OXFORD JOURNAL
OF STUDENT
SCHOLARSHIP

Surface Porosity and Flight Stability in Pickleball: A Review of the Aerodynamic Evidence and a Proposed Venting-Imbalance Mechanism

Abraham Anantha, Partha Loura
abrahamanantha@gmail.com, lourapartha@gmail.com

ABSTRACT

Under current USA Pickleball standards, a regulation ball carries between 26 and 40 circular holes. That leaves manufacturers only three aerodynamically meaningful choices: how many holes, how large, and where. The sport has grown quickly and the aerodynamic literature has not kept pace, and much of what circulates as design rationale traces back to marketing copy with little measurement behind it. This review synthesizes what is actually known about how surface porosity governs pickleball flight, drawing on free-flight trajectory data, wind tunnel work on the closely related Wiffle ball, and the broader sports ball literature on surface roughness and boundary layer separation. Sources are sorted by the kind of evidence they carry, and Section 2 explains how they were selected.

Three findings are supported by the evidence. The only available measurement puts the effective drag coefficient near 0.33 for 40-hole outdoor balls and near 0.45 for 26-hole indoor balls, about 27 percent lower. The two balls also differ in total porosity, so that drop cannot be tied to hole count alone. Perforated balls also generate measurable lift at negligible spin, which the Magnus effect cannot explain and which the existing literature does not adequately account for. And there is still no published wind tunnel data for a pickleball at any hole count, so the field remains dependent on trajectory fitting and on analogy to the Wiffle ball.

To address the second finding, this review proposes a venting-imbalance mechanism, which is still an untested hypothesis. In it, flow through the open shell, divided unevenly among a small number of large apertures, may produce a net transverse momentum flux sufficient to deflect the wake. The mechanism generates testable predictions, and the experimental and computational program that could test it is outlined here.

Keywords: *pickleball, sports ball aerodynamics, surface porosity, turbulent wake, drag coefficient, wake symmetry, Wiffle ball*

1. INTRODUCTION

Every other major sports ball is a closed shell. Golf balls have dimples, cricket balls have a raised seam, soccer balls have panel joints, and in all three cases the air moves around the outside. A pickleball is the exception. Its surface has holes all the way through, so air moves through the ball as well as past it, and

that opens an internal flow path with no counterpart in the aerodynamics of solid sports balls. It is also the reason pickleball flight cannot be predicted by extending existing sphere models alone.

USA Pickleball standards permit 26 to 40 circular holes on a ball of nominal 74 mm diameter (USA Pickleball, 2025). The market has divided along that range. Indoor balls carry roughly 26 large holes and outdoor balls roughly 40 small ones, with newer designs at 32 and 38 holes filling the middle. Manufacturers describe these numbers as the product of extensive testing. The supporting data is not published.

The practical problem motivating this review is directional predictability. Players report balls that drift laterally or drop early even on shots struck with little or no spin, and Lindsey (2025a) puts numbers behind the complaint, recovering non-zero lift coefficients from trajectory fits at near-zero spin rates. When a ball deviates without spin, part of the outcome is left to chance. That makes it an equipment design concern.

Three questions follow. What does the published evidence actually establish about the relationship between hole geometry and pickleball aerodynamics? Where does that evidence run out, and what is being asserted past that point? And if the Magnus effect cannot produce lift at zero spin, what can?

Section 2 sets out how sources were selected and weighted. Sections 3 through 5 work through the evidence, starting with general sphere aerodynamics, moving to the Wiffle ball, and ending with pickleball itself. Section 6 proposes the venting-imbalance mechanism, and Section 7 reads the commercial designs against the evidence. Sections 8 and 9 pull the findings together and lay out a research program capable of testing them.

2. SCOPE AND SOURCE SELECTION

Search strategy and selection criteria. This is a narrative review with no registered protocol. No single database search was run. The sources were collected from the places that publish this kind of work: fluid mechanics, aerodynamics, and sports science journals (Journal of Fluid Mechanics, Annual Review of Fluid Mechanics, Aeronautical Quarterly, AIAA Journal, American Journal of Physics, and International Journal of Racket Sports Science), a university student research forum (Brigham Young University Idaho), Tennis Warehouse University, USA Pickleball, and the Wilson and Selkirk websites. A source was kept if it reported measured or computed aerodynamic results (drag, lift, or boundary layer transition) for a pickleball, a perforated ball, or a sphere with controlled roughness, or if it supplied a method used in Section 9. Sources with only qualitative commentary, or ones that repeated results from a source already included, were left out. Manufacturer sources were kept only where they described the design of a commercial ball discussed in Section 7. The pickleball literature is small, so no source was dropped for quality. Each is weighted by evidence type, as described below. Because no database search was recorded, the selection cannot be reproduced exactly, and non-peer-reviewed and commercial material is the most likely to have been missed (see Section 10).

