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# SPITFIRE L.F Mk.IX

for DCS World



## FLIGHT MANUAL *Fly a legend!*



Eagle Dynamics

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SERIES

Dear customer,

Thank you for purchasing the DCS: Spitfire IX module. This module, the fourth part of a series of aircraft simulators Digital Combat Simulator (DCS) for personal computers, allows you to experience flying legendary British aircraft during the Second World War.

As the owners of one of the biggest parks of restored aircraft from the Second World War, the staff of the Fighter Collection and the developers of Eagle Dynamics were fortunate enough to use their own Spitfire IX and study the experience of its pilots to create the world's most accurate virtual model of the aircraft. Using data from scientific research and volumes of documentation, together with visits to the Fighter Collection hangar, as well as numerous consultations and tests conducted by pilots of the Fighter Collection all made an invaluable contribution to the creation of the flight simulator.

When creating this guide, please refer to this manual regarding on the flight and technical operation of the Spitfire IX.

With respect to the brave pilots of the Second World War, we hope that you will enjoy taking to the skies and riding boldly into battle in this true English legend!

Yours sincerely,

The development team DCS: Spitfire IX

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# INTRODUCTION

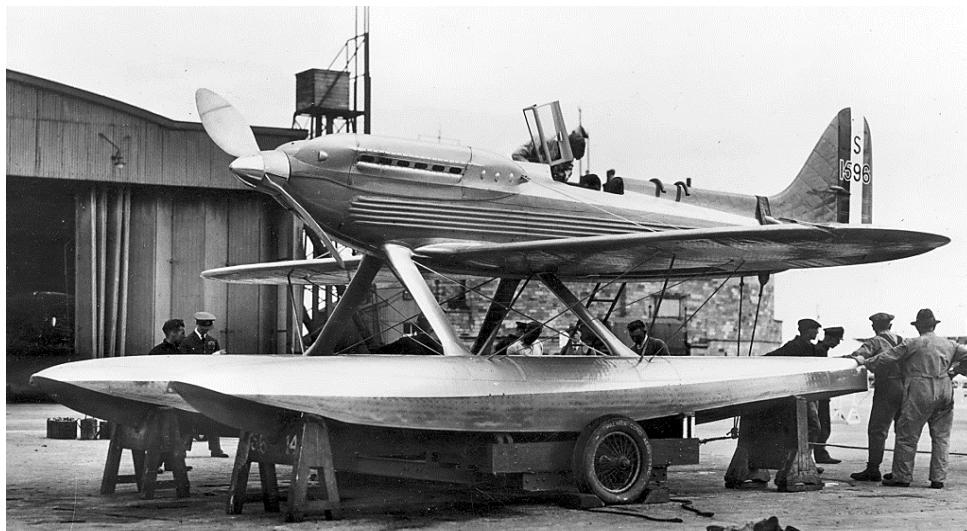


## INTRODUCTION

### The Birth of an English Legend

The Spitfire's story had its beginnings long before the Second World War at the aircraft firm of Pemberton Billing Ltd at Woolston, near Southampton, England. Although the company's main line of work was aircraft repair for the Admiralty, it did build a few of its own designs which were noted more for their originality than the length of their production runs. Shortly before the First World War ended, the company was renamed as the Supermarine Aviation Works. In 1919, the post of Chief Designer was assumed by the talented engineer Reginald Joseph Mitchell at the young age of 24. Mitchell moved to his new job in 1916, when he was 21, and afterwards he managed to advance rapidly in the company.

In the years that followed, Supermarine concentrated on the design and production of seaplanes, and first achieved prominence in 1922 when its Sea Lion biplane flying boat won the Schneider Prize by completing the circuit at an average speed of 145mph. In 1925, the company saw its first design to gain a substantial production order: the twin-engine Southampton reconnaissance flying boat. Eventually, 79 units were built for the Royal Air Force and foreign governments. Supermarine's small racing seaplanes continued their run of successes, and during the period from 1927 to 1931 they won a number of racing events. These successes brought considerable fame to the Supermarine company, but few orders. In the nature of things, the market for high speed racing seaplanes was extremely limited.



**Figure 1: The Supermarine S.6B Racing Seaplane**

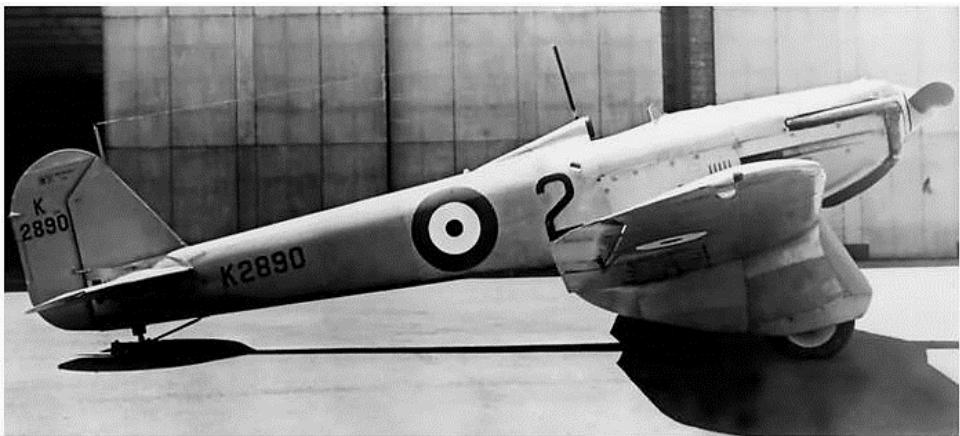
In the autumn of 1931 the Air Ministry issued specification F7/30 for a fighter aircraft to replace the ageing Bristol Bulldog in the Royal Air Force squadrons. The new fighter was to have:

1. Highest possible rate of climb
2. Highest possible speed above 15,000 feet
3. Fighting view
4. Maneuverability
5. Capability of easy and rapid production in quantity
6. Ease of maintenance.

It was to be armed with four machine guns and be able to carry four 20 pound bombs. Any approved engine of British manufacture could be used to power the new fighter.

Supermarine's entry to the competition, the Type 224, was a low-winged monoplane of all-metal construction - a considerable novelty at that time. The Type 224 was to be powered by the 660 horsepower Rolls-Royce Goshawk engine which was the most powerful engine available for this purpose. The Goshawk was designed to work with the newly developed evaporative cooling system, which promised a much cleaner aerodynamic design than was possible with the older system of external radiators to dissipate the heat from the engine coolant.

With evaporative cooling the water coolant was pumped through the water jacket around the engine under pressure, so that although the coolant temperature was higher than the normal boiling point of water, steam did not form. As the water emerged from the engine it was depressurized and steam immediately formed. This steam was then piped through to a condenser fitted in the leading edge of the wing, where it condensed back into water and ran to a collector tank before being pumped back to the engine. The Supermarine design was the only monoplane to use the evaporative cooled Goshawk. In its case the steam condenser ran along almost the entire leading edge of the wing; and when the steam condensed the water trickled down into collector tanks fitted at the top of the fairings of the fixed undercarriage. To increase the rate of heat dissipation, the outer skinning of the leading edge of the wing was corrugated. Compared with what was to follow, the Type 224 was not a very refined design, neither structurally nor aerodynamically.



**Figure 2: The Type 224**

The aircraft made its first flight in February 1934 and soon revealed a fundamental problem in using evaporative cooling in a low-winged monoplane design: engine overheating. The Type 224's Goshawk

was prone to overheating during rapid climbs to altitude - an important function for an interceptor fighter. The fighter had a top speed of only 238 mph and took eight minutes to climb to 15,000 feet. Such shortcomings might have been acceptable if the Type 224 had had a performance greatly superior to that of its competitors, but it did not. The winner of the competition was the far more robust and nimble Gloster 8837, a radial-engined biplane of conventional design, which was to go into service with the RAF as the Gladiator. The SS 37 had a maximum speed of 242 mph - with its rate-of-climb the Gloster fighter was able to clearly demonstrate its superiority: reaching 15,000 feet in six and a half minutes, one and a half minutes earlier than the Type 224. After the service trials at Martlesham Heath the sole prototype went to Farnborough; it ended its days in mid-1937 as a ground firing target on the range at Orfordness. In the meantime, however, the Supermarine design team was to show that it could produce something far better.

In the summer of 1934, even as the Type 224 was undergoing its trials at Martlesham, Supermarine had opened discussions with the Air Ministry regarding an improved design with a better performance. The new aircraft, designated the Type 300, was to be based on the Type 224. But by cleaning up the design a little, fitting a retractable undercarriage, getting rid of the draggy corrugated wing leading edge and lopping more than 6 feet off the wing span, it was estimated that the fighter's speed could be increased by 30 mph to 265 mph using the same Goshawk engine.

Towards the end of July 1934 this proposal was submitted to the Air Ministry as the Supermarine Specification 425a. The Air Ministry was lukewarm towards the new proposal, which offered only a marginal increase in performance over the other fighter. Mitchell was not put off by this rejection, however, and he and his team continued work on further refinement of the Type 300 design. By the early autumn this was being offered as a fighter smaller still with a wing span of 37 ft 1 in, a somewhat thinner wing, a faired cockpit and stressed skin construction. The engine was still to be an evaporatively cooled Goshawk, but the top speed would be around the 280 mph mark. With a better engine the maximum speed would be higher and there was a suggestion that the fighter should be fitted with a Napier Dagger (then in development with specifications at 700 horsepower, with more than 800 planned for newer models.) During a meeting of the board of Vickers (Aviation) Ltd on 6 November 1934 this idea was turned down in favour of an even better engine now in the offing: the Rolls-Royce PV XII, later to be named the Merlin. At this time the PV XII was suffering its share of teething troubles and was not yet ready for production. The target output for the new 27-liter engine was 1,000 horsepower. During November 1934 Mitchell received permission to proceed with the design of a PV XII-powered Type 300 fighter.

The decision to combine the revised Type 300 airframe with the PV XII engine drew immediate interest from the Air Ministry. On 1 December 1934, contract AM 361140/34 was issued, providing £10,000 for the construction of a prototype fighter to Mitchell's 'improved F.7/30' design. The new aircraft was to be ready in October 1935. Several previous accounts have suggested that the new fighter was all throughout a private venture, although documentary evidence from that time suggests that this is not the case. In actuality, the Type 300 with the PV XII engine was a private venture for less than a month, ending with the issue of the Air Ministry contract on 1 December. The contract for the new Supermarine Type 300 fighter was formalized on 3 January 1935 and a new Air Ministry specification, F.37/34, was written around Mitchell's improved design. The specification was in fact a short addendum to F.7/30. The larger PV XII engine weighed about one-third more than the Goshawk, so to compensate for the forward shift of the center of gravity, the sweep-back of the leading edge of the wing was reduced. From there it was a short step to embody the elliptical wing which would be the most distinctive and recognizable feature of the new fighter.

The elliptical wing was aerodynamically the best option for the required purposes because induced drag was lowest when this shape was used while producing lift. The ellipse was the ideal, theoretically perfect shape. As straight-tapered wing starts to reduce in chord from the moment it leaves the root; an elliptical one, on the other hand, tapers only very slowly at first then progressively more rapidly

towards the tip. The ellipse was simply the shape that allowed using the thinnest possible wing with sufficient room inside to carry the necessary internal structure and everything else that was to be crammed in.

Specification F.37/34 had called for a fighter armed with four machine guns, but it was becoming clear that this was insufficient firepower to destroy the faster all-metal bombers then going into service in several air forces. Squadron Leader Ralph Sorley was in charge of the Operational Requirements section at the Air Ministry at the time the F.37/34 was taking shape. He insisted that new fighters be armed with the new Browning gun being tested in Britain, which offered a higher rate of fire. According to Sorley's calculations, the airspeed of these modern bombers would probably allow the pursuing fighter only one chance of attack, so it must be destroyed in that vital two-second burst. Sorley's arguments convinced the Deputy Chief of the Air Staff, Air Vice Marshal Edgar Ludlow-Hewit, and as a result the main 1934 fighter specification, F.5/34, called for an aircraft armed with eight machine guns. However, the new specification had not linked to the aircraft Mitchell was working on. The specification that did affect the new Supermarine fighter was F.10/35, which asked for a fighter with at least six guns though eight were desirable. Towards the end of April 1935 Sorley paid a visit to Supermarine Works to discuss with Mitchell both his new fighter and the latest Air Ministry specification.

So it was that the new Supermarine fighter was brought into line with F.10/35, the armament to be '8 Vickers Mark V or Browning guns with 300 rounds of ammunition per gun.' The revised contract permitted 'the reduction of fuel to 75 gallons, though the actual tankage need not be reduced unless it is necessary to do so to provide space for the guns.' To Reginald Mitchell this was an opportunity to shed 1.6 cubic feet of volume from the engine area and he grasped at it; the prototype of the new fighter was fitted with tanks for only 75 gallons of fuel.

In June 1935 a 1/24th scale model of the F.37/34 fighter (it was never referred to as the F. 10/35, even after it had been altered to conform with this specification) underwent wind tunnel tests at Farnborough to determine its spinning characteristics. In the middle of 1935, the design of the F.37/34 fighter was still unsound in one important aspect: its PV XII engine was still to have evaporative cooling and this, as it was seen, could not be made to work properly on a low winged monoplane. Mitchell was reluctant to resort to the more conventional forms of external radiators, which would have considerably increased the drag of the new fighter. In retrospect, the problem of engine cooling might seem only a trivial part of the story, but as things stood, it could have led to the downfall of the fighter. When the Merlin (as the PV XII was now named) was running at full power it produced about 12,500 centigrade heat units of excess heat each minute, the equivalent of 400 one-kilowatt electric fires running simultaneously. About 90 percent of this heat had to be removed by the liquid cooling system, the remainder by the oil cooler.

