The WWII Fighter Gun Debate

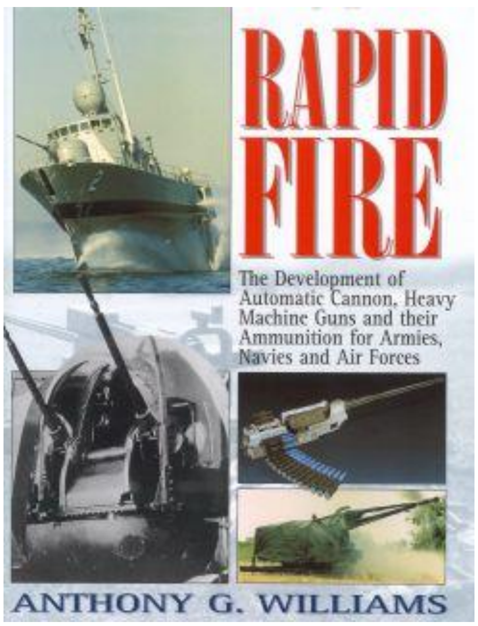
Introduction

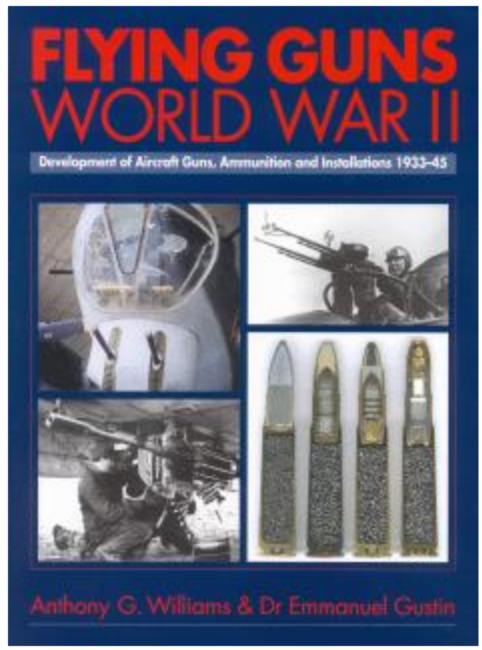
Acknowledgements

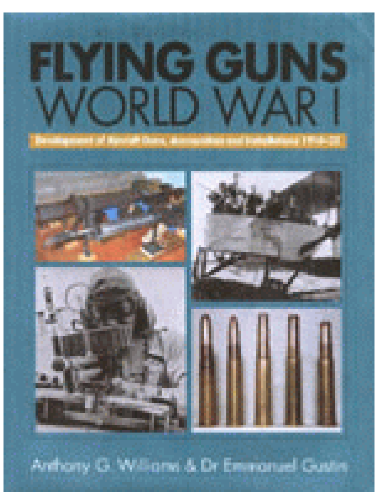
I started this page with optimism and a fair amount of nativity, but fortunately I quickly received comments and help from two people who are far more knowledgeable about guns than I am, Tony Williams and Ted Bradstreet. They have contributed most of the gun data on this page.

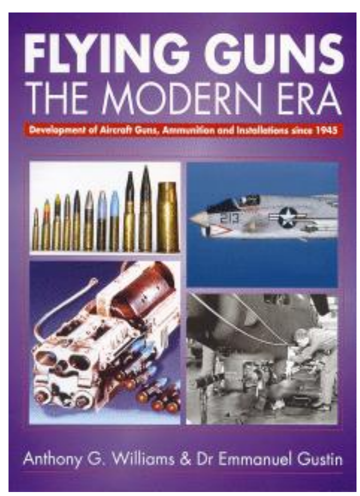
If you have specific information about WWII aircraft guns, especially unpublished information that you would like to share, you can also contact Tony Williams Tony.Williams@quarry.nildram.co.uk or Ted Bradstreet tbstreet@mint.net . Tony Williams now has his own website, in which he announces his book on heavy automatic weapons and has some more information available. He also created a discussion forum at http://forums.delphiforums.com/autogun .

Recommended reading for those interested in technical military history:









For details, click the covers.

Other helpful contributors of information for this page were C.C. Jordan, Ruud Deurenberg, David

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If you have any additional information for this page, you can e-mail me at gustin@uia.ua.ac.be.

The Question

One of the recurring questions about the fighter aircraft of the Second World War concerns the choice of their armament. Although armament is an essential part of a fighter aircraft, it has not been studied very often. Many studies of WWII combat aircraft seem to ignore it entirely. Other sources make wrong assumptions, and too often it has been ignored that there was considerable change in fighter armament during the war. There was an evolution both in the caliber of the guns used, with options ranging from rifle-caliber machine guns to 30mm cannon and heavier, and in the technical performance of these guns.

Some of the basic facts seem to be almost unknown. Even very respectable authors who have done a lot of research on fighter aircraft, can still be caught writing completely erroneous statements such as [Page 375 in Ref. 31]:

> *A recent British book claims that these Tempests outgunned and could outspeed all contemporaries. It is a matter of record that eight .50-cal machine guns or one 20-mm plus four .50s can throw a much greater weight of lead in a given period than four 20-mm cannon can.*

(A comparison of the actual firepower of the Tempest, P-47 and P-38, as well as some other WWII fighters, can be found in this table.) The choice of the .50 machine gun as standard weapon for US fighter aircraft is one of the most controversial armament issues, and many authors seem to seek justification for its use by making highly exaggerated claims about its effectiveness.

These pages try to describe the evolution of fixed fighter armament, with emphasis on the armament of WWII fighters. To give an overview of the texts:

- This page, the introduction, also contains the acknowledgments and some addresses.
- There is a page about WWI fighter armament, to provide an historical background.
- Gun performance tables are given for aircraft guns used during WWII. These discuss guns that saw actual combat service. Prototype guns are ommitted here.
- Some generalities about ammunition are also discussed.
- A related subject is discussed in a few notes about ballistics and gunsights.
- An important section discusses the armament combinations installed in some WWII fighters.
- There is also an analysis of the evolution of fighter armament during the war.
- Upward-firing guns and Schräge Musik, typical armament installations for nightfighters, have their own page.
- I also added a page on big guns and their use in WWII aircraft. Most of these were not used in fighters.
- A lengthy discussion of defensive gun installations.
- There is a postscript discussing the armament of post-war fighters.
- There is a Fighter Armament Table listing fighters since 1934 and their armament.
- A graphical equivalent of these is provided in a number of interactive Java graphs of fighter armament, or a page with simpler figures for those who don't have browsers that support Java. There are some problems with the applets on a number of browsers, I don't know why.
- There is a page with a number of open questions and a reply form, and of course a page with the answers received.
- As a conclusion, a list of sources. There is also a page with various notes.

You can read these in almost any order you want.

Introduction

The subject of World War II fighter armament could be delineated by the start and end dates of the war, but of course the aircraft did not suddenly appear and disappear at these dates. However, there is a suitable technical definition. During World War I and most of the antebellum, the armament of a typical biplane fighter consisted of two rifle-caliber machineguns, installed in the upper decking of the front fuselage, with the breeches within reach of the pilot so that he could clear stoppages. Although some fighters of WWII still had this form of armament, it was quickly abandoned by most. This occurred almost simultaneously with the introduction of the monoplane fighter: The higher combat speeds and the sturdier construction of modern aircraft required more powerful armament. The different construction of a cantilever monoplane also made it possible to install guns within the wings.

The end of World War II armament is also established fairly clearly. During the war fighters were armed with what are generally called linear action guns. Such guns have a single barrel and a single chamber, so that the actions of chambering the round, firing the gun, and ejecting the case have to be performed sequentially. The WWII armament was still used during the Korean War, but soon thereafter revolver and rotary cannon entered service. They did not replace the linear action guns completely: Fighters of the US Navy and the USSR retained the latter for some years. But rotary and revolver cannon have dominated the field since the 1950s.

At the end of WWII the Germans had developed the MG 213C revolver cannon. Such a weapon has multiple chambers in a rotating cylinder, so that rounds can be processed in parallel. For example, at the same time when one round is fired, two or three are being chambered and an empty case is being removed from another chamber. Obviously, this significantly increases the possible rate of fire. An alternative design is the rotary gun, often called "Gatling" gun, which not only has multiple chambers but also multiple barrels. This eliminates the need for a seal between the barrel and the rotating chambers, but the gun is bulkier and heavier. Generally, rotary guns have a higher rate of fire, but a relatively long spin-up time, so that if only a short burst is fired, the revolver gun puts out about as many rounds as the multi-barrel gun. Modern fighter guns are either revolver guns or rotary guns, with the notable exception of the Russian GSh-30-1.

The specifics of gun action were generally derived from a few basic designs. Especially the Browning and Oerlikon designs were much copied. Refinement could substantially increase the rate of fire of a gun, for example the Browning .50 was boosted from 750rpm in the M2 version to 1200rpm in the post-war M3 version. But all other things being the same the rate of fire is lower for a gun with a larger calibre, because the ammunition and the working parts of the gun are heavier, and therefore larger forces are needed to move them. For similar reasons, a gun with a high muzzle velocity fires slower than one with a low muzzle velocity. Especially for 20mm and 30mm cannon it was a challenge to increase the rate of fire, and substantial improvements were achieved during the war.

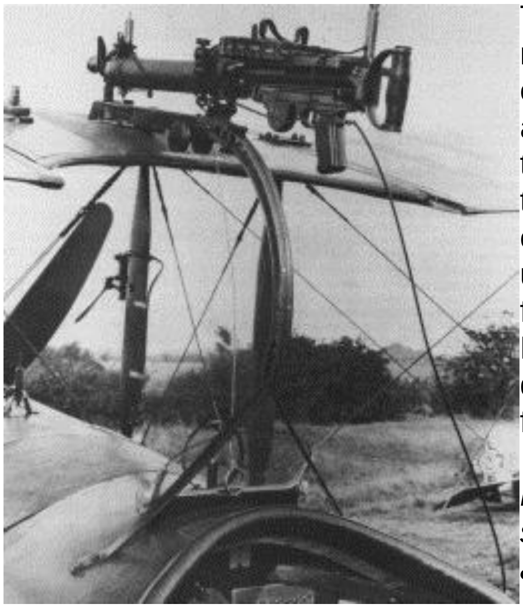
It is not the purpose of these pages to explain gun action. However, there is one that deserves comment and that is the Oerlikon design, a derivative of the WWI Becker design. Nine cannon listed in the gun tables are Oerlikon guns or copies of them, and the reader might grasp that these guns were light and popular, but also that most of them were slow-firing, and that although this design was popular in the early years of the war, it later fell out of favour. (See Note 2.) The operating principle behind these weapons is known as *Advanced Primer Ignition Blowback*. Basically, this means that the rear end of the chamber is not closed by a part that is *locked* in place, as in more conventional designs. Instead, the chamber is extended to a greater length than is required by the length of the round, and a *sliding* bolt follows the cartridge into the chamber, driven by a powerful spring. The propellant is ignited while the cartridge and bolt are still moving forward into the chamber. The inertia of the heavy forward-moving bolt guarantees that the sliding bolt is not expelled from the rear of the chamber before the projectile has left the barrel and the gas pressure has dropped again. Depending on the design, firing the gun compresses or extends the spring, thus providing the energy for firing the next round. The rate of fire of such a design is linked to the resonance frequency of the bolt-and-spring assembly; and as the bolt needs to be fairly heavy, the rate of fire is usually low. Another consequence is that the cartridge cases invariably have rebated rims, otherwise they could not be pulled from the extended chamber.

Early Experiments

Sir Hiram Maxim's experimental biplane. The inventor can be seen standing in front of the aircraft, between the guidance rails. The monster was powered by advanced, light and powerful steam engines. [33]

In a sense the association of the aircraft and the machinegun began before the first existed. The first automatic machinegun was developed by Sir Hiram Maxim, and it was used in the colonial warfare of the late 19th century. Maxim devoted some of his wealth to the construction of a giant steam-powered biplane, tested in 1894 in Britain. He was wise enough to try to keep the aircraft under control with guiding rails, that allowed it to raise only a few centimeters above the ground. But during a test the rails broke and the aircraft was destroyed.

It is not known whether Maxim envisaged that his guns would be fitted to aircraft. The early aircraft were much smaller than Maxim's 3.5 ton giant, and the weight of the gun and its ammunition was a heavy burden for small aircraft with limited engine power. The development of more powerful aircraft was only a matter of time, however. Rifle-calibre machineguns were not that heavy, and the weight could be reduced by deletion of water-cooling jackets and circuits: On aircraft air cooling was sufficient. The jacket was often retained, but perforated to reduce the weight and improve cooling.



The problem then became the development of a suitable gun mount. We will skip over the problems of observer guns, and only consider forward-firing guns. There was no real problem on aircraft with a pusher engine: The machinegun could be put in the nose. However, such aircraft had a complicated design with tailbooms around the propeller; this was heavy and induced a lot of drag. Therefore, the performance of pusher aircraft was usually inferior to that of the more compact tractor designs. At first this was not a serious problem. At the start of WWI the French even decided to equip their air force entirely with pusher designs, simply because this would make it easier to distinguish friend from foe: The Germans employed mainly tractor aircraft.

Left, the Foster mount on an SE.5a. When this aircraft entered service the Foster mount was obsolescent, but it did have the advantage that it could be used to fire upwards. [4]

On tractor designs, with the propeller in front, the gun could in principle be fitted outside the propeller circle. On two-seat monoplanes a high gun mount could be installed, and the gunner could stand to fire over the propeller: It was tried on some aircraft, but it was not a good solution. On biplanes the machinegun could be installed on top of the upper wing. Unfortunately the gun was then out of the reach of the pilot, and WWI machineguns were rather unreliable. Pilots needed to clear stoppages frequently, and often carried a small hammer for this purpose. For drum-fed weapons, such as the Lewis, there was also the problem of changing drums: Flying the aircraft with one hand while handling a heavy ammunition drum with the other was a difficult task, and many pilots chose to break off combat and descend to lower altitude before attempting to do this. Finally, the recoil of the gun was enough to disturb the aim. Nevertheless some Allied aircraft, used a Lewis gun, because this was more reliable than the Vickers, and used this arrangement. Later the so-called "Foster mount" was installed on SE.5a fighters. This was a curved rail that allowed the pilot to slide the gun backwards and downwards.

The final alternative, the most practical one but also the technically most complicated one, was to install some form of interruption or synchronization mechanism, so that the machinegun could fire through the propeller disc. Several such mechanisms had been designed before the war. The Swiss engineer Schneider, who had worked for Nieuport in France and LVG in Germany, patented his design, of which drawings were even published in *The Scientific American*. In Russia, Poplavko experimented with synchronization in 1913. In Britain, the Edwards brothers patented another gear, and demonstrated a working model. The French engineer Saulnier also worked on synchronization, but he discovered that the Hotchkiss machinegun fired too irregularly: It was not suitable for synchronization. Far too often a round would "hang" and put a bullet in the propeller. As a safeguard, the French had developed wedge-shaped steel deflectors that were fitted to the propeller to protect it, but the results were not encouraging.

Despite all this experimentation before the war, the the French and British air services entered the war with only two machineguns each, and the Germans had none. Therefore, the first shots in air warfare were fired with pistols and rifles, very unsuitable weapons for this kind of combat, but readily available to the crews, who often came from infantry or cavalry units. The RFC (Royal Flying Corps) authorized only the standard service rifle, a far too unwieldy weapon. Apparently the British pilot Lanoe G. Hawker was the only one to win any victories with a carbine.

A Vickers F.B.5 captured by the Germans. [61]

The pusher design was the first to be applied. Already in September 1912 Vickers had tested a biplane with a machinegun. By 1913, Vickers had developed the EFB.2, perhaps the world's first purpose-designed fighter aircraft. The EFB.2 was a two-seat pusher biplane, so that the gunner in front had a free field of fire. The installation of the Vickers machine gun, in a fairing in the tip of the nose, was entirely unpractical. By June 1914 a more practical gun mount had been developed, but it was July 1915 before the first Vickers FB.5, nicknamed "Gun Bus", appeared in France! Unfortunately the Vickers was underpowered and slow, and the machinegun initially so unreliable that many gunners took a rifle with them anyway.

A similar installation was made on some French Voisin biplanes, with Hotchkiss machineguns that were operated by the observer. The pilot sat in the front seat, and the observer fired the gun over his head. On 5 October 1914 a Voisin piloted by Joseph Frantz and with Louis Quenault as observer shot down a German Albatross biplane. It was the first victory in the air. By February 1915 the French had installed about 50 machineguns on their aircraft: Not very much, but enough to force the German aircraft to a hasty retreat whenever they appeared over the battlefield.

A fixed machinegun on a single-seater would be even more effective. The famous pilot Roland Garros dispensed with the synchronizing gear altogether, and installed a machinegun and deflectors on his Morane-Saulnier L, a parasol monoplane. His mechanic worked hard to improve the design of the deflectors. Starting on 1 April 1915, he shot down five German aircraft in seventeen days, before he and his aircraft came down behind the lines and were captured by the Germans. His success was so convincing that the Morane L and N, equipped with fixed guns and deflectors, soon equipped three French squadrons and some RFC units.

Fokker E.III. [22]

In Germany, the aircraft manufacturer Anthony Fokker was asked to deliver a synchronisation mechanism. Engineers Heinrich Luebbe and Fritz Huber were already developing a suitable mechanism, and after a few days Fokker could demonstrate the prototype. (The Fokker mechanism infringed Schneider's patents, and the legal battle would continue until Schneider's death.) The result of this experiment was the Fokker E.I, a modified M.5K monoplane with an Oberursel rotary engine, and a single fixed forward-firing machinegun. The first Fokker Es were delivered in the summer of 1915, and came in the hands of pilots such as Boelcke and Immelmann. The Fokker E.I, and the improved E.II and E.III, did not have a very good performance, but their armament was very effective. One or two fixed forward-firing machineguns became the standard armament for the fighters of World War I and the antebellum, usually installed on top of the front fuselage.

The Fokker became famous, but already before it entered service the Allies had put in production superior designs: The Airco DH.2 pusher, and the Nieuport 11 with the machinegun on the upper wing. Hence the *Fokker Scourge* was relatively brief. Far more deadly were the Albatross biplane fighters, with two synchronized machineguns. They took a heavy toll in "bloody April" of 1917, and set the standard pattern for the rest of the war and the antebellum.

The Sopwith F.1 biplane fighter received the name Camel *because of the hump that covered the two Vickers guns. The fairing was often partially cut away to make it possible to clear stoppages in the air. Note the loading handles in the cockpit.* [23]

There was a wide array of different synchronization mechanisms. The early ones were not very reliable, and accidents were common. The most successful was the C.C.-gear, named after its inventors Constantinesco and Colley. This operated with an hydraulically instead of a mechanical link, and that gave much more flexibility. The C.C.-gear could be used with any engine and any machinegun.

A refinement that was useful for air combat was the development of incendiary ammunition, but this was not without danger: The earliest German incendiary ammunition was so unreliable that it could seriously damage the aircraft that fired it. The quality of ammunition was a problem throughout the war, and a wise fighter pilot personally checked every round that was loaded in his guns. Rounds with slightly irregular dimensions were likely to jam a gun.

Guns of WWI

Note that rate of fire would be strongly reduced when a gun was synchronized.

Name	Ammunition	Rate of Fire	Muzzle velocity	Weight
Hotchkiss Mle 1909	8 x 50R	600 rpm	725 m/sec	12.3 kg
Lewis Mk.I	7.7 x 56R	550 rpm	745 m/sec	11.4 kg
Lewis Mk.II	7.7 x 56R	700 rpm	745 m/sec	7.7 kg
Vickers Mk.I	7.7 x 56R	850 rpm	745 m/sec	13.0 kg
LMG.08/15 Spandau	7.92 x 57	450 rpm		5.9 kg
MG 14 Parabellum	7.92 x 57	700 rpm	890 m/sec	4.3 kg
Becker	20 x 70RB	325 rpm		30 kg
Schwarzlose 07/16	8 x 56R	570 rpm	625 m/sec	
Browning .30	7.62 x 63	490 rpm		7.2 kg
Madsen Mdl 1902	7.62 x 54	425 rpm		4.1 kg
Fiat Revelli 1914	6.5 x 52	450 rpm		7.7 kg
Marlin 1917	7.7 x 63	640 rpm		4.5 kg

The Vickers was the standard Allied machinegun in fixed installations, typically two guns directly in front of the pilot. It was recoil-operated, but aircraft versions used the muzzle blast to speed up the mechanism. It was belt-fed, initially by a fabric belt, but this was changed to a disintegrating belt of metal links. The Vickers remained the standard armament of British biplane fighters until the late 1930s. The Mk.II version was characterized by a cooling jacket of smaller diameter, for installation within the fuselage. During WWI, an 11mm version was hastily developed, mainly for use against balloons and Zeppelins: It could carry a larger incendiary load. The 11mm version was not very successful.

The gas-operated Lewis was designed in the USA. It was an improved version of the gun designed by McClean, and in June 1912 it became the first machinegun fired in the air. However, the US Army rejected it, because it had adopted the Benet-Mercie (a weapon that was unsuitable for aircraft use). The Lewis then entered production in Belgium and Britain. It was the standard flexible gun of the Allies. Occasionally it was found in fixed installations, especially on pusher aircraft such as the DH.2 and FE.8, and on top of the wing of the Nieuport 11 and the SE.5a, but it was not suitable for synchronisation. It was fed with 47-round (Mk.I) or 97-round (Mk.II and Mk.III) drums. Even the fixed installation retained a pistol grip with a conventional trigger. In later aircraft designs the pilot had a Bowden cable to pull this trigger, but the pilot of a Nieuport 11 had to reach up to fire his gun.

The French Hotchkiss was a good gun, put it was fed by clips and too hard to reload in the air. It was quickly replaced by the Vickers and Lewis.

The LMG.08/15 was better known as the Spandau, after the place where it was manufactured. This German development of the Maxim machinegun was the standard fixed armament of their fighters. It was fed with a fabric belt.

The MG 14, also known as the Parabellum, was an improved, lightened version mostly used as flexible weapon. The name Parabellum was the codename of the DWM (Deutsche Munitions und

Waffenfabriken). Apparently the Parabellum was less reliable than the Lewis, for German aircraft readily used captured Lewis guns.

The Becker 20mm cannon was the precursor of the Oerlikon cannon. This weapon was installed on some German bombers, not on fighters.

Austrian fighters used the Schwarzlose, a machinegun with blowback operation. It was slow-firing and short-ranged. For this gun, ammunition with case lengths of 50mm or 52mm was also in use. In addition, it was often installed in a bulky fairing on the upper wing of biplanes, were the pilot could not reach it to clear a jam.

The Marlin was used by the USAAS and the USN from 1917 to 1921, a fairly short career. This gas-operated weapon was reliable and fast-firing, but was soon replaced by the Browning machinegun.

Gun Tables

The Columns

For every gun in the tables, the following parameters are given:

The **Name** of the gun. This should be an obvious fact, but alas there is a lot of misinformation around. Especially Japanese guns are very poorly documented, and as there were a great number of different guns in service in the Japanese Army and Navy, the potential for confusion is enormous.

The **type of round** as, for example, *13 x 64B*. The first number is the *caliber*, in millimeter. This represents some approximation of the diameter of the barrel and the projectile. It is not a very accurate parameter, because there are several different conventions to measure this, and to make things even worse, armed forces sometimes choose arbitrary numbers for administrative convenience. The second number is the *length of the cartridge case*, again in millimeter. The length of the case is used instead of the length of the projectile or of the overall length of the cartridge, because the first is characteristic for the gun, while the other two are dependent on the type of projectile used. To this case length one appends an indication for the shape of the base of the cartridge case, if required: **R** for Rimmed and **SR** for Semi-Rimmed cases, **RB** for reBated Rimless cartridges (some authors list these as RR), and **B** for Belted cartridge cases. Such variations in shape are usually linked to the operating principle of the gun.

The **weight of the projectile** in gram. Note that guns are usually able to fire several types of ammunition, and different types of ammunition were usually mixed. Hence an average is given, or in some cases a typical value. Because projectiles with different weights have different muzzle velocities, this implies that the value for the muzzle velocity is also an average.

The **rate of fire** in rounds per minute. Note that for synchronized guns, which fire through the propeller disc, the average rate of fire can be significantly lower.

The **muzzle velocity** in meter per second. For those more familiar with feet: A foot is 0.3048 meter. A high muzzle velocity gives a flatter trajectory, a shorter time of flight towards the target, and better armour penetration. The muzzle velocity is a characteristic of the gun, but also depends on the weight of the projectile and the type of propellant in the cartridge case, so again may vary depending on the ammunition type.

The **weight** of the gun, in kilogram. A pound is 0.4536 kilogram. The importance of weight for aircraft designers is obvious. For reference, it is good to keep in mind that the empty weight (without fuel, ammunition and pilot) of a single-engined, single-seat World War II fighter varied between 2000 kg and 5000 kg. Another consideration is that the guns were often in the wings, far from the center of gravity, and to achieve good manoeuvrability it is best to concentrate the mass around this center. The need for ammunition storage, structural reinforcement, and access panels of course added significantly to the installed weight. Larry Bell estimated the weight penalty for four .50 Browning M2 wing guns as about 1000 lb [26].

The **quality factor Q** is a standard that Russian designers have been using to evaluate and compare guns. Basically, it is a power-to-weight ratio: The kinetic energy at the muzzle (which is one half the projectile weight multiplied with the square of the muzzle velocity) multiplied by the rate of fire in rounds per second, and divided by the weight of the gun. Essentially, this says how much power a gun produces for a given weight, and is similar to the horsepower-per-weight figure for engines. This Q value is a measure of the efficiency of a gun, not of its firepower: A light gun with a modest ballistic performance will have a better Q value than a powerful, but too heavy gun. Evidently it contains no information about reliability, accuracy, range, ammunition performance, or manufacturing cost. Nevertheless it is a sensible way to compare guns.

The factor **M** is another quality factor: The mass output, divided by the weight of the gun. The mass output is the weight of the projectiles, multiplied by the rate of fire in rounds per second. This too is a measure of the efficiency of the gun, not of its power.

Rifle-caliber machineguns

Rifle-caliber machine guns (RCMGs) ranged from 7.5 mm to 8 mm. Such weapons were standard armament for fighters during the First World War. Even then it was observed that they were somewhat deficient in destructive power, and too easily countered by installing armor. Yet they were still in use in the early years of WWII. Compared to the guns of WWI the RCMGs were substantially improved: They were more reliable and had a higher rate of fire. Nevertheless most of the rifle-caliber guns were withdrawn from service by the second half of the war, because they were ineffective against the new generation of combat aircraft, that carried armour plate and self-sealing fuel tanks. The Browning .303 gun survived in the gun turrets of British bombers, but only because an alternative was not readily available.

Name	Cartridge	Proj. Weight (gram)	Rate of Fire (rpm)	Muzzle velocity (m/s)	Gun Weight (kg)	Q (kW/kg)	M (1/s)
United States							
Browning .30 M2	7.62 x 63	10.5	1200	870	10.4	7.6	20.2
United Kingdom							
Browning .303	7.7 x 56R	10.6	1150	750	10	5.7	20.3
France							
Darne	7.5 x 54	9.2	1100-1200	830	7.8	7.8	22.6
MAC 1934	7.5 x 54	9.2	1200-1500	830	8.5	8.4	24.4
Germany							
MG 17	7.92 x 57	10.8	1200	775	12.6	5.1	17.1

MG 81	7.92 x 57	10.8	1600	745	6.3	12.7	45.7
Italy							
Breda-SAFAT	7.7 x 56R	10.6	800-900	730	12.5	3.2	12.0
Japanese Army							
Type 89 Flexible	7.7 x 58SR	10.5	1500	810	28	3.1	9.4
Te-4	7.7 x 58SR	10.5	750	810	9.1	4.7	14.4
Type 89 Fixed	7.7 x 58SR	10.5	900	810	12.7	4.1	12.4
Type 98 Flexible	7.92 x 57	10.8	1000	775	7.2	7.5	25.0
Te-1	7.7 x 58SR	10.5	900	810	11.8	4.4	13.3
Type 100 / Type 1	7.92 x 57	10.8	2200	775	16.7	7.1	23.7
Japanese Navy							
Type 92 Flexible	7.7 x 56R	10.6	600	750	8.5	3.5	12.5
Type 97 Fixed	7.7 x 56R	10.6	900	750	11.8	3.8	13.5
Type 1 Flexible	7.92 x 57	10.8	1000	775	6.8	7.9	26.5
USSR							
ShKAS	7.62 x 54R	10.9	1800	870	10.6	11.7	30.8

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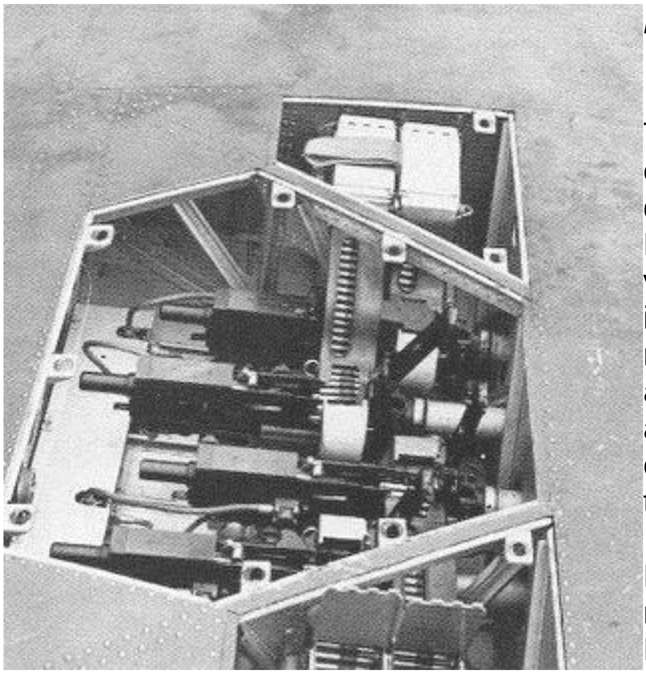


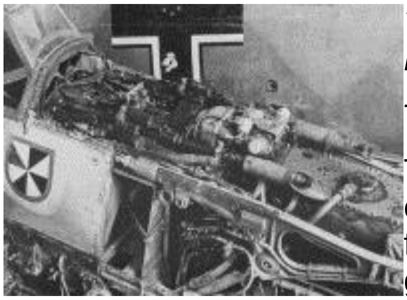
Browning .303 machineguns in the wing of a Hurricane. The leading edge is to the right. [4]

The best known gun in this list is the Browning. The origins of this recoil-operated weapon go back to a gun designed in 1917 for use by the infantry. (The earlier Model 1895 Browning was gas-operated.) The M2 version was developed in the early 1920s for installation in aircraft, and had a higher rate of fire than the older models. The British version fired rimmed .303 ammunition instead of rimless .30 ammunition, and was also modified to fire from an open bolt instead of a closed bolt, because the British used cordite propellant that was sensitive to heat.

Eight .303 Browning guns were installed in the first monoplane fighters of the RAF, the Spitfire and the Hurricane, although concerns about the effectiveness of rifle-calibre machineguns had already been voiced during WWI. A major advantage of the Browning over the older Vickers guns was its reliability. The pilot could not reach guns installed in the wings to clear stoppages, so reliability was essential.

