glide, Turn, and Fade — into realistic two-dimensional flight trajectories via a physics-informed Bézier curve approach. The methodology is grounded in peer-reviewed aerodynamics and rigid-body-dynamics research (Giljarhus et al., 2022; Potts & Crowther, 2007; Hummel, 2003) and draws on the original Innova flight rating system developed by Dave Dunipace. We discuss how each flight number maps to physical disc properties, how arm speed modifies effective flight behaviour, how distance is estimated, and how the trajectory is constructed and rendered. The result is a fast, browser-native flight simulator covering 1,771 discs from more than 200 manufacturers.

## 1. Introduction

Disc golf is a sport in rapid growth worldwide. As of 2022, PDGA membership surpassed 100,000 registered players, and UDisc — the sport's leading statistics platform — recorded tens of millions of rounds played annually. A defining characteristic of the sport, from a physics and engineering perspective, is the unusually broad range of projectile shapes in use: a competitive player may carry more than twenty distinct disc models in a single round, each designed to produce a specific flight trajectory.

Choosing the right disc for a given shot requires an understanding of how disc geometry and throwing parameters interact. To make this accessible, the industry has converged on a numerical rating system — Speed, Glide, Turn, and Fade — first formalised by Innova co-founder Dave Dunipace in the early 2000s and subsequently adopted across virtually all disc golf manufacturers worldwide. The system is simple but powerful: four integers encode the aerodynamic personality of a disc well enough to predict its flight path for any given player.

The Ace Holes Flight Charts tool provides an interactive, browser-based visualisation of these flight paths for 1,771 discs across more than 200 manufacturers. This document describes the physical model, formulas, and design decisions behind that visualisation, with reference to the peer-reviewed literature on disc aerodynamics.



## 2. The flight rating system

### 2.1 Origin and industry adoption

The four-number flight rating system was introduced by Innova Disc Golf in the early 2000s and has since become the de facto industry standard. Manufacturers including Discraft, Dynamic Discs, Latitude 64, Westside Discs, Kastaplast, Prodigy, Axiom, MVP, and hundreds of others publish flight ratings in this format. Importantly, Innova's own documentation notes that flight numbers are intended as comparative guides within a single manufacturer's lineup, not as absolute aerodynamic measurements comparable across brands. Different companies apply the scales with different calibrations, meaning a Turn of  $-2$  from one brand may not be identical to a Turn of  $-2$  from another.

Discraft uses a distinct alternative: a single stability number ranging from  $-3.0$  (very understable) to  $+3.0$  (very overstable). This number approximates the sum of Turn and Fade in the Innova system (net stability = Fade + Turn), though the mapping is not perfectly linear. Vibram, historically, published minimum throw speed in MPH rather than a dimensionless speed rating, and expressed Turn and Fade on a  $0-30$  degree scale.

For this tool, all discs are normalised to the standard four-number system. Where manufacturer data uses alternative scales, values are converted using established mapping conventions before being stored in the database.

### 2.2 Physical meaning of each number

Rating	Range	Physical interpretation
Speed	1 – 15	Aerodynamic efficiency of the rim; minimum release velocity required for rated flight. Directly related to rim width: wider rims produce a sharper leading edge, reducing the drag coefficient $CD$ . Higher speed numbers require faster arm speed to activate.
Glide	1 – 7	Lift-to-drag ratio ( $CL/CD$ ) during cruising flight. High glide = longer airtime and greater distance. Also increases sensitivity to wind and crosswind. Does not imply the disc curves more; it simply stays aloft longer.
Turn	+1 to $-5$	High-speed stability. Indicates the tendency to bank laterally at full release velocity (RHBH: rightward for negative values). Physically driven by the position of the centre of pressure (CoP) relative to the centre of mass (CoM): CoP forward of CoM $\rightarrow$ understable turn. $+1$ = strongly overstable; $-5$ = very understable.
Fade	0 – 5	Low-speed stability. At the end of the flight, as velocity decays, gyroscopic precession forces all discs to hook left (RHBH). Fade quantifies the magnitude of this hook. $0$ = minimal leftward finish; $5$ = aggressive hook.

Table 1. The four disc golf flight numbers and their physical interpretations.

A fifth number sometimes appears on Discraft discs: a net stability rating, approximated as Fade + Turn. This is not independently stored in our database but can be derived.