Fortunately, at this time Fred Meredith at Farnborough had been conducting some experiments, which showed that a new type of ducted radiator could solve the problem. In Meredith's radiator, the air entered from the front through a duct whose cross-sectional area was progressively widened, to reduce its velocity and therefore increase pressure. The slightly compressed air then passed through the matrix of the radiator where it was heated and so expanded; then it was passed through a divergent duct at the rear which caused an increase in the velocity of the airflow. Thus, the ducted radiator acted rather like a ramjet: the ram air was compressed, heated, and then expelled from the rear with increased velocity to produce thrust. The amount of thrust produced by the ducted radiator was small and only under optimum conditions would it exceed the drag, although, compared to alternative cooling systems, Meredith's design was greatly superior. The efficiency of the cooling system was further improved by the use of ethylene glycol, which had a boiling point considerably higher than that of water, as the coolant. This meant that the radiator could be run much hotter, and consequently, necessary heat dissipation could be accomplished with a smaller and lighter radiator holding less coolant. It was also found that an ethylene glycol system could be built for between a third and a half the weight of an equivalent water cooling system.

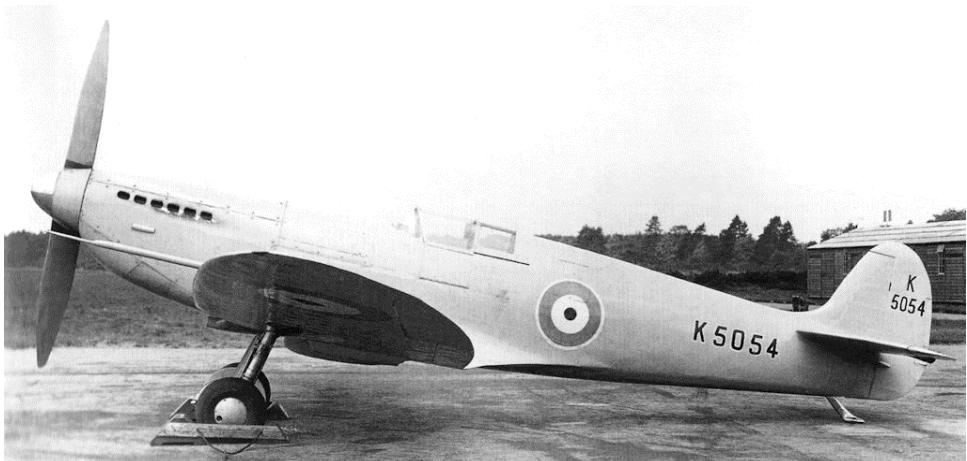
Reginald Mitchell knew good ideas when he saw them, and enthusiastically incorporated the new cooling system into his fighter. By August 1935 the design saw alterations in several key aspects from the F.37/34 submission at the beginning of the year, though the external appearance of the aircraft had changed relatively little. The revised design now carried eight guns instead of four, no bombs, tankage for 75 gallons of fuel instead of 94, it had a slightly longer fuselage and a raised tailplane, a wing of increased dihedral and ducted radiator in place of evaporative cooling. Work had begun to cut the metal that would transform the nice-looking design into what was hoped would be a successful aircraft.

## Service Trials

On February 18<sup>th</sup>, the F.37/34 had been completed and was undergoing engine runs on the hardstanding on the River Itchen side of the works at Woolston. Once these were done, the wings were removed and the aircraft was loaded on to a lorry, which took it to the works airfield at Eastleigh for reassembly prior to the maiden flight. After reassembly at Eastleigh the prototype F.37/34 underwent further engine runs.

During the first week of March 1936, the prototype of the F.37/34, K 5054, was in the Supermarine hangar at Eastleigh undergoing final preparations for the first flight. The aircraft was fitted with a fine pitch wooden two-bladed propeller, to give optimum performance for takeoff and at the low speed end of the performance envelope. At that time retractable undercarriages were still considered a new feature, so for the initial flights the main undercarriage legs were locked down and the fairing doors were not fitted.

On 5 March 1936, K 5054 made its maiden flight. That day the weather was good: clear skies, visibility moderate to good and a light wind coming mainly from the southwest. Vickers Company's Chief Test Pilot, Captain J. 'Mutt' Summers climbed into the cockpit and strapped in, then started the engine. When he was satisfied that all was as it should be he waved away the chocks, then with a burst of power the little fighter surged forward over the grass. The first flight took about 20 minutes. During the three days following the maiden flight the fine pitch propeller was replaced by one of coarse pitch designed to take the fighter to its maximum speed; undercarriage doors were fitted, the legs unlocked and the mechanism tested. Summers made the second flight on the 1<sup>st</sup>, during which he retracted the undercarriage in the air. On the following day, he made the third flight.



**Figure 3: The Spitfire Prototype K 5054**

In the course of the initial flight testing the only real fault found on the new fighter was that the rudder horn balance was too large and as a result the control was unacceptably light; at high speed the aircraft became directionally unstable. Otherwise there was little to complain about, except that K 5054's maximum speed was well below the 350 mph that had been predicted. It was hoped that this would be increased with the incorporation of certain planned minor modifications, and after testing with a selection of different propellers. Early in April the initial test program was complete and K 5054 had to undergo ground resonance tests. During the tests it was found that wing flutter was liable to occur at speeds somewhat lower than expected. As a result, the never-to-be-exceeded maximum airspeed for the prototype was set at 380 mph indicated. Then the prototype was undergone initial modifications at Eastleigh, the main ones were that the size of the rudder horn balance was reduced and the top of the fin squared off, the carburetor air intake was lowered slightly to increase the ram air pressure and the engine cowling was strengthened-there had been some problems with it rattling in flight. To raise the maximum limiting speed of the aircraft would require a major structural redesign of the wing; K 5054 was to continue with the wing it had.

Also at about this time the Vickers parent company suggested and the Air Ministry accepted a name for the new fighter: Spitfire. By all accounts, Mitchell himself was not pleased with the choice and was heard to say 'Its the sort of bloody silly name they would give it!'

After the modifications were completed, K 5054 was flown again by the test pilot Jeffrey Quill on the 13th, then on the 14th he conducted high speed dives to take it to the maximum permissible speed. During the first he reached 360 mph indicated and found that the aircraft handled perfectly and there were no problems. Quill pulled out, then climbed back to 20,000 feet for the second dive. Again, the speed built up rapidly and as it reached 380 mph, the maximum allowed and equivalent to a true airspeed of 465 mph, there was a loud bang. Gently the pilot eased the aircraft out of the dive and took it back to Eastleigh. After landing it was found that the lower fairing on the port undercarriage leg had broken away and struck and damaged the underside of the fuselage. The damage was not serious, however, and by the following day it had been repaired and the prototype was able to resume trials.

At this time there was considerable pressure to get the new fighter to the Royal Air Force trials establishment at Martlesham Heath as soon as possible. The Hawker fighter, which later became the

Hurricane, was already there and if the Spitfire did not begin service trials soon it might fail to get an order by default. But at this stage the Spitfire was still not yet fit to be delivered.

Finally on 26 May everything was ready and Mutt Summers delivered the Spitfire to Martlesham. Even at this early stage the new fighter received special treatment. It was usually about 10 days before a new aircraft came out for its first flight, but there were orders came from the Air Ministry that the prototype was to fly same day. The first flight in K 5054 at Martlesham was made by Flight Lieutenant (later Air Marshal Sir) Humphrey Edwardes-Jones. The trial flights of the prototype Spitfire continued a few days and on the 6th and the 8th speed trials were flown. During these trials, the maximum speed of the prototype was measured at 349 mph at 16,800 feet, 1 mph more than Jeffrey Quill had recorded three weeks earlier. The trials at Martlesham ended on 16 June, when Jeffrey Quill arrived to collect K 5054 and take it back to Eastleigh for the press day planned for two days later.



**Figure 4: The K 5054 in Test Flight**

In a week, K 5054 was ready for the first public demonstration. Hugh Edwardes-Jones went to Eastleigh to pick it up and fly to Hendon, and on the 27th he showed the Spitfire off in front of a large crowd at the Royal Air Force Pageant there. Two days later Mutt Summers demonstrated the Spitfire at the SBAC show at Hatfield. Public interest in the new fighter was immediate and the *Flight* magazine waxed lyrical about the show Summers had given at Hatfield:

"It is claimed - and the claim seems indisputable - that the Spitfire is the fastest military aeroplane in the world."

By 1 July the prototype was back at Martlesham and being prepared to resume the service trials. On 11 July, Edwardes-Jones took the prototype Spitfire up to its highest altitude yet, 34,700 feet, which took him 37 minutes to reach. Towards the end of this series of trials K 5054 was fitted with a Fairey-Reed three-bladed metal airscrew and on 29 July Jeffrey Quill journeyed to Martlesham to test it. He found that with the three-bladed the take-off was similar to that with the wooden two-bladed airscrew, but climbing performance and top speed were slightly worse. The two-bladed airscrew was refitted and on 1 August Quill returned K 5054 to Eastleigh. The initial service trials were now complete, and the

prototype was now to be fitted with the 8-gun armament and receive several minor modifications. Then was followed by spinning trials, trials with different propellers and experiments with aircraft riveting.

On the 23rd the Spitfire was flown back to Martlesham. The main feature of the new series of trials was to be the firing of the Spitfire's guns (there were no facilities for this at Eastleigh). On 26 February the four port guns were tested on the butts and fired perfectly; on 1 March the four starboard guns were similarly tested. On 6 March the fighter was taken up to 4,000 feet with a full load of ammunition and the guns fired again; all functioned perfectly.

On 22 March, K 5054 suffered its first major accident. Flying Officer Sam McKenna was testing the Spitfire with revised gearing between the stick and the elevators, following complaints of elevator buffeting when pulling out of loops and tight turns. McKenna made a series of loops, pulling steadily increasing accelerations up to 4 G. Then he dived the aircraft to 350 mph indicated and made tight turns at up to 4 G. When the trial was complete however, and he throttled back to 1,600 rpm to return to Martlesham, the oil pressure suddenly fell to zero and the engine began to run roughly and noisily. This condition got steadily worse so McKenna switched off the engine and decided to make a forced landing. He selected a strip of heath-land near Sutton beside the Woodbridge-Bawdsey road, and glided the Spitfire in with flaps lowered and undercarriage up; fortunately, the propeller had come to rest in the horizontal position. The tail wheel touched first and ran along the ground for about 100 yards, then the fuselage dropped and the aircraft slithered across the ground for a further 50 yards before it came to rest just ten yards short of a hole eight feet deep.

Unfortunately, Mitchell would not live long enough to witness his fighter enter service in the RAF. At the time, Reginald Mitchell's health had been deteriorating steadily and since the beginning of 1937 he was able to spend less and less time at Supermarine. An operation to arrest the cancer proved unsuccessful and his condition was found to be incurable. Reginald Mitchell died on 11 June at the age of 42, a great loss to all who knew him. Then, shortly after Mitchell's death, Joe Smith was promoted from Chief Draughtsman to Chief Designer at Supermarine.

On 19 September the Spitfire was flown for the first time with an ejector exhaust system. The system could provide about 70 pounds of additional thrust - the equivalent of 70 horsepower at 300 mph - almost for nothing. It was a useful addition, which would increase the speed of the prototype to about 360 mph. Early 1938 saw a series of night flights that resulted in a landing accident on 15 March, though the damage incurred was relatively minor and was quickly repaired with the aircraft ready for flight by 19 March, just three days after the incident.

In the meantime, however, the importance of the prototype had been eclipsed by the maiden flight of the first production Spitfire, K 9787, on 15 May. The main task of the prototype was now to prove the effectiveness of modifications considered for production aircraft, the most important of which were the modifications intended to solve the nagging problem of providing sufficient gun heating at high altitude. With the successful completion of the gun heating tests, K 5054 ends its role in the development of the Spitfire.

The flying career of K 5054 came to an end on 4 September 1939, the day after England entered the Second World War. The aircraft suffered serious damage while landing, the pilot succumbed to his injuries two days later, and K 5054 was never repaired afterward.

## Serial Production

In 3 June 1936, before the service trials of the prototype Spitfire had really begun at Martlesham, the Air Ministry had placed an order for 310 examples of the new fighter. Eight weeks later, at the end of July, the Air Ministry issued Specification F.16/36, which set out the respects in which production Spitfires were to differ from the prototype. The most important details concerned the revision of the

wing structure to make it stiffer and raise the maximum limiting speed to 450 mph (indicated), 70 mph higher than that of the prototype. Other important changes to the airframe were that the fuel tankage was to be increased from 75 gallons on the prototype to 84 gallons on production Spitfires, and the flap travel was increased from 57 degrees to 85 degrees. Apart from the changes demanded by the Air Ministry, there were those incorporated by the company to ease the complex task of mass production. In the production of the aircraft, several parts were to be forged or cast rather than built up from separate pieces, and much more extensive use was to be made of pressings and extruded sections.

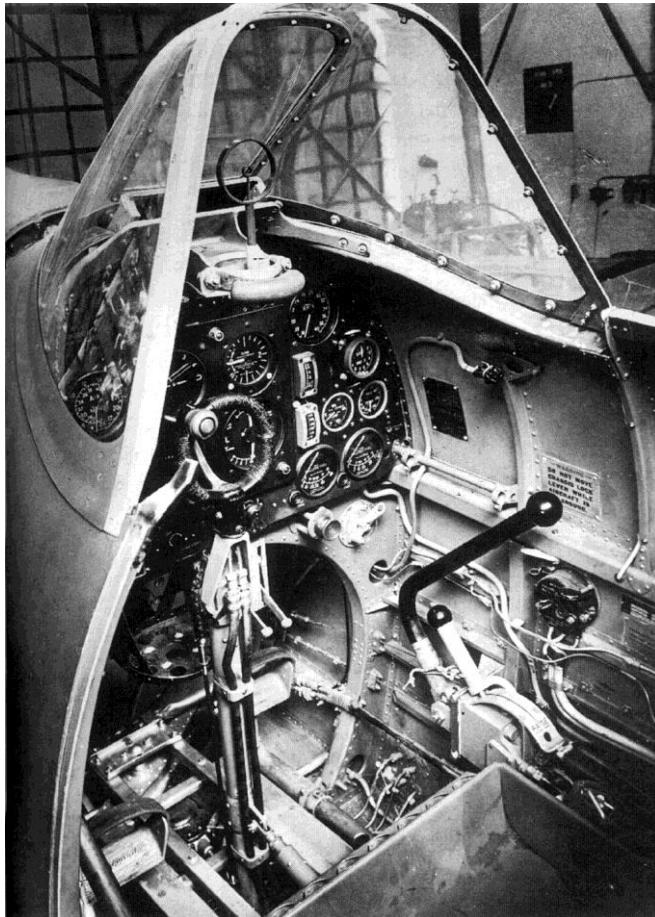


Figure 5: Spitfire Mk I Cockpit

In February 1936, shortly before the prototype made its first flight, Sir Robert McLean (the Chairman of Vickers Aviation Ltd.) had said his firm would be able to begin production of the new fighter 15 months after the placing of the order, at a rate of five aircraft per week. Soon it became clear that the firm did not have enough productive capacity to provide the required production rate. The Supermarine company employed about 500 people and was engaged in fulfilling orders for 48 amphibious vehicles

and 17 flying boats for the RAF. The simple fact was that the small company did not have resources to be able to fulfill the large order it had landed. Fortunately, a solution was found relatively quickly: subcontract part of the work; thus in November 1936 General Aircraft Ltd at Feltham received an order to build Spitfire tails. The production program was revised and it was now planned to build four Spitfires in December 1937, 6 each in January and February 1938, eight in March and ten each in April and May.