FN also produced versions of the Browning in several different calibres, and speed the gun up to a nominal 1500 rpm (1400 rpm for a new gun, 1700 rpm for a gun that had been run-in). This FN-Browning was also used by the French air force in their 7.5x54 calibre, mostly for imported aircraft.

The gas-operated French 7.5 mm Darne was used in both fixed and movable installations. It was not a very reliable gun, and before war broke out the air force had retired the weapon. It was still in service in naval aircraft. The air force instead switched to the MAC 1934, which was also a 7.5 mm weapon. The initial version was drum-fed, using large 300-round drums, but in 1939 a belt-fed model was introduced.



Twin MG 17 guns were installed under the engine cowling of Messerschmitt Bf 109s, until they were replaced by the MG 131 in the Bf 109G-5. This is a Bf 109E-4. [24]

The German MG 17 was derived from the Swiss Solothurn design. It was often in synchronized installations, on the engine cowlings of German fighters, and this reduced rate of fire to 1000 rpm. The standard flexible gun, the MG 15, was very similar. In 1939 the Luftwaffe introduced the superior Mauser MG 81, a development of the MG 34 of the Army. The MG 81 was much lighter than the MG 17 and had a high rate of fire. But because the Luftwaffe recognized that the 7.92 mm calibre was obsolete as fighter armament, the MG 81 was used almost exclusively in defensive installations on two-seat fighters and bombers. There the MG 81 was usually found in the twin-gun MG 81Z installation. It was the best performer of the RCMGs, slightly superior even to the Soviet ShKAS.

The Italian Breda-SAFAT 7.7 mm gun was fairly important in the early years of World War II, and earlier in the Spanish civil war. It was used in combination with the 12.7 mm version, in an attempt to boost the feeble firepower of the underpowered Italian fighters without inflicting a too large weight penalty on them.

No country had so many different guns in use as Japan, with so many different types of ammunition. The Japanese Army and Navy independently produced nearly identical weapons, and with non-interchangeable ammunition; this is symbolic for the lack of cooperation between the two services.

The Army used copies of the Vickers as the Type 89 fixed and the Te-1, which was a flexible version of this gun. The 7.7 mm Type 89 flexible was an indigeneous magazine-fed design used in flexible, defensive installations, twin guns being placed on a single mount. If these guns were used individually, they were known as the Te-4 or Type 89 (modified single). The Type 100 or Type 1 were Japanese versions of a Czech design, also used in twins, and firing 7.92 x 57 ammunition. Finally, the German MG 15 was used the Type 98 flexible.

The Japanese Navy used the Type 92, a copy of the Lewis and again used in flexible installations, the Type 97, an improved Vickers, and the Type 1, also based on the MG 15.

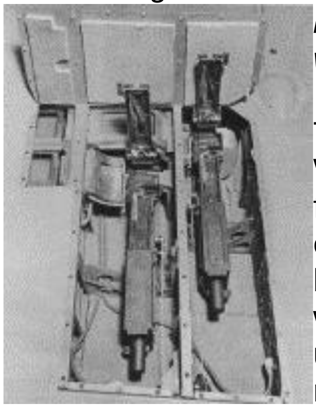
The Russian ShKAS had a high rate of fire and a high muzzle velocity, and was the best of the RCMGs found in fixed installations. The powerful ammunition carried special marks, to prevent its accidental use in rifles. There was also an upgraded model, the Ultra ShKAS, which had an extremely high rate of fire for its time: 2700 rpm. Some of these guns were installed on I-16s and used in combat during the Winter War with Finland, but it was insufficiently reliable to be put into series production. Russian fighters were also quick to adopt medium-calibre machineguns and cannon, making further development of the rifle-calibre weapons superfluous.

Medium-calibre Machineguns

Traditionally one distinguishes *rifle-calibre* and *medium-calibre* machineguns. The latter are often called *heavy machineguns* (HMGs), but this can lead to confusion because that term is also applied to some rifle-calibre machineguns. Medium-calibre weapons are .50 and similar, in practice ranging from 11 mm to 15 mm. The bullet is up to four times heavier than that of a rifle-calibre machinegun, and can be fired at a high muzzle velocity. Hence it usually has good ballistic characteristics. The rate of fire is usually much lower than that of rifle-calibre weapons.

As the war progressed, aircraft were modified with more effective armour and better self-sealing tanks. The US Navy, for example, considered its aircraft well protected against .50 fire, and even 20 mm rounds.[68] German and British fighters were designed to be protected against .50 fire from the front, and 20 mm fire from the rear. However, the .50 remained a reasonably effective weapon against fighters and the lighter bombers, if enough guns were installed; usually six in American-built fighters. Only during the war in Korea the .50 was clearly proved to be deficient in destructive power.

Name	**Cartridge**	**Proj. Weight**	**Rate of Fire**	**Muzzle velocity**	**Gun Weight**	**Q**	**M**
		(gram)	(rpm)	(m/s)	(kg)	(kW/kg)	(1/s)
United States							
Browning .50 M2	12.7 x 99	43.3	750-850	880	29	7.7	19.9
Japanese Army							
Ho-103 (Type 1)	12.7 x 81SR	34.2	800-900	765	23	6.2	21.1
Japanese Navy							
13 mm Type 2	13 x 64B	36.2	900	730	17	8.5	31.9
13 mm Type 3	13.2 x 99	49.5	800	795	31	6.7	21.3
Germany							
MG 131	13 x 64B	36.2	900	730	17	8.5	31.9
MG 151	15 x 96	64.5	700	905	42	7.3	17.9
Italy							
Breda-SAFAT	12.7 x 81SR	34.2	700	765	29	4.0	13.8
Scotti	12.7 x 81SR	34.2	700	765	23	5.1	17.3
USSR							
UBK	12.7 x 108	52.0	1050	860	25	13.5	36.4
UBS	12.7 x 108	52.0	800	860	25	10.3	27.7



Most US fighters of the war carried Browning .50 M2 guns. Usually six were installed. These are the inboard guns in the left wing of a Grumman F4F-4 Wildcat. Two more guns were further outboard.[25]

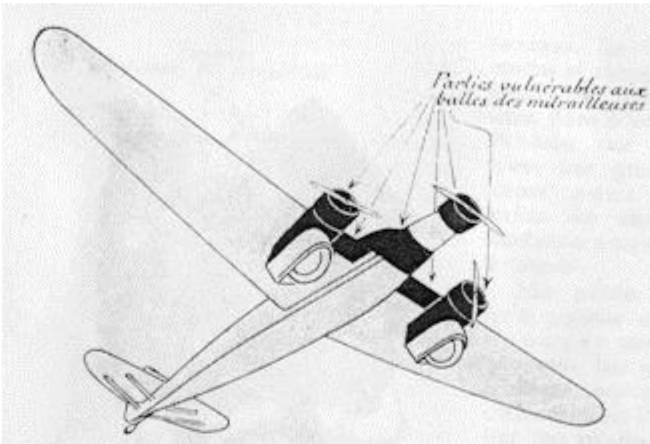
The Browning M2 was the standard armament of US fighter aircraft during WWII. Its development began at the end of WWI, primarily as a weapon for fighters, because it was understood that rifle-calibre machineguns did not have enough destructive power and range. (Similar attempts were made in Britain, but the British .50 guns did not enter widespread service.) The Browning .50 was first adopted in the early 1920s as the M1921, but did not reach maturity until the M2 model was introduced in 1932. By the standards of WWII it was rather heavy and its rate of fire was unremarkable, but muzzle velocity was high and the ballistic characteristics very good. The gun was also easy to manufacture and extremely reliable, although the barrels wore out quickly especially if long bursts were fired. In slightly different versions it was used by all US military services, and it was easy to exchange spare parts or switch factory output from one service to another.[67] The Browning .50 still was the standard armament of USAF fighters during the Korean war, but then in the upgraded M3 model, introduced in the last months of WWII. The rate of fire of the M3 was increased to 1200 rpm.

The Japanese Army Ho-103 was a copy of the Browning .50. The copy was lighter and had a higher rate of fire, but it also fired a smaller round, with a cartridge case 81 mm long instead of the 99 mm of the Browning. The Japanese Navy also copied the Browning, to create the Type 3, but in typical style it chose to use different ammunition! The 13.2 mm calibre was the same as used by Hotchkiss anti-aircraft guns, although the 99 mm cartridge case was almost identical to that of the Browning. The Navy also used the Type 2, which was a copy of the German MG 131, retaining the dimensions of its 13 x 64B ammunition, but with percussion firing instead of electrical ignition.

The German MG 131 with its light 13 mm ammunition was developed for synchronized installations, typically in the engine cowling of German fighters. It had electrical firing to simplify the synchronisation. The MG 131 was a light weapon, but this was achieved by combining a modest muzzle velocity and a light projectile. Despite its limitations, it was used in German fighters until the end of the war, because it was not possible to install the MG 151 in the engine cowling of small fighters such as the Bf 109 or Fw 190; only the Do 335 and Ta 152C had the MG 151 as cowl gun. The MG 151 was a much heavier, much more powerful weapon, and it replaced the 20 mm MG-FF as centreline armament on the Bf 109F. During the war a copy of the MG 151 was designed in the USA, modified to fire a very powerful .60 (15.2 x 114, 76.5 g) round. But this T17 gun never reached service, and only about 350 were made.

The Italian Breda-SAFAT was the main weapon of Italian fighters in the early years of the war, and most (CR.42, G.50, Re.2000, and C.200) carried only two. Unfortunately for them, it was not a very good gun. It fired a Vickers 12.7 x 81SR cartridge, the same as adopted by the Japanese Army for the Ho-103, but the Japanese gun was lighter and fired faster. The Breda-SAFAT was reliable and accurate, however, and its ammunition was considered very effective. A Scotti gun in the same calibre was also produced. It was considered superior, and was mostly used in flexible installations.

Again, the Soviet Berezin UB was probably the best gun, with a ballistic performance similar to that of the Browning gun, but a considerably higher rate of fire. The UBK was the version for installations in aircraft wings. The synchronized UBS for cowling gun installations had a lower rate of fire, though a still creditable 800 rpm. This was significant, for most Soviet fighters had their guns on the engine cowling.



The 20mm cannon

The advantage of cannon firing high-explosive rounds, as illustrated in a pre-war French source. Only the black parts of the bomber are vulnerable to machineguns: Crew, engines, fuel tanks. Cannon hits anywhere may cause sufficient damage to down the aircraft. [36]

Cannon are now usually defined as weapons with a calibre of 20 mm or larger, but historically operators have used several other definitions.

It is usually considered that 20 mm is the smallest practical calibre in which explosive projectiles can be used. Smaller ones have been made, and the Japanese even made HEI ammunition for rifle-calibre machineguns. But usually light and heavy machineguns were loaded with a mixture of incendiary and armour-piercing rounds. Such ammunition also existed for 20 mm cannon, so the projectile was not necessarily high-explosive.

Fusing was always critical for high-explosive rounds. A too sensitive or too fast fuse would make the projectile ineffective, as it would explode when hitting the outer plating of the aircraft. A too slow fuse could also have disadvantages, as the projectile could pass through the aircraft before exploding. It took some time to develop suitable fuses. Early British 20 mm rounds were ineffective because they exploded too fast, and for some time solid AP rounds were the most used ammunition for the Hispano cannon.

Name	Cartridge	Proj. Weight	Rate of Fire	Muzzle velocity	Gun Weight	Q	M
		(gram)	(rpm)	(m/s)	(kg)	(kW/kg)	(1/s)
Switzerland							
Oerlikon FF F	20 x 72RB	128	520	600	24	8.3	46.2
Oerlikon FF L	20 x 101RB	128	500	750	30	10.0	35.6
Oerlikon FF S	20 x 110RB	122	470	830	39	8.4	24.5
Germany							
MG c/30L	20 x 138B	134	300-350	950	64	5.1	11.3
MG-FF	20 x 80RB	134	530	600	28	7.6	42.3
MG-FF/M	20 x 80RB	104	530	640	28	6.7	32.8
MG 151/20	20 x 82	105	700-750	725	42	7.9	30.2
USSR							
ShVAK	20 x 99R	95	800	750 - 770	42	8.7	30.2
B-20	20 x 99R	95	800	750 - 770	25	14.6	50.7

France							
HS.9	20 x 110RB	122	360-420	830	48	5.7	16.5
HS.404	20 x 110	130	700	880	60	9.8	25.3
United Kingdom							
Hispano Mk.II	20 x 110	130	600	880	50	10.1	26.0
Hispano Mk.V	20 x 110	130	750	840	42	13.7	38.7
Japanese Army							
Type 94 Flexible	20 x 99RB	127	380	675	43	4.3	18.7
Ho-1	20 x 125	144	400	805	45	6.9	21.3
Ho-3	20 x 125	144	400	805	45	6.9	34.6
Ho-5 (Type 2)	20 x 94	96	750-850	715	37	8.8	43.0
Japanese Navy							
Type 99-1	20 x 72RB	129	520	525	26	5.9	43.0
Type 99-2	20 x 101RB	128	490	750	34	8.6	30.7

Information about Germans guns on the Luftwaffe Resource Page.
S.V.Vladimirov, co-designer of the ShVAK.
M.E.Berezin, designer of the UB and B-20.
VYa-23 page in the Russian Aviation Museum.
Russian Aviation Gunnery Page.

The Swiss Oerlikon guns provided the inspiration for many 20mm guns. The original Oerlikon aircraft cannon was designated FF for *flügelfest*, wing-mounted. Later the gun was adopted for three types of ammunition, and the original version became the FF F, while the other two were called FF S and FF L. The FF F was copied as the Japanese Type 99-1, while the Type 99-2 was a license-built copy of the FF L. The French Hispano-Suiza HS.7 and HS.9 were based on the FF S. The German MG FF was based on the FF F, but the weapon was entirely redesigned.

The Luftwaffe at first experimented with the MG c/30L, a weapon derived from a Flak gun. It was very powerful, and in principle it could be used to engage the enemy from a safe distance. But it was also heavy and slow-firing. (A lighter version, the Lb 204, which fired different ammunition (20 x 105B or 20 x 105, 134 g) at 400 rpm, later appeared as defensive armament on Do 18E and Bv 138 flying boats.)

Instead the Germans adopted the Ikaria MG-FF, a weapon that was much lighter and had a modestly higher rate of fire, but also had a low muzzle velocity. It was a reengineered version of the Oerlikon FF F cannon. The MG-FF was usually fed from a 60-round drum. The MG-FF/M version was modified to fire the new 92 g projectile, often called *Minengeschoss*. This was a thin-walled HE projectile, with more high explosive than the older, conventional 134 g HE projectile, and therefore greater destructive power against "soft" targets. The main disadvantage of the MG-FF was that it was a short-range weapon, and its ballistic characteristics were very different from those of the 7.92 mm machineguns installed on the same fighters (mainly the Bf 109E).

Left, the MG 151/20 20 mm aircraft cannon, here installed post-war in a French Piasecki H-21 helicopter. The four cylinders around the base of the barrel are recoil absorbers, and belong to the gun mount, not to the gun. [53]

From the end of 1940 onwards the MG-FF was replaced by the excellent Mauser MG 151/20 cannon, derived from the 15 mm MG 151. The changes were limited to a change in projectile and barrel. The overall length of the cartridge remained the same, and because the 20 mm version fired a heavier projectile with less propellant, it had a lower muzzle velocity than the 15 mm gun. Some weight was saved by reducing the length of the barrel. In the table these changes produce a slight increase in Q and a large increase in M.

The MG151/20 was an excellent weapon against fighters, but the Bf 109F carried only one. Later fighters began carrying more of these guns, but against sturdy bombers such as the B-17 even the MG 151/20 was insufficient. This weapon was also used by the Italians, and some were shipped to Japan by submarine.

The USSR had an excellent cannon in the ShVAK, a compact, fast-firing and powerful weapon. The ShVAK was basically an enlarged ShKAS, and it also existed in a (very rare) 12.7 mm version. The ShVAK was fitted to the I-16 Typ 12 (also known as the I-16P), which was first flown in the summer of 1936 and entered service in 1937. A relatively small number of these aircraft, which were the first cannon-armed fighters in service, were completed. Larger number were produced of the Typ 17, which was powered by the more powerful M-25V engines. The ShVAK remained standard armament on Soviet fighters throughout the war, but in 1945 its replacement by the equally performant, much lighter B-20 began. The B-20 was one of the best aircraft guns of the war.

Left, the Bristol Beaufighter carried four 20 mm Hispano cannon in ventral compartiments. In early models, the gun was fed by 60-round drums. When these were empty, the second crewmember had to replace them by full ones... The installation of belt-fed guns was a much welcomed improvement. [15]

For French fighters such as the Dewoitine D.501 and Morane-Saulnier MS.405, Hispano-Suiza had manufactured a licence-built version of the Oerlikon cannon, as the HS.7 and HS.9. Engine designer Mark Birkigt decided to develop a new 20 mm cannon, the HS.404, with a higher performance. The HS.404 had a different action, a higher rate of fire, and a much higher muzzle velocity. The British were impressed, and by 1939 the Hispano was in production in Britain. Originally it was fed from a 60-round drum, but in the autumn of 1941 a satisfactory belt-feed mechanism was produced. The Hispano was slim, but long (2.36 m long, compared to 1.76 m for the ShVAK) and heavy. Rate of fire of the Mk.II version was lower than that of other 20 mm cannon, but the muzzle velocity was high. Initially, solid AP ammunition was preferred, but later in the war a mixture of HE/I and SAP/I was introduced. The Mk.V was a lighter and faster-firing version, without in-flight cocking mechanism and with a shorter barrel. (See note 5.) .

As the Hispano M1 or M2, this weapon was used on a limited scale by the USAAF and slightly more by the USN. In American service, there were frequent complaints about the unreliability of the guns and feed mechanisms. Some of the changes that had been made in British guns to improve reliability were not included in the US guns, which were made directly from French drawings. It also appears that parts were made with excessive tolerances. The USAAF used the Hispano in the P-61 nightfighter and in the P-38 day fighter. The USN installed it in some attack aircraft, such as the Curtiss SB2C dive-bomber, and a small number of F4U fighters. Only after WWII did the USN adopt the 20 mm cannon, then in the improved M3 version, as its standard weapons for fighters.

Again, the Japanese Army and Navy used different weapons. The Army showed an early interest in the use of 20 mm guns in defensive installations, and the Type 94 was installed as a flexible gun in the Ki-20 bomber. It was a derivative of the Oerlikon L, not of the FF-series of aircraft guns developed by Oerlikon, and was already obsolete. Later developments of the Type 97 anti-tank gun were put in service as the Ho-1 and the Ho-3, the Ho-1 for flexible installations and the Ho-3 for fixed installations. These guns were slow-firing and fairly heavy. Some Army fighters were equipped with the German MG 151/20. In August 1943 a submarine had brought 800 of these cannon from Germany, and they were installed in Ki-61s. Finally, the Army adopted the Ho-5, a derivative of the Browning .50 that probably was the best Japanese fighter gun of the war. The Ho-5 was lighter, had a high rate of fire, and it was belt-fed instead of drum-fed. But near the end of the war the Japanese had a shortage of high-strength alloys, and to compensate for the reduced strength of the guns the Army reduced the pressures. Hence the muzzle velocity of the Ho-5 dropped from 820 m/s to 700 - 730 m/s.

The Navy cannon were the Type 99-1 and Type 99-2, copies of the FF F and FF L respectively. Formally (though not in practice), they were adopted in the same year, the Japanese calendar year 2599, or 1939. Both the Type 99-1 and Type 99-2 were produced in different models, and the later models of both guns were belt-fed. Earlier models usually had 60-round ammunition drums. The Type 99-1 was light, but had a poor rate of fire and a low muzzle velocity. It was carried by early models of the Mitsubishi A6M "Zero", but experience with it was disappointing. Therefore the more powerful Type 99-2 replaced it in later models of the A6M and in the new fighters the Navy introduced near the end of the war. Because it had a bigger cartridge case and a longer barrel, the muzzle velocity of the Type 99-2 was considerably higher; but the rate of fire was lower. The final Japanese development of this weapon was the Type 99-2 model 5, which was speeded up to 620 rpm. This was a very respectable performance for an Oerlikon-derived gun, but it arrived too late and saw no service.

Heavier Cannon

Big cannon were designed for two different roles: Bomber interception and ground attack. The ground attack guns were given a high muzzle velocity for better armour penetration, in combination with an armour-piercing projectile, often with a core of tungsten or another dense metal. Bomber killer guns could have a lower muzzle velocity, to achieve a weight reduction, and they usually fired projectiles with a large amount of high explosive. Generally these weapons were not intended to be used against fighters: The 20 mm weapons were sufficient to destroy fighters, but bombers were much tougher targets. Sometimes high-velocity guns were used to attack bombers from a large distance, outside the range of the defensive armament of the bombers. Therefore this list includes some weapons that were designed for ground attack.

At this point it may be useful to draw attention to the range of Q and M values. For rifle-calibre machine guns, medium-calibre machine guns, and cannon, the average Q is 6.4, 7.8 and 8.3, respectively. For M these values are 20.2, 23.9, and 30.5. Apparently increasing the calibre results in some efficiency benefits: A single 20 mm cannon will be more efficient than its equivalent firepower in multiple rifle-calibre machine guns. However, this variation is still small compared to the quality differences between different guns in the same calibre, so these factors remain reasonably fair values to compare the performance of guns in different calibres. Among these large-calibre cannon we will now find some quite good performers, with a high Q and a high M. Indeed, in terms of mass output vs. weight the 30 mm MK 108 is the most efficient cannon of all. We also find some abysmally bad performers, however, such as the BK 5. These weapons were not designed for aircraft applications, so their designers attached less importance to weight reduction. For their designed purpose, as tank, anti-air or anti-tank weapons, such cannon might still have been excellent; but they were unsuitable for aircraft.

Name	**Cartridge**	**Proj. Weight**	**Rate of Fire**	**Muzzle velocity**	**Gun Weight**	**Q**	**M**
		(gram)	(rpm)	(m/s)	(kg)	(kW/kg)	(1/s)
United States							
37 mm M4	37 x 145R	680	140	580	96	2.8	16.5
37 mm M10	37 x 145R	680	160	580	109	2.8	16.6
37 mm M9	37 x 223SR	744	140	860	181	3.5	9.6
Germany							
MK 101	30 x 184B	330	230	920	180	3.0	7.0
MK 103	30 x 184B	330	360-420	860	141	5.6	15.2
MK 108	30 x 90RB	330	600-650	505	60	7.3	57.3
BK 3,7	37 x 263B	660	160	810	295	2.0	6.0
MK 214 A	50 x 419R	1540	160	920	490	3.5	8.4
BK 5	50 x 419R	1540	50	920	540	1.0	2.4
MK 112	55 x 175RB	1045	300	595	274	3.4	19.1
USSR							
VYa	23 x 152B	200	550	880	69	10.3	26.6
NS-23	23 x 115	200	550	690	37	11.8	49.5
NS-37	37 x 195	748	250	890	170	7.3	18.3
NS-45	45 x 182	1065	250	850	170	9.4	26.1
Japanese Army							
Ho-155-I	30 x 114	253	400	650	50	7.1	33.7
Ho-155-II	30 x 114	253	500	650	44	10.1	47.9
37 mm Type 94	37 x 134R	644	manual	580	122	--	--
Ho-203	37 x 112R	475	120	570	89	1.7	10.7
Ho-204 (Type 4)	37 x 144	475	300-400	710	130	5.4	21.3
Ho-301	40 caseless	585	450	245	132	1.0	33.2
Ho-401	57 x 121R	1500	80	495	150	1.6	13.3
Type 88	75 x 497R	6490	manual	720	480	--	--

Japanese Navy							
30 mm Type 2	30 x 92RB	264	400	710	51	8.7	34.5
30 mm Type 5	30 x 122	345	500	760	70	11.9	41.1

Information about Germans guns on the Luftwaffe Resource Page.
The USAF museum has a BK 5.
The USAF museum has an M10 on display with the V-1710 engine.
Russian Aviation Gunnery Page.
VYa-23 page in the Russian Aviation Museum.

The Bell XFM-1 Airacuda had remote-controlled 37mm M4 cannon, (right) mounted with a coaxial .30 Browning M2 (left). [26]

The Browning M4 was installed in US fighters such as the P-39 Airacobra and early versions of the P-38 Lightning. (See Note 1.) This was a slow-firing cannon, with a low muzzle velocity and a limited ammunition capacity, but for its calibre it was light. It was intended to destroy bombers from a distance, but its performance was not sufficient for the task. Nevertheless, Lend-Leased P-39s and P-63s with the M4 gun proved effective medium-altitude fighters on the Eastern Front. A later development, the M10, had the feed mechanism modified for a disintegrating belt, a change that allowed ammunition to be increased from 30 to 58 rounds, and was combined with a higher cyclic rate. This weapon was installed in later models of the P-63 Kingcobra.

A single P-63D was armed with an M9 cannon, a very different weapon, far more powerful but also far heavier. Its 37x223SR cartridge gave the same HE round as the M4 a considerably higher muzzle velocity. One of the types of ammunition available was a 752 g armour-piercing projectile with a muzzle velocity of 930 m/s, and at a distance of 460 m this penetrated 60 mm of armour plate. At the same distance the M4 could penetrate only 20 mm of armour. It is obvious that the M9 was much better suited for ground attack, but apparently it was too heavy for fighters. It was also experimentally used on a number of attack aircraft, but its only service use was at sea.

The Germans initially developed the MK 101 with the intention of attacking bombers from a safe distance. But its weight and low rate of fire excluded this use; instead it was installed in ground attack aircraft, for example the Hs 129. It was very useful against (lightly) armoured ground targets, firing an AP round with a tungsten core at 960 m/sec. The MK 103 was lighter than the MK 101, had electric firing instead of percussion firing, and fired faster. It was an excellent, powerful weapon, but again a fighter without considerable loss of performance could not carry it. Only at the very end of the war did some fighters carry the MK 103 gun. Installations in the wings tended to be inaccurate, because the enormous recoil twisted the wing; centerline installations as engine cannon were designed for the Ta 152C, Do 335 and Bf 109K, but evidence that this was turned into hardware exists only for the Do 335 and the prototypes of the Ta 152C. The fighter designs that were on German drawing boards in 1945 sometimes made provision for the MK 103, but the favorite weapon was the MK 108.

Below, the MK 108 30mm aircraft cannon. [11]

The MK 108 was put into service because the fight against Allied heavy bombers required a 30 mm cannon that was compact and light enough to be installed in single-engined fighters. The MK 108 used the APIB operating principle of the Oerlikon guns. It was less than half the weight and bulk of the MK 103, and much cheaper to produce, but it also had a much lower ballistic performance. Fighters could carry two or even four MK 108s. This gun had a heavy punch, but because it was a short-range weapon fighter pilots had to get close to their targets, normally opening fire at 300 m. Its use required strong nerves and better training than German pilots received during these last phases of the war. Some effort was made to increase the rate of fire, and a 850 rpm version was apparently perfected, although too late to be adopted.

The BK 3,7 was used successfully against tanks, most notably by the Ju 87G, firing a 405 g *Hartkernmunition* with a tungsten core at 1140 m/s. It was also tried in the air as a weapon against heavy bombers, in Bf 110s. Presumably the conventional APHE (680 g) and HE (640 g) munition was used. It was not successful in this role.

The search for a gun that would destroy a heavy bomber with a single hit produced a series of 55 mm cannon, because these rounds would hold the 450 g of high explosive that was considered to be necessary. As for the 30 mm weapons, the Germans considered both heavy long-range guns, and light guns with a more modest ballistic performance. The advantage of the long-range weapon was that it could be fired at bomber formations from beyond the range of their defensive armament: A return to the concept behind the MK 101 and MG c/30L. As a quick solution, the BK 5 was considered, based on the PAK 38 anti-tank gun. It was light and a good performer by the standards of 50 mm anti-tank cannon, but by the standards of fighter guns it was extremely heavy and slow-firing. It was fed from a closed-loop 22-round belt, and fired 1.54 kg projectiles. It was installed in some Me 410 fighters, but when Allied escort fighters appeared in the German skies these overburned twin-engined aircraft became easy prey. Another interim weapon was the MK 214A, installed only in a single Me 262. Its rate of fire, 160 rpm, was much better than that of the BK 5. Developed from the KwK39/1 tank gun, it still weighed 490 kg. A proposed 55 mm version, the MK 214B, was even heavier.

The light 55 mm cannon was a more realistic weapon. It took the form of the MK 112, in effect a scaled up MK 108. The MK 112 weighed only 274 kg and had a relatively high rate of fire. Because of the lower muzzle velocity, the effective range was much shorter. The MK 112 never went beyond the prototype stage, despite continuation of development post-war in the USA. For such heavy projectiles, rockets proved to be a superior weapon, and the big cannon never entered service.

Russian weapons such as the NS-37 were intended both for air-air combat and for use against ground targets. Usually only a single cannon of this type was carried, typically between the cylinder banks of the Klimov engines of the Yakovlev fighters.

The first gun in service, in 1940, was the powerful VYa, with a 152 mm long cartridge case. It was installed mainly in Il-2 ground attack aircraft, but also in some fighters. In 1942 the NS-37 appeared; this gun could penetrate 40 mm of armour at an angle of up to 40 degrees. The Yak-9T with the NS-37 was quite successful, and 2748 of these fighters were built. Because of the recoil of the gun it was advised to fire thee-round bursts, but a single hit could destroy an aircraft. The Yak-9K carried the large NS-45, an even more powerful weapon which required a large muzzle brake to keep the recoil within acceptable limits. Few Yak-9Ks were built, apparently because the gun was not entirely reliable and a failure could have disastrous consequences. Even larger cannon were tried, but the recoil of the NS-57 was too much for fighter.

From 1945 onwards, the NS-23 was introduced, a version of the NS-37 scaled down to 23 mm. It replaced the much heavier VYa in fighters, but because of the less powerful cartridge was the muzzle velocity was considerably lower. The NS-23 was a more typical fighter weapon, less suitable for ground support missions. It would stay around for a long time.

Late in the war, the Japanese Army had a good 30mm cannon in the Ho-155, sometimes erroneously referred to as Ho-105 or even Ho-151. It was a scaled-up derivative of the Ho-5, itself a derivative of the Browning. Late in the war, the Ho-155 appeared on bomber destroyer versions of some of the best Japanese Army fighters, such as the Ki-61 and Ki-84, but it seems to have seen little combat use. The gun compares favourably with the German MK 108. At the end of the war a lighter, shorter version was developed, the Ho-155-II, but this version never saw combat. It was a far cry from the early days of the war, when most Japanese Army fighters were armed with two rifle-calibre machineguns!

The Japanese Army installed even bigger cannon in twin-engined fighters, developments of the Ki-45 Toryu, but these were unimpressive weapons. A first attempt was made to install the Type 94, a hand-loaded 37 mm weapon originally used in tanks. The achievable rate of fire was about 15 rpm. The automatic Ho-203, with a 15-round closed-loop belt, was a much-needed improvement. Apparently it was designed for single-shot firing, hence its low rate of fire. References to the use of the Ho-203 on single-engined fighters, such as the Ki-44, can not be correct, because of the enormous bulk of this gun. They could refer to the Ho-204, another enlargement of the Browning, that appeared in 1944. It was adopted in some experimental twin-engined fighters, and saw service as an upward-firing gun in the Ki.46-III-KAI.

