On the influence of air density on bat speed

Patrick Dufour, April 9th 2026

An interesting article recently published on FanGraphs by Ryan Blake showed that bat speed decreases in cold weather and increases in warm conditions. The effect is modest, about 0.2 mph per 10°F.

Seeing this, Alan Nathan raised a natural follow-up question on Bluesky: could air drag be responsible for part of this effect? Since drag opposes motion, it reduces acceleration and therefore lowers the final bat speed. And because air density is higher at lower temperatures, drag should indeed be stronger in the cold. His suggestion was simple: do a simplified calculation and see if the temperature dependence from drag alone is in the right ballpark.

Having recently taught a course called “order-of-magnitude in astrophysics,” where students learn the art of estimating just about anything, even when they don’t know shit about it, and where “I don’t know” is not an acceptable answer, I try to hold myself to the same standard. So, the nerd in me felt compelled to give it a shot before bed last night.

Before getting into the equations, here is the game plan. Air resistance exerts a force on the bat as it moves through the air. If we approximate the swing as a pure rotation about an axis near the hands, that distributed force along the bat translates into a torque that opposes the motion. This opposing torque reduces the angular acceleration and therefore the final bat speed. Since air density depends on temperature, we can then estimate how this torque changes with temperature and how that translates into a change in bat speed.

Before going further, it is also worth pointing out that a real bat swing is not a pure rotation. There is also a translational component. That said, I will model the swing as a simple rotation about an axis near the hands. I believe this is a sufficient approximation, and that adding the extra complexity of translation is not worth the trouble for what we are trying to estimate here.

The reason is that air resistance scales as v^2, while the torque scales linearly with distance from the rotation axis. As a result, the contribution to the total torque is heavily dominated by the far end of the bat, where both the speed and the lever arm are largest. In other words, most of the drag-induced deceleration comes from the barrel. A more detailed treatment of the motion near the handle would therefore have only a minor impact on the result.

Ok, let’s dive in.

First, I will assume a constant acceleration of the bat, with the tip going from $v = 0$ to v_f, the final bat speed. If we let the bat rotate about a pivot near the hands, the final speed at the tip is

$$v_f = \omega_f L,$$

where L is the distance from the pivot to the tip and ω_f is the final angular velocity.

With constant angular acceleration α, the angular velocity is

$$\omega(t) = \alpha t.$$

If the tip reaches v_f after a time τ, then

$$\alpha = \frac{\omega_f}{\tau} = \frac{v_f}{L\tau},$$

so

$$\omega(t) = \frac{v_f}{L\tau}\, t.$$

From this, the speed of a point located at a distance r from the pivot is

$$v(r,t) = \omega(t)\, r = \frac{v_f}{L\tau}\, t\, r.$$

Now consider a small slice of the bat of thickness dr at distance r, with local diameter $D(r)$. Using a simple quadratic drag model, the force on that element is

$$dF = \frac{1}{2}\, \rho\, C_D\, D(r)\, v(r,t)^2\, dr.$$

Substituting $v(r,t)$,

$$dF = \frac{1}{2}\, \rho\, C_D\, D(r) \left(\frac{v_f}{L\tau}\right)^2 t^2 r^2\, dr.$$

The corresponding torque contribution is

$$d\tau = r\, dF,$$

so

$$d\tau = \frac{1}{2}\, \rho\, C_D\, D(r) \left(\frac{v_f}{L\tau}\right)^2 t^2 r^3\, dr.$$

Integrating along the bat, the total drag torque is

$$\tau_D(t) = \frac{1}{2}\, \rho\, C_D \left(\frac{v_f}{L\tau}\right)^2 t^2 \int_0^L D(r)\; r^3\, dr.$$

If the moment of inertia about the pivot is I, the drag-induced angular deceleration is

$$\dot{\omega}_{\text{drag}}(t) = -\frac{\tau_D(t)}{I}.$$

So

$$\dot{\omega}_{\text{drag}}(t) = -\frac{1}{2I}\,\rho\,C_D\left(\frac{v_f}{L\tau}\right)^2 t^2 \int_0^L D(r)\ r^3\,dr.$$

The total change in angular velocity over the swing is

$$\Delta\omega = \int_0^\tau \dot{\omega}_{\text{drag}}\,(t)\,dt,$$

which gives

$$\Delta\omega = -\frac{\rho C_D}{6I}\ \frac{v_f^2\,\tau}{L^2}\int_0^L D(r)\ r^3\,dr.$$

The corresponding loss in tip speed is

$$\Delta v_{\text{tip}} = L\ |\ \Delta\omega\ |,$$

so

$$\boxed{\Delta v_{\text{tip}} = \frac{\rho C_D}{6I}\ \frac{v_f^2\,\tau}{L}\int_0^L D(r)\ r^3\,dr}$$

At this point, one could plug in a realistic bat profile $D(r)$, but for an order-of-magnitude estimate it is sufficient to approximate the bat as a cylinder of constant diameter D. Taking D to be the barrel diameter slightly overestimates the contribution from the handle, but this is not a big deal. It partly compensates for the simplifications in the velocity near the hands (no translation), and, as said earlier, the dominant contribution comes from the barrel anyway, where both r and v are largest.