Not until 15 May was the first production Spitfire, K 9787, ready to fly. Jeffrey Quill took it up on that day and found it was all that had been expected, and with the extra 28 degrees of flap travel it came in steeper than the prototype and was easier to land. Subsequent flutter tests at Farnborough revealed that the aircraft could be taken up to 470 mph indicated airspeed, 20 mph more than the Air Ministry had demanded. Now the Spitfire could dive faster than ever before, Jeffrey Quill discovered a new problem: at speeds above 400 mph indicated, the aircraft's ailerons became almost impossible to move.

On 19 July the RAF receive its first production Spitfire, K 9788 the second in the batch, which was delivered to Martlesham for trials. It was followed by the first production aircraft K 9787, on the 27th. On 4 August No 19 Squadron at Duxford, which was to be the first unit to receive the new fighter, received its first Spitfire K 9789; K 9790 arrived on the 11th and K 9792 on the 16th.

Only two Spitfires were delivered to the RAF in September 1938, but in October there were 13 and production continued at this rate until the end of the year. By the beginning of 1939 a total of 49 Spitfires had been delivered to the RAF. Although the new fighter was now coming off the production lines in useful numbers, the aircraft was still deficient in one important respect: the early production Spitfires lacked gun heating, which meant their guns could not be relied upon to fire at high altitude. Gun heating was built into production aircraft in early 1939, when 60 of the new fighters had been already delivered.

With the war clouds gathering over Europe it was clear that far more Spitfires were going to be needed than could be built at the Supermarine plants around Southampton. Work on building the new plant began in July 1938; it would play an important part in the Spitfire story, but later.

## In Service

On 19 July 1938 the first Spitfire to be delivered to the RAF, serial K 9788, arrived at Martlesham Heath for trials. Eight days later it was followed by the first production aircraft, K 9787. No 19 Squadron at Duxford was chosen to introduce the new fighter into service and its first aircraft, K 9789, arrived on 4 August. Two further Spitfires were delivered in August and No 19 Squadron and No 66, a sister squadron at Duxford earmarked to receive the new fighter, were ordered to undertake intensive flying trials with a couple of Spitfires. The purpose of these trials was to discover any bugs that had not been ironed out of the aircraft.



**Figure 6: Spitfire Mk V in Flight**

The test-pilots at Duxford were greatly impressed with the Spitfire and considered it a major improvement over the Gauntlet biplanes they had flown before. But there was room for improvement, as according to the memoirs of one of the test-pilots, there were a number of critical issues: the engines of these first Spitfires were difficult to start, because the low-gearied electric starter rotated the propeller blades so slowly that when a cylinder fired there was usually insufficient push to flick the engine round to fire the next. The early Merlin engines leaked oil terribly; it would run from the engine, down the fuselage and finally get blown away somewhere near the tail wheel. Another problem was what the pilots called 'Spitfire Knuckle': when pumping up the undercarriage it was all too easy to rasp one's knuckles on the side of the cockpit. There was also another problem for the taller pilots, who were always hitting their heads on the inside of the low cockpit canopy.

All of these problems had been pointed out by the Supermarine test pilots, and modifications were in hand to address them. A higher speed starter motor solved the engine starting problem. A new bulged canopy provided the necessary extra headroom for the taller pilots. An engine driven hydraulic system to raise and lower the undercarriage did away with the need to hand pump, and thus the resultant 'Spitfire Knuckle' was no longer a concern. These improvements were all introduced on the production line early on. The improved oil seals for the Merlin took longer to bring in, and indeed leaking oil was to remain a problem throughout the engine's long career.

New Spitfires arrived at Duxford from the makers one at a time at irregular intervals. And it was December 1938 before No 19 Squadron had its full complement of sixteen Spitfires. During the early months of 1939 the rate at which Spitfires left the assembly hangar at Eastleigh increased steadily; in May there were 41. The first 77 production Spitfires were delivered with the two-bladed wooden airscrew. From the 78th aircraft the de Havilland three-bladed metal airscrew was fitted as standard. By then all new aircraft had the bulged cockpit canopy; and production Spitfires were being delivered with the hot air ducting in the wings to keep the guns warm at high altitude.

By the late 1930s, bombers were beginning to appear carrying armor protection for the crew and vital parts of their structure. Something heavier than the .303-in Browning gun would be necessary to penetrate steel armor of any thickness. The weapon selected by the Royal Air Force for its fighters was the French Hispano 20 mm cannon, which had the best armor penetration capability of any weapon of

that caliber then available. In July 1939 a Spitfire, L 1007, was tested at Martlesham fitted with two 20 mm Hispano guns each with 60 rounds, in place of the eight Brownings. The early service career of the Hispano gun in the Spitfire, however, was a sad tale of frequent stoppages and failures, as the cannon tended to shake itself and the feed system apart during firing; nevertheless, further experiences in combat would eventually prove that the Hispano was a very effective weapon when it works.

When war came, in September 1939, a total of 306 Spitfires had been delivered to the RAF. A further 71 Spitfires were held by maintenance units, either for fitting of operational equipment or awaiting delivery to operational squadrons to replace losses; 11 of these fighters were being employed for trials work and one was being flown at the Central Flying School. The remaining 36 Spitfires delivered before the war had all been written off in accidents.

The Spitfire first saw action against the Luftwaffe on the afternoon of 16 October 1939, when two 3-aircraft sections from No 602 and 603 Squadrons engaged nine Junkers 88 bombers of Kampfgeschwader 30 trying to attack Royal Navy warships in the Firth of Forth. The Spitfires broke up the attack, claimed at the time to have been made by 'Heinkel 111s'. Squadron Leader Ernest Stevens, commanding No 603 Squadron, shot down one of the bombers into the sea off Port Seton and the section from No 602 Squadron got another off Crail. At least one other Junkers 88 was damaged, without loss to the Spitfires.



**Figure 7: Pair of Spitfire Mk IX aircraft**

For the rest of 1939 and the early part of 1940 Spitfires saw infrequent action during the rare occasions when German bombers and reconnaissance aircraft came within range of their bases in England.

In May and early June 1940, in the period leading up to and during the Dunkirk evacuation, the Spitfire first encountered its German equivalent, the Messerschmitt 109E, over northern France, Belgium and Holland. Still no Spitfire fighter squadrons had been based outside Britain and the fighters had to operate near to the limit of their radius of action from airfields in southern England. Nevertheless, the fighter proved itself well and its appearance came as a nasty surprise for some of the Luftwaffe units operating in the area.

## Spitfire Mark IX

Early 1942 saw the introduction of the superb German Focke-Wulf 190 A on the Channel front, which took the RAF by surprise. The next planned Spitfire general-purpose fighter, the Mk VIII, incorporated several refinements developed in the previously developed Mk III prototype, and extensive re-tooling was necessary to get production underway. The main improvement of the Mk VIII, however, laid in the introduction of the new two-stage two-speed-supercharged Merlin engines, but this aircraft involved a significant redesign of the basic Spitfire, and it would take time to produce in the numbers required. The most expedient solution to make these available to the RAF was to adapt the readily available Mk V airframe to this engine.

The Mk IX came into being as an impromptu countermeasure against the Fw 190 A. The first Mk IX was basically a slightly strengthened Mark Vc airframe coupled to a heavier and more powerful Merlin 61 engine (fitted with a two-stage supercharger and intercooler). A four-bladed propeller was installed to harness the increased horsepower. Apart from the longer nose profile, Mk IX's another distinctive feature was a revised system of underwing radiators (which featured two symmetrical, oblong section radiator housings, one under each wing). Early-production Mk IXs retained the rounded fin and rudder tip of the Mark V. However, the torque produced on take-off by the new, powerful engine was so great that it was necessary to introduce the broad-chord, pointed-tipped rudder. Early Mk IXs, fitted with the 'C' type wing, were armed with two 20 mm Hispano cannons and four 0.303-in machine guns. Many late-model Mark IXs, fitted with the 'E' type wing (which was introduced in 1944), exchanged the ineffective 0.303s for two 0.50-in Browning machine guns (one per wing), mounted inboard of the 20 mm cannons.



Figure 8: Mk IX on the airfield at RAF Northolt

A few late Mk IXs had the cut-down rear fuselage and teardrop hood seen on other late-mark Spitfires. The Mk IX lost nothing of the Spitfire's famed maneuverability, whilst it offered a much better rate of climb and speed than Mark V. At altitudes above 20,000 feet the Mk IX was outstandingly better than its predecessor. A comparative trial revealed that Mark IX and Fw 190 were closely matched in terms of performance. So great was the Mk IX's success that the aircraft, which was conceived as a stopgap solution, eventually became the second-most produced Spitfire variant. Throughout its service life the Mk IX was extensively modified, both internally and externally. The three main sub-variants were: F Mk IX (powered by 1,565 hp Merlin 61 or 1,650 hp Merlin 63 engines), LF Mk IX (1,580 hp Merlin 66) and HF Mk IX (1,475 hp Merlin 70). The LF (Low-Altitude Fighter) variant, which entered service in

early 1943, frequently featured the so-called clipped wings (reduced wingspan for enhanced maneuverability).

Initially (and unofficially) the standard F variant was referred to as 'Mk IXa', and the LF variant as 'Mk IXb'. The LF designation was in itself somewhat misleading, for this variant attained its maximum speed at 22,000 ft (the standard F variant at 28,000 ft). Series production of the standard Mk IX went underway in June 1942. No 34 Sqn RAF at Hornchurch was selected as the first for conversion, taking deliveries the same month. No 611 Sqn RAF followed the suit in July, Nos 401 and 402 (Canadian) Squadrons in August, and No 133 (US Eagle) Squadron in September. In the Mediterranean Theatre of Operations the premier unit to re-equip with Mk IXs was No 81 Sqn (in January 1943), at that time stationed in Algeria, followed shortly by No 72 in Tunisia. In Spring of 1943, the 31st and 52nd Fighter Groups of the USAAF - the two American Spitfire outfits operating in the theatre - received shipments of Mk IXs (and operated them well into 1944, before converting to P-51 Mustangs).



**Figure 9: Spitfire Mk IXs in Formation**

## Summary

From spring of 1935, when the prototype assembly began, until February 1948, when the last Mk.24 was built, about 20,400 Spitfires were produced. (No consensus exists as to the exact number). This number does not include the Seafire variant, which remained in production until March 1949.

The story of the Spitfire might have turned out differently, had its creator, Reginald Mitchell, still been alive. Mitchell's character was that of an innovator, not a continuuer. Most likely, he, much like Sidney Camm of Hawker, would have created a number of new and different aircraft instead of squeezing all the juice from the Spitfire. In any case, the Spitfire saw action from the beginning of the war until its very end, and the Spitfire Mk.24 was regarded as one of the world's best piston engine fighters.

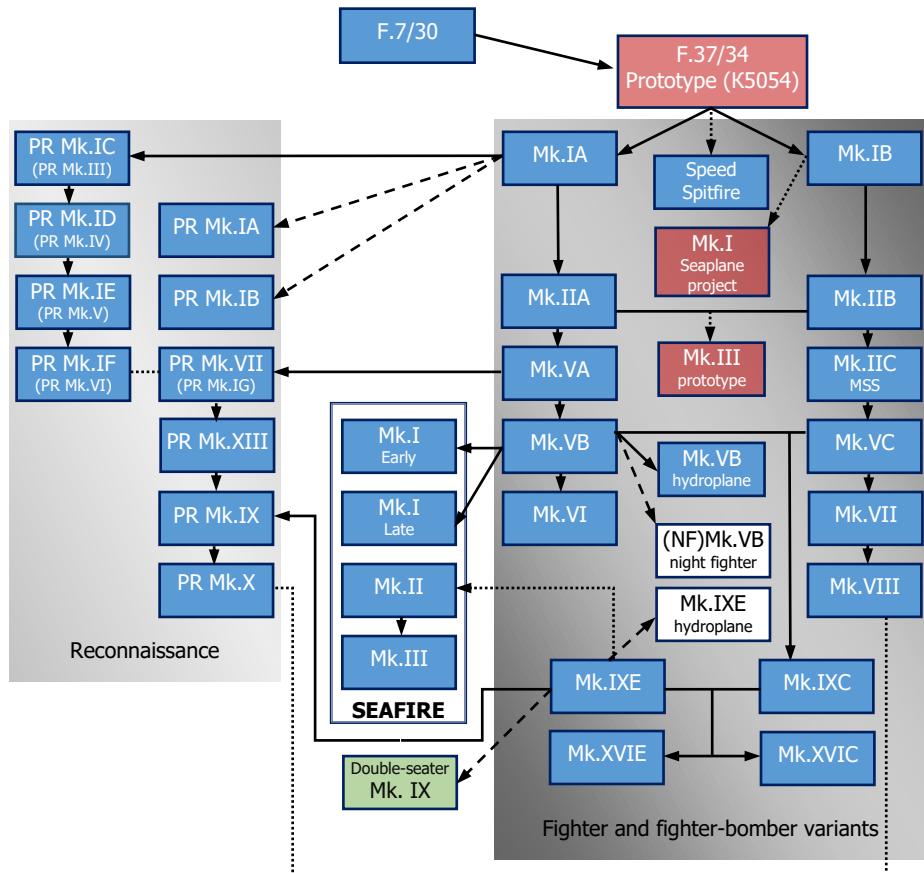
Compared with its prototype, the Mk.24 was a third faster, had twice the rate of climb, and its weapons' burst mass was five times more. In addition, the Mk.24's takeoff weight, in comparison with the prototype's, increased by 3080 kg, which, according to airline rules was equal to the mass of 30 passengers (assuming 20 kg of luggage per passenger). These figures give an idea of how far the development of the aircraft has gone.