The 57 mm Ho-401 was an enlarged Ho-203, with a similar 15-round closed-loop belt and low rate of fire. It was used mainly for anti-armour and anti-shipping attacks, but occasionally it was used against B-29 bombers as well, because the Japanese did not have any better defense against the B-29. A desperate measure was the installation of the 75 mm Type 88 anti-aircraft gun in a Ki-67 bomber, to create the Ki-109 "fighter". It seems obvious that this was a bad idea, especially as the gun itself was rather mediocre, and without the planned but never available turbosuperchargers the Ki-109 could not even get close to the B-29s. Nevertheless the Japanese did not abandon 75 mm cannon, and development of the Ho-501, a 75 mm version of the Ho-203, seems to have been completed at the end of the war.

The Ho-301 was one of the most unusual cannon used during the war. It fired caseless rounds, which had the propellant charge in the back of the projectile. It had an effective range of only 150 m, but because there was no need to extract the case and eject it, the rate of fire was fairly high for a gun in this calibre. It was also light.

The Japanese Navy also showed interest in 30 mm cannon. The Type 2 was a scaled-up Oerlikon gun, sometimes erroneously described as a copy of the MK 108. It never became a standard service weapon, although it was tested on a number of aircraft and formally adopted. A better alternative was available, the Type 5, an entirely original design. Though fairly heavy, this was a powerful weapon with a good performance. If the war had laster longer, it would have become the standard weapon, fitted in fighters such as the Kyushu J7W Shiden. But it saw service in only a few aircraft, being wing-mounted in the Mitsubishi J2M5 and installed in upward-firing installations on some nightfighters, such as the P1Y2-S.

Ammunition

Ammunition Types

Left, one more unusual type of ammunition was this T-44 .30 frangible round. The projectiles were made from a mixture of lead and bakelite, and trainee gunners fired them at specially armored Bell RP-63 Kingcobras. Despite the RP-63's armor, muzzle velocity had to be kept down to 415m/sec, and the recoil-operated Browning .30 M2 guns needed some gas assistance to function. Gunsights and aircraft speeds were chosen to give trainees the correct "feeling" of the .50 that was the standard USAAF armament of the time. [27]

The following types of ammunition are common for anti-aircraft use:

AP. Armour-piercing rounds may be simple, solid projectiles. More often they have a sleeve of soft, light metal wrapped around a hard core, for example hardened steel or tungsten. The hard core is the penetrator. The sleeve is kept light to reduce the total weight of the round, so that the projectile is given a higher velocity. Its softness reduces the probability that the projectile will glance off armour. And in small-calibre weapons, it also grips the rifling of the barrel. Post-WWII developments such as discarding-sabot AP ammunition (APDS) are not commonly used against aircraft, but may be carried for use against ground targets.

HE. High Explosive rounds were traditionally made by boring out the core of a solid projectile, then filling it with explosive. The German Minengeschoß rounds introduced a different manufacturing technique: A thin shell was drawn, in the same way as a cartridge case is drawn. This resulted in a much larger explosive capacity for the same calibre, and became widespread after the war. It is commonly assumed that HE ammunition is really effective only in calibres of 20mm or larger, but it was also made for 12.7mm and even rifle-calibre weapons.

I. Incendiary rounds were first developed in small calibres during WWI. The bullet was filled with incendiary rather than explosive material. Early on, the material was often phosphorus, ignited by the actual firing of the round. Later fused projectiles, which ignited only when hitting the target, also appeared. Pure incendiary ammunition was often replaced by high-explosive ammunition with an incendiary compound mixed in, HE/I.

SAP/I or SAP/HE. Semi-Armour Piercing rounds are similar to the traditional designs for HE and I rounds, but the hollow outer shell is stronger and made of hardened material, so that some armour-penetrating capacity is retained. Optimists may call such ammunition AP/I or AP/HE. Modern fillings can combine both effects, so that SAPHEI ammunition is created.

Tracer rounds have some material in the base of the projectile, which burns during flight and indicates the trajectory. For use at night "glowing" ammunition, which gives a fainter light, was developed. The disadvantage, especially in rifle-calibre ammunition, is that the tracer rounds have a different trajectory from the rest. In addition, the high visibility of tracer alerts the target, but it may also have a deterrent effect.

Self-destruct systems can be simple chemical systems, which take a preset time to burn, or intricate mechanical fuses. They are designed to avoid "collateral" damage, and may also be used for training.

Ammunition had to be fed into a gun, and it had to be stored in the aircraft. The two main alternatives are the drum and the belt (clips are hardly an option for aircraft guns). The drum is the simplest solution: It contains loose rounds, which are often fed into the gun by means of a circular spring. However, drums often have inconvenient shapes for installation in aircraft, they are bulky, and they contain a fixed, often small number of rounds. A much better solution was to link the rounds together to a belt, that could be stored in a box or tray with a convenient shape. Often the belt is of disintegrating type: After removal of the rounds, it falls apart in links which can be stored or dumped overboard. The belt can be made as long as the feeding mechanism can pull. However, the design of a belt feed mechanism is more complicated than that of a drum, and suitable feed mechanisms took a long time to perfect. Therefore most cannon had drums at the time of their first application, but at the end of the war almost everyone had switched to belts.

Ammunition Belt Composition for German Fighters

These are the belt compositions for fighters, used against air targets, as given given in a German manual, published in in 1944. (Ref. 204.) Note that these were more or less advisory: Local commanders were encouraged to determine the armament mix that suited them.

7.92 mm (MG 17)

- 5 SmK-v
- 4 PmK-v
- 1 B-Patrone-v

SmK ammunition was AP with a hard steel core and a lead sleeve. The probable explanation of the acronym is *Spitzgeschoss mit Kern*, pointed ball with core. *PmK* also had a steel core, but the core was surrounded by phosphorus, which ignited when the round was fired. Finally *B-Geschoß* was a *Beobachtungs* or observation round: It had a small HE charge and some incendiary material, and exploded on contact with the target. In this way the pilot was able to verify that he was hitting the target. During the Battle of Britain, the British used the *Dixon-De Wilde* round for similar purposes, and pilots generally felt that this was extremely useful.

13 mm (MG 131)

- 1 Panzergranatpatrone L'spur o. Zerl
- 2 Brandsprenggranatpatronen L'spur o. Zerl

The 13mm *Panzergranatpatrone* was a solid AP round. The *Brandsprenggranatpatrone* was a conventional HE/I round, a bored-out projectile filled with an explosive mixture. German armourers were warned that the first round fired had to be an AP round: The cap over the muzzle had to be destroyed first, and there was the possibility that the HE/I round would go off when it hit this. Note that for both rounds, tracer was chosen (L'spur, or *Leuchtspur*) but that there was no selfdestruction (o. Zerl, or *ohne Zerlegerung*).

15 mm (MG 151)

- 4 Brandsprenggranatpatronen L'spur m. Zerl
- 1 Panzergranatpatrone L'spur o. Zerl

Rather similar to the 13mm, except that the HE/I rounds now do have self-destruction mechanisms. It was common to use a combined self-destruction fuse and tracer: The projectile exploded when the tracer was burnt out. On some projectiles, special self-destruction fuses were used. They were set to 3 seconds, except before April 1941 when they were set to 1.7 seconds.

The MG 151 was a high-velocity weapon, and for ground attack missions *Hartkernmunition*, AP with a tungsten core, was loaded.

20 mm (MG-FF, MG 151/20)

- 2 Minengeschoß m. Zerl.
- 2 Brandsprenggranatpatronen L'spur m. Zerl
  oder Brandgranatpatronen
- 1 Panzersprenggranatpatrone o. Zerl
  oder Panzerbrandgranatpatrone (Phospor) o. Zerl.

Here the *Minengeschoß* appears for the first time. A version of the 20mm M-Geschoß with tracer did not exist, so tracer was used on HE/I (*Brandsprenggranatpatrone*) or pure incendiary (*Brandgranatpatrone*) rounds. The latter was apparently a new development in 1944, intended to replace the less effective HE/I. The fifth round was a semi-AP projectile, explosive or incendiary. Apparently the main reason this was used instead of a solid AP round was that a solid projectile would have been too heavy.

It was recommended that more AP or semi-AP ammunition would be loaded when the probable targets were well-armoured attack aircraft such as the Il-2. On the other hand, against the four-engined bombers of the RAF and USAAF the high explosive types were more effective.

30 mm low-velocity (MK 108)

- Minengeschoß 108 El o. Zerl.

Only the *Minengeschoß* was fired by the MK 108, also in versions with day or night tracer. The ammunition was not interchangeable with that of the much more powerful MK 101 and MK 103, hence the addition 108. The letters El probably indicate the presence of *Elektron*, an incendiary compound, in the projectiles. Surprisingly, self-destruction fuses were not used, although German fighters were operating over the home country at this time in the war. Probably it was felt that this reduced the effective range too much.

30 mm high-velocity (MK 101, MK 103)

- 1 Sprenggranatpatrone L'Spur o. Zerl
- 1 Minengeschoß L'Spur o. Zerl
- 1 Panzersprenggranatpatrone L'Spur o. Zerl
  oder Panzerbrandsprenggranatpatrone L'Spur o. Zerl

The MK 103 was a high-velocity weapon with a much better armour penetration than the MK 108. Hence the addition of the older type of HE round and semi-AP ammunition to the mix. The exception were the nightfighters, which used only the *Minengeschoß* with a glowing trace (*Gl'spur*).

For anti-tank missions, Hartkernmunition with tungsten cores was used, but it would be wasteful to use this scarce ammunition against aircraft.

Ammunition Belt Composition for Bombers

For bomber defensive guns of 7.92mm and 13mm calibre, the following combinations were recommended:

7.92 mm (MG 15, MG 17, MG 81)

- 2 SmK
- 2 SmK L'spur
  oder SmK Gl'spur
- 2 PmK
- 2 SmK
- 2 SmK L'spur
  oder SmK Gl'spur
- 1 PmK
- 1 B-Geschoß

The main difference with the ammunitions mix for fighters is in the use of tracer, avoided for fighters except to mark the end of the belt. On the other hand, only one in twelve rounds is the *B-Geschoß*.

13 mm (MG 131)

- 1 Panzergranatpatrone L'spur o. Zerl
- 1 Brandsprenggranatpatrone o. Zerl
- 1 Sprenggranatpatrone L'Spur Üb m. Zerl

This load is a mixture of AP and HE/I with training ammunition (*Übung*) with self-destruct fuses! This was used in the MG 131 because it detonated after about 700m, and the flashes had a deterrent effect on attacking fighters. The relatively generous use of tracer and phosphorus ammunition in the MG 17 probably had a similar background.

The Fighters

The Fighters

We can now have a look at the armament of some WWII fighters. For convenience, I sorted them by hitting power, in terms of **fired weight** per second. There is also a chart of the evolution of fired weight per second, which requires Java, or a plot in static gif format.

Fired weight per second is at best a rough approximation of destructive power. It is a reasonable approximation if the destruction is to be caused by the high-explosive or incendiary chemicals contained in the ammunition. The amount of explosive or incendiary material is of course related to the weight of the projectile, but it is not a linear relationship: Rounds of smaller calibre have proportionally thicker walls, and a smaller fraction of their weight is available for chemical loads. Therefore the fired weight per second is usually more relevant for larger calibre guns.

As a second measure of the destructive power, the **muzzle power** is given, in kilowatt. This is the rate of production of kinetic energy. AP or "ball" rounds that contain no chemical load only have this kinetic energy to cause damage to the target. More is not always better; a round with a too high kinetic energy might pass clean through the target without doing more damage than two neat, round holes. The optimal velocity to do maximal damage a metal plate is just below that required to penetrate it. Of course projectiles lose a lot of the muzzle energy before they hit the target, because of drag. In general larger calibre projectiles retain their kinetic energy longer.

A disadvantage of AP rounds is that they cause damage in a more limited area than incendiary or explosive rounds. Therefore semi-armour-piercing explosive or incendiary rounds were used more often. These require kinetic energy to penetrate the armour, and have chemical energy to cause destruction afterwards.

A third number given is the **number of projectiles** fired. If the target is not armoured, the same weight of non-explosive projectiles does more damage when distributed over numerous small projectiles than in a single large one, and the number of projectiles is the most important. But if the target carries armour the smaller projectiles are more likely to be stopped, and that reduces the effectiveness, especially of the rifle-calibre weapons. On the other hand, a larger number of projectiles means that the probability of a single hit increases.

To summarize: Fired weight per second is given as an approximation of the *chemical energy* that can be transferred to the target, muzzle power as a measure of the *kinetic energy*, and the number of rounds fired indicates the *spreading* of this transfer over a number of hits. All three are factors that must be considered in a consideration of the firepower installed in an aircraft. A "firepower formula" that would allow us to actually calculate a single number as a measure of the firepower, would be a nice thing to have. However, too many factors are involved, and the effectiveness of ammunition depends very much on the nature of the target.

Occasionally, firepower effectiveness was measured experimentally. The Germans famously determined that a large sturdy bomber such as a B-17 or B-29 could be shot down with 20 hits of 20mm ammunition, three hits with 30mm HE ammunition, or one single 55mm hit.

Fiat C.R.42 Falco

The CR.42 is a good candidate for the best biplane fighter ever built. But it was a contemporary of the first generation of monoplane fighters, and completely outclassed. [21]

- Two 12.7mm Breda-SAFAT guns, with 400 rounds per gun. Ammunition for 34 seconds.
- They fired 23 rounds per second, corresponding to 0.86 kg. Total muzzle power was 248 kW.
- This pathetic armament was very much the standard for the Italian fighters of 1940. Some fighters had two 7.7mm guns added, and that raised their firepower to 1.13 kg/sec. But because they were underpowered they could not carry much more. The Italians finally had to adopt German engines and German guns for their fighters.

Nakajima Ki.43 Hayabusa

A captured Ki.43 in Chinese markings. The superficial similarity to the A6M is obvious, and caused considerable confusion. The Ki.43 was extremely agile, but by the standards of 1942 it was slow, undergunned and woefully vulnerable. Nevertheless the type stayed in production until the end of the war! [60]

- Two 12.7mm Ho-103 guns with 250 rounds per gun, enough ammunition for 17 seconds.
- 30 rounds per second, or 1.14 kg/sec. Total muzzle power was 362 kW.
- The production of the Ki.43 actually began with two Type 89 7.7mm guns. This was clearly insufficient, and when production of the Ho-103 allowed, it first replaced one and then both of the smaller weapons. The Ki.43 was still under-gunned, and remained so until the end of the war.
  Aircraft of the World

Supermarine Spitfire Mk.IA

A Spitfire Mk.I with a three-bladed de Havilland airscrew. The gun ports in the wing have been patched over with fabric, a standard practice at the time to protect the guns from frost. [19]

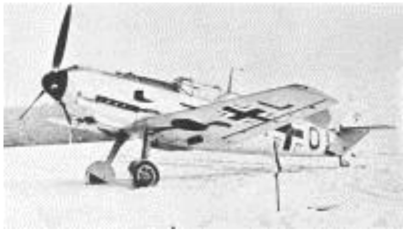
- Eight Browning .303 guns installed in the wings. 300 rounds per gun, enough for 16 seconds of fire.
- 152 rounds per second, or 1.72 kg/sec output. Total muzzle power 480 kW.
- The RAF was quick to understand that heavy firepower was needed, but its initial choice was an unfortunate one. The .303 was chosen over the .50 because of its higher rate of fire and better reliability, but the .303 round lacked the power to penetrate armour, and was far too light to do structural damage. Pilots preferred to use incendiary rounds, also because they could see them hit the target. Although some pilots had their guns "synchronized" to converge at a point, it was more common to have some spreading, to simplify aiming.
  Supermarine Spitfire
  Supermarine Spitfire
  Supermarine Spitfire

Yakovlev Yak-3

Yakovlev Yak-3. This was a highly specialized low-altitude interceptor, with brilliant performance and handling at low levels. [57]

- One ShVAK cannon mounted between the cylinder banks of the engine, with 120 rounds. One Berezin UBS in the forward fuselage decking, with 250 rounds. That was enough for 9 and 19 seconds, respectively.
- Both guns fired 13 rounds per second, but the ShVAK cannon put out 1.28 kg and the machinegun 0.64 kg: A total of 1.92 kg/sec. Muzzle power was 473 kW for the ShVAK and 230 kW for the UBS, a total of 703 kW.
- The Yakovlev fighters had a high performance at low and medium altitude, but their small size and limited engine power restricted their armament. The Lavochkin fighters, although also small, had more engine power and could carry heavier armament. To some extent these disadvantages were compensated by the excellence of the Soviet guns, but their effectiveness was reduced by the primitive gunsights.
  Russian Aviation Museum

Messerschmitt Bf 109E-3



Left, a Bf 109E-3. [14]

Right, armament installation of a Bf 109F-1, with its engine removed. The breech of the MG 151 gun was in the cockpit, between the feet of the pilot. The cowl guns are MG 17s. [14]

- Two MG-FF cannon in the wings, with 60 rounds each; two MG 17 machineguns in the engine cowling, with 1000 rounds per gun. The cannon ammunition was enough for 7 seconds, the machineguns had ammunition for 55 seconds.
- Output per second was seventeen 20mm shells and 37 7.92mm bullets. The cannon were responsible for firing a weight of 2 kg/sec. The contribution of the MG 17s was 0.37 kg/sec. The muzzle power of the MG-FF guns was 418 kW, and that of the MG 17 guns 114 kW; a total of 532 kW.
- The two MG 17 machineguns were too light to be very effective. The MG-FF cannon fired effective, but low-velocity ammunition, with a short range. Ballistic characteristics of the MG-FF and MG 17 were too different. The Bf 109E probably was a better bomber interceptor than the British fighters, but its role in the battle of Britain was that of an escort fighter.

[Messerschmitt Bf 109]
[Messerschmitt Bf 109]

Mitsubishi A6M2 model 21 Reisen 'Zeke'

Mitsubishi A6M2 taking off during the Battle of Santa Cruz. The A6M2 had good performance for a carrier-based fighter and a long range, but it was a poor basis for development. [59]

- Two 7.7mm Type 97 machineguns in the front fuselage, with 500 rounds per gun. Two 20mm Type 99-1 cannon in the wing, with 60 rounds per gun. The cannon had ammunition for 7 seconds, the machineguns for 30 seconds.
- The cannon fired 17 shells per second, or 2.24kg. The machineguns fired 33 rounds in the same time, or 0.38kg. The total was 2.62kg/sec. Muzzle power 308 kW for the cannon, and 106 kW for the machineguns; a total of 414 kW.
- To install cannon in a fighter was an advanced concept, and here the Japanese Navy had a lead on some other services, notably the Japanese Army: The A6M had more than twice the firepower of the contemporary Army fighter, the Ki.43. But the Type 99-1 was too slow-firing, had a too low muzzle velocity, and its ballistic characteristics did not match that of the machineguns. There is a remarkable similarity with the Bf 109E.
  [Aircraft of the World]
  [Aviation History Group]

Mitsubishi A6M5b model 52B Reisen 'Zeke'

Later developments of the A6M remained inferior to their opponents. This is an A6M5c, armed with two Type 99-2 20mm cannon (inboard) and two 13.2mm Type 3 machineguns (outboard) in the wings, and a third Type 3 gun in the engine cowling. [58]

- In the front fuselage one 7.7mm Type 97 with 500 rounds, and one 13.2mm Type 3. Wing cannon two 20mm Type 99-2 with 125 rounds per gun. The cannon had ammunition for 15 seconds, the light machinegun for 30 seconds.
- The cannon 16 fired shells per second, or 2.11kg. The 13.2mm machinegun fired 13 rounds in the same time, a weight of 0.69kg. The light machinegun contributed 17 rounds, or 0.19kg. The total is 2.80 kg/sec. Muzzle power was 53 kW for the light machinegun, 216 kW for the medium-calibre machinegun, and 412 kW for the two cannon. Note that in comparison with the

A6M2, the weight per second fired by the cannon is down, but the muzzle power has increased a lot.

- Upgrading the armament of the A6M gave later models a modestly greater killing power. Much of this was because of the Type 99-2 cannon, still slow-firing but with much better ballistic characteristics, and in its final models equipped with a belt-feed that increased the ammunition supply. This improvement came too late for the A6M, which was already obsolete. The last IJN fighters of the war, such as the N1K2-J Shiden-KAI, had four Type 99-2 cannon.
  Aircraft of the World
  Aviation History Group

North American P-51D Mustang

Compared with previous Mustangs, the P-51D had two more .50 guns, and the armament installation had been redesigned to make it more reliable. [20]

- Six Browning .50 machine guns. The two inboard guns had 400 rounds each, enough for 32 seconds. The four outboard guns had 270 rounds, enough for 22 seconds.
- Output per second was 75 rounds, or a weight of 3.64kg per second. Muzzle power was 1374 kW.
- Six .50 guns was the armament of most US fighters. Most pilots liked the .50 gun, but it lacked the power to do structural damage to enemy aircraft. Postwar research demonstrated that only armour-piercing incendiary rounds were really effective, by setting fire to ammunition or fuel. This armament was sufficient for the Mustang, because it was an escort fighter, that had to fight mostly against enemy fighters. The guns were usually set to converge at 300 yards, and 2 degrees above the normal flight attitude. The ammunition supply was relatively large, and that was also beneficial for an escort fighter. Last but not least, the Browning was very reliable and had good ballistics.
  Effects of the P-51 Mustang
  American Militaryary Aircraft Encyclopedia
  Aviation History Group
  Gun Diagram at Zeno's Warbirds

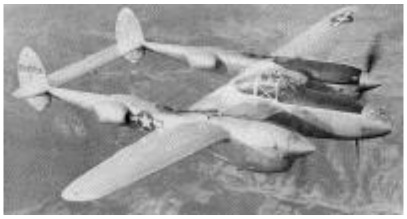
Yakovlev Yak-9T

Yakovlev Yak-9T. The Yakovlev family of fighters were small aircraft, very manoeuverable and with good performance below 5000m, where most combat at the Eastern front occurred. [56]

- One NS-37 cannon mounted between the cylinder banks of the engine, with 32 rounds. One Berezin UBS in the forward fuselage decking, with 220 rounds. That was enough for 8 and 17 seconds, respectively.
- The NS-37 put put out 3.06kg per second, and the machinegun 0.64kg: A total of 3.7kg/sec. Muzzle power of the NS-37 was 1240 kW, the machinegun contributed another 230 kW.
- Compare this with the Yak-3. The powerful 37mm cannon of the Yak-9T had a relatively low rate of fire, but a single hit would destroy an aircraft. The Soviets calculated that on average 31 rounds were fired to down an aircraft, compared with 147 rounds for the 20mm cannon. Normal firing ranges were 100m to 400m against fighters, and 500m to 600m against bombers, but the maximum effective range was about 1200m. On the downside, the recoil was so large that pilots were trained to fire three-round bursts.

  Russian Aviation Museum

Lockheed P-38 Lightning



The P-38 was the most successful twin-engined fighter of the war. Some early models had one 37mm cannon, two .50s and two .30s, but production soon standardised on one 20mm cannon and four .50s. [32]

- One 20mm Hispano A/N-M2 cannon with 150 rounds, and four .50 Browning M2 machineguns with 500 rounds each. The cannon had ammunition for 15 seconds of fire, the machineguns for 40 seconds.
- The cannon fired 10 rounds per second, an output of 1.3kg/sec. The machineguns contributed 50 rounds, or 2.43kg/sec. The total is 3.73kg. The muzzle power was 503 kW for the cannon and and 918 kW for the machineguns.
- Because of its twin-engined configuration, the P-38 carried all its armament in the nose, and no synchronisation or harmonisation were necessary. Later models of the P-38 were the best twin-engined fighters of the war, the equals in combat of any single-engined fighter. Whether this justified the additional cost and size of the P-38 is another debate. A comparison with the P-51 shows that the 20mm Hispano was the equivalent in weight of fire and muzzle power of two .50 Brownings; its more deadly ammunition was another advantage. (The US Navy estimated that the 20mm cannon was the equivalent of three .50s, reducing to 2.5 at long range.) On the other hand the ammunition supply of the cannon was limited.

  Planes & Pilots of WWII

  Gun Diagram at Zeno's Warbirds

  American Military Aircraft Encyclopedia

Supermarine Spitfire Mk.XIVE

A late-production Spitfire FR Mk.XIVE. Note the modified nose contours for the Griffon engine, five-bladed propeller, bubble cockpit and camera port in the aft fuselage. [18]

- Two Hispano cannon in the wing, with 120 rounds each. Two Browning .50 guns, with 250 rounds each. The cannon ammunition lasted for 12 seconds; the machinegun ammunition for 20 seconds.
- The two cannon fired 20 rounds per second, the two machineguns 25. Total output was 3.81kg per second. Muzzle power was 1006 kW for the two cannon, and 458 kW for the two machineguns. Total 1464 kW.
- Because the original armament of eight Brownings was too weak, later Spitfires had the "C" or "universal" wing which allowed the installation of eight .303 guns, two 20mm cannon and four .303 machineguns, or four 20mm cannon. But the late production Mk.IX and the Mk.XIV had the "E" wing, with the definitive wartime armament for the Spitfire: Two 20mm cannon and two .50 guns. The Spitfire was a small fighter, and its thin wing complicated armament installations. But the E-wing armament was very effective. An important factor was the use of gyroscopic gunsights by the Allies, because they greatly improved accuracy. The Germans developed similar gunsights, but they were never reliable enough to be useful.
  Supermarine Spitfire
  Supermarine Spitfire
  Aviation History Group

Kawasaki Ki.61-I-KAI-Hei Hien 'Tony'

The Nakajima Ki.61 Hien, or Army Type 3 Fighter, Allied codename Tony*, was at first believed to be a copy of a German or Italian design. In fact only its Ha-40 engine was a licensed version of the Daimler-Benz DB 601.* [17]

- Two 20mm Ho-5 guns with 120 rounds per gun, and two 12.7mm Ho-103 guns with 200 rounds. The machineguns had ammunition for 13 seconds and the cannon for 9 seconds.
- The cannon put out 28 rounds per second, or 2.81kg/sec. The machineguns contributed 30 rounds, or 1.14kg. Total 3.95 g/sec. Muzzle power was 944 kW for the cannon, and 362 kW for the machineguns; a total of 1306 kW.
- The Ki.61 was the first fighter of the Imperial Japanese Army that was the equal of or better than the Western designs it encountered. The best Japanese Army fighter of the war, the Ki.84, initially carried the same guns, although with more ammunition. Later versions of the

Ki.84 had four Ho-5 cannon, or even two Ho-5 and two Ho-155 cannon. This marked a switch by the Army from lightly-built, lightly-armed dogfighters such as the Ki.43, to sturdy, heavily armed all-round fighters.
Aircraft of the World
Mark's Japanese Aviation

Republic P-47D Thunderbolt

With eight .50s, the P-47 carried the heaviest armament of the US single-seat fighters. [31]

- Eight Browning .50 machine guns. Up to 400 rounds could be carried, enough for 32 seconds of fire, but the ammunition load was often reduced to compensate for the carriage of bombs or external fuel tanks.
- Output per second was 100 rounds, or a weight of 4.85kg per second. Muzzle power was 1835 kW.
- The Thunderbolt was designed around the R-2800 radial and its turbosupercharger. It was one of the largest fighters of its time, and also one of the most rugged. It carried eight .50 guns in the wings, with ammunition storage in the outer wing panels. The P-47 had a successful career as fighter-bomber after the P-51 replaced it as escort fighter.
American Military Aircraft Encyclopedia
Gun Diagram at Zeno's Warbirds

Focke-Wulf Ta 152H-1

Above, a Ta 152H-1. Note the slender long-span wings of this development of the Fw 190, and the Jumo 213 V-12 engine with annular radiator. [11]

- One MK 108 cannon firing through the propeller spinner, and two MG 151/20 cannon in the wing roots. The 30mm cannon had 90 rounds, the 20mm cannon had 175 rounds each. This was ammunition for respectively 9 and 14 seconds of fire.
- Per second, ten 30mm shells and 25 20mm shells were fired. This amounted to a weight of 5.96kg. The muzzle power of the MK 108 was a modest 398 kW, and the 20mm cannon contributed 720 kW. Total 1118 kW.
- This high-altitude interceptor was armed to fire a short, heavy burst at its target. The MK 108 cannon was a low-velocity weapon, designed to inflict fatal structural damage to the heavy

bombers of the 8th AF.
Aircraft of the World

Hawker Tempest Mk.V

Hawker Tempest Mk.V. This one is armed with Hispano Mk.V cannon. Early Tempests had Mk.II cannon, and the longer barrels extended in front of the wing leading edge. [63]

- Four Hispano Mk.V cannon, installed within the wing, with 200 rounds per gun. That was ammunition for 16 seconds.
- Per second 50 rounds were fired, with a total weight of 6.5 kg. Total muzzle energy was 2292 kW.
- This was the definitive armament option for British WWII fighters, although a number of designs and prototypes featured six Hispano cannon. It was also retained by the first generation of jet fighters, becoming a de facto standard in the first year after the war. The exceptions were the USAAF, that continued to rely on the .50, and the USSR, that prefered 23mm and 37mm cannon.

Messerschmitt Me 262A-1a

A Messerschmitt Me 262, photographed in April 1945 in Switzerland.[55] *Allied observers at first criticised the choice of four 30mm cannon, estimating that the rate of fire could scarcely exceed five per second.*[64] *But the MK 108 fired two times faster than that.*

- Four MK 108 cannon in the nose. Two had 80 rounds, two had 100 rounds, for respectively eight and ten seconds of fire.
- Forty 30mm shells per second, or 12.5kg per second. Muzzle power 1592 kW.
- The armament of the Me 262 was deadly against heavy bombers. The ammunition for the MK 108 cannon was of the "Minengeschoss" type, thin-walled high-explosive shells. Because of the low muzzle velocity of the MK 108, it was not very suitable for fighter-vs-fighter combat, but in principle the Me 262 could outrun any enemy. In practice the Me 262 were always heavily outnumbered by the escort fighters, and their success was quite limited.
  Stormbirds
  Me 262 Net

Comparison Table

Name	Rounds	Weight	Energy
	(1/sec)	(kg/sec)	(kW)
Fiat CR.42 Falco	23	0.86	248
Nakajima Ki.43 Hayabusa	30	1.14	362
Supermarine Spitfire Mk.IA	152	1.72	480
Yakovlev Yak-3	26	1.92	703
Messerschmitt Bf 109E-3	54	2.37	532
Mitsubishi A6M2 Reisen	50	2.62	414
Mitsubishi A6M5b Reisen	46	2.80	681
North American P-51D Mustang	75	3.64	1374
Yakovlev Yak-9T	17	3.70	1470
Lockheed P-38J Lightning	60	3.73	1421
Supermarine Spitfire Mk.XIVE	45	3.81	1464
Kawasaki Ki.61-I-KAI-Hei Hien	58	3.95	1306
Republic P-47 Thunderbolt	100	4.85	1835
Focke-Wulf Ta 152H-1	35	5.96	1118
Hawker Tempest Mk.V	50	6.50	2292
Messerschmitt Me 262A-1a	40	12.50	1592

A longer list of fighter armaments is reproduced elsewhere. It is clear from this table that muzzle energy and weight of fire are related, because a heavier weight of fire usually means a proportionally higher muzzle energy. This simply reflects the fact that the muzzle velocities of the guns used are typically around 825 m/sec, so that the kinetic energy per unit of projectile weight is approximately 340 kJ/kg.