Sources fall into three categories, weighted differently here according to the kind of evidence they carry.

Peer-reviewed literature. Achenbach (1972, 1974), Bearman and Harvey (1976), and Mehta (1985) establish how surface roughness, boundary layer transition, and drag relate on spheres and sports balls. Rossmann and Rau (2007) remain the only peer-reviewed wind tunnel study of a perforated ball. Emond, Sun, and Swartz (2024) give the only peer-reviewed treatment of pickleball flight, although their work models trajectories without measuring aerodynamic coefficients. Menter (1994) is cited for the turbulence closure recommended in Section 9.

Non-peer-reviewed technical sources. Lindsey (2025a, 2025b), published through Tennis Warehouse University, is by some distance the largest body of pickleball aerodynamic measurement available: effective drag and lift coefficients fitted from 86 recorded free-flight trajectories. Isaac (2023), a student research forum paper, reports CFD analysis of pickleball geometries. Neither has undergone formal peer review, and both are treated here as credible but provisional.

Manufacturer and retail sources. Wilson Sporting Goods (2023) and Selkirk Sport (2023) describe design intent behind their 32-hole and 38-hole products. These are cited as claims. Neither company publishes underlying data, and both have a commercial stake in the conclusion they state. Wherever this review repeats such a statement, the text labels it as a manufacturer claim.

The distinction matters because a substantial share of what circulates as pickleball design rationale traces back to marketing copy. Separating what has been measured from what has been asserted is one of the things this review sets out to do.

3. SURFACE ROUGHNESS AND DRAG ON SPHERES

A smooth sphere in the subcritical regime carries a drag coefficient near 0.5. Above a critical Reynolds number, the boundary layer transitions to turbulence before it separates, the separation point moves rearward, the wake narrows, and drag drops sharply. Achenbach (1972) measured that transition on smooth spheres and then showed that surface roughness pushes the critical Reynolds number downward, so the drag reduction arrives at lower speeds (Achenbach, 1974).

Bearman and Harvey (1976) demonstrated the practical consequence in golf, where dimples move the drag crisis into the range of speeds players actually produce. Mehta (1985) generalizes the principle across sports: surface features energize the boundary layer, separation is delayed, the wake narrows, and pressure drag falls, at the cost of a modest rise in viscous drag.

Perforations are an aggressive version of the same treatment. Hole edges trip the boundary layer at Reynolds numbers far below what a smooth sphere would require. On that basis Isaac (2023) argues that a pickleball is fully turbulent across the whole range of play speeds, and therefore that no drag crisis should appear inside the operating envelope. If so, the drag coefficient should stay roughly constant with velocity, and the free-flight data agree: Lindsey (2025a) reports only weak velocity dependence for both indoor and outdoor balls across the tested range.

A concrete estimate underlines the point. For a 74 mm ball at play speeds of 3 to 30 m/s in air at 20 °C, the diameter-based Reynolds number (Re) spans roughly 1.5×10^4 to 1.5×10^5. All of that sits well below the critical Reynolds number for a smooth sphere. A pickleball without holes would sit firmly in the high-drag subcritical regime. The perforations are likely what make the ball playable.

4. EVIDENCE FROM THE WIFFLE BALL

Rossmann and Rau (2007) supply the only peer-reviewed wind tunnel measurements of a perforated ball. Their subject is the Wiffle ball, a lightweight plastic ball with large holes on one hemisphere only, which is the extreme case of asymmetric porosity. Their findings carry over to pickleball, and they are also frequently misreported.

Three results are relevant. The aerodynamic force depends on ball orientation and on Reynolds number. Along the axis of the perforations, the force points away from the holes at lower Reynolds numbers. And internal flow through the shell can reverse that direction above approximately $\mathrm{Re} \approx 4 \times 10^4$.