The history of the Spitfire is closely linked to the development history of the Merlin and Griffon engines. The power of the 27-liter Merlin increased from 1000 to 1600 HP, while engine weight increased by

only 15%. After some slight modifications, the aircraft received an upgrade: the 37-liter Griffon engine with a power of 2230 HP. At the same time, its updated engine's mass was only 30% more than the weight of the first Merlin.

Such is the technical history of the Spitfire. But this aircraft was not only a machine of war. For the British and other Commonwealth citizens, the Spitfire was a symbol of the defense of Britain in the difficult days of 1940, and by war's end had become a symbol of victory.

## Spitfire Development Diagram



# AIRCRAFT OVERVIEW



# AIRCRAFT OVERVIEW

## Basic Informations

The Spitfire models IX, XI and XVI had specific letter prefixes which indicated the operational altitude and role.

F – Fighter

PR – Photo Reconnaissance

L – Low

H-High

The addition of the letter (e) indicated a change in the armament. Instead of being equipped with four 7,69 mm guns, these versions had two 12,7 mm MGs. Besides, all versions had the same structural shape.

Variant	Key features
F IX	Engine "MERLIN" 61, 63 or 63A; two cannons caliber 20 mm .4 machine guns 7,69 mm.
<b>LF IX</b>	Engine "MERLIN-66"; two cannons caliber 20 mm .4 machine guns 7,69 mm.
LF IX (e)	Engine "MERLIN-66"; two cannons caliber 20 mm., 2 machine guns 12,7 mm.
HF IX	Engine "MERLIN-70"; two cannons caliber 20 mm., 4 machine guns 7,69 mm.
HF IX (e)	Engine "MERLIN-70"; two cannons caliber 20 mm., 2 machine guns 12,7 mm.
PR XI	Engine "MERLIN" 61, 63 or 70, photo-reconnaissance equipment.
F XVI	Engine "MERLIN-266"; two cannons caliber 20 mm., 2 2 machine guns 12,7 mm.

The 61 and 63 (A) versions of the MERLIN engine were equipped with the S.U. carburetor. The 66, 70 and 266 variants were equipped with the "BENDIX-STROMBERG" pressure carburetor.

All variants were equipped with a 4-blade ROTOL propeller.

The late Mk IX and XVI modifications had special teardrop-shaped fairing and cab lights.

## Construction

The Spitfire is a cantilever monoplane of an all-metal construction with a lower wing position. The wing consists of three parts: the center section, integrated into the fuselage, and two detachable consoles. The shape of the wing is elliptical with a sufficiently thin profile (thickness ratio of 12.6% at the root and 9.57% in the middle). There are two spars, but the frontal spar is significantly stronger than the rear spar and assumes almost the entirety of the load. The thick lining attached to the front spar contributes to an increase in torsional rigidity. The rear spar also works towards torsion and serves for

fixing the ailerons in place. The ailerons are Frise type and are of an all-metal construction. Located under the wing are the pneumatically-driven Shrenk type flaps, divided into inner and outer sections.

Truss ribs are present in the aircraft. The metal wing sheathing is load-carrying, smooth, and countersunk riveted. Wing tips are available in three types: standard (rounded), short (almost rectangular), and elongated/tapered. Aircraft fitted with shorter wingtips often had a spare set of standard wingtips included.

The fuselage is semi-monocoque, which means it has a skeleton comprised of frames, spars and stringers enclosed in a metal shell which receives part of the load. The cross-section of the fuselage is of an elliptical shape. In the nose section of the fuselage, the sheathing is mounted in place by countersunk rivets, while in the tail section this function is performed by rivets with lentiform heads. The cowl panels are removable.

The layout of the fuselage was a classic for single-engine fighters of its time. Located in the front was the powerplant comprised of the engine and propeller, and behind it, two gas tanks separated by a fireproof bulkhead. Just behind the second bulkhead was the cockpit, which is closed off by a Plexiglass-glazed windshield that had a rail-mounted section that slid back. The main feature of the Spitfire canopy was its convexity: the bulges went 80 mm in each direction, providing the pilot improved vision of the back and sides. The pilot could look back and through the rear-view mirror mounted on top of the visor. The visor itself had flat surfaces on the front and sides that provided a clear image free of distortion. The central section of the visor was made of bulletproof glass. Entry to the cockpit is by means of a downwards-opening door on the left side of the aircraft. The sliding section of the canopy can be locked in place in any intermediate position. In emergency situations the canopy can be jettisoned instead of slid open - for which the pilot would simply pull the handles and then push the canopy slightly upwards. Then he would pick up the incoming air flow. Oftentimes however the handle would be torn when the pilot pulled on it, with the canopy remaining in place. For these situations, a crowbar is located in a niche to the left of the cabin door would be used to shatter the canopy.

The pilot sat in a chair made of plastic (Bakelite), well above the floor of the deep cockpit. The chair was composed of four stamped parts held together by duralumin plates. An Irvin parachute was fitted into the seat pan. The seat height could be adjusted by means of the handle located to the right of the pilot. Seat belts were equipped with a spring-retraction system. The pilot could loosen the straps to move forward and then pull back. The rear areas of the pilot seat (the back of the headrest and spinal section) were covered in armor sheets with a thickness of only 5 mm (capable of being penetrated even by German 7.9mm armor-piercing bullets). The pilot flew the plane by a so-called "Spade-type" control stick (with a gimballed upper section) and rudder pedals. English pedals were "two-stage." Typically, the pilot's feet would be resting on the lower part, but during combat, when energetic maneuvers required great effort from the pilot, the pilot would begin to use the upper sections. The seventh frame, located behind the pilot's seat, is reinforced in order to perform the functions of the crash pylon.

The dashboard has two sections. The main panel is made of 6 mm thick fabric-based laminate. On it are the devices for motor startup and miscellaneous backup controls. The navigation devices are on the aluminum panels, mounted on spring shock absorbers in the center of the main board. The compass is located separately on the bracket under the dashboard.

There were no heating systems onboard the spitfire. There were provisions only for the electric heating of the pilot's clothes and gloves, for which the pilot must use special wired gloves and insoles in his flying boots. This system was ultimately unreliable and seldom used. Cabin ventilation was carried out through the hatch on the right side in front of the wind shield. By turning the knob of the adjusting screw, the pilot could regulate airflow.

Behind the cockpit was an additional fuel tank (installed separately), as well as various electrical and radio equipment. These were accessed through a hatch on the left side. Almost the entirety of the tail section of the fuselage was empty. To compensate for the increased weight of the engine compartment in the frontal section, the aircraft battery and oxygen tanks were moved to the tail section.

The 19th frame is double, this place is actually the juncture of the fuselage and the detachable tail section (integrated into the tailfin.) The 20th frame goes up to the top of the tailfin, turning in its spar. The tail has a frame made of aluminum alloy and the same casing. The cantilevered stabilizer with an elliptic planform is comprised of two halves connected together inside the rear fuselage. It is set parallel to the axis of the aircraft. The tailplane frame and sheathing are all composed of an aluminum alloy. The aerodynamic profile of the keel and stabilizer are also symmetrical.

The rudder and trimmers also have a metal frame, but are covered with a cloth soaked in lacquer. Handlebars are horn-balanced. In the earlier models of the aircraft, the rudder had rounded top. Later models introduced a wider rudder with a pointed end to compensate for the increased torque produced by the propeller. Late Spitfire IXs also had elevated horn-balances for their elevators.

Installed on the Spitfire IXs are various modifications of the Merlin 60 Series engines - 61, 63, 66 and 70, all with differing nominal altitudes. The Merlin engine itself was a 12-cylinder liquid-cooling V-engine with a working volume of 27 liters. The motor was mounted on a frame of tubular construction, combining welded, riveted and bolted connections. On the 61 and 63 models were the older float-type carburetors, while types 66 and 70 had the American floatless/membrane Bendix-Stromberg carburetors with automatic control of mixture quality (height adaptation). All of these engines had gear-driven two-stage centrifugal-type superchargers. The first speed worked regularly, while the second speed would automatically activate at predetermined altitudes.

The motor is cooled with a mixture of glycol. It would circulate in the intermediate heat sinks that cooled the air between the supercharger steps, as well as the fuel mixture right before it entered the cylinders. The system's expansion tank was mounted on the engine gearbox. The radiators of the engine cooling systems, supercharger, intermediate radiator and oil system are housed in two symmetrical boxes located under the wings. Under the right wing was one section of the engine radiator and the oil cooler. Under the left wing was the supercharger radiator and the second section of the motor cooling system radiator. The radiators themselves were of a tunnel type. Adjustment of the radiator scoops was automatic, performed by the thermostat. Interestingly, the system blocked the activation of the second stage compressor at temperatures close to the maximum - 115°. (SAR 1565J & L Vol1 Sect 8 para 42.) The switch is mounted on the front section of the intercooler and is connected to the supercharger actuation. The supercharger would be forced back to first speed (M.S.) in case temperatures reached maximum allowable values.

The air for the carburetor is sucked out of the socket from under the wing center section. During dusty takeoff conditions it is covered by an air-gate, and air intake is carried out from the engine compartment. Aircraft later series were equipped with an additional filter, and because of this the air intake was moved forward.

The engine was a system of individual (one per cylinder) jet exhaust pipes, the thrust of which slightly increased flight speed.

Aircraft equipped with Merlin 66 engines used R12/4F5/4 propellers with wooden blades. The propeller has four blades, with automatic pitch variation.

60 Series motors were fed high-quality 100-octane gasoline. In the Soviet Union, imported fuel was used, or in its absence, 88 octave leaded petrol 4B-70. While the English engine didn't explode from the use of this fuel, it was nevertheless incapable of reaching its maximum power.

Fuel was stored in three fuselage tanks. Two of them are located in front of the cockpit in a compartment between two fireproof bulkheads. Lying on the ribs, the bottom self-sealing fuel tank with a capacity of 168 liters was considered the main fuel tank, as the engine drew fuel from it. From the upper non-self sealing tank with a capacity of 218 liters, fuel dripped into the lower tank by means of gas pressure. The upper tanks are covered by a steel armor plate with a thickness of 4 mm. The third tank (not mounted on all series) was installed behind the seat of the pilot. It had a capacity of 132 liters and was used only in conjunction with a large external tank as its filling greatly disturbed the aircraft's balance.

The fighter could carry four types of external fuel tanks. Tanks with a capacity of 135 liters, 205 liters and 410 liters had the form of a trough and lied close to the lower wing centersection. In this case, the suction pipe in the tank was allowed passage. In jettisoning these tanks, they would first slide backwards along rails, after which they would swing downwards. The fourth type of tank in the form of a cigar had a capacity of 227 L and was suspended on the bomb racks under the fuselage. Switching on fuel feed from the external tanks could only be done at an altitude above 600m.

The Spitfire undercarriage looked pretty unconventional. The main landing gears do not fold inwards in the direction of the fuselage, instead folding outwards to the ends of the wing. This allowed for a thinner wing, but limited track length to 5 feet 8.5 inches, making the airplane fairly unstable on uneven floors. The undercarriage was deployed and retracted by means of a hydraulic system, the pump of which is mounted on the motor. In case of pump failure, the undercarriage was deployed by means of compressed carbon dioxide stored in a tank in the cockpit. The landing gears are equipped with Vickers hydropneumatic shock absorbers. Wheels with a size of 600x170mm in the extended position stood with a small collapse which was almost imperceptible to the eye. They are equipped with Dunlop air brakes. In the retracted position, the wheels fit into a niche of the main panel spars. The gear leg and about half of the wheel was closed off by a flap mounted at the gear leg. The tail wheel is free-moving, capable of 360° rotation. Its leg is also equipped with a hydro-pneumatic shock absorber. In the early series of Spitfire IXs, the tail wheel did not retract, while in latter models the rear gear leg folded upwards and fit into the fuselage, closed off by hinged doors on each side of the hatch.

The pneumatic system, fueled by a Heywood SH-6/2 onboard compressor, controlled the landing lights, wheel brakes, flaps, radiator scoops, weaponry, and the activation/deactivation of the supercharger second-stage. The compressed air is stored in two cylinders located on the left side of the cockpit.

The fighter's electrical power source is a 750-watt generator on the engine and a 40 amp-hour battery located in the fuselage rear. Energy consumers are the landing lights (retractable, placed under the cockpit floor), the navigation lights, radio equipment, cabin lighting and gunsight lighting, as well as the various signaling devices. The electric starter for motor startup was powered only by airfield batteries, transported on a special trolley. The socket for use of an external power supply was at the eighth frame under the wing fairings. During emergency takeoff from an unprepared airfield, a Coffman combustion starter was used to start the engine. Network voltage is equal to 12W.

The Spitfire IX had a de-icing system that used a mixture of distilled water and ethylene glycol to wash the canopy visor. The sprayer was mounted in the bottom edge of the visor. The system was driven by a manual pump placed on the starboard side of the cabin.

At high altitudes, pilots used oxygen masks. The oxygen was stored in a 6 liter cylinder at the tail of the aircraft. The English gas system dispensed oxygen not constantly, but periodically, depending on pilot needs.