The exceptions are the MG-FF, Type 99-1 and MK 108. These are all low-velocity weapons, and fighters equipped with these weapons have a lower total muzzle power, although the weight of fire might be quite high. The best example is of course the Me 262.

There is no obvious relationship of either weight of fire or muzzle power with the total number of rounds fired per second. This value also does not show any clear trend towards either an increase or a decrease, although there are a few exceptionally low or high values.

Analysis

Convergence

Although there was a wide variation in armament choice at the beginning of the war, it was followed by a convergence of the arsenals of the major air forces of World War II. By 1943 most air forces had a rifle-calibre, a medium-calibre and a 20mm cannon available. In Germany and Japan there was also a development of 30mm cannon with a modest muzzle velocity but very effective ammunition, suitable for bomber-destroyer applications. Of these the rifle-calibre weapon was becoming less important. There was an universal preference for belt-fed weapons, and their muzzle velocities and rates of fire were quite similar. This was an expression of the "state of the art" in aircraft armament. A comparison can be offered in terms of weight of fire, in kg/sec, of the weapons in these four categories:

	UK	**USA**	**USSR**	**Germany**	**Jap. Army**	**Jap. Navy**
rifle-calibre	0.21	0.19	0.36	0.18	0.16	0.19
medium calibre	0.61	0.61	0.84	0.52	0.57	0.69
20mm	1.30	1.30	1.28	1.28	1.40	1.05
30mm				3.12	2.35	2.62

This table shows that in each category, the major combattants had roughly equivalent guns, with the exception of the 30mm category which was not developed by the Allies. (Some 23mm and 37mm cannon were developed in the USSR.) There were of course exceptions; most notably the Japanese Navy did persevere in employing Oerlikon-derived 20mm cannon with a low rate of fire.

There were important variations in the way the available guns were used, however. The aircraft designers had to balance weight, hit probability, and destructive power. A sufficient hit probability could be achieved by installing a sufficient number of guns, so that the total number of projectiles fired was kept high. Most air forces seem to have been of the opinion that a fighter should have four or more guns. The maximum number of guns carried by a fighter was eight. Well-known is the debate in the German *Luftwaffe* about the armament of the Bf 109F, which carried a single MG 151 cannon and two MG 17 cowl guns. Galland was of the opinion that this armament gave a too low hit probability for pilots of average shooting ability.

For an installation of four to eight guns a balance had to be found between firepower and weight. The bigger guns were heavier and had a larger recoil, which required strengthening of the aircraft structure and imparted an additional weight penalty. During the war fighters became more powerful and were able to carry heavier weapons; at the same time the lightest category, rifle-calibre machineguns, was proven ineffective and gradually replaced.

Evolution

Generally speaking (with all dangers that are included in generalisations) one can distinguish three phases in the development of World War II fighter armament. (See note 4.)

Some WWII fighters were armed with was essentially World War I armament: Two machineguns in the front fuselage. Such armament was carried by Italian and Japanese Army fighters; as a concession to modernity heavy machineguns were substituted for the rifle-calibre weapons. This could be considered a "zeroeth" phase in WWII fighter armament development.

Phase I

In the first phase the rifle-calibre machinegun was still important. Fighters either carried a homogenous armament of such guns, or they used a mixture of rifle-calibre guns with cannon or medium-calibre machineguns. Examples of the first approach are the eight Browning .303s in the Spitfire and the four MG 17s in the early Fw 190. Examples of the second approach are the MG FF and MG 17 weapons of the Bf 109E, the two .50 and four .303 Brownings of the early P-51, or the two 20mm cannon and two 7.7mm guns in the A6M2. This first phase ended when it was understood that the rifle-calibre machinegun was ineffective against modern combat aircraft.

Light machineguns would put a lot of holes in the skin of an aircraft, but they could not cause it to break up. Therefore one aimed for the vulnerable, critical parts of the aircraft: The pilot, the fuel tanks, and the engines. However, armour and self-sealing fuel tanks were an effective defense. Many fighters entered the war without these items, but by 1941 a fighter without them was no longer considered suitable for combat.

Phase II

In the second phase there were still two options. Either a homogenous armament of medium machineguns was used, or a mixture of modern 20mm cannon with machineguns. The first approach was chosen by the USAAF, which equipped most of its fighters with six or eight .50 Browning guns. Examples are the P-40 Warhawk, P-47 Thunderbolt, and P-51 Mustang. The US Navy adopted the same armament. The second approach was more common, and used by fighters such the Spitfire, the Bf 109, or the Ki.84 Hayate. The cannon were now in general belt-fed, high-velocity weapons with a satisfactory rate of fire. The disadvantage of cannon was that their weight and recoil precluded the use of more than one or two. Hence they had to be mixed with machineguns, with different ballistic characteristics, different ammunition and different maintenance requirements.

The disadvantage of an armament of medium-calibre machineguns only was that it lacked the destructive power to be effective against anything but fighters or lightly constructed bombers. Armour that protected reasonably well against .50 projectiles was fitted to fighters, and self-sealing fuel tanks were designed to survive hits in this calibre.

Phase III

A switch to a homogeneous armament of 20mm cannon characterized the third phase, which lasted well beyond WWII. Examples of such armament are the last Spitfire models, the Typhoon and Tempest, the Soviet La-7, and the Japanese N1K-2J. Usually four 20mm cannon were carried. This was also the standard armament for most post-war fighters, except those of the USAAF.

Again, there was a second option: That of heavy "bomber killer" armament. Here the German MK 108 cannon must be mentioned, as installed in the Me 262, and the Japanese Ho-155. This option was mainly chosen by Axis powers, because they were confronted with large numbers of heavy bombers. But these weapons, calibre 30mm or larger, were either low-velocity weapons, or they were extremely heavy. In both cases they reduced the suitability of the fighter for combat against other fighters. Because of this and the introduction of spin-stabilized and folding-fin rockets (and still later, effective guided missiles), such armament was installed in few post-war fighters, but one that must be mentioned is the MiG-15.

The characteristic of this phase is that the goal no longer was to destroy an aircraft by hitting the crew of vulnerable parts of its equipment. Especially the larger cannon were intended to destroy the structure of the aircraft itself: A 30mm hit could cut a fighter in two, and put a large hole in a heavy bomber.

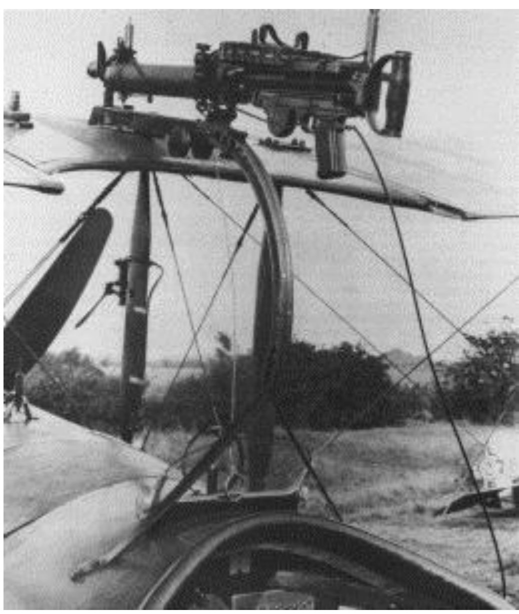
If you have a Java-capable browser, you can have a look at this chart of the evolution of fired weight per second and muzzle power. If not, try the simpler version.

Upward firing guns

A word-by-word translation of the German term Schräge Musik, would be *slanted music*, but it actually means *jazz*. It is more known, however, as the name for an arrangement of upward-firing guns, installed in German nightfighters and used with great effect against British night bombers. There was some irony in the choice of this name, because jazz was officially forbidden in Nazi Germany, rejected as a "degenerate" art.

The First World War

There was nothing new about upward-firing guns. They first appeared during WWI, because the dominant type of aircraft, for all roles except that of fighter and long-range bomber, was a two-seat biplane with a tractor engine. In its more developed form the observer-gunner sat behind the pilot, armed with a flexible Lewis or Parabellum machinegun. He could defend the aircraft against attacks from the upper hemisphere, but was powerless against attacks from the rear and below. This could be exploited by interceptors, but an attack from below either required a climbing attack, which could not be maintained for long, or some form of upward-firing armament.



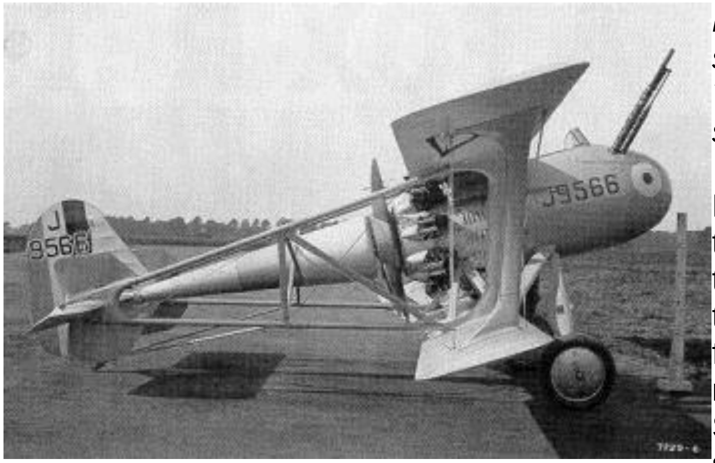
Left, a Lewis gun on a Foster mount. The aircraft is an SE.5a. Note the two posts for a ring-and-bead gunsight on top of the gun, used to fire it upwards. [4]

Before the introduction of gun synchronisation mechanisms some single-seat biplanes had been equipped with a fixed machinegun, usually a Lewis, on the center section of the upper wing, so that it could shoot over the propellor. The best known of these fighters was the *Nieuport 11 Bébé*. To allow the pilot to change ammunition drums, the Foster mount was developed: A curved rail, that made it possible to slide the gun backwards and downwards. In the latter position, the gun pointed upwards, and could be used for attacks from below. This was its only real advantage. Disadvantages were many: It caused drag, changing the ammunition drums was very difficult, and its recoil disturbed the aim. Nevertheless, the success that pilots such as Albert Ball had with the Foster mount explains its presence on the later *Royal Aircraft Factory SE.5a*, at a time when most fighter aircraft had two synchronized guns.

Some German pilots experimented with Foster mounts that had been captured. At the time, it was not unusual for pilots to order considerable modifications to their aircraft. But this seems to have had no influence on later German practice.

The Lewis guns on the upper wing also appeared on the *Sopwith Dolphin* and, interestingly, on *Sopwith Camel* fighters modified for nightfighting. In the latter case, however, the main purpose was to improve the forward view of the pilot by removing the Vickers guns in front of him. After the end of WWI most fighters had twin synchronized guns, even nightfighters.

Interbellum Experiments



Left, the Vickers model 161 was built to specification F.29/27. It was an obvious dead end. The prototype flew little and reportedly fired only 24 shells. [62]

During the interbellum upward-firing guns were tried on a number of British aircraft. This was called the no-allowance method of gunsighting, because the idea was that the attacker would fly in close formation with the target, slightly below it, so that no allowance had to be made for relative speed. Specification F.29/27 called for a single-engined, single-seat fighter armed with a 1½lb COW gun, angled upwards. Development of this weapon, by the Coventry Ordance Works, had continued since before WWI. At 97kg, it was relatively light for a weapon of this size. It fired 37x190 ammunition at a rate of 1.5 per second, fed from five-round clips, and had already been used on a handful of aircraft during WWI. Unfortunately, the two F.29/27 fighters were both disappointing. The *Vickers F.29/27* was a pusher biplane, an obsolescent design with a bewildering array of struts and bracing wires. The *Westland F.29/27* was a low-wing monoplane and looked much better, but had completely unacceptable handling characteristics.

More promising were experiments with the standard .303 Vickers and Lewis guns. In 1927 the *Boulton-Paul Bittern* made its first flight, a nightfighter built to specification F.27/24. The second prototype of the Bittern had vertically swivelling Lewis guns machineguns on the side of its nose, so that they could be set at an angle between 0 and 45 degrees. A ring-and-bead gunsight was to be mounted on a frame, which could be set at the same angle. But the underpowered Bittern never entered service.

A simpler approach was represented by two *Bristol Bulldog* biplane fighters, that were modified in 1934 with Lewis or Vickers guns mounted at the side of the cockpit, at an angle of 60 degrees up. During tests, the installation demonstrated great accuracy: Flying 100ft below their targets, the fighters scored 90% hits. However, the armament of two rifle-calibre machineguns was too weak.

One interesting aircraft, flown just before the beginning of WWII, must also be mentioned. The prototype of the *Gloster F.9/37* twin-engined monoplane fighter was armed with five 20mm Hispano cannon, angled up 12 degrees. This angle was determined by practical considerations: Three of the guns were behind the cockpit, in the space originally allocated for a gun turret. They had to be angled up to clear the cockpit. It is not clear what attack mode was envisaged for this aircraft.

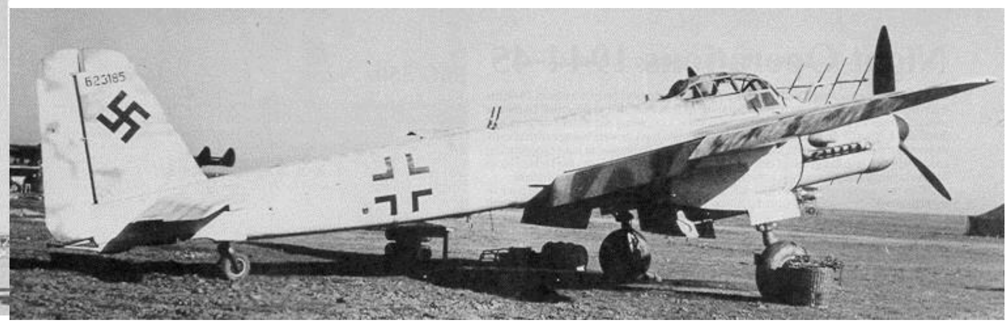
Schräge Musik

One of the first effective British nightfighters was the *Boulton-Paul Defiant*. The Defiant, armed with four .303 guns in a powered turret, had failed as a day fighter. Its natural approach as a nightfighter was to attack from below, because the guns in the turret could not fire straight forward. But the career of the Defiant as a nightfighter was fairly short, and apparently it made no impression on the

Germans. Effectiveness was certainly limited, because of the light firepower and the blinding muzzle flash.

Shortly before the war, the idea of upward-firing guns for nightfighters had reached the Luftwaffe from several sources. A *Leutnant* Tiede, who had used upward-firing guns in WWI, approached the *Reichsluftfahrtsministerium* with his design, but it was rejected. Reports of Japanese experiments conducted in 1938 and 1939 were received, but apparently these too failed to make an impression. After the outbreak of war, there were several incidents in which observer guns were aimed at the belly of British bombers, but usually these were only 7.92mm weapons.

Apparently the instigator of the adoption of Schräge Musik by the Luftwaffe was Oberleutnant Rudolf Schönert, who started advocating this in 1941. The first installation was made late in 1942, in a Do 17Z-10 that was also equipped with Lichtenstein radar. The results were inconclusive, and development was shelved for a year. Nevertheless it is reported that in the summer of 1942 Schönert, then commanding II/NJG 5, received three Do 217J nightfighters for operational testing of this form of armament. (Schönert had his first combat success with Schräge Musik in May 1943, and then not in a Do 217J but in a field-modified Bf 110.) Wide-scale adoption followed in late 1943, and in 1944 a third of all German nightfighters carried upward-firing guns.

Above and left. One of the most effective German nightfighters was the Ju 88. This is a Ju 88G-6 with liquid-cooled Jumo 213 engines, Lichtenstein SN *radar, and two* Schräge Musik *MG 151/20 cannon installed in the aft fuselage.* [28]

There was more to Schräge Musik than just fitting a few angled-up cannon, usually MG 151/20 or MK 108. These were put in the rear of the cockpit of the Bf 110, in the aft fuselage of the He 219, and behind the cockpit of the Ju 88 and Do 217. It was important to attack undetected, and therefore tracers were not used. Special ammunition with a faint glowing trail replaced them. The guns were given flash reducers. An additional gunsight was installed in the cockpit to aim the guns. The attack from below had the advantage that the nightfighter crew could observe and identify the silhouette of the aircraft before they attacked. At the same time the bomber crew could not see the nightfighter against the dark ground, nor defend itself: The belly turrets of British bombers had been removed because of their limited effectiveness and to reduce drag. The nightfighter usually aimed for the fuel tanks, not for the fuselage, because of the risk that exploding bombs would damage the attacker. Schräge Musik soon produced devastating results. It was at its most successful in the winter of 1943-1944. This was a time when losses became unacceptable: The RAF lost 78 of 823 the bombers that attacked Leipzig on 19 February, and 107 of the 795 bombers that attacked Berlin on 30 March.

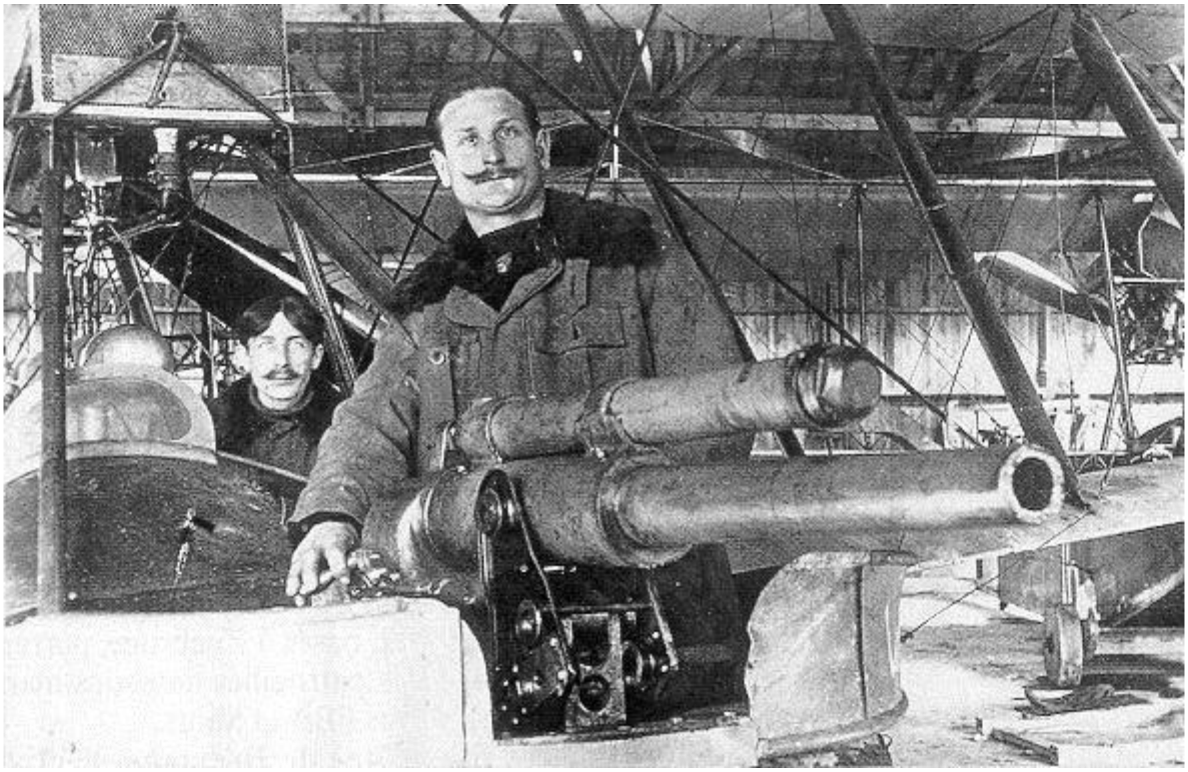
RAF Bomber command compensated for the German lateness to adopt this form of armament by reacting slowly to it. Reports of bomber crews gave no indication, because the German nightfighters managed to stalk their preys without being perceived. Only an analysis of the damage done to returning bombers demonstrated that the Germans were firing from below. This seems to have been understood fairly quick, for the problem was already reported in April 1943. However, it took considerable time to implement a satisfactory solution. Initially, a downward observation window was provided, and Canadian bombers again received belly turrets. But the effectiveness of these measures was small, because the attackers were very hard to see. Radar was a better solution, but the Monica tail-warning radar provided warning only if the attacker approached from astern, not from below. Anyway, in July 1944 the British discovered FuG 227 Flensburg in a captured German aircraft, a receiver that could be used to home in very accurately on the emissions of the Monica radar from a distance of 80km. The tail-warning radar then had to be deleted.

The H_2S navigation radar, that had replaced the belly turret on many bombers, did look downwards; but it did not provide any warning of enemy aircraft approaching from below. The H_2S display showed the radar image starting from the first ground return, so that a map could be drawn. Any echoes preceding this ground return were discarded -- The echoes of aircraft below the bomber. A modification of a H_2S radar proceeded as soon as the developers became aware of the problem, and to avoid administrative delay, development was undertaken more or less clandestinely. In July 1943 the Fishpond modification of H_2S was ready. A display screen was added, that indicated range and bearing of any aircraft below the bomber; an estimate of the relative height could be made by banking the bomber. But Bomber Command was large, and it took considerable time to install the new equipment. By the spring of 1944 most bombers carried Fishpond, and losses dropped sharply. However, there was considerable turmoil when it was discovered that German nightfighters carried the Naxos detector, that allowed them to determine the origin of H_2S emissions. Only after the interrogation of prisoners made clear that Naxos was far too inaccurate to allow nightfighters to home in on an individual bomber, and at best gave an indication of the position of the bomber stream, was confidence in H_2S and Fishpond restored.

An outgrowth of the Schräge Musik concept was the development of a number of vertically firing Sondergeräte, a term which can be translated as "special devices". These consisted of a number of recoilless single-shot guns, firing 30mm or 55mm ammunition. They were triggered by photo-sensitive cell. In theory, all the pilot had to do was pass at a suitable distance (100m to 50m) under a bomber. Use of these weapons remained experimental, and after the war nobody continued the concept.

Cannon with a calibre of 37mm and more have never become popular as aircraft weapons, despite many attempts to adopt them, both for air-to-air combat and for air-to-surface combat. Currently they are very rare. The main attraction of such weapons has always been the possibility of a single-shot kill of a large bomber, a small ship, or a tank. The disadvantages of these weapons are excessive weight, limited ammunition supply and low rate of fire. Recoil is also a significant problem, but in theory this is one that can be avoided by the development of recoilless guns. However, no recoilless gun has ever been really successful.

Early Experiments



Left, Hotchkiss 47mm cannon in the nose of a French Tellier flying boat. [54]

Among the earliest cannon fired from aircraft were the Hotchkiss weapons of calibre 37mm and 47mm, weapons constructed with parts of the automatic cannon of the period. The 37mm was produced in significant numbers, and available in version with a long and a short barrel. A few hundred French aircraft were equipped with them during WWII; mostly on the Breguet 5 and the Voisin 4, both single-engined aircraft of pusher configuration. Because they were loaded manually, the rate of fire was very low; and they were not very effective in air-to-air combat. They were useful as ground attack weapons, however.

The French identified another possible use for large cannon: As anti-submarine weapons. During WWI aircraft were slow enough that a spotted submarine might be able to dive before the aircraft could drop bombs on it. A cannon extended the reach of the anti-submarine aircraft. This culminated in the concept of a "high seas flying boat", for which a specification was written in 1918. This would be an aircraft with a crew of four, an eight-hours endurance, and an armament including two machineguns, 120kg of bombs, and a 75mm cannon with 30 rounds! The aircraft designed to this specification never entered service, but the Tellier T.7 did serve as testbed for the 75mm cannon between 1920 and 1922.

In Britain too, experiments were conducted with a number of large-calibre weapons, mainly for use against balloons and airships, although they were also used for ground attack. Vickers delivered the Vickers 1½-pounder and 1-pounder guns, the 1.59in Vickers Crayford, also known as the "Rocket Gun" because its incendiary projectile left a trail of sparks, and the Vickers 1-inch gun. The automatic 1-pounder cannon, basically a much enlarged Maxim machinegun, was the most successful, but nevertheless remained rare. Its recoil was the largest disadvantage.

More common than the Vickers guns was a weapon developed by the Coventry Ordnance Works, the 37mm 1½-pounder COW gun. The COW gun was automatic, very light for a weapon of this calibre, and had a good ballistic performance. But nevertheless it was a bulky weapon, and it saw little service. During the the interbellum it was carried by a few large aircraft, and a handful of fighters were designed round it, but none of these installations was adopted by the armed forces. The weapon seems to have seen its only actual service on the ground, as anti-aircraft gun...

Cleland Davis designed the recoilless guns named after him. They were simple weapons, basically a barrel with two open ends; the recoil was compensated by firing a lead shot rearwards. The loading procedure required the barrel to be made in fore and aft pieces, joined at the center, so that the round could be inserted manually. Leaks at this joint were a serious design problem. Three versions were produced, a 2-pounder, a 6-pounder and a 12-pounder. Its service life, mainly as anti-Zeppelin weapon, was short. The lead shot fired from the rear, and the rearwards blast, made this weapon highly inconvenient to install in the fragile WWI aircraft. It *was* installed on some aircraft, but generated little enthusiasm among the crews who had to use it.

One of the first aircraft designed for a *really* large cannon was the Admiralty Type 1000, also known as the AD.1. The Admiralty's concern was the German fleet, and it planned three versions: A bomber, a torpedo bomber capable of carrying an 18 inch torpedo, and a *gun machine* armed with a recoilless Davis 12-pounder gun. The latter would be used to lob shells at small warships from a safe distance. Development of the giant seaplane began in 1915, and it was completed and flown in the summer of 1916. Concerns about the rearwards blast of the Davis gun caused to design to be changed for a 12-pounder Naval Landing Gun, a conventional cannon, that would be installed on a mount allowing 49 degrees elevation and 38 degress depression. In the end, no gun was ever installed in the AD.1.

Soviet Recoilless Guns

The recoilless Davis guns inspired the development by B.S. Stechkin and L.V. Kurchyevskii of a series of similar weapons in the USSR. Between 1930 and 1936, when he was arrested and disappeared, Kurchyevskii developed a series of guns, that were installed in experimental and even production fighters. The design of all these aircraft was influenced by the rearwards firing of a compensating mass. Either the guns had to be in the wings, or the barrel had to be extended to the extreme tail of the aircraft.

Project Z, also called TsKB-7, was a small low-wing monoplane fighter developed by Grigorovich. He used parts of the I-5 biplane fighter to speed development. The aircraft had a recoilless 76.2mm DRP under each wing, and a single 7.62mm PV-1 machinegun in the fuselage to assist in aiming. About 50 production aircraft, called I-Z, were built. But because they suffered from handling problems, and the DRP guns were single-shot weapons, they were mostly used for further development work. Grigorovich followed with the IP-1, a refined aircraft armed with APK-4 guns at the wingtips. These could fire five rounds. Although the IP-1 entered production, it was without the recoilless guns: The 20mm ShVAK was preferred. The IP-4, with four 45mm APK-11 guns, remained experimental. Later Grigorovich fighters still had heavy armament, but significantly, stuck with multiple conventional 20mm cannon.

Meanwhile, work had also been underway in Tupolev's design bureau. The ANT-23 had a highly original concept: The crew and the two engines, one tractor and one pusher, were installed in a small nacelle. The long barrels of the recoilless APK-4 guns actually formed the tail booms. However, when a shell exploded in one of the guns the ANT-23 barely landed safely, and the aircraft was abandoned. More promising was the ANT-29. This was a conventional, highly streamlined twin-engined monoplane, with a single 102mm DRP or two APK-8 in the fuselage. The ANT-46, a basically similar design, instead had two APK-11 guns in the wings, and apparently the design goal was to use the 100mm APK-100. But the arrest of Tupolev and the disappearance of Kurchyevskii ended the development of fighters with recoilless guns.

Tank Busters

The interest in large aircraft cannon was revived during WWII by the steady increase in the armour thickness of tanks. Most air forces discovered the need for dedicated anti-tank weapons for attack aircraft. However, experience on the battlefield showed that this was not always the best solution: Tanks were well protected against anything but a direct hit, and that was difficult to achieve. Soft-skinned supply vehicles or horse-drawn artillery where much more rewarding targets, but the power of a heavy cannon was wasted on them.

In the USSR, S.V. Ilyushin managed to convince the Politburo of the need for a modern, heavily armoured ground-attack aircraft. The first prototype of the Il-2 *Shturmovik* flew in 1939. With 990kg of armour, the Il-2 was always a modest performer and highly vulnerable to fighter attack, but it was well-protected against small arms fire from the ground. The Il-2 was, according to Stalin, as essential for the Red Army as bread, and about 36000 were built. This made it the world's most built aircraft, but such production figures were necessary to compensate for the heavy losses. Instead of large cannon, the Il-2 relied on high-velocity guns of small calibre. The initial armament of 20mm ShVAK cannon was insufficient, but they soon replaced by the powerful 23mm VYa. Only in 1943 a number were equipped with the 37mm NS-37. These were considered effective enough against the German tanks, because the rear and top armour was much thinner than the front armour.

P.O. Sukhoi, with his Su-6, had unsuccessfully competed with the Il-2: Although the Su-6 was a better aircraft, it was decided not to halt production of the Il-2. This did not deter him, and in 1942 he got approval for a long-range attack aircraft to complement the short-ranged Il-2. The Su-8 was a sleek, powerful, twin-engined aircraft, again with a heavily armoured cockpit. It could be armed with either four 37mm 11P-37 cannon, or two 45mm OKB-16-45 cannon. The latter were fed by clips. To assist in aiming, four 7.62mm ShKAS guns were installed in the wings. The Su-8 would have had the heaviest forward-firing armament of any WWII aircraft, but it was not put in production, because the war was nearly won. The line of thinking behind the Su-8 was continued with a series of anti-armour derivatives of the excellent Tu-2 twin-engined bomber. The second prototype of the Tu-2Sh carried a 75mm cannon, and the third carried two 20mm ShVAK cannon, two 37mm NS-37 and two 45mm NS-45. The Tu-2RShR had a 57mm RShR cannon installed in the lower fuselage. All these aircraft remained prototypes.

Left, The BK 3,7 cannon under the wing of a Ju 87G, the anti-tank version of the famous Stuka*.* [16]

Initially, the Germans also opted for high-velocity cannon, but they did not have a direct equivalent of the VYa. Instead, the Junkers Ju 87G anti-tank aircraft appeared with two BK 3,7 cannon in pods under the wings, with six rounds each. The BK 3,7 was a 37mm weapon, developed from the Flak 18 anti-aircraft cannon. This armament installation proved highly successful against Soviet armour, despite the vulnerability of the obsolescent Ju 87 design. A purpose-designed attack aircraft was the Henschel Hs 129. As in the Il-2, the cockpit was an armoured box. With two Gnome-Rhone 14M4/5 radials, captured French engines, the Hs 129 was decidedly underpowered. It had a MG 17 and a MG 151/20 on each side of the fuselage, but the anti-tank cannon was carried in a fairing under the belly. It could be the 30mm MK101 or MK103, but also the BK 3,7. There were even experiments with the mighty 75mm BK 7,5, in an attempt to ensure the destruction of Soviet tanks, that carried increasingly heavy armour. Such 75mm cannon, the KwK 39 and PAK 40, also appeared on the Ju 88P, but their weight, recoil, and enormous muzzle blast were too much even for this twin-engined bomber. After the Ju 88P-1, later models switched to two BK 3,7 cannon, or one BK 5, derived from the PAK 38.

