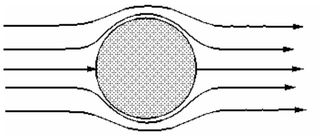
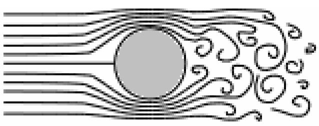
- THE SCIENCE OF SHOOTING (PART 4) -

AERODYNAMICS

At very low speeds, a sphere moving through the air pushes the air gently out of the way, only for the air behind the sphere to come together in a very orderly and controlled manner. This is called laminar flow.



However, speed up the sphere and things start getting more unsettled. As soon as the projectile hits a particular critical speed, the air flow around the sphere becomes turbulent.



Turbulence has baffled physicists for centuries – nobody on the planet (literally, NOBODY) knows how to solve the equations for turbulence, so it's still a bit of a mystery to us all. However after a lot of experimentation, engineers and scientists have managed to deduce some particular relationships which enable us to calculate, with a fair degree of confidence, the drag on a sphere. For the mathematically savvy the equation for drag is...

$$F_D = \frac{1}{2} \cdot C_D \cdot \rho \cdot S \cdot v^2$$

Basically, this means:

Coefficient of drag (C_D):

If the coefficient of drag doubles, the drag on the sphere doubles. This is worked out by experimentation. You'll see many car manufacturers lay claim to their aerodynamic prowess by stating "...our car has a C_D of only 0.17 ..." which is deliberately misleading to be honest. Aerodynamic drag relies on, as the equation above says, C_D times air density times cross-sectional area times velocity squared. Fine, a car could have a C_D of 0.17, but if it's 10 feet high and 20 feet wide, it'll still have to deal with a mountain of air drag.

Density of air (ρ):

If you double the density of the air through which the sphere (shot) is flying, you double the aerodynamic drag on the sphere. So if you go shooting at high altitudes, your shot will fly further and hit harder. Go shooting on the moon, and there's no drag whatsoever (see The Science of Shooting, Part 1).

Cross-sectional area of the sphere (S):

If you double the cross-sectional area of the sphere, its air drag will double as well. Basically, this means that smaller shot has less wind drag acting on it.

Velocity of the sphere (v):

Here's the stickler. Because the velocity term in the equation is squared (ie. we have v^2 and not just v), if you double the velocity of the sphere, you multiply its wind drag by a factor of two-squared (2^2), which is four (4). Likewise, if you triple the speed of the sphere, its drag increases by a factor of three-squared (3^2), which is nine (9).

This squared term has other implications for aerodynamics too. Whilst for air drag the velocity term (v^2) is squared, for power consumption it is cubed (v^3). For example, say you drive your car at 50kph. If we assume that all of the power consumption is going towards overcoming wind drag, then doubling the car's speed to 100kph will not just double the power (thus fuel) consumption, but will increase your fuel consumption by a factor of 2^3 = eight (8)!

Now I'm sorry to do this to you all, but there one last equation you need to know, and that's Newton's Law...

$$F = m \cdot a \quad \underline{\text{or}} \quad a = \frac{F}{m}$$

In this equation, *F* is force (or for the purposes of our discussion, drag force), *a* is acceleration, and *m* is mass.

Basically, this means that the more air drag there is acting on our projectile, the greater its negative acceleration (or deceleration) will be. Keeping all else constant, this means that larger shot sizes will slow down at a quicker rate because have larger cross-sectional areas and thus have more air drag acting on them.

However, and somewhat confusingly, the greater the mass of a single piece of the shot, the slower the rate at which the shot will slow down. Keeping all else constant, this means that larger shot sizes will slow down at a lesser rate because they have more mass.

So which is it? Does bigger shot slow down at a greater or lesser rate than smaller shot? The answer is lesser. It's all to do with the *'air drag to mass'* ratio (ie. F/m).

To cut a long story short (and to save you the pain of the mathematics involved), if we *increase* the diameter of a piece of shot by a factor of two (2), its deceleration will *decrease* by a factor of two ($^1/_2$). Likewise, if we *increase* the diameter of a piece of shot by a factor of three (3) its deceleration will *decrease* by a factor of three ($^1/_3$).

So there you go. Bigger shot means less deceleration, which in turn means it should fly further, and hit harder.

The following table compares (for given shot sizes fired at 1250 fps at an angle of 10°) the maximum ranges, hitting power remaining (% E_k) at 30m, 45m and 60m, and the time (in seconds) to fly these distances.

Shot Size	Range (m)	@ 30m		@ 45m		@ 60m	
		% E_k	time	% E_k	time	% E_k	time
BB	323	58	0.09	44	0.15	34	0.22
B	311	56	0.09	42	0.15	32	0.22
1	297	54	0.09	40	0.15	30	0.22
2	284	52	0.10	38	0.16	27	0.23
3	271	50	0.10	35	0.16	25	0.23
4	257	47	0.10	33	0.16	23	0.24
5	243	45	0.10	31	0.17	21	0.25
6	228	42	0.10	28	0.17	18	0.26
7.5	205	38	0.10	23	0.18	14	0.27
8	198	36	0.11	22	0.18	13	0.28
9	181	32	0.11	18	0.19	11	0.30

As it's easy to see that larger shot performs the best in all categories, the quandary is now: *why on earth do we bother using smaller shot at all*?