The fighter was equipped with a VHF radio, types TR-1133, TR-1133A or TR-1143. TR-1143, the latest model at the time, was matched with an A.1271 radio navigation device, which itself is a primitive blind landing system. The radio station was mounted on a retractable platform which greatly facilitated its maintenance. In England, the machine essentially had an A.R.I. 5025 IFF transponder, with a R-3067

transmitter. Its unit was mounted on brackets on the left side next to the tail. These transponders were considered confidential and were supplied with an explosive charge rigged to self-destruct. Pilots forced to land in enemy territory were ordered to destroy the device. The main radio used an antenna stretched which extended upwards behind the cockpit canopy and ran towards the tip of the keel. The mast was based on the crossbar of duralumin profiles under the fairing. The transponder antennae went from the fuselage sides to the ends of the stabilizer.

The Spitfire IX's armor protection was rather lackluster. Generally, it consisted of 5.4 mm thick steel plates that protected the pilot's back, knees, and back of the head, as well as the upper fuel tank. A visor of bulletproof glass with a thickness of 38 mm was mounted on the canopy windshield. The bottom and sides of the fuel tanks and ammunition compartments are closed off by duralumin plates of 3-4mm thickness.

The aircraft weapons were of two types - C and E, depending on the wingset installed on the fighter. In the first case, the aircraft panels usually housed two British Hispano 20-mm cannon with a reserve of 120 rounds on the barrel and four Browning 7.69 calibre machine guns with a supply of 350 rounds per gun. The guns were mounted close to the fuselage, just behind the niches of the chassis. The barrels extended behind the leading edge and were closed off by a fairing. The cartridge feed mechanisms could not fit within the profile of the wing; designers were forced to create small teardrop-shaped protrusions for this reason.

Machine guns were mounted farther away from the axis of the aircraft - between the reinforced ribs. For the convenience of placing their ammunition boxes the guns were moved longitudinally by 152 mm. Access to the guns is through hatches with hinged lids located on the underside of the wing. To improve gun cooling, pipes were mounted on the gun barrels - the front edges of these pipes were shaped in the form of the wing. For protection against dirt and dust before flight, as well as for the improvement of the aircraft's aerodynamic characteristics, the holes in the front edge of the wing were sealed up with percale and covered with red lacquer. The first shots fired would then break through them. The machine guns were fed from boxes by sectionalized metal belts. These used-up belts and cartridge cases were ejected from the aircraft through gaps under the wing.

But in some rare models, instead of machine guns, two more cannons were mounted on the aircraft. In this case, the ammunition counts were 145 rounds for the inner guns and 135 for the outer guns. The Spitfire IXC could also mount a bomb weighing up to 227 kg on the underside of the fuselage.

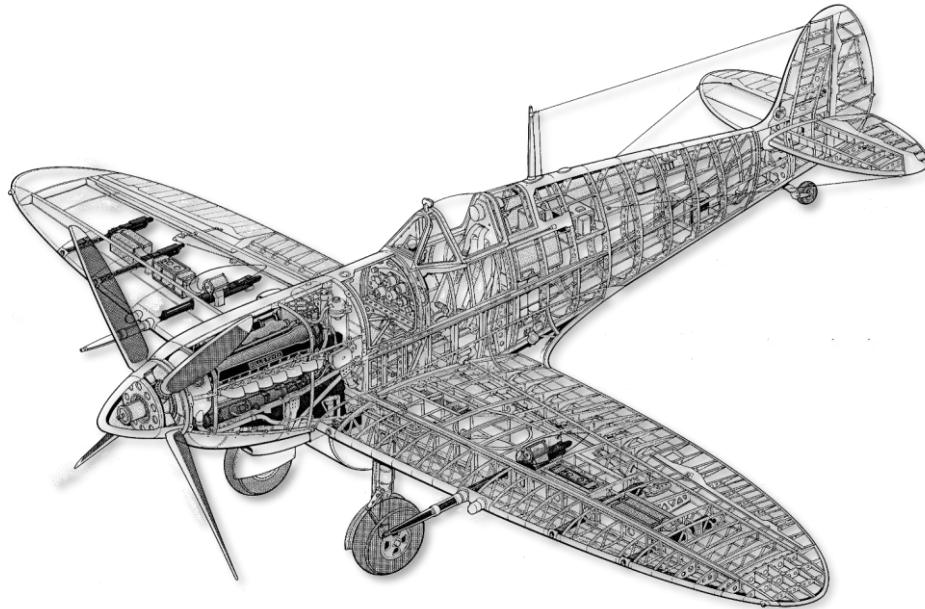
The reinforced wing type "E" allowed for more powerful weapons. One cannon with a reserve of 120 rounds and one 12.7 mm machine gun with 250 rounds could be mounted on each wing. The Spitfire IX also saw the implementation of underwing bomb racks; thus total bomb load could be raised to 454 kg. Usual loadouts saw a bomb weighing 227 kg mounted under the fuselage and an additional two weighing 113 kg mounted under the wings. Munitions used were of the following types: high-explosive, fragmentation, incendiary, armor-piercing high-explosive and smoke - of both English and American production. Spitfire IXe also saw the use of rocket weaponry - a pair of unguided 76 mm rockets. Depending on the weight of the warhead, these rockets could weigh 11.3 kg or 27.2 kg. In either case, the IX could have a combat load of two rockets and one 227-kg bomb.

The weapons compartments were warmed in-flight with warm air, which first passed through the radiator. Aircraft with wing type "C" also used air for heating the machine guns, first heated in the exhaust system of the engine.

The Spitfire had an electropneumatic weapons control system. In earlier series of the aircraft, aiming was done through a GM 2 collimating optical sight, and in later series through a Mk.IID gyroscopic sight. This sight made it possible to preset the range of opening fire and target characteristics (i.e. target size already known to the pilot.) Result monitoring was provided by the G-45 or G-42B camera

gun mounted at the root of the left wing. The camera gun could be activated simultaneously with the cannons and machine guns, or separately from them.

The on-board equipment includes the Plessy six-barreled signal rocket launcher system, with differing rocket colors for varying code messages. They were fired up by means of electrical signals. A supply of water, emergency rations in a sealed tin, and an inflatable raft with a tank of carbon dioxide (in the event of an emergency landing) were also included on board.



**Figure 10: SPITFIRE Mk. IX with standard wingtip**

## Specifications

Specifications for the SPITFIRE IX are:

- Wingspan:
  - standard wings 36 ft 7 in
  - clipped wings 32 ft 7 in
- Length 31.5 ft
- Height:
  - To top of propeller 11 ft 8 in
  - To center of propeller spinner: 6 ft 3 1/2 in
  - To wingtips: 5 ft 4 in (approx)
- Propeller clearance: 11 in

Fuselage:

- Width (max): 3 ft 6 in

- Length (overall) 20 ft 10 in
- Height (max): 6 ft 9 in

Wings:

- Wing profile: N.A.C.A. 2200
- Average chord: 7 ft 1 in
- Incidence: 2° at root, -0.5° at wingtip
- Dihedral: - 6°
- Wing area including ailerons and flaps: 242 ft<sup>2</sup>
- Ailerons, total: 18.9 ft<sup>2</sup>
- Flaps, total: 15.6 ft<sup>2</sup>

Tail:

- Span (over elevators): 10 ft. 6 in
- Chord (max): 4 ft
- Incidence: 0°
- Lateral angle: 0°
- Area including elevators: 31.46 ft<sup>2</sup>
- Elevators, two, with trimming tabs: 13.26 ft<sup>2</sup>
- Trimming tabs, each: 0.38 ft<sup>2</sup>

Fin and rudder:

- Fin area: 4.61 ft<sup>2</sup>
- Rudder area, with trimming tab: 10.7 ft<sup>2</sup>
- Trimming tab: 0.7 ft<sup>2</sup>

Gear:

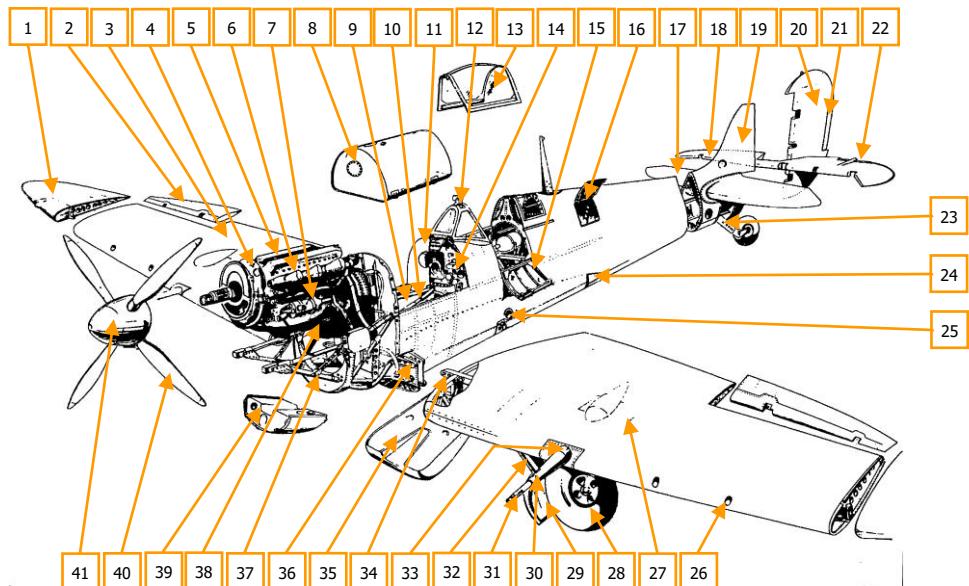
- Track: 5 ft 8.5 in

# AIRCRAFT DESIGN



# AIRCRAFT DESIGN

## Main elements



**Figure 11: Aircraft structure**

- |                               |                                     |
|-------------------------------|-------------------------------------|
| 1. Wingtip                    | 16. Access door radio compartment   |
| 2. Aileron                    | 17. Tail                            |
| 3. Right wing                 | 18. Elevator                        |
| 4. Header tank (cooling tank) | 19. Tail unit                       |
| 5. Engine "MERLIN-66"         | 20. Rudder                          |
| 6. Exhaust manifolds          | 21. Rudder trimming tab             |
| 7. Generator                  | 22. Elevator trimming tab           |
| 8. Upper fuel tank            | 23. Tail wheel unit                 |
| 9. Lower fuel tank            | 24. Tail portion main plane fillet  |
| 10. Engine struts             | 25. Main plane attach fitting, rear |
| 11. Flameproof bulkhead       | 26. Browning guns bays              |
| 12. Windscreen                | 27. Magazine door                   |
| 13. Jettisonable hood         | 28. Main wheel                      |
| 14. Instrument panel          | 29. Main wheel leg strut fairing    |
| 15. Pilots access door        | 30. Hispano gun fairing             |

- |                                       |                     |
|---------------------------------------|---------------------|
| 31. Hispano gun                       | 37. Engine mounting |
| 32. Main wheel strut                  | 38. Suppressor      |
| 33. Hispano gun adjusting ring        | 39. Oiltank         |
| 34. Top boom main spar                | 40. Rotol propeller |
| 35. Jettisonable fuel tank            | 41. Spinner         |
| 36. Root attach main plane front spar |                     |

## Fuselage

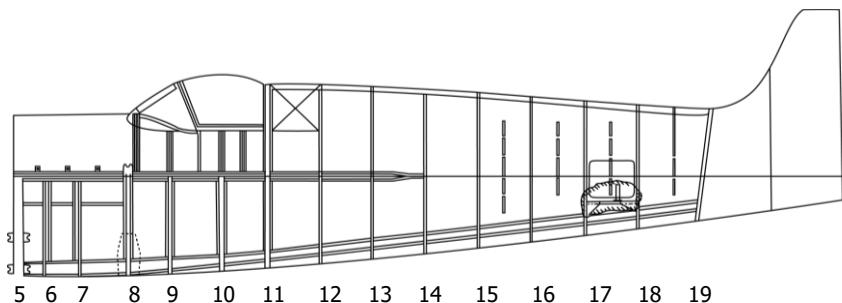
The fuselage is of an all-metal semi-monocoque construction, designed with a load-carrying skin and detachable tail section. The fuselage may be divided into three parts: front, main and rear. The frontal section houses the fuel tanks, and just behind the tanks is the pilot's cockpit which is closed by a jettisonable sliding canopy made of transparent material. Transparent glazing is also present behind the cockpit and in the upper part of the fuselage for better rear visibility. The canopy windshield is reinforced with armored glass in the central part. To enter the cockpit, a hinged door is on the left side of the fuselage, attached to the main fuselage spar. Behind the visor in the cockpit are rails for the gunsight light filter which is used by the pilot to minimize glare in very bright conditions. In normal conditions, the gunsight filter is kept in the retracted position mounted on the rails under the canopy windshield.

Hatches for maintenance of the components of the aircraft are found on the skin of the fuselage. Mounts for equipment and controls are present inside in different places of the aircraft structure. Armor plates are also installed behind the fireproof bulkheads as well as behind the pilot seating.

The fuselage consists of five spars: two lower spars, two main spars, and one upper spar, and 15 frames, numbered from 5 to 19. The frames on the frontal part of the fuselage until the 11th are open and U-shaped, followed by closed frames. The lower spar is box-shaped, formed by two angle bars from the 5th to the 10th frame. After the 10th frame, the lower spar has a V-shaped profile. The main spars are located at the centerline of the fuselage and have a U-shaped profile. Both spars are reinforced by steel sections with a thickness of 1.016 mm. The right side spar is reinforced from the 5-th to 7-th frame, while the left side rail is reinforced from the 5-th to 6 inches from the 8-th frame. From the 14 th to 19-th frame, the main spars are of a Z-shaped profile. The upper spar is V-shaped. The main spars have leveling points on the sides of the cockpit for spirit leveling. The covering is of a duralumin alloy, covered with aluminium, riveted to the frames and supported by Z-shaped stringers.

The tail part of the fuselage is detachable and consists of the tail and stabilizers. The tail section is bolted to the fuselage on the 19-th frame.

For convenience of description, the fuselage can be divided into three parts: front, main and rear.



**Figure 12: Fuselage scheme**

### Front Part

Begins with the 5th frame, which is also the firewall until the 11th frame. In the front part are the fuel tanks and the cockpit. The 8th frame forms a closed loop, and in the middle of the top of the frame are mounted two strut supports, which are connected to the nodes connecting the motor and the main spars on the 5th frame. Installed after mounting the bottom of the fuel tank.