The RAF and USAAF never had an armoured ground-attack aircraft similar to the Il-2. Instead, they increasingly used fighter-bombers. Compared with the Il-2, these were more vulnerable to small arms fire from the ground, especially those with liquid-cooled engines, but on the other hand they could defend themselves succesfully against enemy fighters, and in general formed a force with superior range, speed, and flexibility. Both approaches can be defended. The Germans seems to have considered the Allied air superiority on the Western front more threathening, but then the front in the East was much longer, and air support was spread thinner.

Below, a table of anti-tank cannon carried by WWII aircraft. The ammunition specified in this table is the AP round used for anti-tank missions, which usually has a higher muzzle velocity than other rounds developed for the same gun.

Name	Ammunition	Rate of Fire	Muzzle velocity	Weight
MK 101	30 x 184B (355 g)	250 rpm	960 m/s	178 kg
MK 103	30 x 184B (355 g)	420 rpm	860 m/s	146 kg
BK 3,7	37 x 263B (380 g)	160 rpm	1170 m/s	295 kg
BK 5	50 x 419R (1250 g)	50 rpm	1200 m/s	540 kg
BK 7,5	75 x (3300 g)		933 m/s	1000 kg
VYa	23 x 152B (200 g)	500 rpm	905 m/s	69 kg
NS-37	37 x 195 (735 g)	250 rpm	900 m/s	150 kg
Vickers S	40 x 158SR (1130 g)	100 rpm	615 m/s	134 kg
Moulins 6pdr	57 x 441R (3170 g)	60 rpm	790 m/s	816 kg

Fighter-bombers could still be armed with large guns, and the Hurricane Mk.IID was fitted with two 40mm Vickers S cannon in pods under the wing, with two Browning .303 retained to assist in aiming. In the North African desert it proved effective, but the type was abandoned because it was vulnerable both to enemy fighters and to light AA guns, and its armament was considered to be ineffective against the newest German tanks. An alternative was the Mosquito Mk.XVIII with an Molins 57mm cannon, but this cannon too was rated unable to cope with the armour of a Tiger tank. The Mosquito Mk.XVIII, nicknamed *Tsetse*, was instead sent to Coastal Command for use against U-boats. The Allies switched to rockets as anti-tank weapons, and did not consider cannon again.

Near the end of the war a new breed of attack aircraft started flying. These were aircraft with the general configuration of light bombers, but a performance closer to that of fighter-bombers. A good example was the Beech A-38 Grizzly, a compact, clean aircraft powered by two mighty R-3350 radial engines. The A-38 carried the powerful T15E1 75mm cannon in the nose, with 20 rounds of ammunition. Unfortunately for the A-38, all R-3350 engines were required for the B-29 program.

Anti-ship installations

The Mosquito Mk.XVIII was not the only example of an attack aircraft for anti-ship missions, armed with a big gun. The best known example are variants of the B-25 Mitchell medium bomber. The B-25G carried a 75mm M4 gun, and the B-25H switched to the T13E1. The M4 was an army weapon, light and compact enough to be installed in the nose of a B-25. The T13E1 was a lightened version, more adapted to aircraft installations. The weapon was effective against small vessels, but because it was manually loaded only a few rounds could be fired during an attack. Near the end of the war suitable targets became scarce, and the 75mm gun was often replaced by additional .50 machineguns.

A much more ambitious project was the Piaggo P.108A. The P.108 was Italy's modern four-engined bomber, a neat aircraft in the class of the B-17. Only a handful were built, and they equipped the only strategic bomber squadron of the *Regia Aeronautica*. The P.108A --- A for *Artigliere* --- carried a naval 102mm cannon in the nose, angled slightly downwards. With the recoil system, this gun weighed no less than 1500kg, and a generous 50 rounds of ammunition were provided, adding another ton to the installed weight. Apart from the need for some local strengthening and the compilation of new firing tables, the aircraft was considered a success. Plans for production of series aircraft, and conversion of P.108B bombers to P.108A configuration, were halted by the Italian surrender.

Heavy Bomber Interceptors

For the use of heavy cannon against bombers two approaches were possible. The cannon could be mounted fixed and aimed in the same way as conventional fighter armament, or it could be made flexible, and aimed either manually or by a powered system. The latter approach required a rather large and heavy aircraft, but this was less of an objection for a fighter armed with 37mm or even heavier cannon, because it was already expected to be unwieldy. The perceived advantage was the greater accuracy that could be achieved with sophisticated gunsights and automatically aimed guns. This would make it practical to open fire from a large distance, well outside the range of the defensive armament of bombers. The effectiveness of the latter was generally overestimated during the 1930s.

Left, the Bell FM-1 Airacuda was designed around two 37mm M4 cannon in the engine nacelles and their gunnery control system. [26]

The most famous example of such a fighter is the Bell FM-1 Airacuda, a twin-engined aircraft first flown in 1937. The FM-1 was a low-wing monoplane with pusher propellers, driven by turbosupercharged Allison V-1710 engines. This arrangement left room for a 37mm M4 cannon in the nose of each engine nacelle, hydraulically controlled, with a coaxial machinegun to assist in aiming. A gunner in the nose of the FM-1 used a Sperry autopilot, a fire control system originally developed for anti-aircraft cannon, and an optical sight to aim these weapons. Impressive it was, but nobody could find a real need for it, or invent the tactics for its use; and the FM-1 faded into obscurity. There were attempts to revive the concept, for example the British Vickers 414, armed with a 40mm Vickers S cannon, but they remained paper designs.

Bell had become enthusiast about the 37mm cannon, and it proposed such armament for its new single-seat fighter, the P-39 Airacobra. This small fighter was also intended as a high-altitude bomber interceptor. As initially designed it had a turbosupercharged V-1710 engine, similar to those of the FM-1, but the gun was installed fixed, in the nose. The engine was put behind the pilot to make room for the gun, and drove a tractor propeller by a long extension shaft. Deletion of the underdeveloped turbosupercharger installation turned the P-39 into a mediocre medium-altitude fighter, and in combat the M4 revealed its weaknesses of low firing rate and modest ballistic performance. The weapon, in its improved M10 version, was also retained by the later P-63 Kingcobra, with exception of one P-63D that had the far more powerful M9. The USAAF had no use for these fighters, and both the P-39 and P-63 were mainly produced for Lend-Lease to the USSR, where they were surprisingly successful. The M4 continued to feature in fighter designs, such as the McDonnell P-67, proposed with six such weapons in the wing roots! But the only other fighters to enter service with the M4 were the first Lockheed P-38 Lightings, and in this aircraft it soon gave way to the 20mm Hispano. This was a much more useful weapon for a fighter.

Soviet enthusiasm for the P-39 and P-63 may be related to their own use of 37mm and 45mm weapons in fighters. The Yak and LaGG fighters were powered by the Klimov M-105, a Soviet development of the French Hispano-Suiza 12Y. This engine was suitable for installation of a cannon on the centreline, firing through the propeller hub. Initially this was the 20mm ShVAK or the far more powerful 23mm VYa, but soon heavier weapons were considered. The initial choice was the 37mm Sh-37, installed in a small number of LaGG-3 and Yak-9T fighters, but soon replaced by the competing NS-37. A small number of Yak-9TK and Yak-9K aircraft received the NS-45, a straightforward modification of the NS-37 to fire a larger shell. Later the NS-37 was replaced by the lighter N-37. That these weapons also could be carried by the final Yakovlev piston-engined fighter, the Yak-9P, indicates that they were considered a success. Yet their recoil was such that the pilots were trained to fire three-round burst with the NS-37, and single shots with the NS-45. They were also instructed to do so only at high airspeeds. The pilots were carefully selected for their shooting ability, and perhaps this contributed to the relatively high effectiveness of these weapons. Experiments with the NS-57 in the Yak-9 lead to the conclusion that the recoil of this weapon was really too high, and it was not installed in production aircraft.

Heavy cannon could be carried more easily by heavier fighters, especially twin-engined fighters. Although prototypes of twin-engined fighters were built in the USSR, their production fighters were single-engined and diminutive in size. Germany, on the other hand, built a large number of twin-engined fighter aircraft, and equipped them with heavy cannon in an attempt to combat the Allied heavy bombers. This started with subtypes of the Messerchmitt Bf 110, the Bf 110G-2/R1 and Bf 110G-4a/R1, that carried the BK 3,7 cannon in a ventral gondola. The Me 410 was developed as a more powerful replacement for the Bf 110, and in line with this the Me 410A-2/U4 and Me 410B-2/U4 carried the 50mm BK 5. The appearance of long-range escort fighters made both the Bf 110 and Me 410 far too vulnerable to operate in daylight, and removed this threat. An alternative was the installation of 50mm cannon in the Me 262 jet fighter, and prototypes of this aircraft with the BK 5 and the MK 214A were produced. Development of a light, low-velocity 55mm cannon, the MK 112, was never completed. The Me 262 also pioneered the use of the R4M rocket, an unguided air-to-air weapon. Rockets had been used for air combat before, mainly by the Russians, but it was the German development and successful use of the R4M that finally doomed heavy cannon as fighter weapons. They were a far more efficient, if less accurate, way to get a heavy warhead to the target.

The other nation to make widespread use of twin-engined fighters was, remarkably enough, Japan. For the Army the Kawasaki Ki.45 and Ki.102 twin-engined fighters were developed, and they were produced both in escort fighter, heavy fighter, ground attack, and anti-shipping versions. They were equipped with a surprisingly wide array of heavy cannon, including the 37mm Type 94, Ho-203, and

Ho-204, the 40mm Ho-301, and the 57mm Ho-401. The 37mm Type 94 was also installed in a the fighter derivative of the Mitsubishi Ki.46 high-altitude reconnaissance aircraft, in an upward-firing installation. This was a desperate measure, for the light construction and slow climb of the Ki.46 made it unsuitable as a fighter. In addition, the Japanese adopted a 75mm anti-aircraft cannon for airborne use as the Type 88, and installed this in a fighter derivative of the Ki.67 bomber, the Ki.109. The motivation for many of these experiments was to shoot down the B-29 bomber, a large and well-defended aircraft. Most of them could be considered failures in this role, simply because they could barely reach the operating altitudes of the B-29. In any case, this was mostly a story of too little, too late.

Fighter Armour

During World War I and thereafter, several air forces developed armoured "ground attack fighters" with the layout of a conventional fighter, but much heavier armour. However, these aircraft were not expected to be fully effective fighters. Something more about them, and armoured attack aircraft in general, can be found here.

One of the first dedicated single-seat fighters with armour installed was the Polikarpov I-16 Typ 4, which flew in 1934, full-scale production starting in 1935. In the final batch of the Typ 4 and on later models, a small plate of 8 mm thick headrest armour was installed. The windscreen remained a simple sheet of curved plexiglass. Nevertheless the little Soviet fighter, the most advanced single-seat fighter of its day, was once more far ahead of its time. Aviation armour had been under consideration in the USSR since about 1930, with the development of suitable nickel-molybdenum steel alloys. Most nations did not install armour in their fighters before 1940, and some waited much longer.

For example, the Hawker Hurricane and Supermarine Spitfire both entered production without any armour plate. The necessity was quickly understood after the outbreak of the WWII, and modifications had a high priority. Most of the RAF fighters to participate in the Battle of France, and that was most of the strength, did not yet have armour installed, but all fighters were modified before the Battle of Britain began. For the Spitfire this included 33 kg of armour plate, and an externally bolted-on armourglass windscreen, which cost nearly 10 km/h in speed. Later the armoured windscreen was internalized, and the armour increased.

At about the same time the Germans installed armour in their fighters. The Messerschmitt Bf 109E-4 introduced a more angular cockpit with an armoured windscreen and an angled armour plate behind the pilot's head. The 8 mm armour plate was also retrofitted to older models. The later G-model introduced a cockpit canopy with even more armour and a 90 mm thick windscreen. The heavily framed and armoured Bf 109 canopies were criticised for restricting the view of the pilot, but they offered good protection. Much later, at the end of the war, the *Erla Haube* was fitted. This new canopy, also rather inaccurately called the "Galland Hood", offered a considerably improved field of view.

Combat experience from Europe soon reached the USA. British representatives ordered aircraft from American manufacturers, but they demanded modifications to make them combat-capable, including armour. In addition, they supplied examples of captured German equipment for evaluation; this e.g. offered the US Navy the opportunity to perform firing tests on a Bf 110. Hasty modifications of US fighters followed. For example, the Bell P-39 Airacobra was first designed and flown without any armour, but in late 1939 not less than 120 kg of armour was added. Installing self-sealing fuel tanks added another 109 kg to the empty weight. The USAAF demanded these modifications for the P-39D model, but at first it insisted that they would be made at no extra cost and with no reduction in performance! It was soon forced to adopt a more realistic attitude. Perhaps Bell was being overly generous with armour plate. In the successor to the P-39, the P-63 Kingcobra, the weight of the armour was reduced to 55 kg.

Maybe a bit slower to react, the US Navy installed 68 kg of armour plate in the Grumman F4F Wildcat from the summer of 1941 onwards. But its main opponent, the Japanese Navy, neglected to armour its fighters. The first version of the Mitsubishi A6M Reisen *(Zeke)* "Zero" to carry armour behind the pilot's seat was the A6M5c, which entered service in the autumn of 1944! By then even the Japanese Army had had 13 mm armour plate in its fighters for two entire years. The F4F was in many ways inferior to the A6M, but it could survive the fire of the Japanese fighter, while the A6M was incredibly vulnerable. Later US Navy fighters outperformed the A6M and were well protected against .50 and even 20 mm hits. This helped the USN pilots to survive, even if their aircraft were quite often impossible to repair on board of the carriers and had to be dumped. The failure of the IJN to protect the lives of the pilots contributed to the rapid and fatal depletion of its trained cadres. When the A6M5 finally entered service, there were few experienced pilots left and the training of the new pilots was very poor.

Of course fighters that entered service during the war had the benefit of experience, which allowed a more efficient distribution of armour. The Focke-Wulf Fw 190 had a 13 mm plate to protect head and shoulders of the pilot, 8 mm seat armour, some 5 mm and 6 mm plate to fill in the gaps around the seat, and an armoured windscreen 50 mm thick. Armoured rings of 5.5 mm and 6.5 mm were installed around the lip of the engine cowling. An unique modification was the Fw 190A-8/R-8, modified to attack US heavy bombers from a close distance. Most fighters were protected only against from the rear and front. But the /R8 modification provided protection against fire from the sides as well, because this could be expected when the fighters got close in the bomber formations. The nose and headrest armour were made heavier, 30 mm armourglass was fitted to the side of the canopy, and 5 mm plate was installed at the sides of the cockpit and behind the instrument panel. The wing ammunition boxes for the 30 mm cannon were also protected, for any explosion of the ammunition would be fatal.

Self-sealing fuel tanks were as important as armour. Early attempts involved covering the inside or outside of a metal tank with some soft material, which expanded in contact with fuel, to seal any bullet holes. But this was not very efficient, and it was soon discovered that the bullet entry holes were a comparatively minor problem. The exit holes made by the tumbling bullets were considerably larger. Worse, the shock of impact and the pressure wave inside the tank caused it to rupture. In the first American tests, the entry holes were small, but the entire rear of the tank was knocked out.[68] The answer was a flexible fuel cell of self-sealing material, with as few seams as possible, and suspended in straps so that it could absorb shocks without rupture. Such a tank should not be in direct contact with the fuselage skin, because the moving tank could cause the skin to buckle, the torn metal skin could cut into the tank, sparks were often generated when the projectiles passed through the metal skin, and the skin might trigger explosive rounds.

Evidently, self-sealing fuel tank installations were costly both in weight and in volume compared with conventional fuel tanks. And of course there was also a limit to their usefulness. The US Navy designed its self-sealing tanks to resist .50 hits and found that they also offered some protection against 20 mm hits. But if an explosive round blasted a large hole in the wall of the tank there was no hope to seal it. For high-altitude aircraft the fuel tanks had to be pressurised, but that made sealing far more difficult. Hence self-sealing tanks were increasingly replaced by integral fuel tankage after the war, despite the higher vulnerability.

The risk of explosion did only exist if there was a suitable fuel/air mixture. A leak would of course provide such a mixture, but there was also a risk if an incendiary or explosive projectile entered the tank. Soviet designers found a solution: The fuel tanks were pressurised with cooled and filtered exhaust gases. The Lavochkin LaGG-1 of 1940 had 10 mm seat armour and self-sealing fuel tanks with such a fire surpressing system. It was also installed in other Soviet fighters. A disadvantage was that the exhaust gases tended to react with the self-sealing material, and it was preferable to use the system only in combat zones. Another feature of the Soviet fighters was that instead of a headrest with armour plate they had a slab of armoured glass installed behind the pilot's head, to improve the view towards the rear. Similar installations were made in the Bell P-39 and P-63, of which large numbers were delivered to the USSR.

How effective was the armour? It's thickness varied from 8 mm to about 13 mm. The armour was certainly effective against rifle-calibre machineguns, but these weapons were increasingly replaced by far more powerful medium-calibre machineguns or by cannon. The American .50 AP M2 round, a projectile with a high muzzle velocity, was expected to penetrate 1 inch (24.5 mm) at 100 yards (91 mm) and the AP-I M8 round still 7/8 inch. However, such armour penetration figures are traditionally measured against a homogeneous "standard" plate, while the armour plate fitted to aircraft would be face-hardened plate of good quality, to achieve maximal protection for minimal weight. Also important was that before it could hit the armour, the projectile had to pass through the aircraft skin and maybe structural members, which would deflect it or slow it down and was likely to cause tumbling, which would considerable reduce armour penetration. In this way relatively thin plates could greatly increase the protection. Equipment in the aft fuselage could be carefully arrange so that the bullet would have to pass it first, before it could hit the pilot. Finally, typical firing distances were of the order of 300 yards. Most airforces seem to have felt that the armour of their fighters offered substantial protection against .50 and even 20 mm rounds.

The Spitfire F Mk.21, a late war model, was considered protected against German 20&nsbp;mm AP rounds in a 20 degrees cone from the rear, and against 13 mm rounds from the front. The US Navy expected fighters to carry armour able to stop a .50 rounds at 200 yards. Early in the war the relatively slow projectiles of the Type 99-1 cannon were often stopped by the armour of the F4F. Protection against US .50 rounds was the required standard for German fighters. Indeed it would not have made much sense for most German aircraft to carry armour that would not stop the .50 at combat distances, for this was the standard weapon of the USAAF, the enemy that was most often met in daylight combat.

Armoured glass windscreens were more difficult to make in sufficient strength while maintaining good transparancy, and armoured glass is also very heavy. The laminated glass panels developed for the B-17 were about 40 mm thick, and they would stop a rifle-calibre bullet at 100 yards. But these large panels and weighed 88 kg per square meter (18 lb per sq. ft.). Fighter windscreens were smaller, and could be thicker and better supported; armourglass of up to 90 mm was used. Even so the front remained less well protected than the rear. In single-engine fighters the pilot was protected against fire from the front by the engine. Protection of the engine itself and the vulnerable cooling systems of liquid-cooled engines was almost impossible.

There were a few exceptions. The most heavily armoured aircraft of the war were close-support types such as the Ilyushin Il-2 and the Henschel Hs 129. Their role brought these aircraft within reach of small-arms fire from the ground, which was highly dangerous, especially after specialized anti-aircraft vehicles appeared. The armour of the Il-2 was part of the fuselage structure itself, in an attempt the save weight. Pilot and engine were enclosed in in welded shell, with a thickness varying between 4 mm and 12 mm. The windscreen was 65mm thick. The vulnerable coolant radiator was protected by installing it inside the fuselage, behind the engine; air was ducted to it from an intake on top of the cowling. The weight of all this armour was no less than 990 kg, and accounted for the Il-2's rather sluggish performance. The rear gunner's cockpit was not armoured, and it is claimed that the casualties of the rear gunners were seven times higher than those of the pilots. Il-2 losses were rather high, because the aircraft did very dangerous work and could not hope to evade enemy fighters.

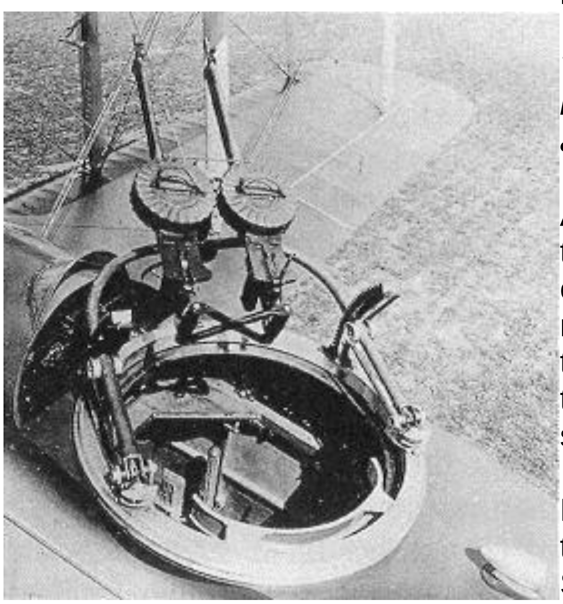
The German Hs 129 represented a slightly different philosophy. Again, the pilot sat in an welded armoured box, 6 mm to 12 mm thick and with a 75 mm windscreen. Although the box was as small as possible --- so cramped indeed that the gunsight had to be installed outside the cockpit --- the armour weighed 1075 kg. Two air-cooled engines were used instead of a single liquid-cooled engine, thus removing the problem of protecting the cooling system. In the Hs 129B production versions the engines were captured French Gnome-Rhône 14M radials, which turned out to be rather unreliable. Performance was poor, but like the Il-2 the Hs 129 was an effective anti-tank aircraft, although it too suffered high losses.

Defensive Armament

Although the subject of these pages is a different one, it would be an omission not to discuss the defensive, flexible, armament of multi-seat aircraft. The evolution of flexible armament was different from that of fixed armament, mainly because the gun mounts imposed more constraints on the guns that could be used. Smaller weapons survived in defensive positions after they became obsolete as fighter armament.

Open Positions

The first aircraft used by military services were a mixture of monoplanes and biplanes. After the first months of the First World War the biplane became prominent. The original lay-out for two-seaters placed the observer in the front seat, between the center section of the wings, and the pilot behind him. The result was a poor field of view and of fire for the observer, so in the second generation of military aircraft the observer was moved to the rear seat. This made it possible for him to defend the rear sector with a flexible machinegun, typically a drum-fed rifle-calibre weapon.



Twin Lewis guns as the rear defense of a de Havilland D.H.4 bomber. They are trained far forward; probably it would not be advisable to fire in that direction! [39]

Accurate fire required a steady gun mount, that would allow the gun to be pointed at the target in such way that the gunner could always look over the sight. A simple pintle mount did not meet that requirement. The most common solution was to fix the machinegun on a ring fixed over the rim of the cockpit, so that it could be aimed in all directions. The best known solution is the *Scarff ring*, named after its British inventor.

Multi-engined bombers could carry more than one gunner, but the choice of the gun positions presented a problem in itself. Some bombers had long, rectangular fuselages, which allowed for gun positions in the extreme nose and the extreme tail. The Germans also devised the "tunnel gun", a gun which fired rearwards and downwards through a "tunnel" in the bottom of the aft fuselage. This protected the bomber against attacks from below. Innovative designers did not hesitate to put gunners on top of the wing, or in the aft ends of the engine nacelles.

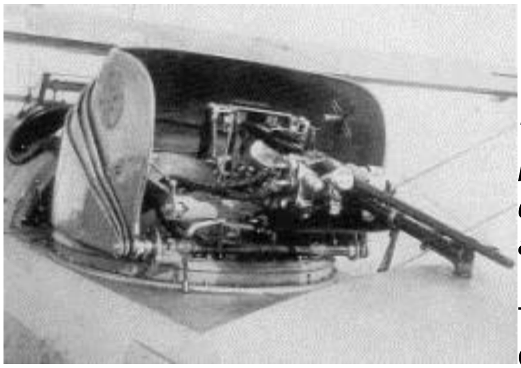
Handley Page O/100 bomber. There was a gunner in the tip of the nose and one in the fuselage, aft of the wing trailing edge. The nose gunner had a wide field of fire, but his position was rather uncomfortable. [69]

An important day for strategic bomber operations was 13 June 1917, when daylight bombardments on London began with an attack by 20 Gotha G.IV bombers. During the very first attacks the defence was poorly organized and ineffective. But already on 22 August the Germans suspended daylight attacks because of the high attrition suffered by KG 3. After that date, the large bombers would operate only at night.

The vulnerability of bombers to fighter attack resulted, already during WWI, in the creation of specialized day and night bombers. Only the faster, nimbler aircraft, often single-engined, could operate safely during the day. Less performant aircraft had to seek the protection of the night. These included large multi-engined aircraft capable of carrying a heavy bomb load, but also various obsolescent light bombers or even obsolete fighters. For example, the British retaliation for the German attacks on London consisted of attacks using the de Havilland DH.4 at day, and the Royal Aircraft Factory FE.2B and Handley-Page 0/100 at night.

The first turrets

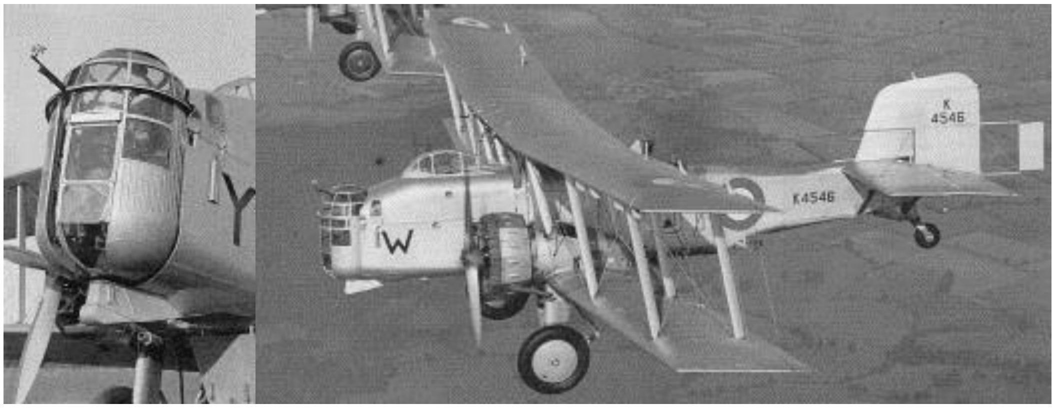
The disadvantages of open gunnery positions are many. The gunners were exposed to the elements at low altitudes, or to the cold and thin air at high altitudes. The drag was considerable. The slow bombers of the First World War did not create a strong enough airflow to interfere with aiming, but on faster biplane bombers, such as the Hawker Hart and its fighter development the Demon, this began to be a problem. The installation of windscreens to deflect the airflow was at best a partial solution. And one or two rifle-calibre machineguns turned out to be all that a gunner could handle, although the Germans did experiment with the 20mm Becker cannon during WWI.



The Hawker Demon was a fighter development of the Hart bomber. The prototype was fitted with this "lobster shell" turret, designed by Frazer-Nash. But its weight and the disturbed airflow around it prevented its adoption as standard. [70]

The solution was the enclosed gun turret, initially manually operated, but soon using external power to drive the traverse. A well-designed turret provided a stable gun mount, and allowed the use of heavier armament and better gunsights. Because there needed to be openings in the turret for the guns, the gunner's position remained cold and draughty, but it was better than being completely exposed. On the negative side, many turrets were so cramped that they did not allow the gunner to wear a parachute, and were difficult to leave in an emergency. Heavy framing often restricted the view of the gunner.

A well-designed turret would not have too much drag, but many were bulky and heavy, and the aircraft that carried them often suffered a significant performance penalty. This was especially true for the so-called "dustbin" ventral gunnery positions, retractable gunnery positions which were lowered from the fuselage in the air. These provided a more effective downward and rearward defensive than a gun that was simply pointed through a window in the belly of the aircraft, but only at the cost of enormous drag. They were later replaced by a variety of belly turrets, most of them awkward to use or very uncomfortable for the gunner.

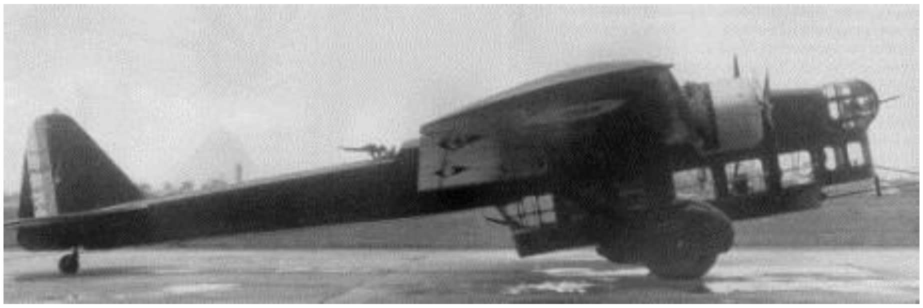


The Boulton-Paul Overstrand, a development of the earlier Sidestrand bomber, and its nose turret. This turret was pneumatically driven for rotation, while a hydraulic system moved the gunner's seat up and down for elevation. The turret was cramped, as can be seen in the close-up picture. [71]

Initial installations of gun turrets were made in improved biplane bombers, such as the British Boulton-Paul Overstrand. In the mid-1930s a series of fast monoplane bombers appeared, streamlined aircraft inspired by the new generation of commercial transports. The Tupolev SB, Martin B-10 showed that a substantial performance improvement could be achieved by modern design techniques. These fast bombers outpaced contemporary fighter aircraft. They featured gun turrets, although simple ones, and set the trend for the next decade.

In the 1930s the theory was developed that nothing could stop modern bombers. As general Westover of the USAAC stated it, "no known agency can frustrate the accomplishment of a bombardment mission." The increased speeds of the bombers reduced the time to the target, and because they flew higher any intercepting fighters lost more time in climbing. This would make it impossible to send fighters in the air in time to intercept the bomber force. Standing fighter patrols would spread out the available forces very thinly, and if the bombers were intercepted, their heavy armament would enable them to defeat the attackers. Of course this thinking did not into account the development of radar, which would provide earlier warning and would allow the defenders to control their fighters far more effectively. It was also wildly optimistic about the effectiveness of defensive armament. For the moment the theory seemed sound, however. The air war in Spain, with the infamous bombardment of Guernica, seemed to confirm it.

One of the consequences of this thinking was the development of the "air cruiser." The logic behind the concept of the "air cruiser" was deceptively simple: If it was assumed that bombers could defend themselves against fighters, then it was also a good idea to create "fighters" with a similar armament as the bombers, just more of it. They would help to defend the bomber formation and fight for air superiority. WWI experience with this idea was unpromising, but conflicting. A number of multi-seat fighters had been complete failures, utterly useless in combat. The French air force had employed the Caudron R.11, a large twin-engined three-seat biplane, as long-range escort fighters for its bombers, and at the time the R.11 was considered a very useful aircraft. But in fact the formations of bombers and R.11s had suffered heavy losses on the occasions when they operated without the escort of single-engined, single-seat fighters!