The third result is the one most often lost. The popular account holds simply that a perforated ball curves toward its holes. The measurements indicate otherwise. Direction is regime dependent, and internal flow is a first-order contributor, much more than a small correction to the external boundary layer effect. Rossmann and Rau measured interior velocities on the order of a few tenths of the freestream, which is fast enough for the internal path to matter in a momentum balance.

The limits of the analogy matter just as much. A Wiffle ball is asymmetric by design, with every hole on one hemisphere, while a regulation pickleball distributes holes over the full sphere. The Wiffle ball therefore settles the straightforward question, which is that large asymmetric porosity produces large lateral force. It says nothing about how much residual force survives once the pattern is nominally symmetric, and that is the question pickleball design actually turns on. No published study has closed the gap.

5. EVIDENCE SPECIFIC TO PICKLEBALL

5.1 Drag

Lindsey (2025a) recorded 86 free-flight trajectories of indoor 26-hole and outdoor 40-hole balls on high-speed video, then fitted effective aerodynamic coefficients by matching simulated trajectories to the recorded paths. Figure 1 summarizes the reported results. All values in it are Lindsey's (2025a), and the percentage difference below is our own calculation from those means.

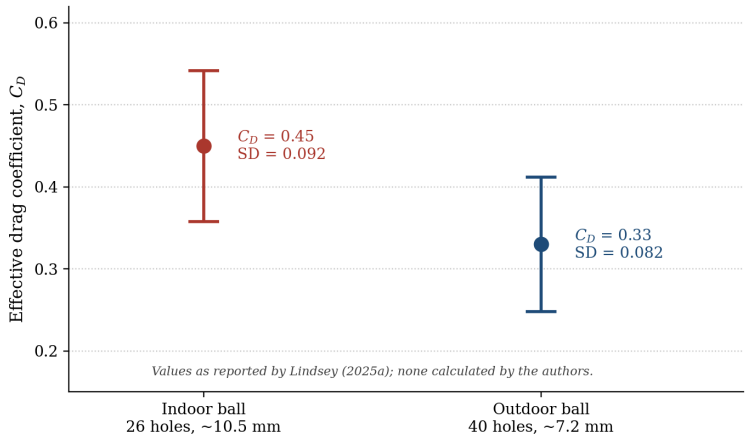


Figure 1. Reported effective free-flight drag coefficients (C_D) for regulation indoor and outdoor pickleballs. Markers show means and bars show standard deviations (SD), both as reported by Lindsey (2025a). Replotted by the authors; nothing in this figure was calculated or estimated by us.

The 40-hole ball carries a mean effective drag coefficient (C_D) of approximately 0.33 against approximately 0.45 for the 26-hole ball, a difference of roughly 27 percent. Two features of the dataset warrant attention. The difference is large enough to change flight distance materially at constant launch conditions, though it cannot yet be tied to hole count alone (see below). The 40-hole ball is also somewhat more repeatable, with a standard deviation of 0.082 against 0.092, and that gap is small compared with the overlap between the two distributions. Repeatability matters as much as magnitude here, because a ball whose coefficient varies from shot to shot produces a trajectory that cannot be predicted from launch conditions, even by a player striking it identically twice.

One methodological caveat applies to every coefficient Lindsey reports, and Lindsey states it plainly. A coefficient fitted from a trajectory is an effective quantity. It absorbs every aerodynamic influence acting over the flight, Magnus force and internal flow and any gravitational effect on the boundary layer included, so it is not equivalent to a fixed-orientation coefficient measured on a force balance. The values are the best available and they are internally consistent. They are not a substitute for direct measurement.

A second and more serious interpretive problem is built into the commercial geometries themselves. Figure 2 shows the two standard configurations. Hole diameter falls faster than hole count rises, so total porosity (φ, the summed hole area divided by the surface area of the ball) is actually lower on the 40-hole ball than on the 26-hole ball, approximately 0.095 against approximately 0.131. We calculated these values from the hole counts and diameters in Table 1, and Lindsey (2025a) does not report them. The two balls therefore differ in two variables at once: more holes and less total open area. No published study separates them, so the observed drag difference cannot presently be attributed to hole count alone.