With this approximation,

$$\int_0^L D(r)\ r^3\,dr = D\int_0^L r^3\ dr = \frac{DL^4}{4}.$$

So we obtain

$$\boxed{\Delta v_{\text{tip}} = \frac{\rho C_D D L^3}{24I}\, v_f^2\, \tau}$$

This expression gives the reduction in bat speed due to air drag in this simple constant-acceleration, pure-rotation model.

In other words, if a batter applies a torque that would produce a final speed v_f in vacuum (assuming a human could do that, although a few players who don't seem entirely human might be able to… looking at you Shohei), then in air of density ρ, the final bat speed is reduced by an amount given by the expression above.

Typical numbers :

- $\rho \approx 1.20\ \text{kg m}^{-3}$
- $v_f = 75\ \text{mph} = 33.5\ \text{m s}^{-1}$
- $\tau = 0.15\ \text{s}$
- $L = 0.84\ \text{m}$
- $I \approx 0.22\ \text{kg m}^2$
- $D = 2.625\ \text{in} = 6.67\ \text{cm}$

The drag coefficient of a cylinder depends on Reynolds number and surface roughness and varies during the swing. Based on laboratory measurements, a value in the range $C_D \sim 0.8$–1.2 is reasonable, so I will adopt $C_D \approx 1$.

Plugging in these numbers, we find

$$\Delta v_{\text{tip}} \approx 1.51\ m/s = \ 3.38\ \text{mph}.$$

This is the total speed loss from vacuum to air. What we actually want, however, is the much smaller change in bat speed between two different temperatures (and thus densities).

Since everything in the derived expression is independent of temperature except ρ, we can group all the other factors into a constant K, so that

$$\Delta v_{\text{tip}} = K\rho,$$

With $K \approx 1.26$ (m3/kg). The problem then reduces to finding how ρ changes with temperature. For an ideal gas, $\rho \propto 1/T$, so

$$\frac{d\rho}{dT} = -\frac{\rho}{T}.$$

Therefore,

$$\frac{d(\Delta v_{\text{tip}})}{dT} = K\frac{d\rho}{dT} = -K\frac{\rho}{T} = -\frac{\Delta v_{\text{tip}}}{T}.$$

The minus sign simply reflects that this is the *loss* due to drag: as temperature increases, the loss becomes smaller, so the actual bat speed increases. So for a small temperature change,

$$\delta v_{\text{tip}} \approx -\frac{\Delta v_{\text{tip}}}{T}\,\delta T.$$

If we take a typical temperature $T \approx 20$ C (about 68°F), and $\Delta v_{\text{tip}} \approx 3.38$ mph:

$$\delta v_{\text{tip}} \approx -\frac{3.38}{293}\,\delta T \approx -0.0115\ \text{mph/K} \times \delta T = -0.0064\ \text{mph per}\ \circ\text{F}$$

or equivalently

$$\boxed{\delta v_{\text{tip}} \approx -0.064\ \text{mph per}\ 10^{\circ}\text{F}}$$

So how does this compare with the numbers reported by Ryan Blake?

Using the scaling derived above, a typical temperature change of about 20–25°F corresponds to a change in bat speed of roughly 0.1–0.15 mph. That is somewhat smaller than the $\sim$ 0.4mph spread quoted by Blake (from 71.3 to 71.7 mph), but it is clearly in the same ballpark.

What should one make of this? The model assumes pure rotation, constant angular acceleration, a cylindrical bat, a fixed drag coefficient, and ignores the translational component of the swing as well as any temperature dependence of the batter's body, or grip. So the estimated δv_{tip}could easily be off by a factor of 2–3. Still, the fact that this simple air-drag argument lands in the same ballpark as Blake's result suggests that air density could be part of the story, even if it is probably not the whole story.

To conclude, as pointed out by Alan Nathan, a simple observational test would be to compare bat speeds at Coors Field with those at other venues. Since the drag-induced change in speed is proportional to air density, and the density difference between Denver and sea level is roughly 9 times larger than that produced by a 10°F temperature change, the effect should be significantly easier to detect.

I do not have access to the data, but if air drag is indeed responsible for the temperature dependence of bat speed, then a measurable difference should appear when comparing home and away games. Conversely, if no significant difference is observed, it would suggest that the approximations used in this simple model overestimate the role of air density, and that the real culprit may lie elsewhere.