The first Amiot 143. This much-maligned aircraft was the victim of endless delays. Designed in the late 1920s, it was kept in production until 1938, and saw combat in 1940. There were four gunnery stations: An upper nose turret, a lower nose position, a dorsal position and a ventral position. [72]

Nevertheless, the French recreated the concept of the "multiplace de combat", the multi-seat combat aircraft, which would operate as fighter, bomber, and reconnaissance aircraft. Powerful armament and good performance were of course required. The Amiot 143, the best known aircraft of this type, had none of these characteristics, and during WWII they were unsuitable even as bombers. But the Amiot 143 was the unfortunate victim of the fast technical advance of the time and the unsatisfactory performance of the French industry, which kept it in production long after it had become obsolete. When it appeared the aircraft was quite impressive.

The Second World War

Hesitations

In 1939 many people were still convinced that *the bomber will always get through*, as Stanley Baldwin had said in 1932. Devastating air raids with chemical weapons were seen as inevitable in a modern war. Estimates of the number of casualties that could be expected were later revealed as far too pessimistic. Chemical weapons were not used during WWII, although preparations were made by all sides. Nevertheless fear for retaliation initially limited the use of bombers.

The British bomber force included both night and day bombers. There were four main twin-engined types: The Vickers Wellington, Armstrong-Whitworth Whitley, Handley Page Hampden and Bristol Blenheim. There was also a single-engined bomber in service, the Fairey Battle. Of these, only the Blenheim and Battle were really classified as day bombers; the others were called night bombers. That did not mean that they would never operate during the day, however.

The Vickers Wellington had the characteristic nose and tail turrets of the British night bombers, mounting Browning .303 machineguns. The presence of these turrets largely determined the shape of the fuselage. The windows for the beam gunners can also be seen on this picture. Their typical shape was a consequence of the geodetical construction of the aircraft. [40]

The Wellington and Whitley were designed with nose and tail turrets mounting two or four Browning .303 guns. This became the standard pattern for British bombers, later shared by the four-engined Stirling, Halifax and Lancaster. The Whitley also had a rectractable "dustbin" under the belly; the Wellington initially had one, but it was later deleted. The Blenheim had a dorsal gun turret; the Hampden had dorsal and ventral gun positions. The Battle only had a rear gunner armed with a single machinegun, and was extremely vulnerable to fighter attack.

The Browning .303 was almost universal, but in manually aimed positions one could also find the Vickers K, a gas-operated gun that had nothing in common with the WWI Vickers.

After the outbreak of war the night bombers began to drop leaflets, but not bombs, over Germany. It was an useful exercise for the crews, but of course had no military effect. Even the leaflets were primitive. Meanwhile, German bombers attacked targets in Poland, and Warsaw, a defended city and therefore in principle a legitimate target, was heavily bombed. But bombing operations against Germany itself, especially the Ruhr, remained forbidden, also because of French opposition. With a considerably weaker airforce than Germany, the French were understandably concerned about the German reaction.

From the start, British day bombers were allowed to operate against warships at sea, while the Luftwaffe tried to attack the Royal Navy. Both sides were unsuccessful. A frustrated British government allowed attacks on warships in port, on condition that these would not result in "disproportionate" losses. Indeed small formations of Wellington bombers operated without loss, although also without inflicting damage, on 3 and 14 December. But on 18 December 1939, 12 out of 22 Wellingtons on a mission to Whilhelmshaven were shot down. This did not immediately make Bomber Command aware of the vulnerability of its aircraft. The loss of six Hampdens and five Wellingtons on 12 April, however, resulted in a decision that daylight bombing missions would in the future only be flown by units equipped with the Blenheim.

Finally, on 15 June 1940, after Rotterdam had been bombed by the Germans, the British war cabinet approved the bombing of the German industrial center of the Ruhr. No losses were suffered through enemy action. Night operations, at least for the moment, seemed safe. That they were also horribly inaccurate was not known.

It is often claimed that Bomber Command tried day bombing of Germany, and abandoned it because of heavy losses. This is incorrect. The strategic bomber force was always intended to operate at night, and as we have seen this policy goes back to WWI. In the early months of WWII, the RAF just removed from day operations those aircraft that had been designed for night operations! The Fairey Battle and Blenheim bombers continued to operate in daylight, despite heavy losses, until the highly vulnerable Battle was retired from combat. They were given a fighter escort if possible, but medium and light bombers turned out to be easy targets during tactical operations. For example, attacks on bridges over the Meuse on the 14th of June resulted in the loss of 35 aircraft out of 71... The bombers were exposed to the German light anti-aircraft artillery, which was very effective, and the proper tactics for escort fighters still needed to be developed.

The Battle of Britain

After the defeat of France in the summer of 1940, the Germans were in the position that they had won a fantastic victory in battle, but had not won the war. The tactical mobility of the German army and the far superior performance of its leadership had resulted in swift defeat of the once very much feared French army. Surprised by the speed of its own success, the German army had not planned future operations; in particular there were no ready plans for operations against Britain. The improvised plans that were put on the table were unsatisfactory, but they did lead to the first attempt to achieve a major goal of war by a strategic bombing offensive.

It is often claimed that the German airforce was purely tactical in orientation, and that this was a major, even a fatal, flaw. It should of course be remembered that the decisive value of tactical air support during WWII is undisputed; while the effectiveness of the strategic bombing offensive is still debated. In 1940 the Germans certainly had the finest tactical airforce in the world, far superior to anything the British or French could bring in the field.

Pre-war models of the He 111 had an fuselage with a stepped nose and wings with an elliptical planform. The dorsal gunnery position was open, and the ventral position was a retractable "dustbin." [44]

This late-war He 111H-10 has an unstepped assymetric nose and wings with straight leading and trailing edges. The dorsal position has been faired over, the ventral position has been replaced by a fixed "bathtub," and the nose gun is now a 20mm cannon. A remote-controlled machinegun was installed in the tail cone. [74]

One would be mistaken to conclude from this that the Luftwaffe did not consider strategic operations. Evidently, it lacked a fleet of four-engined, heavy, long-range bombers. Preference had been given to twin-engined medium bombers instead. Cost was an important consideration: Germany's economic power was limited, and the larger aircraft were also more expensive. They were not totally rejected, however. It had been decided that the German first-generation heavy bombers, the Junkers Ju 89 and Dornier Do 19, were unsatisfactory, and that the Luftwaffe would wait until more advanced aircraft, such as the Heinkel He 177, were available. It is very dubious that this decision had an important influence on the outcome of the Battle of Britain. For the distances within Western Europe, medium bombers had sufficient range, and this was also true for attacks on Britain. Most British aircraft factories, for example, were located within range of the German bombers. Given the absence of a suitable escort fighter, the four-engined bombers would have been almost as vulnerable to British fighters as the twin-engined ones, although because of their greater sturdiness they might have been harder to shoot down.

Somewhat more reasonable is the claim that the German bombers had insufficient defensive firepower. It is hard to define what sufficient defensive firepower would be, and if this is the kind of armament that makes unescorted daylight operations possible, then no WWII bomber had sufficient firepower. But one can safely say that the defensive firepower of German bombers was smaller and less efficient than that of their British equivalents. The Germans of course sought to cure this defect of their bombers, and this resulted in a fantastic number of armament variations. In general they made less use of powered turrets than the Allies.

The Junkers Ju 88, a versatile aircraft with good performance. One gun aimed was through the windscreen, and often another one was installed for the bombardier. A gunner defended the lower rear from the offset *ventral bath under the cockpit. One or two circular disc mounts at the rear of the cockpit provided a defense of the upper rear sector.* [29]

At the time of the Battle of Britain, the German bombers were the Heinkel He 111, Dornier Do 17, and Junkers Ju 88. The best German bomber was the Ju 88. This had a crew of four, grouped together in an extensively glazed but rather small cockpit. Defense against rear attacks was provided by a gun position at the rear of the cockpit, consisting of a rotating disc with a gun mount. Later two gun mounts were installed instead of one, and the discs were armoured. To defend the bomber against attacks from below a ventral bath was installed under the cockpit, with another gun mount facing rearwards. The frontal defense initially consisted of one weapon that was fired through the windscreen of the cockpit, and later another was installed in the nose. A high degree of interchangeability was maintained. Initially, single MG 15 rifle-calibre machineguns were installed, but these provided inadequate firepower. During the Battle of Britain, additional gun positions were improvised.

German Improvements?

The evolution of the German bombers was slow. One new aircraft was introduced later in the war: The Dornier Do 217 a newly designed aircraft to replace the superficially similar Do 17. The old He 111 and the Ju 88 were improved, and of course received more powerful armament. In general, the Germans avoided the use of bulky multi-gun turrets, except in the dorsal position. Gun turrets were used, but they were carefully streamlined. The MG 81Z twin machinegun replaced the MG 15, and was an important step forward. Other weapons installed in defensive positions were the MG 131 and MG-FF. Even the powerful MG 151/20 was occassionally used in flexible installations, for example in the nose of the Junkers Ju 188.

Rear defense of a Ju 188. The compact EDL turret with a single 13mm or 20mm weapon was often deleted to reduce drag. The rotating disc mount, heavily armoured in the later years of the war, was standard fit on the Ju 88 as well. Note that the turret gunner has a reflector sight, but the other one only a ring-and-bead sight. [28]

The Luftwaffe had not ignored the need to replace its bombers by more modern aircraft. The so-called *Bomber-B* program had already begun before the war. Among the innovations included in these new aircraft were some of the first remote-controlled gun turrets. These were technically complicated, but they promised the best compromise between firepower and streamlining, and allowed the gunner to be in a pressurised cabin. But the "Bomber-B" program was a failure: It produced an extensive series of prototypes of bombers, such as the Junkers Ju 288, but nothing more.

The twenty-two prototypes of Ju 288 had a lot of armament variations, but the general pattern was that the defense consisted of four remote-controlled turrets: A dorsal turret, a ventral one, one forward-firing under the nose, and a tail turret. All were controlled from the pressurised cockpit, by means of periscopic gunsights. (This was a weakness, for combat experience showed that the view through periscopic sights was much too limited.) Turrets could also be installed on the wings. Different designs were tried, using single or twin MG 131 or MG 151/20 cannon. The intention seems to have been to install the 20mm MG 213C cannon as soon as it was ready, and this advanced weapon would have given the Ju 288 considerable firepower: At 1400rpm, it fired almost twice as fast as other 20mm cannon. But as said, the Ju 288 never entered production, and the MG 213C also remained a prototype.

Another promising project that ultimately turned out to be a waste of efforts was the Heinkel He 177. Its development spanned most of the war, but the type was never satisfactory. The He 177 represented an attempt to develop a twin-engined heavy bomber, a decision that has been invoked derisory comments from many authors. It must not be ignored that similar attempts were made by the British, who developed the (equally unsuccessful) Avro Manchester. The engines of the He 177 were created by coupling two DB 601 or DB 605 V-12 engines to drive a single propeller. Although this was a source of problems, the idea was far from unreasonable: In the USA, Allison made a similar coupling of two V-1710s to create the V-3420 engine. One serious error was made, however: A lot of time was wasted in an attempt to make the He 177 suitable for *dive* bombing. The dubious potential for greater accuracy did not justify the enormous structural problems this generated for such a large aircraft. The idea was abandoned, but not before it had caused delays.

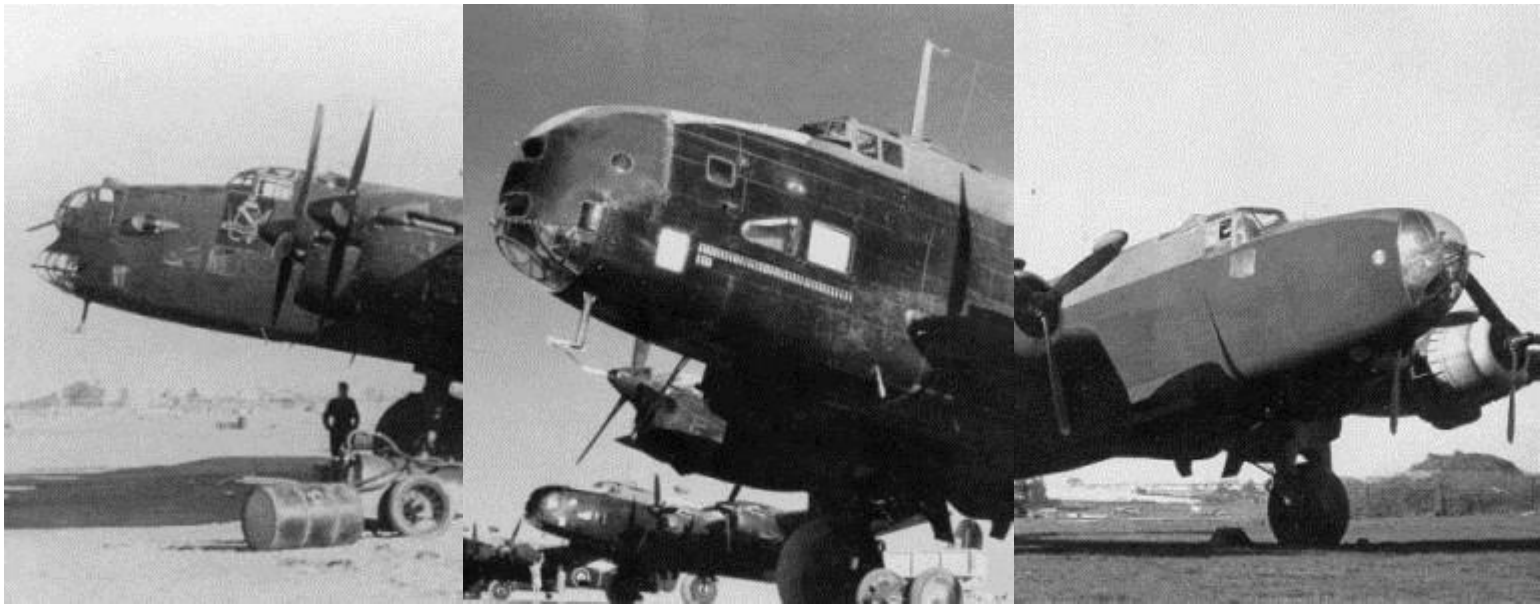
The nose of a He 177A-3/R1. The armament installation is almost schizophrenic: The weapons in the tray under the cockpit and the turret behind the cockpit are remote-controlled, but there is also a manually aimed MG 81, pointed through the small circular opening in the cockpit glazing... [41]

The He 177 can perhaps best be described as the German equivalent of the Boeing B-29 Superfortress, although inferior in overall performance. Both aircraft were technically advanced and complicated. Both had an inauspicious early career, and for the same reason --- engine fires. Both aircraft featured a fully glazed nose, instead of a stepped cockpit; a feature that was relatively common for German bombers. And both featured remote-controlled armament, although that of the He 177 was far simpler. In effect only the guns in the tray under the cockpit and the first of the two dorsal turrets, with two 13mm machineguns, were remote-controlled. The second turret, with the same armament, was manned. It is unclear why the designers chose this strange arrangement. The He 177 also had a tail turret, and a single gun fired through the nose glazing. In several versions, the tray under the cockpit was used to install powerful, fixed guns.

More prototypes of advanced bombers were built; the best known was the Messerschmitt Me 264 *Amerika-bomber*. But in the end, German attempts to replace the bombers with which the Luftwaffe had entered the war were failures. The short range of the German fighters, and the need to concentrate the available fighters for home defense, also ruled out an effective fighter escort. The German bombers were increasingly forced to seek the protection of the dark.

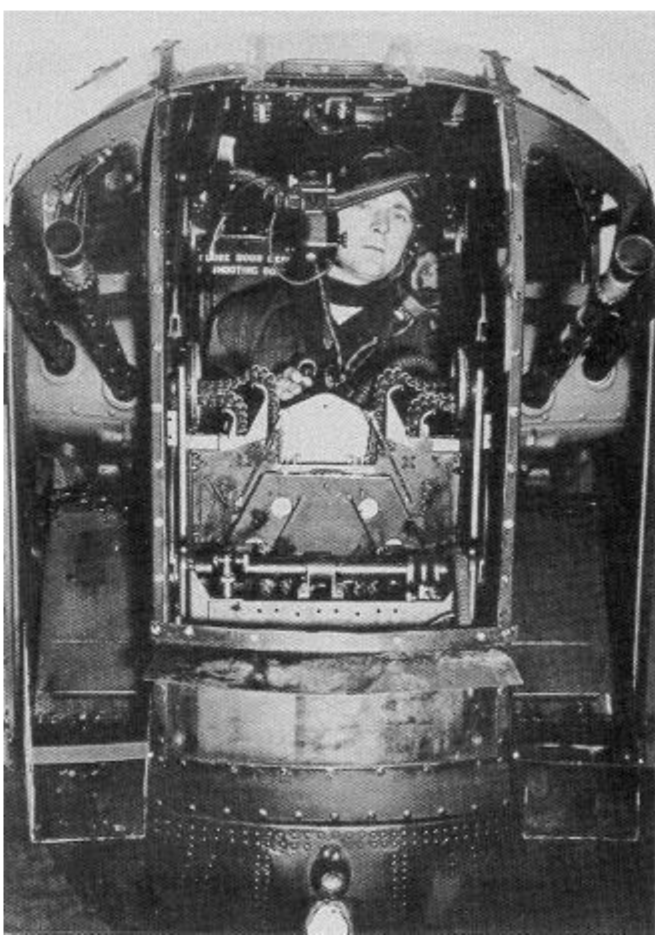
Night heavies

RAF Bomber Command evolved in quite different direction, although it also operated at night. A new generation of four-engined bombers replaced the Hampdens, Wellingtons and Whitleys. The first of them was the Short Stirling, but the Avro Lancaster became the mainstay of Bomber Command and the Handley Page Halifax its second most important bomber. The success of the Lancaster and Halifax was almost an accident. Both had initially been designed as *twin-engined* bombers to specification P.13/36. The design of the Halifax was converted to four engines while still on the drawing board, while the Lancaster was a four-engined development of the twin-engined Manchester. But because P.13/36 had called for the carriage of torpedoes, both retained a capacious, unobstructed bomb bay.



Evolution of the Halifax nose.
The original twin-gun turret was soon deleted and replaced by the "Z" fairing; this reduced losses by improving performance. Later a simple perspex blister with a single gun was designed. [42]

As first built, the Halifax had four Boulton-Paul gun turrets: A four-gun turret in the tail, and two-gun ventral, dorsal and nose turrets. But this apparently logical and effective arrangement did not survive long. The ventral turret was soon deleted because it was difficult to operate, although it was optional on some later Halifax marks. To reduce drag, the nose turret of the early versions was at first deleted and simply faired over, and later replaced by a perspex nose with a single manually operated Browning or Vickers K gun. The tall dorsal turret was also often removed, and even when it was replaced by a more compact one with four machineguns, also a Boulton-Paul product, this was sometimes omitted. The absence of the dorsal turret could be compensated, to some extent, by installing beam guns: Single or twin Vickers K machineguns on each side, pointed through windows in the fuselage. The only gun turret that was always retained was the tail turret.



The Lancaster had Frazer-Nash turrets, initially in the same arrangement as on the early models of the Halifax. The Lancaster happened to have much better aerodynamics than the Halifax, and the great majority of Lancasters retained their nose, dorsal and tail turrets. The ventral turret was deleted, and on many aircraft it was replaced by a fairing for the H2S radar.

Four Browning .303 machineguns were installed in the tail turret of a Lancaster. The gunner also had the best view towards the rear, where any attacker was likely to appear, and he controlled the defense. On his signal the pilot would start the evasive "corkscrew" manuever. [32]

The absence of any form of ventral armament would make the four-engined bombers very vulnerable to the upward-firing Schräge Musik installations, used by German nightfighters with devastating success in the winter of 1943-1944. The nightfighter, flying below the bomber, would have been very difficult to see anyway: It is not certain that the presence of ventral guns really would have made a large difference. Nevertheless, it can be argued that the absent ventral armament would have been far more useful than the nose or dorsal guns.

Another concern was the continuing use of the .303 machineguns as bomber armament, although .50 guns were occasionally installed. After the first years of the war most fighters had armour plating and windscreens that rendered the .303 ineffective. But it was not that easy to redesign the gun turrets for heavier weapons, and to make things worse no British .50 was available. American Browning .50s were apparently not in sufficient supply to re-arm Bomber Command's aircraft entirely. And the 20mm Hispano was a slim, but long and heavy weapon, not ideal for installation in a gun turret.

The protection of the night soon turned out to be a very relative one. The development of better radars by the Germans could make night attacks almost as costly as unescorted daylight attacks. Night bombers, it turned out, also needed escort fighters. After a disastrous attack on Nuremberg in March 1944, in which 95 bombers (11.9%) were lost, Bomber Command at last received three additional squadrons of Mosquito nightfighters, two of them equipped with the new centimetric radar, in addition to the three squadrons of *Serrate*-equipped fighters its already had (See note 6). Nightfighter operations and successful jamming of German radars and communications soon helped to keep losses to an acceptable level.

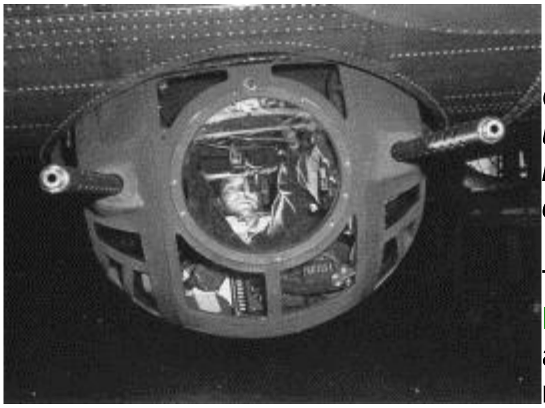
But the de Havilland Mosquito was a bomber as well as a nightfighter. Calculations showed that the unarmed Mosquito, relying on speed and altitude to evade German fighters, was a more efficient way to deliver bombs to the target than the four-engined "heavies". Not carrying armament resulted in enormous savings in weight and drag, reduced the crew to two, and reduced the cost of the aircraft. This resulted in the creation of the Light Night Strike Force. Evidently, a bomber that relied purely on high performance was vulnerable to technical developments; but the Mosquito was a brilliant design, and remained extremely difficult to intercept throughout the war. Only at its very end the Germans managed to put a small number of jet-engined nightfighters in service.

The 8th AF

In July 1942 the first aircraft of the 8th Army Air Force arrived in Britain. Initially the American commanders restricted themselves to cautious attacks on targets within the range of the available escort fighters, but soon they ventured beyond the range of the escort fighters. On 27 January 1943 a target in Germany was attacked for the first time: 91 heavy bombers attacked Wilhelmshaven and Emden.

All precedents indicated that unescorted daylight attacks would result in heavy losses of bombers, but the leaders of the 8th AAF nevertheless adopted this as a tactic. They believed that only daylight attacks could have the precision needed to take out the German war industry. Day bombardments, Ira Eaker argued, were five times as accurate as night bombardments; and in 1943 this was probably true. Only later in the war, when better navigation aids became available and marking techniques were improved, did night bombardments rival the accuracy of day bombardments. Besides, the 8th AAF was a day bombing force, and switching to night attack would have required a complete reorganisation, re-training and re-equipment.

The answer to the fighter treat, it was believed, was to have more and heavier guns per bomber, attacks by fleets of 300 or more bombers, and close-packed formations that were carefully arranged to give each gunner the best possible field of fire. The "combat boxes" would be able to bring more firepower to bear on the enemy fighters than any bomber formation had ever done before.



Only small men would fit in the ball turret of a B-17. Although uncomfortable, this was a much more effective defense than remote-controlled weapons with periscopic gunsights, and it caused less drag than a "dustbin" turret. [32]

The Boeing B-17 Flying Fortress and Consolidated B-24 Liberator certainly were heavily armed. In the first versions, the armament of the "Flying Fortress" had consisted of only five manually operated machineguns, an arrangement that invoked sharp criticism from the British, who considered the aircraft "practically indefensible against any modern fighter."[34] But when the 8th AF began operations, the US heavy bomber had been redesigned, taking into account the combat reports from Europe. They had dorsal turrets and ventral "ball" turrets with two Browning .50 M2 machineguns. A tail gunner controlled two more .50s. Two windows in the waist of the aircraft each accomodated a single .50 gun. In the B-17 another single .50 was fired from the radio room. Of course all this armament was rather heavy, to a total of over 2580 kg (5700 lb),[66] and that was more than the bombload on long-range missions. In principle this gave them excellent defensive firepower in the entire rear hemisphere. Optimists declared that it meant "almost certain death" for any enemy fighter to approach a Flying Fortress.[67]

The front was a weak point, however. Although the prototype had had a nose turret, the frontal defense of the production B-17 was limited to a number of manually aimed machineguns, initially a single .30 machinegun; it was soon replaced by a .50, and one or two more .50s were installed in small "cheek" windows. The B-24 had similar armament. This was not enough, because the Germans soon understood that the B-17 was really vulnerable to frontal attack. Not only was the forward firepower limited, there was no armour to protect the crew from such attacks. The German pilot Anton Hackl commented:[11]

> *One accurate half-second burst from head-on and a kill was guaranteed. Guaranteed!*

The Germans concluded that in a head-on attack, four or five 20mm hits would destroy a bomber, while it usually required more than 20 hits when attacking from another angle. Of course the head-on attacks were difficult to set up, and required very experienced pilots. But clearly something had to be done. The cockpit windows were soon replaced by laminated armoured glass,[65] and the nose armament was increased. At first units in the field improvised more powerful nose armament, but the B-17G and B-24H introduced powered nose turrets with two .50s.

These nose turrets were a fortunate spin-off of new experiments with the "air cruiser" concept: The YB-40, a heavily armed "escort fighter" version of the B-17, and the XB-41, a similar version of the B-24. Only one prototype of the XB-41 was completed, but twenty-one YB-40s were created. Combat experience showed that the YB-40s with all their additional armament, armour and ammunition were too slow to maintain formation with the B-17s, and that ended the experiment.

The single XB-41. Note the two dorsal turrets and the chin turret, B-17G style. Waist gun positions were fitted with two power-operated guns each. This was not just a bad idea, the aircraft had poor flying characteristics as well. [32]

Even the best all-round armament was never enough. Deep penetrations in German territory turned out to be extremely costly. The most famous examples are the attacks on Regensburg and Schweinfurt: The first attack, on 17 August, resulted in the loss of 60 bombers out of a force of 363. Some consolation was found in the claims by the gunners, which amounted to a total of 228 enemy fighters shot down; even after careful evaluation of claims the 8th AF estimated the German losses to be between 148 and 100. In fact the Luftwaffe had lost only 25 fighters. A repeat attack on 14 October gave a confirmation, if any was necessary: 65 more B-17s were lost. The initial claim of enemy fighters downed was even higher than in the first attack, 288; but even the official figure of 104 was way above the real German loss: 35. (See Note 3.)

The infamous attacks on Schweinfurt were not unique. They were merely the most serious in a long series of disasters for the 8th AAF. In 1943, it was clearly losing the battle with the German fighter defenses.

Why did the heavy bombers fail? Apparently the leaders of the 8th AF simply underestimated the difficulty of the task the gunners faced. There were some skeptics, such as Col. Claude E. Putnam, the commander of the 306th BG, who estimated in 1943 that only 10% of the gunners who could theoretically have fired at an enemy aircraft really did so, and that at least four gunners needed to fire to have a 50% probability to shoot an enemy aircraft down. The commander of the 308th shared his doubts, wondering whether the guns were not more a hazard than a protection.[35]

The attacking fighters were small targets in an often confusing battle, and it was not at all evident that gunners would see them, identify them, estimate their distance and speed, aim correctly, and fire at the right time. This looked good on paper, but in practice it was an almost impossible task. During WWII, the hit probability for fixed, forward-firing guns was estimated to be only about 2% for an average pilot; and the operation of flexible guns is far more complex. The German fighter pilots flew short missions; the gunners spent long hours in cold, draughty, and incredibly noisy aircraft, shaking in the turbulence created by the large bomber formations. The gunsights were often primitive: The powered turrets had some form of computing sight, but most hand-aimed guns had simple ring-and-bead sights. The field of view and fire from some positions, notably the radio room of the B-17 and the waist positions, was quite limited. Overall, the German fighters held a clear advantage.

Another factor was that the gunners were not trained well enough.[27] After the outbreak of war a large training program was created, but there was little experience in the field, little equipment, and it was very difficult to find and retain competent instructors. During the war some improvements were made, but as late as 1944 a War Department report admitted that some gunners simply didn't know how to operate their gun turrets! Operational units had priority for equipment, and gunnery training was sadly neglected: It was mid-1944 before enough aircraft were made available to gunnery schools and gun cameras became available for training purposes.

The assumption that the concentrated fire of a "combat box" would fend off fighters also had a fundamental flaw: It ignored that the fighters would react by concentrating their attacks. Initially the Luftwaffe went after the lower groups, but later it often attacked the lead group, because they knew that it contained the lead bombardier. The formation did offer significant protection to the bombers; indeed any bomber that left the formation became an easy kill. But it was not enough.

The exaggerated kill claims gave a false impression of the effectiveness of the defensive guns, and for this reason the 8th AF continued unescorted daylight attacks for far too long. The usual reason given for the excessively high claims is that any German aircraft shot down was claimed by multiple gunners, who had all fired in its direction. In addition, too often any puff of smoke from a German aircraft was interpreted as a sign of a fatal hit, while it often enough just indicated a rough handling of the throttle. The gunners had to do an impossible job in extremely dangerous conditions, and can hardly be blamed for compiling incorrect statistics.

Bombing Japan

The Boeing B-29 Superfortress was probably the best bomber of WWII. It set new standards in range, bomb capacity, speed, altitude, and crew comfort. It also introduced a new armament installation. The weapons installed were the traditional .50 Brownings; an additional 20mm cannon in the tail position was often deleted. It was the control system that was new. The two dorsal and two ventral turrets were remote-controlled by a computer system. All had two guns, but the front dorsal turret was later replaced by a four-gun turret. The gunner worked in transparant domes, feeding data into the computer by tracking the target with their gunsight. One or more turrets could then be assigned to fire. Only the tail guns were controlled directly by their gunner.

A B-17 and a B-29. The family resemblance is obvious. The cleaner aerodynamics of the B-29 are greatly helped by remote-controlled turrets. Originally retractable turrets with periscope sights were specified, but these turned out to be impractical. [72]

Primitive by modern standards, this was the most advanced system fitted to any WWII bomber. Whether it was effective enough to defend the B-29 against enemy fighters is dubious: The Japanese air defenses were poorly organized and poorly equipped for their task, but in December 1944 they began shooting down four or five B-29s on every operation. Yet the unreliability of the B-29's engines was still a more serious problem than the Japanese defense. Accuracy was poor too, because US meteorologists had insufficient knowledge about the jetstream, the fast high-altitude wind which disrupted formations and invalidated the calculations of the navigators and the bomb aimer.

Confronted with the failure of the high-altitude daylight attacks, general Le May made the drastic decision to switch to night attacks at relatively low altitude. Most of the defensive armament of the B-29s was removed to save weight. Because the climb to high altitudes would no longer be made, less fuel was needed and the unreliable engines were spared. The weight savings were converted in a larger bomb load, with a lot of incendiary bombs. Le May in effect adopted British tactics and methods for his bombers: He did exactly what the 8th AF had always refused to consider. Of course the Japanese did not have a very effective light anti-aircraft artillery; nor did they have a substantial and effective nightfighter force. These tactics were thus even more suitable over Japan than they had been over Germany. The effect was devastating. The bombing of Tokyo on 9 March 1945 is generally considered the most deadly of the war. More people were killed than in the British bombardments of Hamburg or Dresden; more too than in the nuclear bombardment of Hiroshima and Nagasaki. Such indiscriminate slaughter of tens of thousands of people was against US policy, but Le May justified it by pointing out the highly dispersed nature of the Japanese war industry, which meant that almost everyone contributed to it.

