Blowback Firearms Design: Theory & Practice

Orion's Hammer, 2010-01.
Most high-powered guns have a locking bolt, where locking lugs hold the chamber closed during firing. This includes bolt-action or break-action rifles, as well as rotating-bolt semiautos like the AK or AR. "Blowback" guns, by contrast, just use the inertia of the bolt to hold the chamber closed. Here's a schematic view of a blowback gun, from George Chinn's 1955 masterpiece, "The Machine Gun", volume 4, part X. This is a public-domain government publication, so I'm reproducing the figures here directly.

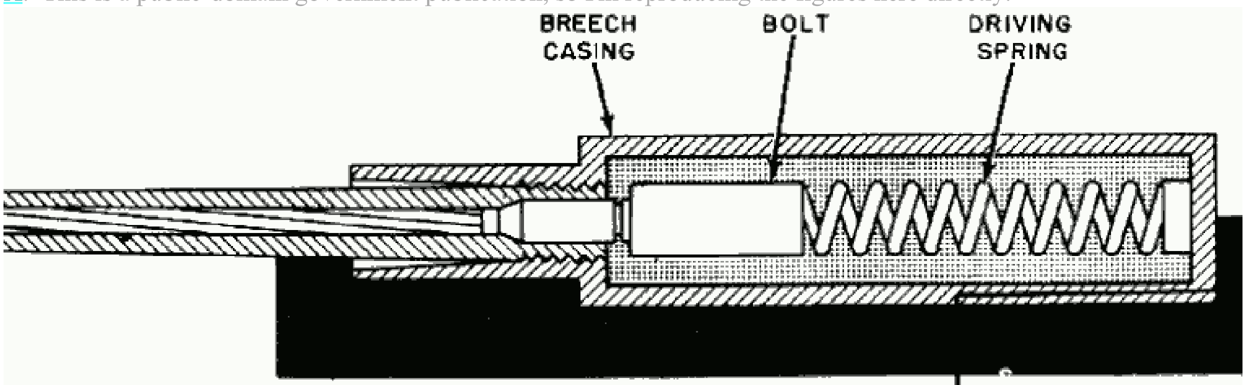

Figure 1–5. Simplified Schematic of Blowback Mechanism.

Blowback guns are actually a lot easier to build in a garage than locking bolt guns, because:

- There are no mating or rotating parts; in fact, the only moving part can be the bolt!
- You don't need to machine locking lugs into the bolt or chamber.
- There is no "headspace", or cartridge slop before the bolt hits the locking lugs.
- The force on the bolt face is mostly just compression, instead of the tension at the back of the lugs (see Dan Lilja or Varmint Al for locking bolt analysis). So you can build working blowback bolts from crappy materials like mild steel (of course, harder steel will wear better).

Blowback designs are legal in most US states, as long as you use a semiauto hammer or striker. The federal government forbids most use of open-bolt (fixed firing pin) designs, since they're extremely easy to make fully automatic.

Case Head Separation

So why aren't all guns blowback? Well, blowback guns do have this little tendency to explode if designed incorrectly.

Here's a typical cartridge pressure curve. You can record your own pressure curve with a strain gauge like a Pressure Trace, but traces from different cartridges and guns are surprisingly similar, and different mostly in peak pressure (from about 10Kpsi to 60Kpsi).