The fireproof bulkhead is attached to the 5th frame. Four bars which form the hinge of the front wing spar are mounted at the bottom of the 5th frame. The mount for the auxiliary wing spar is installed in the bottom of the 10th frame. The spar mounts are located behind the fuselage skin.

The fireproof bulkhead consists of a sheet of asbestos located between the two metal sheets and reinforced by vertical and horizontal load-bearing elements. The armor plates are bolted to the back of the upper part of the bulkhead.

The top mounts of the engine mount are bolted to the main spars and struts. The bottom nodes are attached to the lower longerons and to the beam forming the fuselage portion of the main wing spar.

The bottom of the 6th and 7th frames are covered with a layer of cork and are the supports for the bottom of the tank. Frame #9 is supported in the lower part by one transverse and two diagonal elements that go up to the 8th frame and support the pedal nodes. The cabin mount is installed between frames 8 and 11. A load-bearing element (which is also the support for dashboard) of an arcuate shape supports the cabin mount on frame 8. The pilot access door attached by the lower part to the main spar is installed on the left side of the fuselage between frames 9 and 10. The top of the door has two two-position locks that hold the door in the closed and half-open position. The lock lever is located closer to the frontal lock. Turning the handle forward and down opens the locks. The canopy sliding rails are installed on the top of the doors. The half-open position of the canopy sliding door is designed such that it will not suddenly close and hurt the pilot even during an emergency landing.

Frame 11 is of a closed oval-shape and has transverse and diagonal stiffeners to which the pilot seating is attached. Armor plates are mounted to the top of the frame on four studs and curled nuts.

### Main part

The main part is formed from frames 11-19. The frames are of a closed oval-shape, having identical structures, characterized by a decrease in size further down the aircraft body (towards the tail section).

Between frames 11 and 12 the upper part of the fuselage skin is made of a transparent material to improve rear visibility. Mounted under the transparent part of the fuselage sides are the canopy's sliding rails. On the starboard side of the cockpit, the rails mounted on the edging. Reinforcing elements are mounted between frames 12 and 13, the crossing of which supports the radio antenna mast. Load balancing elements are found between frames 17 and 18 to compensate for the increased weight of the engine.

## Tail part

Integrates with the tail fin and is detachable. The tail section is attached to the 19th frame using 52 bolts placed on the frames and four pins on the lower side longerons. The 19th frame is made of an angle bar, while the remaining frames are flat. The tailplane spar is bolted to a reinforced 20th frame, which is the front fin spar. The auxiliary spar of the stabilizer is attached to the auxiliary tailfin spar to which the rudder is attached. The tailfin spars are connected to each other by ribs. The tailfin sheath is riveted on the left side while the right side is attached by screws to the wooden elements bolted to the ribs. The stabilizer sheathing is attached in the same way.

## Canopy frame

The canopy frame is made of steel, fastened by bolts to the cabin edge. The central section of the windshield, bolted to the frame, is a bulletproof visor with a thickness of 1 ½ inches. A rubber layer between the glass and the frame ensures that the visor is sealed in place. The rear frame is shaped to ensure a tight fit of the sliding canopy in the closed position.

The sliding section of the hood seals the cockpit from the windshield until frame 11, and is moved on rails mounted on the cabin edge. On the front of the hood is a locking that holds the hood in the open position - latching onto frame 11; as well as in the closed position - latching onto the visor frame. The lock is opened by turning the levers connected by a rope (for pilot convenience). Turning the levers forward opens the lock, and the cover slides forward. Turning the levers back opens the lock and the hood slides back. When the aircraft is parked with a closed hood, the lock is opened by a small spring-loaded button on the top of the visor. On the transparent part on the left side of the hood is a pane for use in case of a dirtied windshield. The sliding part of the canopy has an emergency jettison system. Next to the lock is a rubber ball suspended on a rope, which, when pulled, removes the brass pins from the canopy hood.

The pilot seating is cast of a phenol-formaldehyde resin (Bakelite), with an underside compartment for the emergency parachute. Mounted on the frame with an elevation adjustment mechanism (found on the right side) on the 11th frame. The mechanism quadrant mechanism has 6 notches, with elevation intervals of 4 inches. Armor plates are attached at the back of the seat. Seatbelts with locking system via cable runs and spring stopper are also present on the pilot seat. A keylock is mounted on the starboard side. When moving the lock latch forward or backward, the seatbelts withdraw from the stopper and allow the pilot to lean without spring resistance. When returning the handle lock to the rear position, the spring is fixed to the stopper and the seatbelts' movement is blocked.

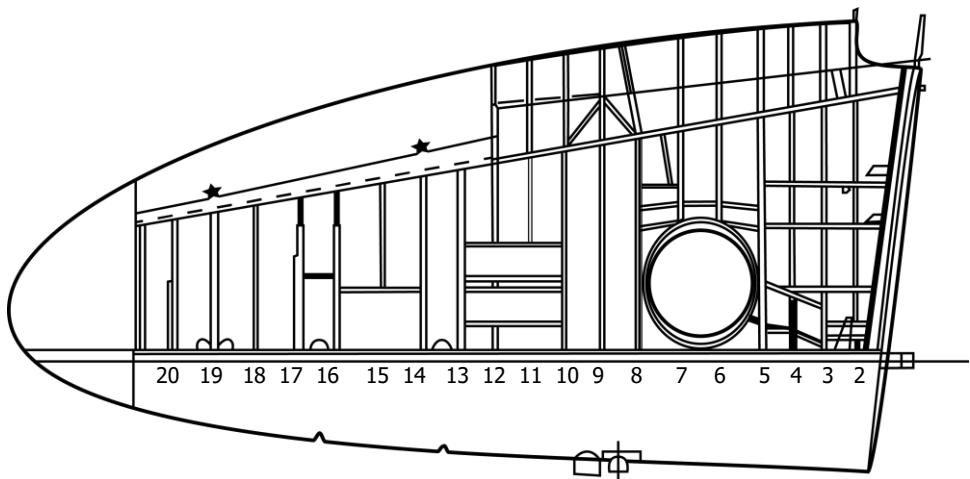
To the top of frame 11, a cylindrical shape headrest is mounted on the seat.

## Wing

Wing modification "C" consists of two detachable parts. Mounted on the sides of the fuselage, the wing and the lower surface of the fuselage are coplanar. Metal Frise type ailerons are attached to the rear of the wing closer to the tips. Two-piece Shrenk-type flaps are hung along the span of the aileron to the fuselage. The flaps are divided into two parts at the point of fracture of the wing and are driven pneumatically. The wingtips are removable and have space for the installation of navigation lights.

The detachable part of the wing has a spar structure: it has a main and auxiliary spar plus 21 ribs. The sheathing is made of a duralumin alloy.

The wing mounts are found at the bottom of the two fireproof bulkheads, the lug mounts for the mooring are lead out to the contour of the fuselage on both sides.



**Figure 13: Wing structure**

### Main spar

The front edge of the main wing spar and formed as a single unit, which is attached to the main part of the wing. The main spar is composed of square shelves and walls in between. The spar cap (pictured) is formed of a steel profile of square section of reducing size, inserted telescopically. This facilitated production and simplified the change of the spar cap sizes in scale. The wall is attached to the rear side of the spar caps. The form of the caps vary from the square section to a tee, and ends in a corner as it approaches the wingtip. The root of the wing spar has two clamps for connecting to the hinge fittings on the 5th frame.

The rib caps are made of an angular profile with diagonal reinforcing of a channel section. The ribs are bolted to the spar, and at the wing root the rib spacing is reduced, a reinforcing elements are in place for holding the hinge fitting of the main column.

The leading edge sheathing consists of an upper and lower part. Both parts are riveted to the ribs and spar. Riveted to the sheathing between the ribs are Z-shaped stringers. On the bottom of the sheathing and in the flange of the spar are hatches for access to the internal cavity.

### Main part of the wing

Consists of an auxiliary spar and ribs. The rib caps are made of a section and reinforced by diagonal struts. The ribs of the root of the removable part of the wing are also reinforced. The auxiliary spar consists of rib caps with an angle bar and web. The spar is divided into three sections by two ribs extending beyond the spar for aileron linkage. A panel on the flaps is supported by load-bearing elements of the angle bar. A mount fitting for the auxiliary spar is installed on the 10th frame.

The upper part and a large part of the lower sheathing is riveted to the flanges of the ribs and longerons; part of the lower sheathing by the wingtips of the detachable wing section is fastened with screws to the wooden elements, which are attached to the ribs and spars.

Below the detachable wing section is a compartment for accommodating the undercarriage and wheels in the retracted position. The compartment is sealed from the rest of the detachable section. There is also a compartment near the roots for the radiators, which are closed off by cowlings, forming a tunnel. Automatically controlled grates are installed at the rear of the cowling. Warm air is taken from the back of each tunnel for use in heating the machine gun and cannon compartments to prevent weapons malfunction due to the lubricant freezing in the firing mechanisms.

The gap between the wing and fuselage skin is closed off by cuffs.

### Wingtip

One unique feature of the aircraft was the presence of wingtip replacements, which could be replaced during operation of the aircraft. In total there are three types of wingtips: standard, extended, and shortened. Standard and extended wingtips are attached to the nodes to the wing spars directly behind the aileron, while the shortened variant is fixed with screws and captive nuts to the skin. When installing a shortened wingtip, the navigation light sockets were installed inside a rib. Extended wingtips were rarely used on Spitfire IXs, and were seen mostly on F.IX. modification models. The shortened endings were installed on some of the L.F. Mk. IX models. Some aircraft with shorter wingtips have an extra fuel tank installed behind the pilot seating, however on these aircraft replacing the shortened tips with standard ones was prohibited. However, tests in the Boscombe Down center showed that shortened wingtips did not provide the aircraft with any boosts in its performance.

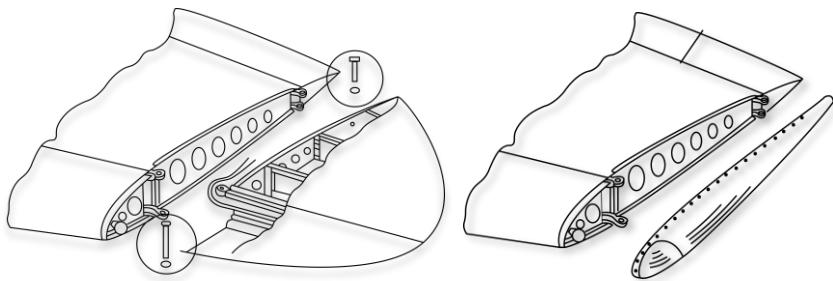


Figure 14: Standard wingtips

## Armor protection

The following armor plates are installed on the aircraft:

1. Front of fuel tank, 4mm

2. Fuel tank cowling, 10SWG/3.251mm
3. Bottom of windsreen, 4mm
4. Bulletproof windsreen, 1.5in
5. Behind pilot seating, 4mm
6. Behind pilot headrest, 6mm
7. Under pilot seating, 4.064mm
8. Deflector plates, 6mm.
9. Ammunition boxes, top and bottom skin, 10 S.W.G./3.251mm
10. Front of ammunition boxes, 6mm.
11. Additional 6mm head protection armor (in later variants)
12. Additional pilot protection from behind, 7 mm

The armor plates on the front of ammunition boxes were removed on later models of the aircraft, and were replaced with additional armor plates of behind the pilot seating and headrest, with a thickness of 7mm and 6mm respectively.

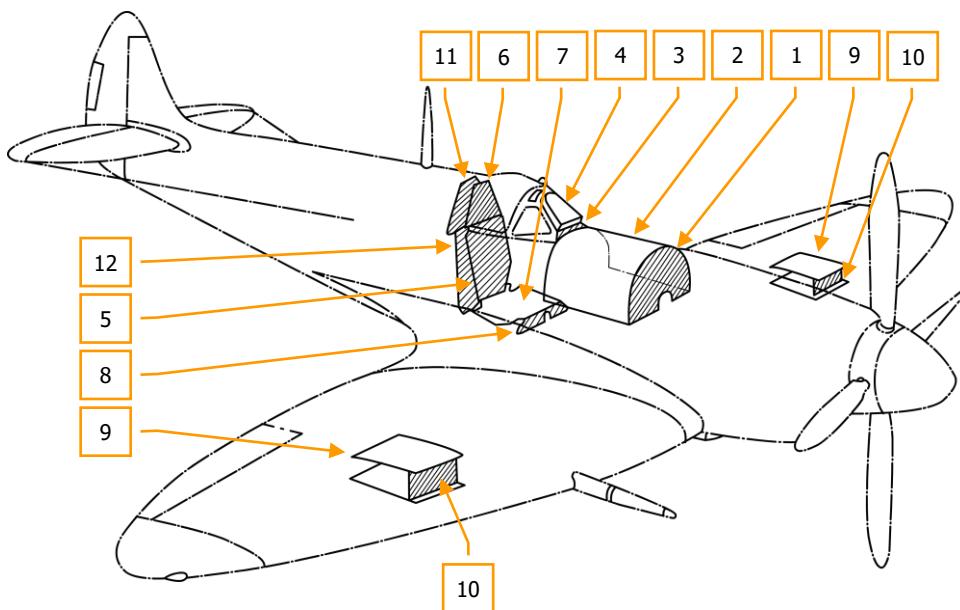


Figure 15: Aircraft armor plate locations

# POWERPLANT



## Powerplant

The Spitfire IX powerplant consists of a Rolls-Royce 60-series Merlin aircraft motor, and a Rotol R12/4F5/4 hydraulic variable-pitch aircraft propeller with wooden blades.

The Spitfire IX also has a Merlin 66 (RM 10 SM model) liquid-cooled, 12-cylinder V-twin four-stroke internal-combustion engine with a capacity of 27 litres, equipped with a Bendix-Stromberg pressure carburetor capable of operating under negative G-loads, and a two-stage, two-speed drive centrifugal compressor with an intermediate cooler.

The engine is driven by a four-blade variable-pitch propeller. Propeller pitch is changed using the constant-speed regulator installed at the front of the engine under the propeller gearbox.