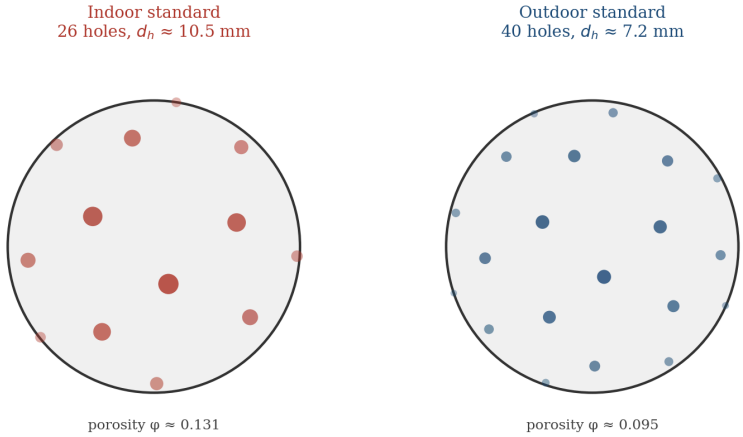


Figure 2. Hole distribution on the two standard regulation geometries, shown in orthographic projection with front-hemisphere holes only. Marker size reflects foreshortening with position on the sphere. Hole counts and nominal hole diameters (d_h) are from Table 1. Porosity (φ) was calculated by the authors as summed hole area divided by the surface area of a 74 mm sphere; prior studies do not report it. Figure prepared by the authors.

5.2 Lift at negligible spin

Both the 26-hole and 40-hole balls exhibit non-zero lift coefficients at negligible spin rates in the free-flight data, and the effect is persistent across the dataset (Lindsey, 2025a, 2025b). Lindsey flags three anomalies: lift coefficients that differ between topspin and backspin, substantial lift at very low or zero spin, and a weak correlation between lift coefficient and spin parameter for backspin.

This review takes up the second one, because it cannot be a Magnus effect. Magnus force requires spin and vanishes as spin approaches zero, so a force that survives at zero spin has to come from somewhere else. Lindsey suggests a gravitational influence on the boundary layer, with air accelerating downward on one side of the ball and altering separation. It is a plausible idea, difficult to isolate experimentally, and Lindsey presents it as such.

There is a more direct clue available. The anomalies fade when the holes are blocked, whether with tape or with an internal obstruction, which suggests the perforations may be the main cause and makes gravity a less likely one. That observation is where the next section starts.

6. A PROPOSED VENTING-IMBALANCE MECHANISM

What follows is a hypothesis proposed by the present authors, consistent with the evidence reviewed above. It has not been experimentally tested. We offer it as a hypothesis for the research program set out in Section 9 to test.

We propose that an open shell takes air in on the windward face and pushes it out on the leeward face. The air leaving the ball could enter the separated shear layer and affect how and where the wake closes. If so, any imbalance in venting between opposing holes would leave a net transverse momentum flux, and with it a lateral force, without requiring any asymmetry in the external boundary layer at all.

The magnitude of that imbalance may depend on how many apertures share the total venting flow. When a small number of large holes carries the flow, each hole carries a large share of it, so a momentary difference between one hole and its opposite partner represents a large absolute difference in momentum. When the same flow is divided among many smaller apertures, each individual difference would be smaller, and differences distributed around the sphere could partially cancel. Figure 3 sketches the argument.

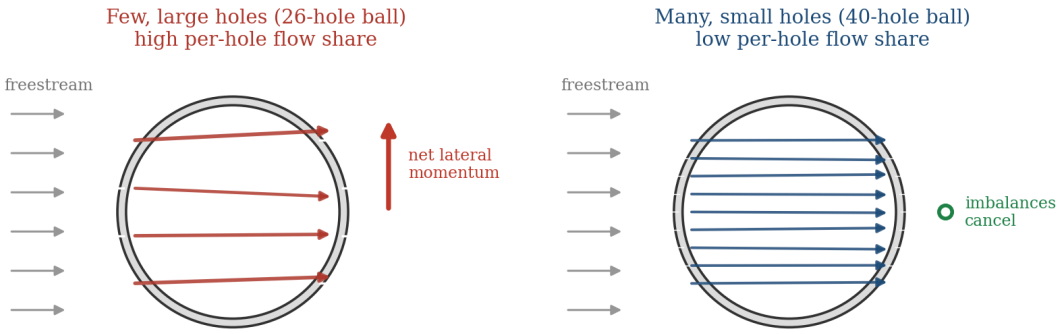


Figure 3. Conceptual schematic of the hypothesized venting-imbalance mechanism, in cross-section. Left: a few large holes, each carrying a big share of the flow, may produce a net lateral momentum flux. Right: many small holes may let the imbalances cancel. Prepared by the authors as an illustration only, with no measured data or simulation behind it.