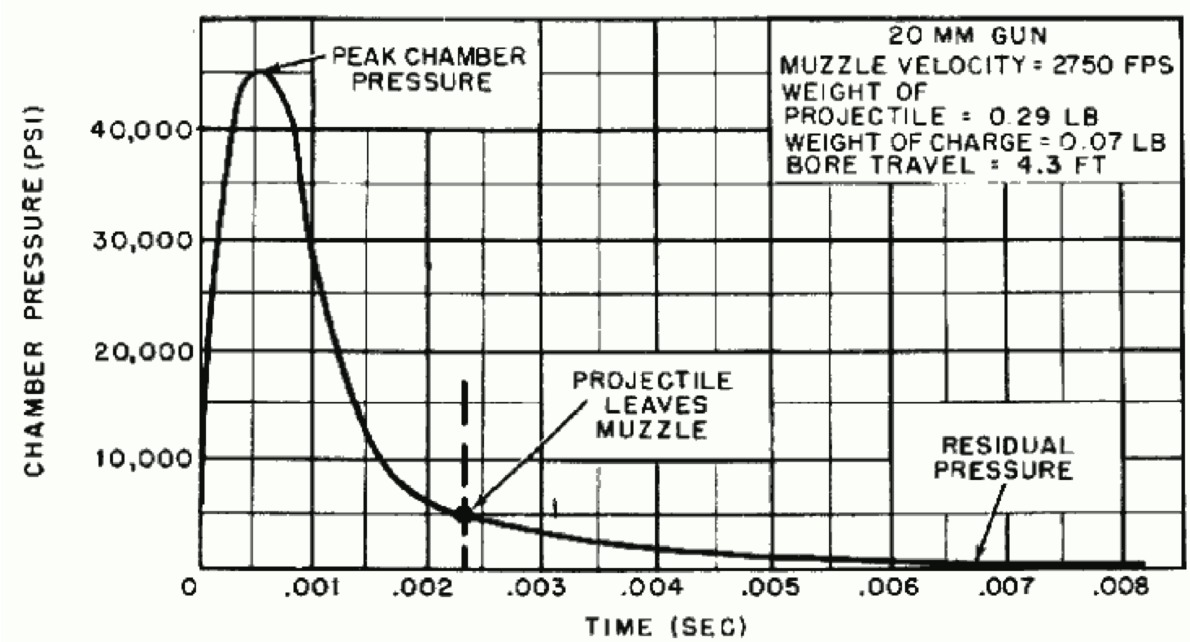

Figure 1–1. Variation of Chamber Pressure With Time.

The tens of thousands of pounds of pressure inside the chamber only last for a millisecond or two, and they're what push the bullet down the barrel.

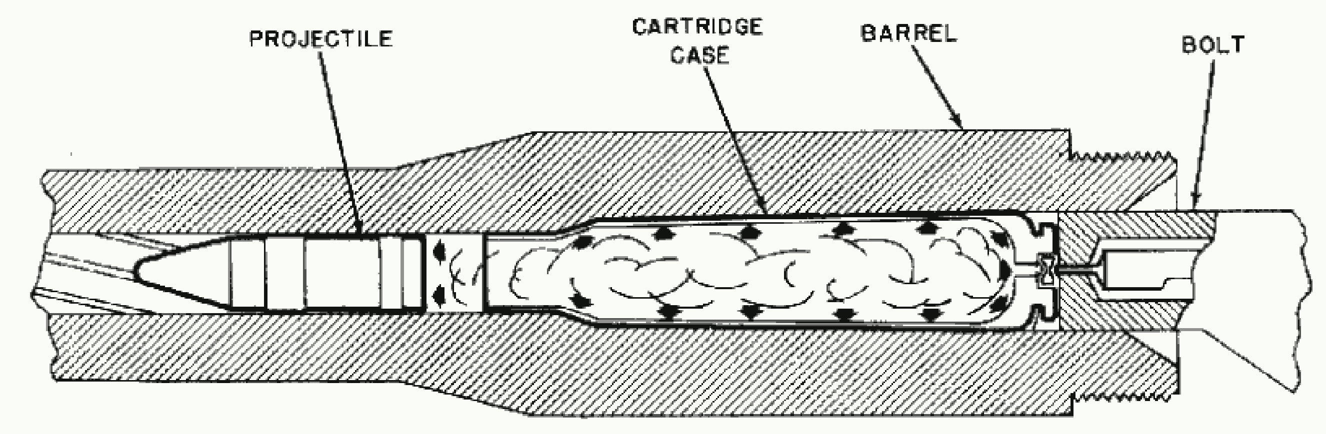

Figure 1-2. Pressure in Chamber.

Note that the chamber pressure pushes back on the bolt with the same pressure that it pushes the bullet down the barrel. This is bad, because if the bolt moves back under pressure, then the cartridge tends to stretch out. If it stretches too far, the case head may separate from the body of the case, and spray hot gas at tens of thousands of PSI in all directions. This "case head separation" can and has killed people, for example by flinging the bolt at high velocity back through the shooter's eye.

Not good.