The Rotol R12/4F5/4 in-flight-variable pitch propeller features wooden blades, manufactured through the Jablo or Hydulignum methods of propeller production, with a "fine pitch" angle of 22° 20', and a propeller diameter of 10'9".

The engine is mounted on a tubular steel frame motor attached to the fire-retardant frame. The pipes and electronic wires to the engine mount by clamps.

The gear and drive ratios of the Merlin 66 engine's centrifugal supercharger are selected in such a way as to ensure maximum power at low altitudes.

The oil tank is mounted under the engine crankcase; oil radiator in the tunnel under the left plane. The expansion tank of the liquid cooling system is installed in the front part of the engine under the propeller drive, and the 2 radiators of the cooling system are located in the tunnels under each plane. The radiator for the cooling systems of both the two-stage centrifugal supercharger and the intercooler is located respectively under the right plane.

Exhaust pipes are of the fishtail type, with one for each cylinder.

Engine management is handled by the throttle quadrant installed on the right side of the cabin. The throttle quadrant features levers controlling throttle, propeller pitch, and engine shutdown.

## Engine

### History

In 1932, Sir Henry Royce wished to develop an engine that had the reliability of his Kestrel design, combined with the power of the 1931 Schneider Trophy-winning "R" engine in the Supermarine S6B racing seaplanes. The result was called the P.V.12, a 27 litre, V-12, liquid cooled, single-stage supercharged engine (P.V. standing for Private Venture).

Royce died on 22nd April 1933 without ever seeing this engine run and without knowing it would eventually become his most produced design. Just six months after his death, the first P.V.12 engine run was conducted on 15th October 1933.

The prototypes of two other private ventures, the Hurricane and Spitfire fighter aircraft, were designed around the 890 hp (663 kW) Merlin 'C'. The early engine design's performance needed improvement but was sufficient to demonstrate the potential of these new low-wing monoplane fighters. Rolls-

Royce even contributed £7,500 towards the total cost of £15,000 (equivalent to about £850,000 today) of the Spitfire prototype, K5054, which first flew on 5th March 1936.

By 1937, after significant alterations to the cylinder head design, the Merlin II was capable of 1,030 hp (768 kW). All Spitfires and Hurricanes in RAF service at the outbreak of war in September 1939 were fitted with the Merlin II, with the Merlin III being fitted in ever larger numbers by the Battle of Britain in 1940.

Merlin development never ceased and more and more power was extracted from the engine using improved superchargers and fuels. In 1942 the Spitfire Mk IX was equipped with the two-speed, two-stage supercharger, 1, 280 hp (954 kW) Merlin 61. The Mk IX's performance was improved both in speed and ceiling and immediately outstripped the opposition to gain outright air superiority. This improved Merlin was also used in other aircraft, the most famous application being the North American P-51 Mustang which became one of the most successful fighter aircraft of WW2.

## Engine Specifications

Manufacturer: Rolls-Royce Limited

Years of production: 1933 - 1950

Type: four-stroke V-shaped twelve-cylinder liquid-cooled

## Technical Characteristics

Capacity: 27 L

Power: 1 290 h.p. (962 kW) at 3000 rev/min during takeoff mode

Power density: 35.6 kW/L (47.8 h.p./L)

Stroke cycle: 152.4 mm

Number of cylinders: 12

Cylinder diametere: 137.16 mm

Valves: 2 inlet and 2 intake valves per cylinder

Compressor: two-stage two-speed, with intermediate cooling between the second stage of the compressor and the motor

Fuel type: Gasoline with 100 octane rating

Lubrication system: Dry sump with one oil pump

Cooling System: Liquid pressure coolant - a mixture of 70% water and 30% ethylene glycol.

(Supercharger cooling system is independent of the engine cooling system)

Fuel consumption: 177 L/h - 400 L/h

Specific power by weight: 1.58 kW / kg (2.12 hp / kg) at maximum power

## Aircraft Dimensions

Length: 2253 mm

Width: 781 mm

Height: 1016 mm

Dry weight: 744 kg (source: Wikipedia)

Engine Type	V-type, liquid-cooled, geared, equipped with two-stage two-speed supercharger with liquid cooling and intercooler
Number of Cylinders	12
Cylinder Arrangement	2 blocks of 6 cylinders with an angle of 60°
Piston – diameter and throw	5.4 * 6 inches
Working Capacity	1648 in <sup>3</sup> , 27 liters
Compression Ratio	6
Supercharger	2-stage, 2-speed
Gear ratio	First speed - 1:5,79; Second speed - 1:7,06

### Design Description

Merlin 66 (RM 10 SM model) liquid-cooled, 12-cylinder V-twin four-stroke internal-combustion engine with a capacity of 27 litres, equipped with a Bendix-Stromberg 8D-44-1 pressure carburetor capable of operating under negative G-loads, and a two-stage, two-speed drive centrifugal compressor with an intercooler for cooling the air-fuel mixture supplied to the cylindersx

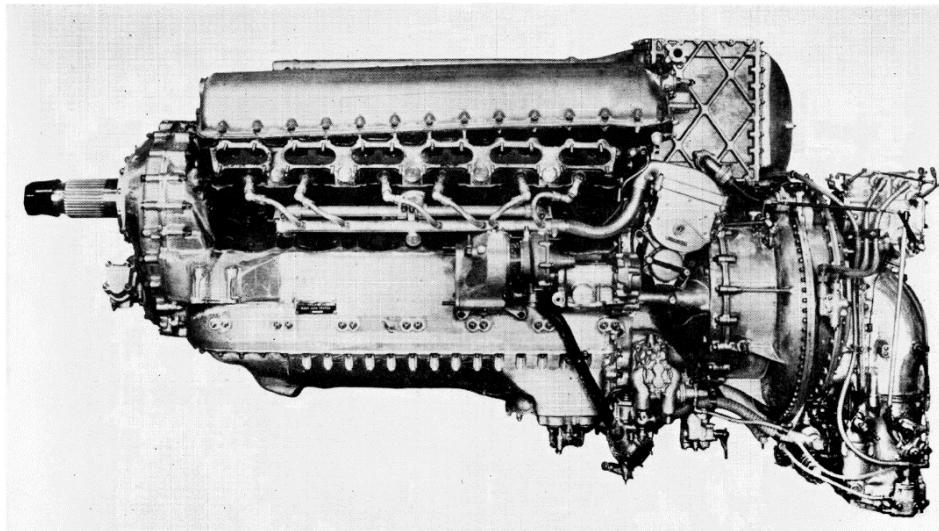


Figure 16: A Rolls-Royce Merlin 66 Engine

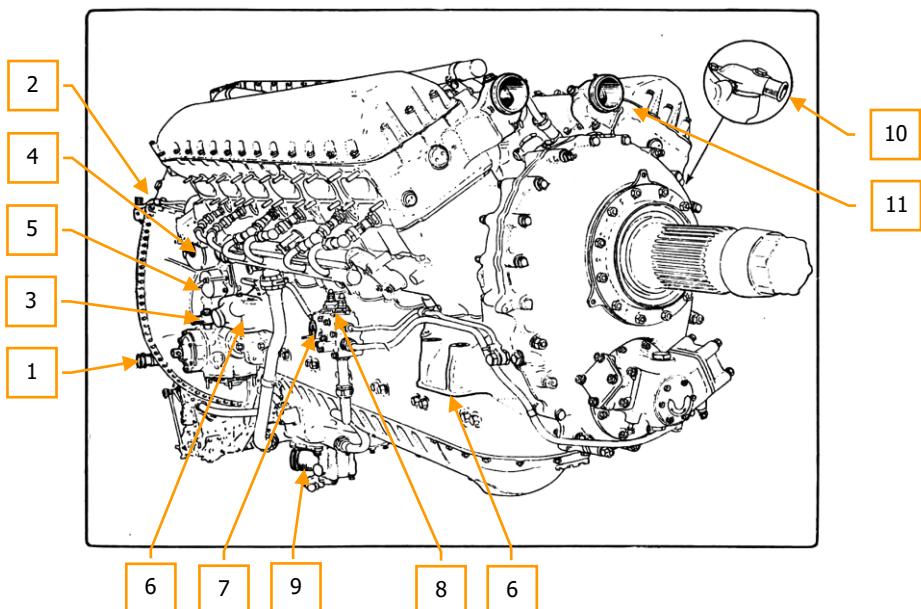
2 blocks with 6 cylinders, each of which are located on the beveled upper surfaces of the crankcase. One block is comprised of the cylinder heads, cylinder skirts made from a light alloy, and steel cylinder liners. The motor cylinder is a steel liner, fixed by its upper section to the block. The lower section of the liner, part of the unit with a loose fit, is sealed with a rubber ring tightened by a nut. Each cylinder

has two exhaust and two suction valves. The exhaust valves are hollow and cooled by sodium; the suction valves are solid and do not have sodium cooling. The adjacent surfaces of the valves are covered by Brightray, a nickel-chromium alloy. The valves are actuated by means of a roller camshaft installed in the center of the cylinder head through the spreader bar. In order to cool the cylinder block cavities are in place for the circulation of coolant material.

In front of the motor is a reduction gear, comprised of a pair of cylindrical gears, one of which is mounted on the flange of the crankshaft, and the other on the flange of the gearbox shaft. On the tailshaft are slots for the installation of the in-flight-variable pitch rotorhead.

The rear of the motor houses the gearbox which transmits torque from the crankshaft to the consumers: the upper and lower vertical transmission, the two magnetos installed on both sides of the motor, and the pump of the main cooling system. The intermediate gear drives the rotation of the oil pumps, the hydraulic pump, the fuel pump and the electric generator. The drives for manual scrolling and the electric starter are also fitted in the box.

Two-speed two-stage supercharger is mounted on the rear of the drive, while a dual-chamber carburettor with automatic height adaptation and boost regulator is mounted by the entrance of the supercharger. On the right side of the motor housing is the centrifugal pump for both the supercharger cooling system and the intercooler.



**Figure 17: Motor assembly. View from starboard side**

1. Scavenge return-oil to tank

2. Fuel priming inlet

- |  |   |
|--|---|
| 3. Wheelcase breather connection<br>4. Magneto booster coil connection<br>5. Magneto earthing connection<br>6. Engine feet<br>7. Oil pressure gauge connection | 8. Oil thermometer connection<br>9. Main oil supply to pressure pump<br>10. Crankcase breather connection<br>11. Connector from surge tank to main engine cooling system. |
|--|---|

## Supercharger

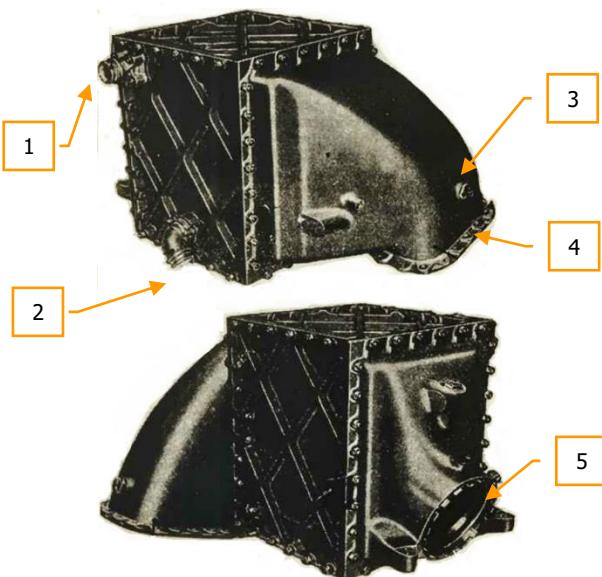
The gear-driven centrifugal-type supercharger mounted on the Merlin engine has a two-stage compressor that raises air pressure at the entrance to the engine cylinders in order to increase both the coefficient of admission and engine power, as well as to maintain a constant air pressure at the entrance to the cylinders during increases in altitude.

It consists of two centrifugal type impellers located on the same shaft. The shaft is rotated through three gear centrifugal clutches. Couplings absorb inertial loads caused by high acceleration during startup, while axial loads are absorbed by the spring-loaded drive shaft. Torque is transmitted to the supercharger by means of a crown gear with a coupling during operation at the first speed, while the other two gears switch on upon setting the supercharger to operate at the second speed. Clutch control, which determines through which gear torque is transmitted, is actualized by means of the claw arm system, which in turn are driven by a hydraulic cylinder via an intermediate roller. The hydraulic cylinder is driven by oil pressure from the pump line. The piston valve of the hydraulic cylinder is controlled via a lever that moves by the pneumatic actuator of the supercharger speed control.

Shifting between the first "M.S" (medium supercharger) and second "F.S" (full supercharger) speeds may be performed automatically, or manually through a 2-stage switch in the cabin. For automatic operation, the toggle switch on the right side of the dashboard must be in the "AUTO" position. In this case, the signal on the solenoid actuator will be coming from the altitude switch, which at a certain altitude will energize the solenoid drive with a supply of compressed air. The actuator is connected via a lever to the slide valve of the speed clutch control hydrocylinder. The aneroid of the altitude switch is set to trigger at an altitude of 14,000 feet (switching from first to second speed) on a climb, and 12,500 feet (switching from the second to the first speed) on a descent. For manual operation, the toggle switch has a second position - "M.S." - which cuts off the circuit to the altitude switch and sets the supercharger to the first speed. On the dashboard is a lamp-switch which lights up upon a shift in supercharger speed. The required pressure in the pneumatic system for operation of the pneumatic actuator is 150 lb/in<sup>2</sup>.

## Intercooler

Tubular-type intercooler with liquid cooling, designed for reducing the temperature of the combustible mixture supplied to the cylinders, installed between the supercharger outlet and the primary inlet manifold. An expansion tank for both the supercharger cooling system and the intercooler is mounted on the fireproof bulkhead.



**Figure 18: Intercooler exterior**

1. Coolant material outlet stack (leading to the expansion tank)
2. Inlet stack for coolant material from the supercharger
3. Boost gauge pressure tap
4. Entry for the combustible material from the supercharger
5. Exit into the main inlet pipe for the cooled combustible material

## Carburetor

The combustible mixture is formed by means of the dual-chamber air intake of the Bendix Stromberg injection-type carburetor (which is a ready-built assembly) mounted to the front of the supercharger. The required amount of fuel is determined by the weight of the air passing through the carburetor air intake. Gasoline is sprayed by the entry to the supercharger. The carburetor works in conjunction with the automatic height correction and constant (boost) pressure regulator.