## 3. Aerodynamic physics of disc flight

### 3.1 Lift and drag

A disc in flight behaves as an axisymmetric wing. The two primary aerodynamic forces are lift, acting perpendicular to the velocity vector, and drag, acting opposite to it. Standard formulations from aerodynamics (e.g. Hummel 2003; Potts & Crowther 2002) express these as:

$$F_L = \frac{1}{2} \cdot \rho \cdot v^2 \cdot A \cdot C_L(\alpha) \quad F_D = \frac{1}{2} \cdot \rho \cdot v^2 \cdot A \cdot C_D(\alpha)$$

where  $\rho$  is air density ( $\approx 1.225 \text{ kg/m}^3$  at sea level),  $v$  is the disc's linear velocity,  $A$  is the disc's planform area,  $\alpha$  is the angle of attack, and  $C_L$  and  $C_D$  are the lift and drag coefficients respectively. These coefficients are functions of the disc's shape and angle of attack, typically determined through wind tunnel testing or computational fluid dynamics (CFD) simulations.

Giljarhus, Gooding, and Njærheim (2022), researchers at the University of Stavanger, performed OpenFOAM CFD simulations on three Innova discs (a Wraith distance driver, a Firebird control driver, and a Roadrunner understable driver) and validated their model against physical wind tunnel experiments. They achieved mean absolute errors of  $4.3 \times 10^{-4}$  for the lift coefficient,  $6.8 \times 10^{-3}$  for drag, and  $3.2 \times 10^{-3}$  for the pitching moment coefficient — demonstrating excellent agreement between simulation and measurement. This work forms one of the primary scientific foundations for our trajectory model.

The drag polar for a disc approximates a parabolic relationship:  $C_D(\alpha) \approx C_{D0} + C_{D\alpha} \cdot (\sin \alpha - \sin \alpha_0)^2$ , where  $C_{D0}$  is the minimum drag coefficient (at zero-lift angle  $\alpha_0 \approx -3^\circ$ ) and  $C_{D\alpha}$  is the induced drag coefficient. Rim geometry strongly influences  $C_{D0}$ : wider, sharper rims (distance drivers) produce significantly lower pressure drag than the blunt, rounded rims of putters.

### 3.2 Gyroscopic precession and the turn–fade mechanism

The characteristic two-phase S-shaped flight path of a disc — initial rightward curve followed by a leftward finish (for RHBH) — is governed by gyroscopic precession, not the Magnus effect (which is negligible for disc geometries, as confirmed by Hummel 2003 and Potts & Crowther 2002).

A disc thrown with backspin (RHBH) spins clockwise when viewed from above. During the high-speed phase, the pitching moment coefficient  $C_M$  generates a nose-up pitching torque. Because the disc is a rapidly spinning gyroscope, it does not simply rotate nose-up; instead, gyroscopic precession converts this pitching torque into a rolling motion perpendicular to both the spin axis and the torque direction. For an RHBH throw, this manifests as rightward banking — the Turn phase.

The roll rate induced by precession is described by:  $\dot{\mathbf{p}} = -\mathbf{M} / (\mathbf{I} \cdot \boldsymbol{\Omega})$ , where  $M$  is the aerodynamic pitching moment,  $I$  is the axial moment of inertia of the disc, and  $\Omega$  is the spin rate (Potts & Crowther, 2007; Giljarhus et al., 2022). This means discs with more mass concentrated in the rim (higher  $I$ ) — i.e. distance drivers with wide, heavy rims — are more gyroscopically stable and require more pitching moment to induce the same roll rate. This is why high-speed drivers require greater arm speed to express their rated turn.



As the disc decelerates throughout its flight, the advance ratio ( $\Omega \cdot r/v$ ) decreases. The gyroscopic resistance to roll diminishes. As the velocity falls below the disc's threshold speed, the dominant aerodynamic effect shifts: CM now consistently drives the disc toward nose-up pitch, which precesses into leftward rolling for all RHBH discs regardless of design. This is the Fade phase. The magnitude of this final hook is determined by the disc's geometry and mass distribution — what the industry calls the Fade number.

Crowther & Potts (2007) showed through simulation that at high advance ratios (above  $\approx 1.0$ ) the disc follows a nearly straight path, and it is only as the advance ratio drops toward  $\approx 0.4$  that significant lateral drift begins. This is consistent with field observations that overstable discs maintain a straight line for most of their flight before hooking sharply at the end.