You can stop the case head from separating by:

- Fluting the chamber, like the HK MP5 or G3, which equalizes the pressure inside and outside the chamber.
- Greasing the cartridges, so the cartridge tends to slide out of the chamber instead of sticking to the walls. Chinn says heavy grease is needed; light oil tends to get squished off the high spots.
- Pushing back against the case head with enough force. This force can come from tricky-to-machine locking lugs, but we'd like to just use bolt inertia.

Note that even a tiny 22 long rifle cartridge pushes on the bolt head with a force of about a thousand pounds, so you can utterly forget about springs (at least, any spring you could possibly cock by hand!), or friction, or magnets, etc.

That last point bears repeating. From the previously cited Chinn Vol 4, page 15 (underline added by me):

> "NOTE: There is one point which requires special clarification at this time. In many descriptions of blowback actions, it is strongly implied that the driving spring contributes a substantial portion of the resistance which limits acceleration imparted to the bolt by the powder gases. Actually, this is not so. Although it is true that the driving spring absorbs the kinetic energy of the recoiling bolt and thus limits the total distance it moves, the resistance of the spring does not have any real effect in the early phase of the cycle of operation. The bolt acceleration occurs mainly while the powder gas pressures are high and are exerting a force of many thousands of pounds on the bolt. The driving spring, in order to permit the bolt to open enough to allow feeding, must offer a relatively low resistance. Although this resistance is sufficient to absorb the bolt energy over the comparatively great distance through which the bolt moves in recoil, it is not great enough to offer significant opposition to the powder gas pressure until the chamber pressure has dropped to a relatively low level well after the projectile has left the muzzle."

The myth that "a stronger recoil spring will prevent case head separations" persists on the internet to this day. This is a myth.

In any blowback design, you can reduce the chance of lethal injury after a case head separation by:

- Venting the escaping gases out as wide an ejection port as possible.
- Making the bolt's front face fairly small, so the escaping gases push on a smaller area.
- Putting a very beefy rear trunnion at the end of the bolt's rearward travel to absorb the bolt's extra energy. This is over and above the normal recoil energy.
- Not having loose parts near the chamber (e.g., sights, extractor gizmo) that could get blown off during an explosion.
- Putting distance between the user and the chamber area. Forward-magazine pistols are good for this (chamber is well forward of the operator's hands), bullpup rifles are very bad (chamber is right next to the user's cheek!).

How Fast will the Bolt Move Back?

Here's how to figure out the forces acting on the bolt.

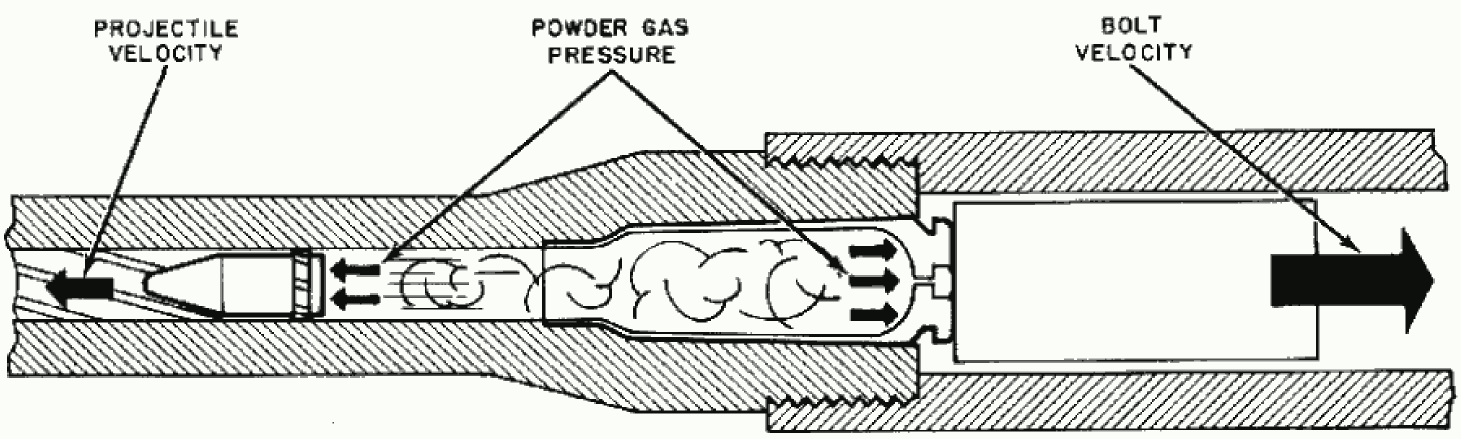

Figure 1–8. Velocities in a Blowback Gun.