Cold War Bombers

When the Soviet military entered Germany at the end of WWII, it was aghast at the degree of destruction caused by Allied bombing of German cities. The enormous fields of ruins were a clear reminder of the might of the Allied strategic bomber forces. The fact that, at the time, only the USA possesed nuclear weapons made this only more frightening. The strategic bomber became the main weapon of interest during the first years of the cold war. For the USA and Britain, this required a reorganisation and re-equipment of their existing forces. For the USSR, which did posses only a very small force of long-range bombers, it implied the creation of an entirely new force.

Tupolev Tu-4. It is often claimed that this was a bolt-for-bolt copy of the B-29, but much of it was redesigned, including the defensive armament, the bomb bays, the engine installation, and the fuel cells. [3]

Although the USSR would have been able to design its own long-range bomber, Stalin chose to use three Boeing B-29s as starting point. These aircraft had made emergency landings on Soviet territory during WWII, and because the USSR was not at the time at war with Japan, the aircraft had been interned. A reluctant Tupolev was given two years to create the Soviet version, which had to be thoroughly re-engineered to make its production possible. A lot was learned in the process, although some techniques used in the B-29 remained beyond the reach of the Soviet industry. In one field, that of aircraft guns, the USSR was ahead of the USA; and the Tu-4 was armed first with 20mm B-20 cannon, and later with 23mm NR-23 guns, instead of the American Browning .50.

While a Tu-4 or a B-29 with a nuclear weapon presented a significant threat, they were hardly intercontinental bombers. Besides, the vulnerability of the B-29 was demonstrated in Korea, where the USAF, lacking an escort fighter that could match the MiG-15, was forced to abandon daylight B-29 operations. A true intercontinental bomber with a better performance was needed. Work on such an aircraft had been underway in the USA since 1941, inspired by the possibility of operations against Germany without the availability of bases in England. The Convair B-36 was a giant six-engined aircraft, armed like the B-29 with guns in remote-controlled turrets. The firepower had been increased by using the M24, a 20mm cannon based on the wartime Hispano.

Ventral guns of a B-36. Its sixteen M24 cannon were installed in pairs in remote-controlled turrets. [43]

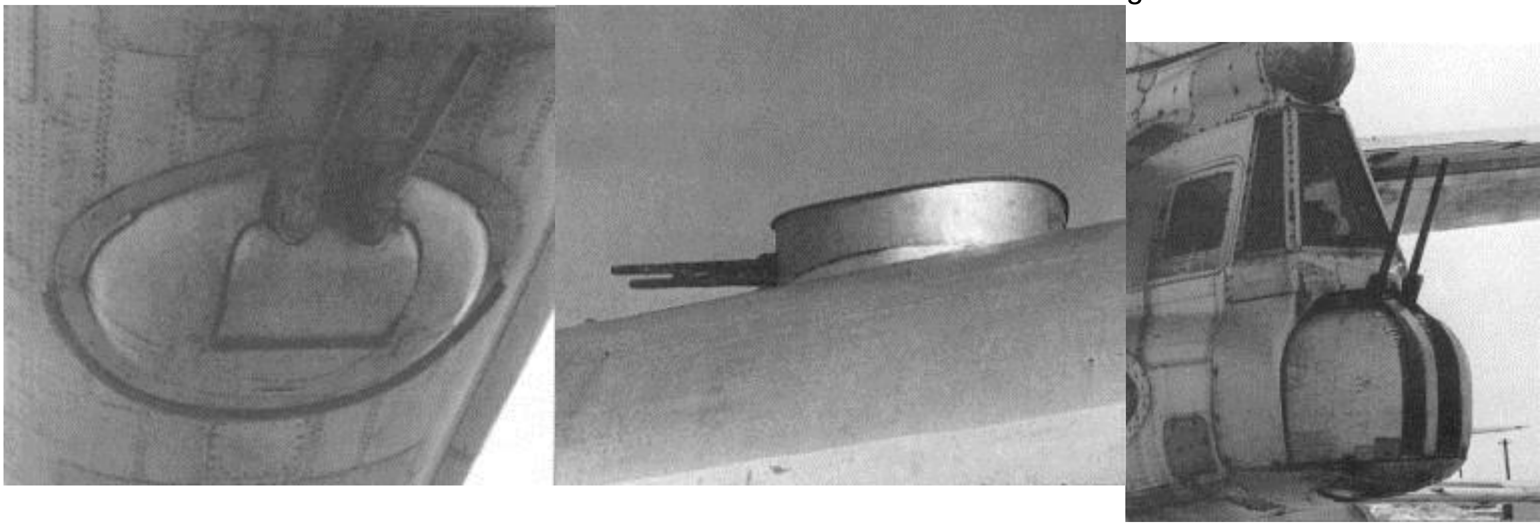
But later the USAAF reversed this policy. Under project *Featherweight III*, all defensive armament was removed from the B-36, except the tail guns. It was felt that the heavy and maintenance-intensive guns would not be enough to protect a B-36 against attack. On the other hand, by removing the armament and other equipment the operational ceiling could be raised to 47,000 feet (14.300 m) or higher. Contemporary jet fighters had difficulty to reach and maintain such altitudes, and the enormous bomber was more manoeuverable than the fighters at high altitude, because of its generous wing area.

One reason for the smaller desirability of defensive armament was the change in tactics, brought about by nuclear weapons. No longer was there a need for large formations of bombers: A single aircraft could destroy a city. And a single aircraft could not hope to defend itself against enemy fighters, but it might be able to evade them. The attackers in a nuclear war would disperse themselves to attack individually, thus making the task of the defenders much more difficult. In the 1950s bombers had the additional advantage that the rapid drag rise in the transsonic region made it very difficult for fighters to be much faster than the bombers.

Most of the bombers of the nuclear age therefore abandoned defensive armament, at most retaining a few tail guns. In Britain a successor to the Mosquito entered service: The Canberra, a fast and unarmed twin-engine jet aircraft. The Canberra was almost as versatile as the Mosquito had been, but as bomber it was only an intermediate solution. The British deterrence was to be constructed around the four-engined V-bombers, the Valiant, Victor and Vulcan. These too were unarmed, relying on speed, altitude, and an effective ECM suite. When SAMs became an effective defense against high-flying aircraft, the tactics were changed to operations at low altitude.

American bombers such as the B-47 , the supersonic B-58 Hustler, and the eight-engined B-52 Stratofortress retained their tail guns, but no other defensive armament. ECM suites, decoys and stand-off weapons were hoped to keep the enormous, but vulnerable B-52 out of harm's way. The B-1B Lancer and B-2 Spirit abandoned all armament, but introduced stealth in addition to the other tricks.

The big exceptions came from the USSR, where the trend to abandon defensive armament also set in, but much slower. Remote-controlled turrets, B-29 style, remained important on Soviet bombers. The weapons installed in them were usually 23mm cannon, at first the AM-23 which was availiable in short-barrelled and long-barreled versions, and later the twin-barrel GSh-23M cannon. The Tupolev Tu-16 *Badger* jet bomber of the early 1950s retained a dorsal, a ventral, and a tail turret. When the enormous turboprop-engined Tupolev Tu-95 *Bear* first flew a few years later, it had two dorsal and two ventral turrets in addition to tail guns, but on the Tu-95M production aircraft the forward upper and lower turrets were removed. On the redesigned Tupolev Tu-142 of the late 1960s all dorsal and ventral turrets were finally deleted. The jet-engined Myasichew 3M *Bison* that was the main competitor of the Tu-95 also had ventral, dorsal and tail turrets. On the other hand the supersonic Tupolev Tu-22 *Blinder* and Tupolev Tu-26 *Backfire* conformed more to modern practices, having only radar-controlled tail guns.



Armament of a Tu-95: A compact non-retractable ventral turret, a retractable dorsal turret, and a tail turret. Also note the gunlaying radar above the gunner's cabin. [75]

An exclusively Soviet practice is the installation of defensive tail guns on large transport aircraft. Military versions of the Ilyushin Il-76 *Candid* can be distinguished from civilian version by their tail turret mounting twin GSh-23 cannon. Similar installations were made on the older Antonov aircraft, such as the An-8 *Camp* and An-12 *Cub*. But no tail guns were installed on the giant An-22 *Cock*, and they are also absent from Antonov's later twin-engined transports. Possibly the use of tail guns on Soviet transport aircraft was primarily related to their role as paratroop carriers, which would bring them over the frontline.

Postscript

Post-War Fighter Guns

The first jet fighters were developed during WWII: The Heinkel He 280, Messerschmitt Me 262, Heinkel He 162, Gloster Meteor, de Havilland Vampire, Lockheed P-80, and McDonnell FH Phantom. Their advantages were so obvious that only a handful of propeller-driven fighters entered service after the war.

Jet fighters brought higher speeds, and that in itself made gun aiming more difficult. The structure of the aircraft became sturdier, with thicker skins. All this increased the need for powerful armament. On the other hand radar equipment, better gunsights and head-up displays promised to make guns far more accurate. At first the electronics systems were maintenance-intensive and poorly suited to the stress of combat, but the sophistication of today's aircraft is such that any round fired has a high probability to hit the target.

Five people at work in one picture: There can be no doubt that this was posed. But it does show how the four Hispano cannon were installed in the nose of a Meteor. [4]

The armament of the first jet fighters was the same as that of the last piston-engine fighters. There was only a change in armament installation: Most jet fighters had their guns in the nose. Installing guns in the nose instead of the wings gave concentrated fire at a wide range of distances. The nose also offered more room than the wings, which were being made thinner to reach higher speeds. And putting the guns in front helped to balance the weight of the jet engine in the tail. A problem, especially for night operations, is the muzzle flash, that might blind the pilot temporarily.

While Germany of course did not design post-war military aircraft, it is interesting to have a look at the designs that were on the drawing boards in 1945. These were eagerly studied by the victorious allies, and inspired many post-war aircraft. The Luftwaffe initially demanded that the replacement of the Me 262 would be a high-altitude jet fighter capable of 1000km/h between 7000m and 9000m, and with an endurance of 60 minutes at full throttle. The pilot had to be put in a pressure cabin, with sufficient armour to stop .50 ammunition. Initially, the Luftwaffe was satisfied with two 30mm MK 108 cannon. But it quickly upgraded its demands to four MK 108 cannon, and two hours endurance. The proposals were all swept-wing jet fighters. Alternatives to the four MK 108 cannon proposed by the designers included two MK 103 and two MG 151/20 cannon, or two MG 213C revolver cannon.

The MG 213C was designed in 1944, and it was a revolver gun with a five-chamber cylinder. By dividing the loading of a cartridge in three steps, a high rate of fire could be achieved while keeping the forces within the gun limited. There were 20mm and 30mm versions. The MG 213C made linear action guns obsolete for fighters, and was copied widely.

Revolver Guns					
Name	**Ammunition**	**Rate of Fire**	**Muzzle velocity**	**Weight**	**Q-factor**
MG 213C/20	20 x 135 (112 g)	1400 rpm	1050 m/s	75 kg	19200
MG 213C/30	30 x 85B (330 g)	1200 rpm	530 m/s	75 kg	12400
BK 27	27 x 145 B (260 g)	1700 rpm	1025 m/s	100 kg	38700
Aden Mk.4	30 x 113 (220 g)	1300 rpm	790 m/s	87 kg	17100
Aden 25	25 x 137 (180 g)	1750 rpm	1050 m/s	92 kg	31500
KCA	30 x 173 (360 g)	1350 rpm	1030 m/s	136 kg	31600
DEFA 554	30 x 113 (275 g)	1800 rpm	820 m/s	80 kg	34700
GIAT 30M791	30 x 150 (275 g)	2500 rpm	1025 m/s	110 kg	54700
M39	20 x 102 (101 g)	1700 rpm	1030 m/s	81 kg	18700

Aircraft Cannon Data.

Russian Aviation Gunnery Page.

IZMASH Page.

In Britain the armament of four 20mm Hispano cannon remained the standard. The Meteor had actually been designed for six such cannon, but the mount of two of them was too unpractical to be safely used. Four 20mm cannon were carried by the last piston-engined fighters and the straight-wing jet fighters. The Hispano remained in use until the first swept-wing fighters appeared with the 30mm Aden cannon, a copy of the MG 213C. With four Aden guns, the Hawker Hunter was considered over-gunned by many observers: A rare distinction for any fighter aircraft. Two Aden guns, as in the Lightning, Jaguar, Saab J35 Draken, and Folland Gnat, was a more common armament.

The evolution in France was almost identical to that in Britain, except that the Hispano was not replaced by the Aden but by the DEFA, a French derivative of the MG 213C. The Aden and DEFA guns initially used slightly different ammunition, but later common ammunition was introduced, creating a de facto standard for 30mm rounds. Because of the successful export of French aircraft, the DEFA gun is still used world-wide. The later developments had an increased rate of fire (up to 1800 rpm) and are fitted to modern fighters such as the Mirage 2000.

Sweden adopted the Swiss 30mm Oerlikon KCA, a very powerful revolver cannon, for the Saab JA 37 Viggen interceptor. It is relatively slow-firing, but has excellent ballistics and it has been estimated that its ammunition has twice the destructive power of the Aden/DEFA ammunition of the same calibre.

The US Navy initially followed the British example. This had already begun during the war, with types such as the F4U-1C and F8F-1B. Its first jet fighters almost all had four 20mm Hispano cannon, for example the FH Phantom, F2H Banshee, and F9F Panther. The M3 version of this gun was boosted to 850rpm. Like the Hispano Mk.V, it had been lightened by shortening the barrel, in this case by

15in. The USN was unusual in that it continued the use of these weapons on swept-wing fighters and right into the supersonic age, although in an upgraded version: The Colt Mk.12. The Mk.12 fired a lighter projectile with a larger charge. But on the Navy's Mach 2 fighter, the Vought F8U Crusader, the Colt guns were an anachronism. They had a good rate of fire and a high muzzle velocity, but were inaccurate, unreliable, and unpopular. But the F8U at least had guns, and they contributed to the good reputation that this fighter acquired in Vietnam. No gun was installed on the F-4 Phantom II, in the belief that the new guided missiles made gun obsolete. And the weight, bulk and vulnerability of the electronics required for their use made it attractive to save weight by leaving the guns out. Experience in Vietnam indicated that it was still highly desirable to have a gun, and currently USN fighters are equipped with the six-barrel M61 Vulcan.

Linear Action Guns					
Name	**Ammunition**	**Rate of Fire**	**Muzzle velocity**	**Weight**	**Q-factor**
Colt Mk.12	20 x 110 (110 g)	1000 rpm	1010 m/s	46 kg	20300
AM-23	23 x 115 (200 g)	950 rpm	690 m/s	39 kg	19300
NS-23	23 x 115 (200 g)	550 rpm	690 m/s	37 kg	11800
NR-23	23 x 115 (200 g)	950 rpm	690 m/s	39 kg	19300
NR-30	30 x 155B (410 g)	900 rpm	780 m/s	66 kg	28300
N-37	37 x 155 (755 g)	400 rpm	690 m/s	103 kg	11600
GSh-30-1	30 x 165 (400 g)	1800 rpm	890 m/s	46 kg	103000

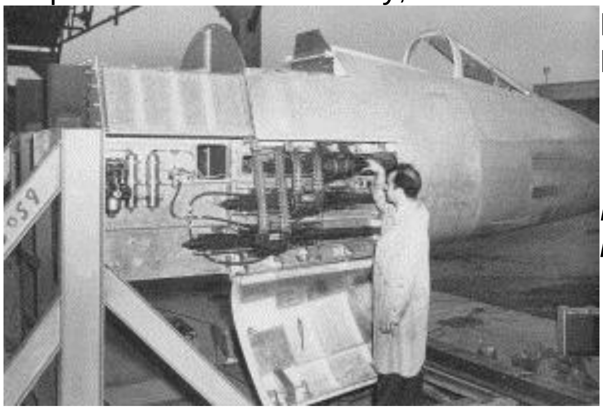
Russian Aviation Gunnery Page.

IZMASH Page.

Aircraft Cannon Data.

The USAF was even more conservative. In the late 1940s the standard armament of USAF fighters, with only few exceptions, was still six Browning .50 M3 guns. It was faster-firing than the M2 version used in WWII, but experience in Korea demonstrated that this armament was painfully insufficient. A report by Colonel Eagleston estimated that two thirds of all MiG-15s hit with the .50 guns escaped. On the other side it was observed that MiG-15s with 40 or 50 hits routinely returned home. The American pilots still held the advantage, because of better training, better gunsights, and generally better equipment.

In some nightfighters and fighter-bombers the USAF installed the 20mm M24 cannon, a version of the Hispano M3 of the US Navy, modified to use electrically primed ammunition. The first versions of the F-89 Scorpion, for example, carried six of these guns. The F-86K carried four.



Left, for testing six M24 Hispano cannon were installed in a mock-up of the nose of the XF-88. [12]

A much-needed improvement was the Pontiac M39, a 20mm revolver cannon broadly based on the MG 213C, but almost entirely redesigned. This far better weapon was installed on fighters such as the F-86H Sabre, F-100 Super Sabre, and Northrop F-5. A switch to 30mm cannon was considered, but rejected in the belief that guided missiles would soon make the cannon obsolete. Apparently, two F-89C protototypes were the only US fighters that ever carried 30mm cannon.

The F-4 and F-106 appeared without cannon, but like the USN the USAF had to change its mind because of combat experience, and during the Vietnam war cannon were installed in these fighters. The standard weapon became the six-barrel M61 Vulcan, and it is still in use today, usually in its M61A1 form. The M61 was the first rotary cannon, generally (and not entirely correct) called a Gatling gun. Such weapons are reliable and offer a very high rate of fire, and by dividing the firing over several barrels their wear is reduced. Of course such guns weigh more than single-barrel weapons. Characteristic of the M61A1, and most US rotary cannon, is the beltless feed mechanism: Rounds are transported on a kind of conveyer belt system, and empty cases are transported back into the drum. The original M61 had a belt feed, but this could not take the strain of firing rates higher than 4000 rpm.

An objection raised against rotary cannon is that the spin-up time is fairly long: It takes 0.4 sec before the M61A1 spins up to its nominal rate of fire, while a revolver gun reaches its nominal rate of fire after 0.05 sec. Hence the advantage of the rotary cannon is minimal or non-existent during a short burst.

Rotary Guns					
Name	**Ammunition**	**Rate of Fire**	**Muzzle velocity**	**Weight**	**Q-factor**
M61A1	20 x 102 (101 g)	6600 rpm	1035 m/s	120 kg	49600
GSh-6-23	23 x 115 (200 g)	8000 rpm	740 m/s	76 kg	96100
GSh-6-30	30 x 165 (400 g)	5400 rpm	850 m/s	145 kg	89700

Description of the M61 on 3-4-9, the F-16 reference page.

The USAF museum has an M61 Vulcan.

Russian Aviation Gunnery Page.

Aircraft Cannon Data.

Left, the N-37. [13]

The Soviet Union was more reluctant to abandon its guns, and it indeed developed a surprisingly large number of new ones in the post-war years. Apparently the USSR was reluctant to copy the MG 213C. It did show a preference for large-calibre weapons, with calibres up to 57mm proposed for installation in fighters. In these early years of the Cold War only the USA had nuclear weapons, and the only means to deliver these bombs was the B-29 or B-50 bomber. Hence Soviet fighters were given armament sufficiently powerful to shoot down B-29s. The first Soviet jet fighter, the MiG-9, was designed for two 23mm NS-23 cannon and one 57mm N-57, but the latter was replaced by the less ponderous 37mm N-37 before the aircraft flew. This was essentially a lighter, less powerful development of the NS-37. Soviet designers estimated that it would take eight 23mm shells, or two 37mm shells, to destroy a B-29. The same armament was retained by the MiG-15, except that the NS-23 was soon replaced by the faster-firing NR-23. In Korea it was shown that this armament, though powerful, was stuck in a fighter that was a poor gun platform and had primitive gunsight. However, the much-improved MiG-17, with the same armament, was very effective in Vietnam.

The supersonic MiG-19 abandoned the N-37. Initial deliveries had two NR-23 cannon, but the standard weapon was the NR-30, basically a scaled-up NR-23. But for its first generation of Mach 2 fighters, the Su-9 and MiG-21, the USSR too abandoned guns. On all-round fighters they soon returned. The twin-barrel GSh-23 guns were installed on the MiG-21 and the MiG-23. This weapon uses the Gast principle, named after its inventor Carl Gast, who developed it in Germany during WWI. In these guns, the firing of one barrel drives the action of the other half of the gun.

Gast Guns					
Name	**Ammunition**	**Rate of Fire**	**Muzzle velocity**	**Weight**	**Q-factor**
GSh-23L	23 x 115 (200 g)	3400 rpm	740 m/s	72 kg	43100

Modern Fighter Guns

The choice for modern fighters is generally between revolver guns and rotary guns. The former are lighter and fire more rounds in a short burst, the latter have a higher sustained rate of fire.

In Britain a new version of the Aden was developed, the Aden 25, that fires the NATO standard 25mm ammunition. This has been adopted for the latest British versions of the Harrier, two being installed in underfuselage packs. US versions of the same aircraft fire the same ammunition, but they have a single rotary gun, the five-barrel GAU-12 Equaliser.

But for the RAF's next generation fighter, the gun is provided by Germany. For European aircraft projects, including the Tornado and the Eurofighter, the Mauser BK 27 was developed. This 27mm revolver cannon is a new design. No attempt was made to use existing ammunition, and the 27mm calibre is unique. The BK 27 was also adopted for the Swedish JAS 39 Gripen. It has been considered to develop a multi-barrel version of this gun for Eurofighter, but this plan seems to have been abandoned.

The French stepped out of the Eurofighter project. Their next-generation fighter is the Rafale, and a new gun has been developed for it: The GIAT 30/791. This is one of the fastest-firing single-barrel guns, thanks to the use of a seven-chamber cylinder.

Current Soviet fighters are armed with the six-barrel GSh-6-23 and GSh-6-30, or with the single-barrel GSh-30-1. The MiG-31 has the very fast-firing GSh-6-23. This is probably the fastest-firing gun in use, and the manufacturer claims rates of fire as high as 10000 to 12000 rpm for this gun! The GSh-6-30 was used on the MiG-27, for ground support missions. But apparently the GSh-30-1 is preferred for the MiG-29 and Su-27 because of its greater destructive power and lower weight. The GSh-30-1 is unique, because it is the only linear action gun used in a modern fighter. Its rate of fire is similar to that of a revolver cannon, and the GSh-30-1 is considerably lighter. And while its muzzle velocity is modest by modern standards, its accuracy is reported to be very good.

The USAF and USN again show conservatism. Development of the new 25mm GAU-7 gun using caseless ammunition was abandoned, and the old M61 is still the main fighter gun. Some effort has been made to reduce the weight of the gun, and a version weighing 93kg is under development. This also decreases spin-up time. The disadvantage of the M61 is now the relatively small killing power of its ammunition: Other nations have now adopted larger calibre guns, that fire rounds two or three times heavier than the M50 ammunition of the Vulcan. These 20mm rounds are still the same size as that adopted for the M39s in the 1950s, and at time deemed acceptable in the belief that guns would soon become obsolete!

The table below gives the firepower parameters of some modern fighters. Note that the apparent advantage of rotary guns in rate of fire would decrease if short bursts are fired, because of their longer spin-up time. Data for the number of rounds fired in the first second by the M61A1 vary from 47 to 72.

Fighters	Guns	Rounds/sec	Weight/sec
MiG-31	1 x GSh-6-23	133.3	26.7 kg/sec
Su-27, MiG-29	1 x GSh-30-1	30.0	12.0 ks/sec
Rafale C	1 x 30M791	41.7	11.5 kg/sec
F-14, F-15, F-16, F-18	1 x M61	110.0	11.1 kg/sec
Mirage 2000	2 x DEFA 554	30.0	8.3 kg/sec
JA 37 Viggen	1 x KCA	22.5	8.1 kg/sec
Eurofighter, JAS 39 Gripen	1 x BK 27	28.0	7.4 kg/sec

This can be compared with the data for WWII Fighters. At the end of WWII, the best fighters had an armament firing about 5kg/sec. All modern fighters are well above that, but the difference is smaller than one would expect. The reason is the decreased importance attached to guns in modern air combat, as missiles are now the primary weapon. The is less pressure to improve firepower than there used to be. This is particularly obvious for US fighters: If only the guns are taken into account, the F-22 will have slightly less firepower than the F-100 Super Sabre!

Fighters of the Korean War

As in the discussion of some WWII fighters, these aircraft are sorted by by hitting power, in terms of fired weight per second. The muzzle power is also given, in kilowatt.

North American F-86 Sabre

The F-86A was the first American swept-wing jet fighter, a development of the Navy's straight-wing FJ Fury based on German research. It was inferior to the MiG-15 in climb, in service ceiling, and in speed above 20,000 ft. But the Sabre had a good performance at lower altitudes and much better handling characteristics at high speeds. Better pilot training gave the USAAF the upper hand in its fight against the MiGs. [45]

- Six Browning .50 M3 machineguns in the nose, with 267 rounds per gun.
- The M3 version of the venerable Browning fired at 1200 rpm, so the Sabre could fire 120 rounds per second for 13 seconds. This gave a weight of fire of 5.8 kg/sec. The muzzle power was 2203 kW.
- Identical armament was installed in the Lockheed P-80 Shooting Star (with 300 rounds per gun) and the Republic F-84 Thunderjet. In terms of weight of fire and muzzle power it was not so bad; but the during the Korean war it became clear that the .50 projectile was inadequate against the sturdy and well-armoured MiG-15. Many MiG-15s returned to base despite numerous hits. Four 20 mm cannon were installed in a few Sabres for combat evaluation, but only after the Korean war did they become standard armament on USAAF fighters.

  American Military Aircraft
  Duncan's F-86 Sabre Website
  Aviation Group
  F-86 Pilots Association

Grumman F9F Panther

This F9F-2 is being loaded with bombs on a carrier off the Korean coast. The nose cone has been extended forward to make the ammunition boxes accessible. Although the F9F was outclassed, the first jet-versus-jet combat ended when a F9F-2 shot down a MiG-15. There is some irony in the fact that the J42 engine was a version of the Rolls-Royce Nene, just like the VK-1 of the MiG-15. [46]

- Four 20mm Hispano M3 cannon in the nose, with 190 rounds per gun.

- The F9F fired 57 rounds per second, a weight of 7.4 kg/sec. Total muzzle power was 2660 kW. It had ammunition for 13 seconds.
- This was the best armament combination available, considerably more destructive than the .50s of the F-86 and without the disadvantages of trajectory and harmonisation of the MiG-15. But the foresight of the USN in the selection of armament was balanced by its conservative approach to aircraft design. Its F9F and F2H straight-wing jet fighters were outclassed by the two swept-wing types. The McDonnell F2H Banshee and the Gloster Meteor (operated in Korea by the RAAF) had the same armament as the F9F, and the same problem. They were used mainly for ground support operations. Grumman developed the swept-wing Cougar from the Panther, but the type was too late to see combat in Korea.
  American Military Aircraft

Mikoyan-Gurevich MiG-15


The MiG-15 shocked Western complacency when in appeared in combat over Korea. The engine had British origins and the aerodynamics were inspired by German research, but nevertheless it was a powerful reminder that the USSR had an advanced aviation industry. The MiG-15 had a higher service ceiling than the F-86, outclimbed it and was faster at high altitude. Evaluation of captured examples such as this one had a high priority.[32] The picture on the right shows the gun installation, in this case in a Polish-built Lim-5.[76] The neat weapons tray could be lowered for reloading and maintance.

- Late-production MiG-15s and the MiG-15bis had one 37mm N-37 cannon with 40 rounds and two 23mm NR-23 cannon with 80 rounds per gun. Early production MiG-15s had NS-23 guns with about half the rate of fire of the NR-23.
- The MiG-15bis fired seven 37 mm and twenty-eight 23 mm rounds, with a weight of fire of 10.7 kg/sec and a muzzle power of 1872 kW. The ammunition was expended in six seconds.
- The MiG-15 represented an approach to fighter armament that was totally different from that of the F-86: Big guns with a modest (690 m/sec) muzzle velocity, firing rounds with a very high destructive power. This armament had been devised to destroy bombers such as the B-29, and the MiG-15 very effective in that role. The USAAF was forced to call a halt to daylight B-29 operations. But for use against fighters this armament suite was less ideal; it mixed guns that were a poor ballistics match. In addition, the MiG-15 was a mediocre gun platform and had an inferior gunsight.
  Comparison Table

Name	Rounds	Weight	Energy
	(1/sec)	(kg/sec)	(kW)
North American F-86A Sabre	120	5.8	2203
Mikoyan-Gurevich MiG-15	22	5.8	1066
Grumman F9F Panther	57	7.4	2660
Mikoyan-Gurevich MiG-15bis	35	10.7	1872

Beyond doubt the best armament in use consisted of four Hispano cannon, in either the American M3 or the British Mk.V version. This offered both high destructive power and a high muzzle velocity. But the two best fighters of the war were the F-86 and the MiG-15: The armament of the first had a high muzzle velocity but was deficient in destructive power, and for the second the reverse was true. This rather absurd situation was the result of different priorities and a too late understanding of the importance of sweptback wing desings.

Fighter Gun Table

Here is a table of fighter armament since about 1935: I did not include the classic twin-gun biplane fighters. The columns in this list indicate:

- The subtype of the aircraft. This is important because armament often changed during production.
- The date of first delivery.
- The country of origin. To Japan, I added (A) or (N) to indicate Army and Navy aircraft, because there was no cooperation between the two services.
- The weight of fire in kg/sec, or the product of rate of fire with the weight of a "typical" round. Evidently, this could vary according to the type of ammunition used.
- The muzzle power in kiloWatts.
- The installed guns. The ammunition supply is indicated between brackets.

Only fixed, forward-firing armament is included. That excludes both flexible, defensive guns, and *Schräge Musik* installations. Multi-seat heavy fighters, fighter-bombers, and nightfighters are included; their names are rendered in boldface to indicate the distinction.

The selection of types and subtypes in this list is somewhat arbitrary, and also depends on the availability of the needed information. Only production fighters are included, not prototypes. The list is in chronological order.

If you have a browser that supports Java, you can also see a interaction representation of these data. If not, try the graphics version.