The mechanism makes three predictions. Each follows from the geometry alone, with no fitted parameters.

Prediction 1. If the mechanism holds, lift at zero spin should scale inversely with hole count. A 40-hole ball should exhibit smaller zero-spin lift than a 26-hole ball, and the difference should survive when total porosity is held constant.

Prediction 2. If it holds, zero-spin lift should depend on hole placement independently of hole count. Clustering holes toward one hemisphere while holding count and porosity fixed should produce a measurable lateral bias.

Prediction 3. If it holds, blocking the internal flow path should eliminate the effect. A ball with sealed holes should show zero-spin lift consistent with a smooth sphere, regardless of its external hole pattern.

Prediction 3 already has some indirect support. Lindsey (2025a) reports that blocking the holes makes drag and lift more repeatable, which fits the mechanism, though that data was not collected to test it and does not distinguish this mechanism from alternatives.

The mechanism is also consistent with the Wiffle ball results reviewed in Section 4. A Wiffle ball is the limiting case of maximum venting imbalance, every aperture on one hemisphere, and it produces the largest lateral forces of any perforated ball in the studies reviewed. A uniformly perforated pickleball sits at the opposite end of the same continuum. Read this way, the two could be one phenomenon seen at different degrees of asymmetry. That would be a more economical account than giving pickleball lift its own explanation, but it remains to be tested.

7. COMMERCIAL DESIGN APPROACHES

Two products occupy the space between the 26-hole and 40-hole extremes, and both say something about how the industry reasons even where the supporting data is unavailable.

The Wilson TRU-32 uses 32 evenly distributed holes in a patented layout, which the manufacturer states produces consistent flight and bounce (Wilson Sporting Goods, 2023). The aerodynamic logic is straightforward. Fewer holes at slightly larger diameter give marginally higher drag and a slower ball, while even spacing preserves symmetry. The predicted result is a ball that flies true but slightly slower than a 40-hole ball, which is exactly how the product is positioned.

The Selkirk Pro S1 uses 38 holes in two different diameters (Selkirk Sport, 2023). The manufacturer states that mixed hole sizes produce consistent flight regardless of spin, velocity, or shot angle. The specific diameters do not appear in any manufacturer or retail listing located during this review, so the geometry cannot be analyzed independently.

The mixed-diameter approach merits examination because the reasoning behind it is not obvious. One plausible explanation, consistent with the mechanism proposed in Section 6, is that a perfectly periodic aperture arrangement can support a coherent venting pattern in which multiple holes shed in phase, and that varying hole size breaks that periodicity without introducing a mean bias. Similar techniques are used to suppress coherent vortex shedding elsewhere in engineering. It should be stated that this is an inference offered by the present authors. It is our own inference. No measurement supports it, and the manufacturer has not stated it.

Table 1 lays out the four configurations and marks explicitly which values are measured, which are estimated, and which have never been disclosed.

Design	Holes	Hole diameter	Drag coefficient, C_D	Basis
Indoor standard	26	10.5 mm (0.41 in)	0.45	Measured; free-flight fit (Lindsey, 2025a)
Wilson TRU-32	32	Not disclosed; approx. 8.8 mm by estimation	Not measured	Manufacturer claim of consistent flight (Wilson Sporting Goods, 2023)
Selkirk Pro S1	38	Two sizes; neither disclosed	Not measured	Manufacturer claim of consistent flight (Selkirk Sport, 2023)
Outdoor standard	40	7.2 mm (0.28 in)	0.33	Measured; free-flight fit (Lindsey, 2025a)

Table 1. Commercial pickleball hole configurations and the evidentiary basis for each reported value. All four designs are nominally 74 mm in diameter with a mass of 22 to 26 g. No wind tunnel data has been published for any of the four.

8. SYNTHESIS

The reviewed evidence supports three conclusions, and it supports them to very different degrees.

Supported, but confounded. Measured drag is substantially lower for the 40-hole configuration than for the 26-hole configuration, by roughly 27 percent in the only dataset available, and the 40-hole configuration is also somewhat more repeatable. Both results line up with the sphere roughness literature, where surface features that distribute the boundary layer disturbance more evenly give lower and steadier pressure drag. The two configurations also differ in total porosity, so neither result can be tied to hole count alone.