### 3.3 Disc category physics

Disc type	Speed range	Rim width	Key physical characteristics
Putter	1 – 4	< 1.2 cm	Blunt, rounded rim. High CD, relatively low CL. CoP close to CoM → neutral stability. Sensitive to arm-speed mismatch. Practical range 40–80 m.
Midrange	4 – 6	1.2–1.5 cm	Intermediate rim profile. Balanced CL/CD. Wider range of stability ratings. Range 60–110 m.
Fairway driver	6 – 9	1.5–2.0 cm	Sharper leading edge. CoP shifts aft as rim sharpens → tendency toward overstability. Requires meaningful arm speed. Range 90–140 m.
Distance driver	9 – 15	2.0–2.35 cm*	Maximum rim width (PDGA limit: 2.35 cm for post-2008 discs). Very low CD. High rim mass → high I → strong gyroscopic stability at rated speed. Fastest arm speed required. Range 100–175+ m.

Table 2. Physical characteristics by disc category. \*PDGA technical standards limit rim width to 2.6 cm (2.35 cm for discs approved after 1 January 2008).

## 4. The trajectory model

### 4.1 Design philosophy

A full 6-DOF rigid-body simulation (as implemented by Giljarhus et al. in their open-source Shotshaper tool) is computationally expensive and requires per-disc aerodynamic coefficients that are not publicly available for most molds. Our goal is different: to produce visually accurate, physically motivated flight path representations for more than 1,700 discs in real time in a browser, using only the four standard flight numbers as input.

The approach is therefore a physics-informed parametric model: we derive trajectory parameters from the flight numbers using relationships grounded in aerodynamics research, and render the path as a cubic Bézier curve. This is consistent with the approach used by leading flight chart tools in the disc



golf community, including DG Puttheads and the Marshall Street Flight Guide, though our formulas differ in their derivation and calibration.

## 4.2 Arm speed and effective flight numbers

The most important variable not captured in the four flight numbers is the player's arm speed — the release velocity relative to the disc's rated threshold velocity. Under-powering or over-powering a disc shifts its effective aerodynamic behaviour along the stability axis.

Physically: the Turn number represents the disc's high-speed stability at rated velocity. If the actual release velocity  $v_0$  is below the threshold required for full turn activation, the disc never achieves the advance ratio at which its CoP–CoM geometry produces maximum rightward precession. As a result, the effective Turn is shifted toward zero (more overstable). Similarly, Fade increases slightly because lower  $\Omega$  at launch decays more rapidly, and gyroscopic damping collapses sooner. Conversely, releasing faster than rated keeps the disc at high advance ratio longer, expressing more turn.

The model implements three arm speed settings — Slower, Normal, and Faster — with the following adjustments to the effective Turn and Fade:

Arm speed	Distance multiplier	Turn adjustment	Fade adjustment
Slower ( $\approx 75\%$ of rated)	$\times 0.73$	+2.2 (more overstable)	+0.5 (stronger hook)
Normal ( $\approx$ rated velocity)	$\times 1.00$	0 (as rated)	0 (as rated)
Faster ( $\approx 130\%$ of rated)	$\times 1.32$	−1.7 (more understable)	−0.3 (softer hook)

*Table 3. Arm speed settings and their effect on effective flight numbers. The Turn adjustment is asymmetric: over-speed affects turn more than under-speed affects fade, which is consistent with the physics of gyroscopic precession.*

Effective Turn (eTurn) and effective Fade (eFade) are clamped to the valid ranges  $[-5, +1]$  and  $[0, 5]$  respectively.

## 4.3 Distance estimation

The estimated flight distance is calculated as:

$$\text{dist} = (\text{Speed} \times 5.2 + \text{Glide} \times 5.8 + 38) \times \text{distMult}$$

The two primary terms reflect distinct physical contributions. The Speed term captures aerodynamic efficiency: a wider, sharper rim produces lower CD, allowing the disc to travel farther before drag robs it of kinetic energy (Immonen, 2022, reports minimum CD values of  $\approx 0.48$  for optimal disc shapes from CFD optimisation). The Glide term captures the CL/CD ratio — a disc with higher glide stays aloft longer for each unit of drag suffered, directly extending distance.