Name	First Delivery	Country	Weight of Fire	Muzzle Power	Armament
Boeing P-26A	34 Jan	USA	0.39	140	2 * 7.62 mm Browning .30 M2
Arado Ar 68F-1	36 Feb	Germany	0.37	110	2 * 7.92 mm MG 17 (500)
Supermarine Spitfire Mk.I	36 Jun	Britain	1.72	480	8 * 7.7 mm Browning .303
Macchi C.200 Saetta	36 Jul	Italy	0.86	250	2 * 12.7 mm Breda-SAFAT
Hawker Hurricane Mk.I	37 Oct	Britain	1.72	480	8 * 7.7 mm Browning .303
Messerschmitt Bf 109C-1	38 Feb	Germany	0.73	110	4 * 7.92 mm MG 17
Nakajima Ki.27-Otsu	38 Mar	Japan (A)	0.32	90	2 * 7.7 mm Type 89 (500)
Curtiss P-36A Hawk	38 Apr	USA	0.80	300	1 * 12.7 mm Browning .50 M2, 1 * 7.62 mm Browning .30
Fiat G.50 Freccia	38 Oct	Italy	0.86	250	2 * 12.7 mm Breda-SAFAT

Messerschmitt Bf 109E-3	38 Late	Germany	2.37	530	2 * 20 mm MG-FF, 2 * 7.92 mm MG 17
Polikarpov I-153	39 Feb	USSR	1.43	480	4 * 7.62 mm ShKAS
Fiat CR.42 Falco	39 Apr	Italy	0.86	250	2 * 12.7 mm Breda-SAFAT
Bloch MB.152	39 Apr	France	3.26	1230	2 * 20 mm Hispano 404, 2 * 7.5 mm MAC 1934
Caudron C.714 Cyclone	39 Jun	France	0.50	140	4 * 7.5 mm MAC 1934
Grumman F4F-3 Wildcat	40 Feb	USA	2.43	920	4 * 12.7 mm Browning .50 M2
Messerschmitt Bf 109E-4	40 May	Germany	2.37	530	2 * 20 mm MG-FF, 2 * 7.92 mm MG 17
Nakajima Ki.43-I-Otsu	40 Jun	Japan (A)	0.73	225	1 * 12.7 mm Ho-103 (250), 1 * 7.7 mm Type 89 (500)
Mitsubishi A6M2 Reisen	40 Jul	Japan (N)	2.62	410	2 * 20 mm Type 99-1 (100), 2 * 7.7 mm Type 97
Bristol Beaufighter Mk.IF	40 Jul	Britain	7.35	2370	4 * 20 mm Hispano Mk.II, 6 * 7.7 mm Browning .303
Messerschmitt Bf 109F-1	40 Nov	Germany	1.04	420	1 * 15 mm MG 151, 2 * 7.92 mm MG 17
Mikoyan-Gurevich MiG-3	40 Dec	USSR	1.55	545	1 * 12.7 mm UB, 2 * 7.62 mm ShKAS
Bell P-39D	41 Feb	USA	3.02	860	1 * 37 mm M4, 2 * 7.62 mm Browning .30, 2 * 12.7 mm Browning .50 M2
Lavochkin LaGG-3	41 Feb	USSR	1.99	710	1 * 20 mm ShVAK, 2 * 7.62 mm ShKAS
Supermarine Spitfire Mk.VB	41 Mar	Britain	2.24	1250	2 * 20 mm Hispano Mk.II, 4 * 7.7 mm Browning .303
Curtiss P-40D	41 May	USA	2.43	910	4 * 12.7 mm Browning .50 M2
Hawker Typhoon Mk.IB	41 May	Britain	5.20	2010	4 * 20 mm Hispano Mk.II
Focke-Wulf Fw 190A-3	41 Mid	Germany	5.20	1210	2 * 20 mm MG 151/20, 2 * 20 mm MG-FF, 2 * 7.92 mm MG17
Nakajima Ki.43-I-Hei Hayabusa	41 Jun	Japan (A)	1.14	360	2 * 12.7 mm Ho-103
Macchi C.202 Folgore	41 Jul	Italy	1.13	320	2 * 12.7 mm Breda-SAFAT, 2 * 7.7 mm Breda-SAFAT
Yakovlev Yak-1	41 Dec	USSR	1.99	715	1 * 20 mm ShVAK, 2 * 7.62 mm ShKAS
Yakovlev Yak-7	41 Late	USSR	2.64	1080	1 * 20 mm ShVAK, 2 * 12.7 mm UBS
Brewster F2A-3 Buffalo	41 Late	USA	2.43	920	4 * 12.7 mm Browning .50

					M2
Messerschmitt Bf 109F-4	42 Early	Germany	1.64	470	1 * 20 mm MG 151/20 2 * 7.92 mm MG 17
Kawasaki Ki.45-KAI-Ko	42 Jan	Japan	2.07	680	2 * 12.7 mm Ho-103, 1 * 20 mm Ho-3 (100)
Nakajima Ki.44-I-Ko	42 Jan	Japan (A)	2.28	720	4 * 12.7 mm Ho-103 (250)
North American Mustang Mk.I	42 Feb	USA	1.99	730	2 * 12.7 mm Browning .50 M2, 4 * 7.62 mm Browning .30
Republic P-47B Thunderbolt	42 Mar	USA	4.85	1830	8 * 12.7 mm Browning .50 M2
Vought F4U-1 Corsair	42 Jun	USA	3.64	1370	6 * 12.7 mm Browning .50 M2
Kawasaki Ki.61-I-Otsu	42 Mid	Japan	2.28	720	4 * 12.7 mm Ho-103
Messerschmitt Bf 109G-5	42 Mid	Germany	2.32	640	1 * 20 mm MG 151/20, 2 * 13 mm MG 131
Supermarine Spitfire Mk.IX	42 Jul	Britain	2.24	1250	2 * 20 mm Hispano Mk.II, 4 * 7.7 mm Browning .303
Messerschmitt Bf 109G-6	42 Aug	Germany	2.46	640	1 * 20 mm MG 151/20, 2 * 13 mm MG 131
Mitsubishi A6M3 Reisen	42 Aug	Japan (N)	2.48	520	2 * 20 mm Type 99-2 (125), 2 * 7.7 mm Type 97
Lavochkin La-5	42 Sep	USSR	2.56	950	2 * 20 mm ShVAK
Macchi C.205V Veltro	42 Sep	Italy	3.69	970	2 * 20 mm MG 151/20, 2 * 12.7 mm Breda-SAFAT
Lockheed P-38F Lightning	42 Sep	USA	3.73	1420	1 * 20 mm Hispano, 4 * 12.7 mm Browning .50 M2
Grumman F6F-3 Hellcat	42 Oct	USA	3.64	1370	6 * 12.7 mm Browning .50 M2
Nakajima Ki.43-II-Ko	42 Nov	Japan (A)	1.14	360	2 * 12.7 mm Ho-103 (250)
Yakovlev Yak-9	42 Nov	USSR	1.92	780	1 * 20 mm ShVAK, 1 * 12.7 mm UBS
Messerschmitt Me 410A-1/U2	42 Dec	Germany	3.29	950	2 * 20 mm MG 151/20 (350), 4 * 7.92 mm MG 17 (1000)
Nakajima Ki.44-II-Otsu	42 Late	Japan (A)	2.28	720	4 * 12.7 mm Ho-103 (250)
North American P-51B Mustang	43 Early	USA	3.64	1370	6 * 12.7 mm Browning .50 M2
Fiat G.55/I Centauro	43 Feb	Italy	5.12	1330	3 * 20 mm MG 151/20, 2 * 12.7 mm Breda-SAFAT
Reggiane Re.2005 Saggitario	43 Feb	Italy	5.12	1330	3 * 20 mm MG 151/20, 2 * 12.7 mm Breda-SAFAT
Kawanishi N1K1-J Shiden	43 Jul	Japan	2.11	820	4 * 20 mm Type 99-2

		(N)			
Kawasaki Ki.61-I-Otsu	43 Sep	Japan (A)	3.69	1080	2 * 12.7 mm Ho-103, 2 * 20 mm MG 151/20
Bell P-63A-1 Kingcobra	43 Oct	USA	2.63	1180	1 * 37 mm M4, 4 * 12.7 mm Browning .50 M2
Yakovlev Yak-3	43 Oct	USSR	2.64	1080	1 * 20 mm ShVAK, 2 * 12.7 mm UBS
Supermarine Spitfire Mk.XIV	44 Jan	Britain	2.24	1250	2 * 20 mm Hispano Mk.II, 4 * 7.7 mm Browning .303
Kawakaki Ki.61-I-KAI-Hei	44 Jan	Japan	3.95	1310	2 * 20 mm Ho-5 (120), 2 * 12.7 mm Ho-103 (200)
Lavochkin La-7	44 Feb	USSR	3.84	1420	3 * 20 mm B-20
Hawker Tempest Mk.V	44 Apr	Britain	6.50	2300	4 * 20 mm Hispano Mk.V (200)
Nakajima Ki.84-I-Ko Hayate	44 Apr	Japan (A)	3.95	1310	2 * 20 mm Ho-5 (150), 2 * 12.7 mm Ho-103 (350)
Kawanishi N1K2-J Shiden-KAI	44 Jul	Japan (N)	2.11	820	4 * 20 mm Type 99-2
Lockheed P-38L Lightning	44 Jul	USA	3.73	1420	1 * 20 mm Hispano, 4 * 12.7 mm Browning .50 M2
Messerschmitt Me 262	44 Jul	Germany	12.48	1590	2 * 30 mm MK 108 (100), 2 * 30 mm MK 108 (80)
Focke-Wulf Fw 190D-9	44 Aug	Germany	3.87	1000	2 * 13 mm MG 131, 2 * 20 mm MG 151/20
Gloster Meteor Mk.III	44 Sep	Britain	5.20	2010	4 * 20 mm Hispano Mk.III
Messerschmitt Bf 109K-4	44 Oct	Germany	4.16	670	1 * 30 mm MK 108, 2 * 13 mm MG 131
Mitsubishi A6M5-Hei Reisen	44 Nov	Japan (N)	3.49	1060	2 * 20 mm Type 99-2, 3 * 13.2 mm Type 3
Republic P-47M Thunderbolt	44 Dec	USA	4.85	1830	8 * 12.7 mm Browning .50 M2
Kawakaki Ki.61-I-KAI-Tei	44 Late	Japan (A)	7.51	1510	2 * 30 mm Ho-155, 2 * 12.7 mm Ho-103
Messerschmitt Bf 109K-6	44 Oct	Germany	10.40	1470	3 * 30 mm MK 108, 2 * 13 mm MG 131
Lockheed P-80A Shooting Star	45 Feb	USA	3.88	1370	6 * 12.7 mm Browning .50 M2
Supermarine Spitfire Mk.21	45 Apr	Britain	5.20	2010	4 * 20 mm Hispano Mk.II
Ryan FR-1 Fireball	45 May	USA	2.75	920	4 * 12.7 mm Browning M2
Kawasaki Ki.100-I-Otsu	45 Jun	Japan (A)	3.95	1310	2 * 12.7 mm Ho-103 (250), 2 * 20 mm Ho-5 (250)

Mikoyan-Gurevich MiG-13	45 Nov	USSR	3.84	1420	3 * 20 mm B-20
Vought F4U-5 Corsair	46 Apr	USA	7.37	2600	4 * 20 mm Hispano M3
Mikoyan-Gurevich MiG-9	46 Oct	USSR	8.69	2070	1 * 37 mm N-37, 2 * 23 mm NS-23
McDonnell FH-1 Phantom	46 Oct	USA	2.59	920	4 * 12.7 mm Browning .50 M2
Lavochkin La-7	47 Feb	USSR	7.32	1740	4 * 23 mm NS-23
Yakovlev Yak-15	47 May	USSR	3.66	870	2 * 23 mm NS-23
Republic F-84B Thunderjet	47 Aug	USA	5.82	1940	6 * 12.7 mm Browning .50 M3
Yakovlev Yak-17	47 Late	USSR	3.66	870	2 * 23 mm NS-23
North American FJ-1 Fury	48 Mar	USA	5.82	2200	6 * 12.7 mm Browning .50 M3
North American F-86A Sabre	48 May	USA	5.82	2200	6 * 12.7 mm Browning .50 M3
McDonnell F2H-1 Banshee	48 Aug	USA	7.37	2600	4 * 20 mm Hispano M3
Mikoyan-Gurevich MiG-15	48 Dec	USSR	8.69	2070	1 * 37 mm N-37, 2 * 23 mm NS-23
Yakovlev Yak-23	49 Early	USSR	3.66	870	2 * 23 mm NS-23
Vought F6U-1 Pirate	49 Mar	USA	7.37	2600	4 * 20 mm Hispano M3
Grumman F9F-2 Panther	49 May	USA	7.37	2600	4 * 20 mm Hispano M3
Lavochkin La-15	49 Late	USSR	3.66	870	2 * 23 mm NS-23
Lockheed F-94A	50 May	USA	3.88	1470	4 * 12.7 mm Browning .50 M3
Northrop F-89A Scorpion	50 Sep	USA	11.05	3900	6 * 20 mm M24
A.W. Meteor NF Mk.11	50 Nov	Britain	6.50	2300	4 * 20 mm Hispano Mk.V (160)
de Havilland Venom	51 Jun	Britain	6.50	2300	4 * 20 mm Hispano Mk.V
Supermarine Attacker	51 Aug	Britain	6.50	2300	4 * 20 mm Hispano Mk.V
Grumman F9F-6 Cougar	51 Dec	USA	7.37	2600	4 * 20 mm Hispano M3
North American F-86F Sabre	52 Mar	USA	5.82	2200	6 * 12.7 mm Browning .50 M3
Supermarine Swift F Mk.1	52 Aug	Britain	9.53	2970	2 * 30 mm Aden
Avro Canada CF-100 Mk.3	52 Sep	Canada	7.76	2200	8 * 12.7 mm Browning .50 M3
Mikoyan-Gurevich MiG-17	52 Oct	USSR	11.37	2710	1 * 37 mm N-37, 2 * 23 mm NR-23
North American FJ-2 Fury	52 Nov	USA	7.32	3740	4 * 20 mm Mk.12
Hawker Hunter F.1	53 May	Britain	19.06	5950	4 * 30 mm Aden
North American F-86H Sabre	53 Sep	USA	11.44	6070	4 * 20 mm M39
Yakovlev Yak-25	53 Late	USSR	10.03	2400	2 * 37 mm N-37L

Republic F-84F Thunderstreak	54 Jan	USA	5.82	2200	6 * 12.7 mm Browning .50 M3
Dassault Mystere IVA	54 May	France	11.90	5550	2 * 30 mm DEFA 541
Douglas F4D-1 Skyray	54 Jun	USA	7.32	3740	4 * 20 mm Mk.12
Gloster Javelin FAW Mk.1	54 Jul	Britain	19.06	5948	4 * 30 mm Aden
North American FJ-4 Fury	54 Oct	USA	7.32	3740	4 * 20 mm Mk.12
Canadair CL-13B Sabre 6	54 Nov	Canada	5.82	2198	6 * 12.7 mm Browning .50 M3
North American F-100C Super Sabre	55 Jan	USA	11.44	6072	4 * 20 mm M39
McDonnell F3H-2 Demon	55 Apr	USA	7.32	3740	4 * 20 mm Mk.12
North American F-86K Sabre	55 May	USA	7.37	2600	4 * 20 mm M24
Mikoyan-Gurevich MiG-19	56 Mid	USSR	18.45	5610	3 * 30 mm NR-30
Supermarine Scimitar	57 Jan	Britain	9.53	5948	4 * 30 mm Aden
Vought F8U-1 Crusader	57 Mar	USA	7.32	3740	4 * 20 mm Mk.12
Grumman F11F-1 Tiger	57 May	USA	7.32	3740	4 * 20 mm Mk.12
Dassault Super Mystere B.2	57 May	France	11.90	2000	2 * 30 mm DEFA 30M552
McDonnell F-101C Voodoo	57 Aug	USA	11.44	6072	4 * 20 mm M39
Republic F-105B Thunderchief	58 May	USA	11.11	5950	1 * 20 mm M61A1
Lockheed F-104A Starfighter	58 Dec	USA	6.73	3600	1 * 20 mm M61
English Electric Lightning F Mk.1	59 Oct	Britain	9.53	2974	2 * 30 mm Aden
Mikoyan-Gurevich MiG-21F	59 Late	USSR	12.30	3740	2 * 30 mm NR-30
Sukhoi Su-7B	60 Early	USSR	12.30	3740	2 * 30 mm NR-30
Dassault Mirage IIIC	60 Oct	France	11.90	2000	2 * 30 mm DEFA 30M552
Northrop F-5A Freedom Fighter	63 Oct	USA	5.72	3036	2 * 20 mm M39
Dassault Mirage IIIE	64 Jan	France	11.90	2000	2 * 30 mm DEFA 30M552
Mikoyan-Gurevich MiG-21PFM	64 Mid	USSR	11.33	3100	1 * 23 mm GSh-23L
Dassault Mirage F.1	69 Mar	France	11.90	2000	2 * 30 mm DEFA 30-553
Mikoyan-Gurevich MiG-23M	70 Late	USSR	11.33	3100	1 * 23 mm GSh-23L
Mikoyan-Gurevich MiG-21bis	72 Feb	USSR	11.33	3100	1 * 23 mm GSh-23L
Grumman F-14 Tomcat	72 Oct	USA	11.11	5950	1 * 20 mm M61A1
Northrop F-5E Tiger II	73 Mid	USA	5.72	3036	2 * 20 mm M39
McDonnell F-15A Eagle	74 Nov	USA	11.11	5950	1 * 20 mm M61A1
Saab JA37 Viggen	77 Nov	Sweden	8.10	4300	1 * 30 mm Oerlikon KCA
General Dynamics F-16A	78 Aug	USA	11.11	5950	1 * 20 mm M61A1
Dassault Mirage 2000C	82 Nov	France	16.50	2770	2 * 30 mm GIAT 30-554
Mikoyan-Gurevich MiG-31	82 Late	USSR	26.67	7300	1 * 23 mm GSh-6-23
Mikoyan-Gurevich MiG-29	82 Late	USSR	12.00	4750	1 * 30 mm GSh-301 (100)
McDonnell F/A-18A Hornet	83 Jan	USA	11.11	5950	1 * 20 mm M61A1 (570)

Panavia Tornado F.3	85 Nov	Britain	7.37	3870	1 * 27 mm BK 27
Saab JAS39 Gripen	93 May	Sweden	7.37	3870	1 * 27 mm BK 27
Sukhoi Su-27		USSR	7.37	4750	1 * 30 mm GSh-301 (150)

Fighter Firepower Chart

Here are plots of the total weight of fire, total muzzle power, and total number of rounds fired per second for a number of fighter aircraft. See the WWII fighters page for a discussion of these parameters.

The four horizontal lines in each plot represent the firepower of eight Browning .303 guns, six Browning .50 guns, four 20mm Hispano Mk.II cannon, and finally two 30mm MK 108 cannon.

You can manipulate the chart:

- Click on a label in the plot to get the name and armament specification.
- You can drag with the right mouse button depressed to zoom in, and click the center button to zoom out again. If you don't have a right or middle mouse button, you can use the left button in combination with the META (Ctrl on Windows system) and ALT keys.

Materials

Here is the source code for the applet, the data plotting class, a national symbols drawing class, an auxiliary math class, and the data file that is read by the applet.

Ballistics

Trajectories

1. Gravity and drag

The projectile, with mass *m* starts its trajectory at a height *h* equal to the height of the aircraft, and with a forward speed *v* that is the sum of the speed generated by the propellant in the cartridge case and the speed of the aircraft. The important variables are the kinetic energy

$$E_k = 1/2\ m\ v^2,$$

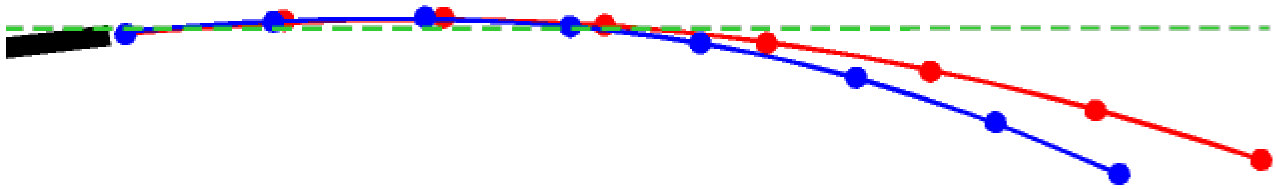
the potential energy

$$E_p = m\ g\ h,$$

and the momentum

$$p = m\ v.$$

Conservation of total energy and momentum are fundamental laws of physics. These quantities can not be destroyed, only exchanged with some other particles, or converted to a different form. As the projectile falls, its potential energy is converted into kinetic energy: It accelerates vertically, with an acceleration *g*. In vacuum the projectile would retain its horizontal speed, and follow a parabolic curve (red).



In air the projectile encounters drag, a speed-dependent force. The air molecules absorb part of the energy and momentum of the projectile, while the friction converts some of the energy to heat. In general this results in a trajectory that is more curved (blue), although a properly designed round might actually have some body lift, counteracting gravity. The line of sight is made to coincide as close as possible with the curve over the ranges expected in combat (green). Often the guns are given a slight upwards angle, to make the match easier. For guns in the wings this is convenient, because the wings have a positive angle of attack.

In addition, in WWII fighters the line of sight itself might be chosen a few degrees above the flightpath, because the view forward and downward was restricted by the contours of the engine; so it was advantageous to move the aiming point upwards, into the field of view of the pilot.

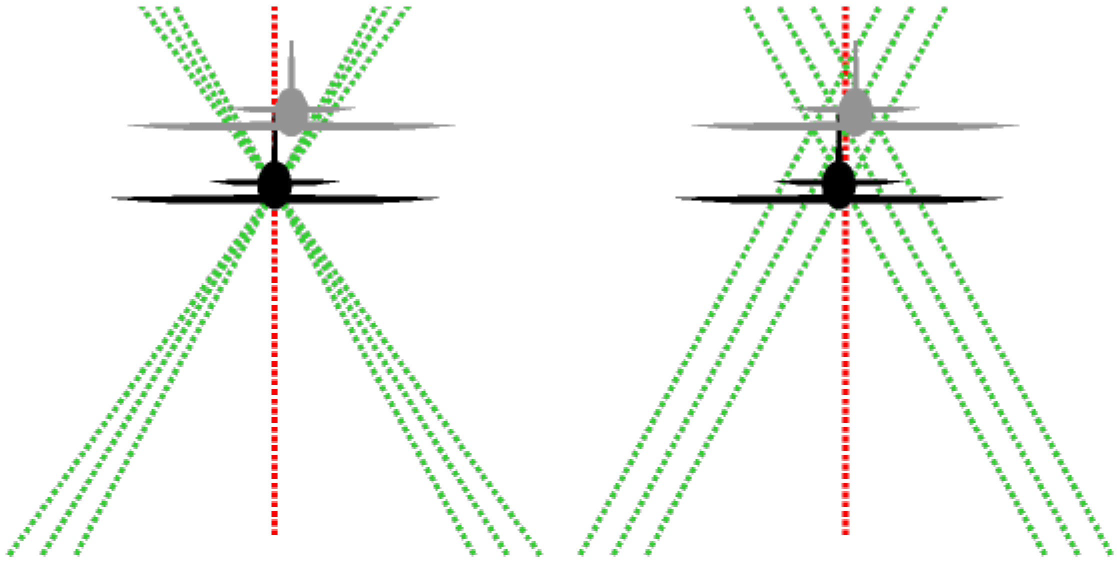
Gravity is of course the same for all projectiles. The drag is determined by their cross-section and aerodynamic shape, but independent of the weight. Drag is a force, and the same amount of drag will slow down a lighter projectile more: It has less momentum than a heavier one flying with the same speed. The mass is proportional to the volume, and therefore to the third power of the calibre; but the cross-section, and hence the drag, are proportional to the square of the calibre. Hence large calibre projectiles tend to retain their speed better, and have a longer range.

An alternative, however, is to fire a sub-calibre round, for example a discarded-sabot or squeeze-bore projectile. Because the gun is relatively powerful compared to the calibre, the initial speed will be high; and because the projectile has a slender profile, the drag will be low. By using an elongated projectile, it can still have a large mass. However, such guns tend to be designed for anti-armour use, not for anti-aircraft roles.

Evidently, rounds with a different mass or drag constant will follow different trajectories. Designers will try to choose propellants and weights to give different types of ammunition approximately the same trajectory, but this is hard to achieve. Tracer ammunition almost always has a different trajectory, because it is lighter and the burning of the tracer produces gas, reducing the drag of the projectile.

The problem is even more complicated when different types of gun are installed. During WWII that was common practice.

2. Harmonisation

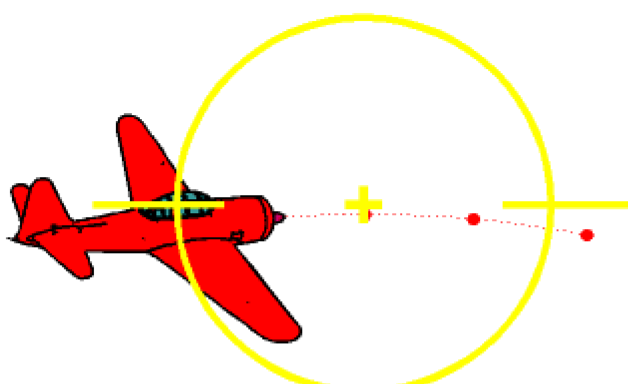


If a gun is close to the centreline of a fighter, the trajectory will be parallel to the course of the aircraft, and there is no harmonisation problem (red). However, on a single-engined tractor aircraft such guns must be synchronised to fire through the propeller disc, and this increases weight, reduces the rate of fire, and imposes strict conditions on the quality of the ammunition. And not all guns can be synchronized; some gun mechanisms are unsuitable. An alternative is arranging a gun to fire through the hollow axis of the propeller, but of course this is restricted to a single weapon.

If the guns are in the wings outboard of the propeller disc, they can be made to converge on a spot in the distance, corresponding with the most common distance of fire. This will give maximal weight of fire on a small spot (left), but requires accurating aiming and judgment of the range. An alternative is to harmonize the guns to a series of different distances (right), to create a larger zone of fire, sacrificing destructive power for a larger probability to hit the target.

For most jet aircraft this problem is eliminated. There is no propeller, there is room in the nose for weapons because the engine has been moved aft, and their thin wings are not very suitable to fit armament in anyway. On the downside, ingestion of gun gases by the engines must be carefully avoided.

3. Deflection shooting



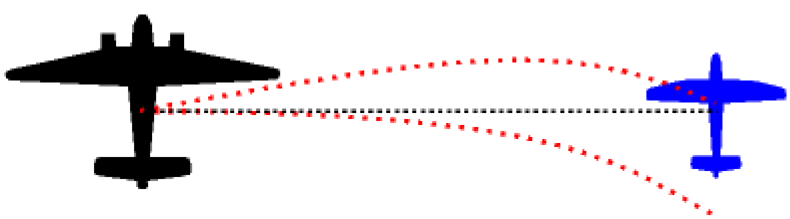
If the target moves across the course of the fighter, a certain amount of *lead* has to be taken into account: One has to fire at the point in space where the target will be when the projectiles arrive. The fighter therefore has to fly a curve while firing, i.e. it is turning at some rate. Evidently, there would be no problem if the projectiles arrived instantaneously. Of course they do not, but it is advantageous to reduce the *time of flight* as much as possible, by using guns with a high muzzle velocity. For example, the time of flight to 500 yards for the Browning .50 gun is 0.62 seconds. A flighter flying at 650km/h travels 112m in that time!

For most of WWII, the amount of lead required was left to the judgment of the pilot, with minimal assistance by his gunsight. Typically, deflector gunsights offered some means of estimating range, by comparing the known, dialled in, wing span of the enemy with markers (horizontal lines above) controlled by the pilot. The projected ring then gave an indication of the amount of deflection needed, but only an indication: The speed of the target across the firing line had to be estimated. Most pilots were not good at deflection shooting.

At the end of WWII gyroscopic gunsights were developed in Britain, and they soon appeared on both British and American aircraft. (A German equivalent was produced, but it was not sufficiently reliable.) The range still had to be determined in the same way. But if the pilot then turned the fighter at a certain rate to keep the target in sight, the gunsight would present a prediction of where the projectiles would be at that range. It did this by measuring the acceleration felt by the gyroscope, corresponding to the turn rate. The figher pilot then only had to make this spot coincide with the target. The result was a large increase in armament effectiveness.

After WWII, radar ranging gunsights appeared, often with computers built-in to provide an accurate prediction of the trajectory. Today's gunsights, if properly used, ensure an almost certain hit.

4. Own speed factor



Defensive gunners on a bomber aircraft, operating flexible guns, also have to cope with curved trajectories and deflection. In addition, they have the problem of the *own speed factor*. If they fire at a target on the beam, the bullets have the forward speed of the aircraft. Drag will not only curve the trajectory in the vertical plane, it will have the effect of "blowing back" the projectile, resulting in a trajectory that is curved backwards.

Various computing and compensating gunsights were developed before and during WWII, but apparently they were relatively little used for simple flexible gun installations. Powered gun turrets had more sophisticated sighting systems.

Notes

1. The M4, M10 and M9

By a publicity effort the American Aircraft Co. (AAC) managed to associate itself with the M4 and M10 series of cannon, and it is sometimes named as its manufacturer. In fact AAC's cannon was far inferior, and never seems to have been used in combat by anyone. The M4 was designed by Browning, and production was undertaken by Colt.

Another source of confusion is that rather frequently, the performance data for the Oldsmobileproduced M9 are listed in tables, creating the impression that this was a standard weapon in US aircraft, or that the performance of the M9 was somehow representative of that of far less powerful and more common M4 and M10 (for example in Ref. [26]). I have found no record of any installation of the M9 in production aircraft, the weapon seems only to have been used in a few prototypes. There are unproven rumours that it was installed in some aircraft Lend-Leased to the USSR...

2. Oerlikon cannon

The relatively modest performance of the Oerlikon cannon has been generalized by many people to the inaccurate conclusion that *all* WWII 20mm cannon were slow-firing, low-velocity weapons. A good example is Ref. 37, in which R. Mikesh makes a valuable effort to analyze the Zero's armament, but simply ignores the fact that the Japanese Navy made a poor choice when it adopted the Type 99-1 and 99-2 Oerlikon derivatives. The locked-breech weapons that replaced the Oerlikon in most services had considerably superior performance.

3. B-17 losses

In early 1943, before the distasters of Schweinfurt and Regensburg, the book "The Air Offensive Against Germany" by Allan A. Hitchie (Henry Hall & Co, NY, 1943) was published. The author of this work was obviously influenced by the RAF, and he gave a very realistic assesment of the defensive firepower of the B-17s and B-24s, and its limitations. These defeats did not happen without prior warning.

4. Evolution

Ref. 35 gives the following statistic: In the last 6 months of 1942 only 40% of the hits recorded on B-17 bombers were cannon hits. In the autumn of 1943 this had risen to 80%. In 1944 there were 35% more cannon hits than machinegun hits.

5. Hispano Mk.V

The British reduced gun stoppages with the Hispano to 1 in 1500 rounds, and the deletion of the in-flight recocking device illustrates their confidence in the weapon. But in US service complaints about the reliability of the Hispano, especially its feed mechanism, were frequent. (e.g. "Great enthusiasm was expressed over the 20mm cannons in the SB2Cs, even though feed-mechanism discrepancies occur frequently." *Ed Heinemann*, by E. Heinemann and R. Rausa, Naval Institute Press, 1980.) The causes of this discrepancy are unclear. They may be related to maintenance problems or to the design of the gun mounts. American-made Hispano cannon were considered satisfactory by the RAF.

6. Serrate

Serrate was a homing device tuned to the emissions of the German Lichtenstein SN-2 radar. This allowed the Mosquito to operate against German nightfighters. There was a reluctance to allow radar-equipped Mosquitos to operate over Germany, because the highly advanced radars would almost inevitably fall into German hands.

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