Reported but unexplained. Perforated pickleballs generate measurable lift at negligible spin. The observation holds across 86 trajectories and both ball types, and no published mechanism accounts for it satisfactorily. This review proposes venting imbalance as a candidate. The proposal is untested.

Asserted but unmeasured. That hole count and hole distribution independently govern directional stability is repeated constantly, manufacturers included, but no published study isolates either variable. And because of the confound identified in Section 5.1, where hole count and porosity move in opposite directions across commercial designs, even the drag difference cannot be pinned on hole count by itself.

On balance, of the configurations with data, the 40-hole geometry (approximately 7.0 to 7.5 mm holes, spaced near-uniformly, with no unperforated region anywhere on the sphere) has the lower measured effective drag coefficient, near 0.33, and somewhat greater repeatability in the available dataset (standard deviation 0.082 against 0.092). Only two configurations were compared, the data come from a single non-peer-reviewed source, and hole count is not separated from total porosity, so the result says little

about overall performance. It is also the geometry of the outdoor balls already commercially available, so the finding supports current practice and does not call for a change. What this review contributes is the evidentiary basis for that geometry, together with a specific account of what about it remains unverified.

9. GAPS IN THE LITERATURE AND A PROPOSED RESEARCH PROGRAM

The largest gap is the simplest to state. No wind tunnel measurements of a regulation pickleball, at any hole count, appear in the published literature. The field currently depends on trajectory fitting, which yields effective coefficients that combine several influences, and on analogy to a ball whose hole pattern is deliberately asymmetric. Three studies would materially advance things.

9.1 Wind tunnel measurement on additively manufactured shells

Balls printed to controlled geometry and mounted on a multi-axis force balance would give the first isolated drag, lift, and lateral force coefficients for pickleball geometries. Printing carries one decisive advantage: it permits a constant-porosity series, with hole count varying while total open area stays fixed. That breaks the confound identified in Section 5.1 and tests Prediction 1 directly. Running multiple ball orientations at each condition would test Prediction 2, and sealed-hole control specimens would test Prediction 3.

9.2 Computational study resolving internal flow

A CFD study would complement the tunnel work by resolving the internal flow field, which no force balance can observe. One requirement is essential and easy to overlook: the internal cavity has to stay in the fluid domain. Model the ball as a solid boundary and the internal path disappears, taking the mechanism proposed in Section 6 with it.

A suitable setup would place the ball in a domain extending at least ten diameters upstream and laterally and twenty downstream, giving a blockage ratio below one percent. Achenbach (1974) showed that tunnel blockage measurably shifts sphere drag, so this is better designed out than corrected afterward. Meshing is the principal difficulty. Structured meshes do not conform to hole edges, and an unrefined unstructured mesh will not resolve the shear layers formed at each aperture. Local refinement placing at least eight cells across the smallest hole diameter, with prism layers on both internal and external shell surfaces, is a reasonable target. The k-omega SST closure of Menter (1994) suits the problem, holding near-wall accuracy while reverting to k-epsilon behavior in the free shear layers of the wake. Any such study should report a mesh independence assessment and should validate against the smooth-sphere data of Achenbach (1972) before reporting a single perforated result.

One limitation is worth anticipating. Steady RANS resolves mean forces and mean wake structure, but it cannot capture the unsteady oscillation responsible for the shot-to-shot variability players report. Predicting deviation amplitude would take large eddy simulation or a well-resolved unsteady formulation.

9.3 Trajectory measurement under controlled crosswind

Emond, Sun, and Swartz (2024) model pickleball trajectories under varying wind and find that wind sensitivity materially changes optimal shot selection. Their model relies on assumed coefficients with no measurements behind them. Pairing controlled crosswind trajectory measurement with the coefficients from Section 9.1 would close that loop and test the claim, so far supported only by player report and manufacturer assertion, that higher hole counts confer wind resistance.

10. LIMITATIONS OF THIS REVIEW

This review is bounded by the literature available to it, and that literature is thin. Only one substantial body of pickleball aerodynamic measurement exists, it has not been peer reviewed, and it reports only effective coefficients. Any conclusion resting on it inherits that uncertainty. This review is also a narrative review (Section 2), so the choice of sources reflects our judgment, and commercial and non-peer-reviewed sources may be underrepresented.

The mechanism proposed in Section 6 is a hypothesis. It fits the reviewed evidence and it generates testable predictions, but consistency with existing observations is a weak form of support, and nothing presented here excludes the alternatives, Lindsey's gravitational hypothesis among them.