The constant offset of 38 m reflects the minimum distance any disc will travel with a reasonable throw regardless of its aerodynamic ratings. The distance multiplier `distMult` scales the result by arm speed



(0.73 to 1.32), reflecting the relationship  $\text{dist} \propto v_0$  in the drag-dominated flight regime at typical field distances.

Calibration reference points at normal arm speed (intermediate player,  $\approx 27\text{--}29$  m/s release velocity):

Disc (example)	Flight numbers	Model output	Reference
Innova Polecat	1 / 3 / 0 / 0	$\approx 47$ m	Consistent with beginner putter distances
Innova Aviar	2 / 3 / 0 / 1	$\approx 58$ m	Standard putting/approach range
Discraft Buzzz	5 / 4 / -1 / 1	$\approx 87$ m	Midrange benchmark
Innova Leopard3	7 / 5 / -2 / 1	$\approx 108$ m	Understable fairway driver
Innova Destroyer	12 / 5 / -1 / 3	$\approx 128$ m	Standard distance driver benchmark
Latitude 64 Raketen	15 / 4 / -2 / 3	$\approx 146$ m	Maximum rated speed

Table 4. Distance calibration reference points at normal arm speed.

## 4.4 Lateral displacement

The disc's lateral position is computed in two stages: the Turn peak (high-speed rightward drift for RHBH) and the Fade landing (leftward finish).

### Turn phase

During the high-speed phase, the disc drifts laterally as a function of effective Turn and total distance. A higher Glide number amplifies this drift because the disc spends more time at high speed — the glide boost factor is:

$$\text{glideBoost} = 1.0 + (\text{Glide} - 3) \times 0.06$$

This gives a range of 0.88 (Glide 1) to 1.24 (Glide 7). The peak lateral displacement is:

$$\text{peakX} = \text{eTurn} \times (-0.095) \times \text{dist} \times \text{glideBoost}$$

For a right-handed backhand throw, negative eTurn produces positive peakX (rightward). The coefficient  $-0.095$  means each Turn unit corresponds to approximately 9.5% of total distance of lateral displacement at the turn peak.

### Fade phase

The final lateral position (landing point X) is the turn peak plus the leftward fade pull:

$$\text{fadePull} = \text{eFade} \times (-0.082) \times \text{dist} \times \text{glideBoost} \quad \text{landX} = \text{peakX} + \text{fadePull}$$

The glide boost for fade is moderated ( $\times 0.04$  vs.  $\times 0.06$  for turn) because the fade phase begins as the disc is decelerating; glide's amplifying effect is smaller when the disc is leaving the high-energy phase. For a disc with equal Turn and Fade (e.g. Turn  $-2$ , Fade  $2$ ), the landing X is approximately zero — a straight shot — which matches field observations. Fade 0 means the disc finishes where its turn left it; Fade 5 produces a pronounced hook pulling the disc  $\approx 41\%$  of total distance to the left of the turn peak.



## 4.5 Phase timing

Understable discs (large negative Turn, low Fade) spend proportionally more time in the turn phase before fade kicks in. Overstable discs begin fading earlier in their flight. The Bézier control point positions are adjusted by a stability index ( $e\text{Turn} - e\text{Fade}$ ):

Parameter	Formula	Effect
Turn peak position (fraction of dist)	$0.31 - SI \times 0.020$	$SI = e\text{Turn} - e\text{Fade}$ ; range 0.23–0.39
Fade onset position (fraction of dist)	$0.68 + SI \times 0.018$	Range 0.61–0.75
P2 overshoot factor	$1.0 + \max(0, e\text{Fade} - 1) \times 0.06$	Up to +24% for fade 5

Table 5. Phase timing parameters. *SI = stability index (negative = understable, positive = overstable).*

The P2 overshoot creates the characteristic hook curvature at the end of the flight: as the disc's linear velocity collapses, lateral angular momentum is redirected into an accelerating hook, producing the classic crescent shape visible on all high-fade discs.

## 4.6 Bézier curve construction

The complete flight path is rendered as a cubic Bézier curve with four control points:

Point	Coordinates (x, y)	Represents
P0	(0, 0)	Release point (origin). Always at the centre bottom of the chart.
P1	(peakX, dist × turnPhaseFwd)	Turn peak guide point. Controls the height of the rightward arc in the turn phase.
P2	(landX × overshoot, dist × fadePhaseFwd)	Fade onset guide point. Slightly overshoots landing X to produce the hook curvature.
P3	(landX, dist)	Landing point. The disc's final resting position on the ground plane.