The same chamber pressure that pushes the bullet down the bore, pushes the bolt backwards. If the bolt weighed the same amount as the bullet, then it would fly back with bullet velocity, shooting the shooter! So our basic tool to keep the bolt velocity down is mass.

Chinn claims that, ignoring friction:
momentum of bolt = momentum of projectile + momentum of gas (+ momentum of barrel?)
$m_{bolt} * v_{bolt} = m_{bullet} * v_{bullet} + m_{gas} * v_{gas}$ $(+ m_{barrel} * v_{barrel}?)$

For small cartridges like pistols, a typical charge weight is 3-6 grains of powder to push a hundred-something grain bullet, so we can usually ignore the momentum contribution of the gas. However, chamber pressure in any bottlenecked case pushes the barrel forward quite hard, so I don't think we can safely ignore the barrel's momentum like Chinn does.

The basic problem here is that though the *pressure* pushing the bullet and bolt are equal, the *areas* are not equal. Cartridges are always at least a little bigger at the back end, and sometimes much bigger. This causes "bolt thrust" issues with the new short fat cartridges like 300 WSM, even at quite reasonable chamber pressures. In fact, unlike Chinn, I'm going to ignore the gas momentum and start out by assuming:
pressure on bolt face = pressure on bullet back

Since pressure = force / area, the forces on the bolt face and bullet will differ by the ratios of their areas.
force on bolt face / area of bolt face = force on bullet base / area of bullet base
or
force on bolt face = force on bullet base * (area of bolt face / area of bullet base)

Now we're getting somewhere! Momentum is the integral of force over time (force is actually defined as the time derivative of momentum), so if we integrate both sides above by time (that is, integrate the pressure curve), then we get:

momentum of bolt = momentum of bullet * (area of bolt face / area of bullet base)

The area of a circle is of course pi * radius^2, or pi/4 * diameter^2, so this is equal to:
momentum of bolt = momentum of bullet * (diameter of bolt face / diameter of bullet base)^2

We can easily look up the momentum of a fired bullet. If we scale that by the area ratio, we get the bolt's momentum. If we divide by the bolt weight, we get the bolt's velocity. If we divide by a target bolt velocity, we get the required bolt weight.

Blowback Bolt Weight (FINALLY!)

We really want the gun not to blow up when it fires. To do this, we have to hold the chamber closed until the pressure drops to a reasonable level. A heavy enough bolt will hold the back of the case on this way. Using the equation for bolt momentum above, given the basic ballistics (bullet mass and velocity) and caliber information (diameters of various parts), we can solve for the required bolt mass for any bolt velocity.

Which bolt velocity do we need? Sadly, this depends greatly on the exact design of the cartridge case (thicker and stronger walls are better), the chamber (more support is better), and the powder used (faster burning is better). A typical semiauto has a bolt travelling about 4m/s (about 12fps). In the half millisecond that it takes to reach peak chamber pressure, a 4m/s bolt would travel 2mm; the actual travel is substantially less than this because the bolt is accelerating nonuniformly, and does not reach 4m/s until the bullet is gone.

ASSUMING a 4m/s bolt velocity is safe, then the required bolt mass is:
bolt mass in pounds = 1.09×10^{-5} * bullet mass in grains * bullet velocity in fps * (diameter of bolt face / diameter of bullet base)^2
The conversion constant 1.09×10^{-5} comes from asking Google to express 1 grain * 1 foot/second / 4 m/s in pounds. Here's the above bolt

mass figured for some common cartridges:

Cartridge	Bolt weight	Bolt thrust	Bullet	Velocity	Caliber	Base	Proof
Units	pounds	Kpounds	Grains	Fps	Inches	Inches	KPSI
22lr	0.4	0.9	29	1240	0.223	0.224	31.2
32acp	0.8	1.8	71	905	0.312	0.338	26.7
380acp	1.1	2.4	90	1000	0.356	0.374	28.0
38special	1.3	2.5	110	945	0.358	0.379	28.6
9x19 Parabellum	1.7	4.6	88	1500	0.355	0.391	50.1
7.62x25 Tokarev	2.0	4.0	87	1390	0.312	0.387	44.5
40s&w	2.2	4.9	135	1324	0.400	0.424	45.5
357magnum	2.2	5.0	125	1450	0.358	0.379	57.2
45acp	2.3	3.7	200	975	0.452	0.476	27.3
9x23winchester	2.4	5.4	125	1450	0.356	0.392	58.5
45colt	2.4	2.9	185	1100	0.456	0.480	20.8
45gap	2.5	4.1	185	1150	0.452	0.476	29.9
357sig	2.6	5.6	125	1368	0.355	0.424	52.0
10mm	2.8	5.3	170	1340	0.400	0.425	48.8
410bore	2.8	2.4	109	1755	0.410	0.478	17.6
30 carbine	3.2	4.0	100	2200	0.308	0.356	52.0
44magnum	3.8	5.9	210	1495	0.432	0.457	46.8
454casull	5.4	10.2	240	1916	0.458	0.478	74.1
500s&w	5.5	11.0	275	1650	0.500	0.530	65.0
50ae	6.0	8.1	300	1579	0.500	0.543	45.5
7.62x39	6.3	6.9	123	2350	0.311	0.443	58.5
6.8spc	6.6	8.2	85	2900	0.268	0.421	76.7
223 Remington	7.0	6.9	80	2869	0.224	0.376	80.6
30-30	7.2	6.4	150	2390	0.309	0.420	59.8
7.7arisaka	9.9	8.3	180	2200	0.311	0.473	61.1
45-70	9.9	6.4	400	1900	0.458	0.504	41.6
308 winchester	11.3	10.8	168	2680	0.308	0.470	80.6
8mm Mauser	11.8	9.9	198	2625	0.324	0.470	74.1
7.62x54R	12.2	10.5	180	2575	0.311	0.485	74.1
7mm Mauser	12.3	10.0	154	2690	0.285	0.472	74.1
50alaskan	12.6	8.3	450	2150	0.500	0.548	45.5
30-06	12.8	10.4	190	2700	0.309	0.470	78.0
375h&h	14.2	12.8	235	3000	0.375	0.513	80.6
300wsm	17.4	15.7	150	3300	0.308	0.555	84.5
300 winchester magnum	17.8	13.2	190	3150	0.309	0.513	83.2
338lapua	24.4	18.4	250	3000	0.338	0.587	88.4
300lapua	25.0	18.4	220	2910	0.309	0.587	88.4
50bmg	54.3	27.4	660	3080	0.511	0.804	70.2
20gauge	5.5	4.6	218	1800	0.615	0.699	15.6
16gauge	7.7	5.0	350	1600	0.662	0.746	15.0
12gauge	9.4	7.2	437	1600	0.729	0.812	18.2
10gauge	12.9	6.3	765	1280	0.775	0.855	14.3
Units	pounds	Kpounds	Grains	Fps	Inches	Inches	KPSI
Cartridge	Bolt weight	Bolt thrust	Bullet	Velocity	Caliber	Base	Proof

Here's the Excel spreadsheet used above.

As a check, note that the blowback Ruger 10/22 bolt weighs 0.4lbs, exactly as predicted. Typical pistol-caliber submachinegun (SMG) bolts for 9mm, Tokarev, or 45acp are around 1.4lbs, although open-bolt SMG requires only half as much bolt mass (the chamber pressure has to slow down and stop the closing bolt before pushing it open again). Note that most rifle cartridges would require an absurd bolt weighing over ten pounds, and 50bmg would weigh over 50 lbs. This is of course all ASSUMING the 4m/s bolt velocity is slow enough to prevent the case from exploding!

The second column gives the peak-pressure force on the bolt, which is shown in ***thousands*** of pounds (Kpounds). The pressures used for figuring bolt thrust are proof loads, 30% over the maximum SAAMI or CIP pressure. These huge forces are the big thing complicating locking designs--the locking lugs have to be really tough!

Your mileage may vary. If you don't understand the above engineering or physics, stick with factory designs. Like I do, you should STRAP ANY NEW GUN TO A TREE and fire off dozens of rounds remotely from a safe location, carefully examining both the gun and the fired cases, BEFORE you fire the gun anywhere near your body!