Manufacturer claims for the 32-hole and 38-hole designs could not be independently verified, and hole diameters for the Selkirk Pro S1 are not disclosed in any source located during this review.

Environmental variation lies outside the scope of this review. Humidity, temperature, and altitude all affect air density and viscosity, and outdoor play spans a wide range of all three. Ball material stiffness varies with temperature as well, and hole geometry changes as a ball wears over the course of a match. None of these effects is addressed in the reviewed literature.

11. CONCLUSION

Surface porosity governs pickleball flight through three geometric parameters whose effects are not interchangeable: how many holes, how large, and where. The published evidence shows that the 40-hole ball has a lower and somewhat more repeatable measured drag coefficient than the 26-hole ball, though it comes from a single non-peer-reviewed source. It reports lift at negligible spin on perforated balls but offers no explanation for it. It does not separate the contribution of hole count from that of total porosity. And it contains no wind tunnel measurement of any pickleball at all.

This review has proposed, as an untested hypothesis, that lift at zero spin comes from imbalanced venting through the open shell. If it is right, the mechanism ties the pickleball observations to the Wiffle ball measurements of Rossmann and Rau (2007) and predicts an inverse scaling with hole count. The program in Section 9 can test it, and a constant-porosity wind tunnel series on its own would be a decisive first test.

The broader point is that a sport with tens of millions of participants rests on equipment standards backed by very little public aerodynamic measurement. The hole count range of 26 to 40 defines a design space

that is one manufacturers have explored and researchers have mostly left alone. Closing that gap requires no exotic apparatus. A wind tunnel, a force balance, and a set of printed shells would be sufficient.

REFERENCES

Achenbach, E. (1972). Experiments on the flow past spheres at very high Reynolds numbers. *Journal of Fluid Mechanics, 54*(3), 565–575. https://doi.org/10.1017/S0022112072000874

Achenbach, E. (1974). The effects of surface roughness and tunnel blockage on the flow past spheres. *Journal of Fluid Mechanics, 65*(1), 113–125. https://doi.org/10.1017/S0022112074001285

Bearman, P. W., & Harvey, J. K. (1976). Golf ball aerodynamics. *Aeronautical Quarterly, 27*(2), 112–122.

Emond, K., Sun, W., & Swartz, T. B. (2024). Pickleball flight dynamics. *International Journal of Racket Sports Science, 6*(2), 1–8. https://doi.org/10.30827/ijrss.32618

Isaac, C. (2023). *Computational fluid dynamics analysis of pickleballs.* Brigham Young University Idaho College of Physical Sciences and Engineering Research Forum. https://brightspotcdn.byui.edu/f5/ef/bfdce4934c0c97c93cee95c8d33e/isaac-creerf23.pdf

Lindsey, C. (2025a). *The physics of pickleball aerodynamics and trajectories: A revised model of lift and drag.* Tennis Warehouse University. https://twu.tennis-warehouse.com/learning_center/pickleball/pickleball_aerodynamics.php

Lindsey, C. (2025b). *Pickleball aerodynamics: What makes a pickleball fly the way it does.* Tennis Warehouse University. https://twu.tennis-warehouse.com/learning_center/pickleball/pickleball_aerodynamics_light.php

Mehta, R. D. (1985). Aerodynamics of sports balls. *Annual Review of Fluid Mechanics, 17*, 151–189. https://doi.org/10.1146/annurev.fl.17.010185.001055

Menter, F. R. (1994). Two-equation eddy-viscosity turbulence models for engineering applications. *AIAA Journal, 32*(8), 1598–1605. https://doi.org/10.2514/3.12149

Rossmann, J., & Rau, A. (2007). An experimental study of Wiffle ball aerodynamics. *American Journal of Physics, 75*(12), 1099–1105. https://doi.org/10.1119/1.2787013

Selkirk Sport. (2023). *The Selkirk Pro S1 pickleball: Why 38 holes make all the difference.* https://www.selkirk.com/blogs/paddles-and-product-education/the-selkirk-pro-s1-pickleball-why-38-holes-make-all-the-difference

USA Pickleball. (2025). *Equipment standards manual: Ball specifications.* https://usapickleball.org/what-is-pickleball/official-rules/equipment-standards

Wilson Sporting Goods. (2023). *TRU-32 pickleball launch.* https://www.wilson.com/en-us/explore/pickleball/tru-32-ball-launch