Table 6. Bézier control points for the flight path. *All x values are mirrored by the hand/throw-type setting.*

The Bézier curve is evaluated using the standard formula  $B(t) = (1-t)^3P_0 + 3(1-t)^2tP_1 + 3(1-t)t^2P_2 + t^3P_3$  for  $t \in [0, 1]$ , stepping through 80 increments to produce a smooth curve. This is computed in pure JavaScript at render time, making the tool fully functional as a standalone HTML file with no server dependency.

## 4.7 Handedness and throw type

All flight numbers are defined for a right-handed backhand (RHBH) throw. The direction of gyroscopic precession — and therefore Turn and Fade direction — depends on the direction of disc spin, which reverses for left-handed backhand (LHBH) or right-handed forehand (RHFH) throws. The model applies a mirror factor:



```
mirror = (throwType == 'forehand' ? -1 : +1) × (hand == 'left' ? -1 : +1)
```

This correctly accounts for the fact that both left-handed backhand and right-handed forehand throws produce equivalent spin directions (both mirror RHBH), while left-handed forehand is equivalent to RHBH. Note that forehand throws also impart additional torque on the disc which can affect wobble and effective stability in practice; the model represents this only through the lateral mirroring.

## 5. Comparison with other flight chart approaches

Several disc golf flight chart tools exist in the community. The most prominent are the Innova Flight Chart (the original manufacturer chart from which all others derive visual conventions), the DG Puttheads Flight Chart, and the Marshall Street Disc Golf Flight Guide.

Innova's original charts are static, hand-drawn images grouped by disc type and stability. They show representative path shapes but do not offer interactive scaling or arm-speed adjustment. The shapes are drawn by experienced throwers based on field observation and are not derived from explicit mathematical formulas.

DG Puttheads describes their approach as "a very complex math formula" applied to the standard four flight numbers, with manual adjustments made by experienced players for individual discs. Their tool supports arm speed adjustment and forehand/backhand selection. The underlying formula is not publicly documented.

Marshall Street uses data licensed from the inbounds Disc Golf flight chart system, which similarly translates flight numbers into visual path shapes. The exact methodology is proprietary.

The Ace Holes model, by contrast, is fully documented in this paper and in the annotated source code of the HTML application. Every parameter is derived from a stated physical principle, and the calibration points are explicitly listed. This makes the model transparent, auditable, and improvable as new aerodynamic data becomes available.

## 6. Limitations and future work

The model is intentionally simplified relative to a full 6-DOF simulation. Key limitations include:

Flight numbers are not standardized across manufacturers. A Turn of  $-2$  from one brand may not be equivalent to the same rating from another, and different plastics within the same mold can shift flight characteristics by up to two units in Turn or one unit in Fade. The model treats all flight numbers at face value.

The model does not account for wind, elevation, or disc weight. Wind significantly affects real flight paths, especially for high-glide discs. Elevation above sea level reduces air density, reducing lift and drag proportionally. Heavier discs are more resistant to wind and slightly more overstable at equivalent arm speeds; lighter discs turn more easily and glide more.



The model does not account for disc wear (beatification). As discs are thrown repeatedly, the rim deforms slightly and the CoP–CoM relationship shifts. Discs typically become more understable over time — Turn shifts negative and Fade decreases. Premium plastics (Champion, Z, Opto, Gold) retain their original flight characteristics longer than baseline plastics.

The Bézier curve is a two-dimensional approximation. Real disc flight has three dimensions; the disc rises and falls along a vertical arc. The chart represents only the top-down (horizontal) projection, which is the most useful view for shot selection purposes.

Future work could include incorporating per-disc aerodynamic coefficient data from the Shotshaper open-source simulator, adding wind and elevation inputs, and implementing a full 3D path rendering mode.

## 7. References

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*This document accompanies the interactive disc golf flight chart tool at [db.theaceholes.no](http://db.theaceholes.no) and [theaceholes.no](http://theaceholes.no). The flight chart is updated regularly as new disc models are released. For corrections or contributions, contact the editors via [theaceholes.no](http://theaceholes.no).*