The constant pressure regulator is a device for keeping the supercharger pressure within certain limits.

Air flows into the carburetor through the air inlet located at the bottom of the motor. The air intake has a damper covering the passageway, thus in this case the air enters the duct through the air filter of the engine compartment. The air intake damper is controlled from the cabin using a handle on the left side of the cockpit labelled "**CARB. AIR FILTER CONTROL**" and having two positions:

- **"NORMAL INTAKE"** – where the damper is open.
- **"FILTER IN OPERATION"** – where the damper is shut and air comes from the engine compartment.

In the extreme positions, the valve is held by a stopper. The air inlet must be closed during engine operation on the ground; i.e taxiing, takeoff and landing, as well as in flight in conditions of heavy dust or sand pollution in the air.

Movement of the handle must be smooth and it is recommended to move the handle at a flight speeds of about 200 mph indicated.

## Oil System

Friction generated in the mechanism of the operating motor causes a loss of power, as well as heating and wear of its parts. To reduce friction, the rubbing surfaces of the parts are lubricated by pressurized oil which, by filling the gaps, form an oil cushion and separate the friction surfaces of each other thereby reducing friction, heat and wear. In addition, the oil circulating in the gaps between the parts washes away particles of waste material. With this, the oil system provides a cooling effect for the motor.

The engine oil system is realized through the dry sump setup. A block of gear-type oil pump is mounted in the rear of the oil trough (the bottom of the crankcase) below. It consists of a single pressurizing stage and two oil suction stages. In addition to the main task to ensure lubrication of the engine, the oil system ensures both the operation of the variable pitch propeller by means of a high-pressure line, as well as the operation of the hydraulic cylinder in switching the supercharger speed by means of a low-pressure line. Pressure relief valve reduces oil pressure for the low-pressure line. Lubrication of the propeller gearbox, cam rollers, traverse valves and auxiliary drives is provided by the low-pressure line.

The oil tank is located under the engine and is completely covered by the lower hood. The filler well is located on the left side of the oil tank, and its location provides the required amount of oil refueling on aircraft parking. The volume of the oil tank is 7.5 gallons (\*liters), whereas the volume of airspace is 1.6 gallons.

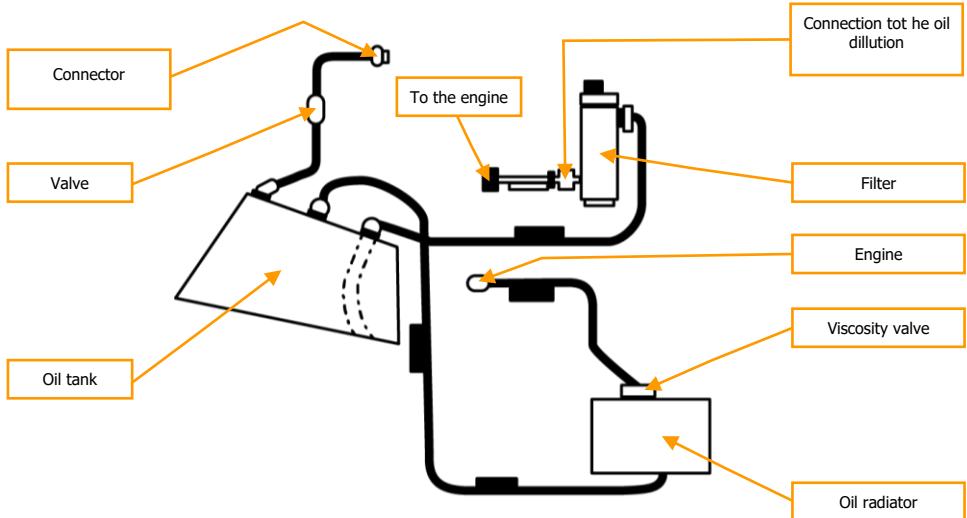
Oil flows from the tank through the filter to the engine, then the oil enters the radiator, positioned under the left plane, through a conduit. A thermostatic valve is mounted on the radiator, which releases cold oil passing through the radiator, accelerating engine warmup. With further increase in temperature, oil is then passed through the radiator. The cooled oil flows back into the oil tank. The air separated from the foamed oil is then discharged from the oil tank along the vent pipes into the crankcase. Thus, the foam formed in the case of tank overfill is not vented to the atmosphere, and instead goes directly into the crankcase. Simultaneously, such a drain system protects the oil system from dust and air moisture, which reduce foaming of the oil. A dual-action valve is integrated into the drain line, maintaining a pressure of 2.5 lb/in<sup>2</sup> in the oil tank gauge. The valve maintains a pressure of no higher than 1 lb/in<sup>2</sup> in the engine crankcase. An oil thermometer on the outlet of the engine and a gauge indicating the pressure in the oil gallery are in place to monitor the performance of the system.

The readings on thermometer and pressure gauge completely characterize the operation of the aircraft oil system.

A system for thinning oil with gasoline is in place to facilitate engine startup in low-temperature conditions. Before engine stoppage, the valve supplying gasoline to the intake pipe of the engine will open depending on outside temperature. Gasoline thins the oil upon mixture, reducing viscosity. The hose from the fuel system brings fuel to the feed pipe after oil filtration, thus providing the engine parts with oil of lesser viscosity.

Amount of time the valve remains open for oil filtration and thinning:

1. For temperatures, higher than -10° C - 1 minute.
2. For temperatures, lower than -10° C - 2 minutes.



**Figure 19: Oil system parts and locations.**

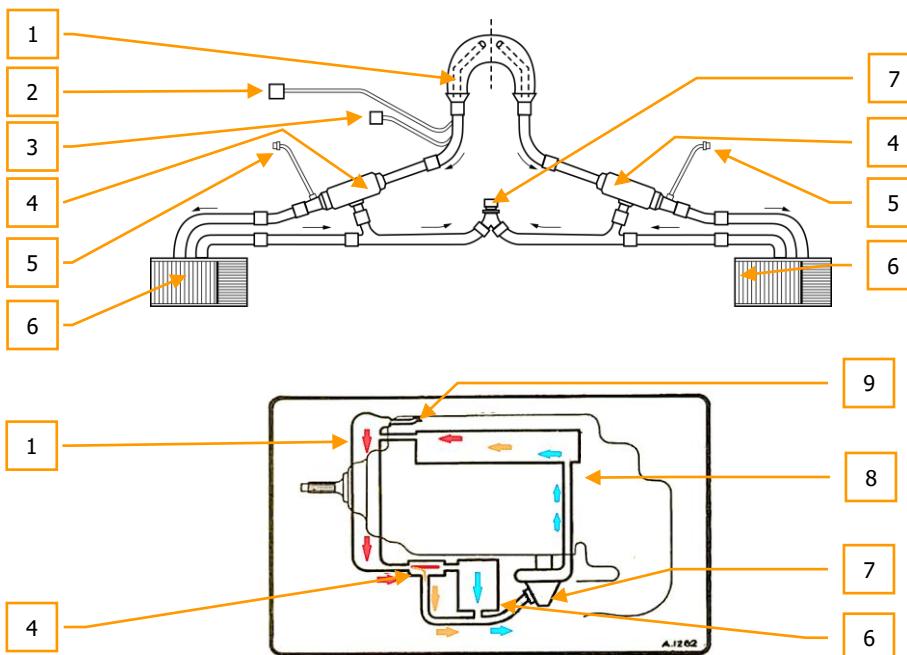
## Cooling System

### Motor Cooling System

The cooling system uses a mixture of 70% water and 30% ethylene glycol and has a volume of 13.5 gallons. An expansion tank in the shape of a horseshoe is mounted above the propeller gearbox. The centrifugal pump has two output lines of feed lines for each cylinder block and one output for the pump line. The pump delivers the coolant to the cylinder block, where the fluid, flowing through the cavity in the cylinder jackets and cylinder heads, is heated, thereby cooling the engine parts. The warmed fluid is then directed to the expansion tank, in the form of a horseshoe and mounted above the propeller gearbox. A dual steam-valve, installed in the expansion tank, maintains the necessary pressure in the system - 2.5 lb/in<sup>2</sup>. The valve performs four different tasks: releasing air from the system during warmup; preventing the coolant from boiling up to temperatures of 125°C, thus maintaining the balance of pressure and temperature in the cooling system; working as a safety valve in case of overpressure; and finally, operating as a check valve allowing air into the surge tank in case of a reduction in system temperature. The filler neck of the expansion tank determines the system fill level.

Inlet pipes in the expansion tank directly feed fluid into the outflow pipes, which ensures the preservation of the kinetic energy of the fluid and improves its circulation within the system. The output lines supply the liquid to the thermostats at the front edge of the wing and into the radiators placed under each half-plane in the tunnels formed by the cowling. A drain valve to release air pockets occurring in the system during filling is installed in the fluid supply lines to the radiators.

When the coolant temperature is below 80°C, thermostats guide the fluid directly to the pump inlet, bypassing the radiators. The radiator tunnels are equipped with automatic valves that regulate the coolant temperature and oil. Tunnel dampers open when the thermostat detects a coolant temperature of 115°C. The thermostat is installed between the expansion tank and the thermostatic valve on the left side of the engine. Installed on the dashboard is the coolant temperature indicator for controlling the operation of the system, while a switch is in place on the left side of the cabin for checking the operational status of the radiator shutters control system. Shutters open when the switch is pressed. The technician located by the plane must be the one to control the opening of the radiator tunnel valves.



**Figure 20: Illustration of the motor cooling system**

1. Expansion tank.
2. Thermal (radiator valves control system).
3. Thermometer.
4. Thermostatic valve.

5. Drain valve.
6. Section of the main cooling system radiator.
7. Cooling system pump.
8. Cylinder blocks.
9. Double-steam-valve.

## Intercooler and Supercharger Cooling System

A separate cooling system is in place for reducing the temperature of the fuel-air mixture after its exit from the supercharger. This system consists of a tubular-plate intercooler, centrifugal pump, expansion tank and radiator for cooling the fluid circulating in the supercharger and intercooler.

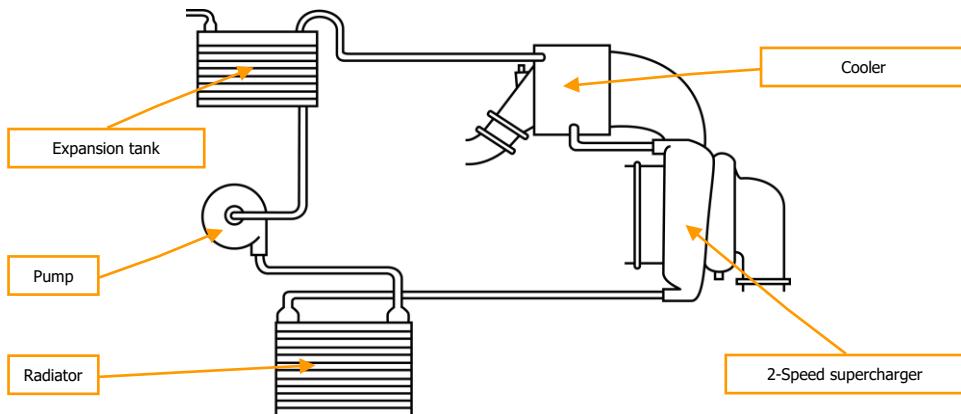
The intercooler is mounted between the supercharger and the intake manifold.

The coolant from the surge tank is fed by a separate centrifugal pump into the radiator located in the tunnel under the right half-plane. Next, the cooled liquid washes the body of the supercharger and is supplied to the intermediate cooler. After passing through the radiator, the coolant fluid enters the surge tank. The differential pressure is provided by the radiator relief valve built into the drainage line. The system is autonomous and does not require pilot input to function. The volume of the surge tank is at 5.75 pints - 5 pints for the coolant, and 0.75 for air.

On earlier models of the aircraft, a thermal switch was installed in the intake manifold, which set the supercharger to the first transmission in case of a temperature rise in the fuel mixture.

A thermal switch mounted on the supercharger housing forcibly switched the supercharger to first speed if the coolant temperature rose excessively.

A switch to first gear is indicated by a reset of the spring-loaded switch, mounted on the dashboard. Re-enabling the second gear of the supercharger is possible after a decrease in the temperature of the gas mixture (and/or coolant) by pressing the switch. However, if the temperature fails to decrease, for example, in case of cooling system failure, the switch will reset, and the supercharger will have to be kept at first speed.



**Figure 21: Supercharger cooling system.**

## Propeller

On the output shaft of the motor gear unit is the ROTOL R12/4F5/4 four-blade variable-pitch propeller. The blades are made of pressed wood which have been further processed mechanically.

The propeller is automatic, capable of maintaining in-flight a consistent RPM, as set by the pilot. The blades be automatically set within a range of 35° (from 22° 20' to 57° 20') at any level of engine power, depending on the operation mode of the motor. This allows the pilot to take full power of the motor under all conditions of flight, as well as to establish the most economical mode of operation of the motor.

Automatic maintenance of the contant RPM is performed by a constant speed regulator installed on the left side of the propeller gearbox.

Depending on the speed of the motor, the regulator switches the flow of oil from the high pressure pipeline to the rod end or the rodless cavity of the propeller head.

On high pitch, the rotation of the propeller blades is caused by the force of oil pressure on the cylinder piston; on low pitch, propeller rotation is caused by the centrifugal moment of the blades themselves.

The propeller pitch system consists of a lever installed on the inside of the engine throttle, and a Teleflex cable that leads to the constant speed regulator. Moving the lever changes the engine speed within a range of 3000 to 1800 rpm.

## Engine mount

Tubular construction with a transverse U-shaped frame. The engine is mounted on four supports: two on the front pipe, and two on the frame. The attachment points of the motor: the top two meet at the 5-fuselage frame bracket with the main longitudinal members and diagonal struts, while the two lower nodes meet on the bracket along with the lower longerons of the fuselage on the beam, forming the fuselage portion of the main wing spar.

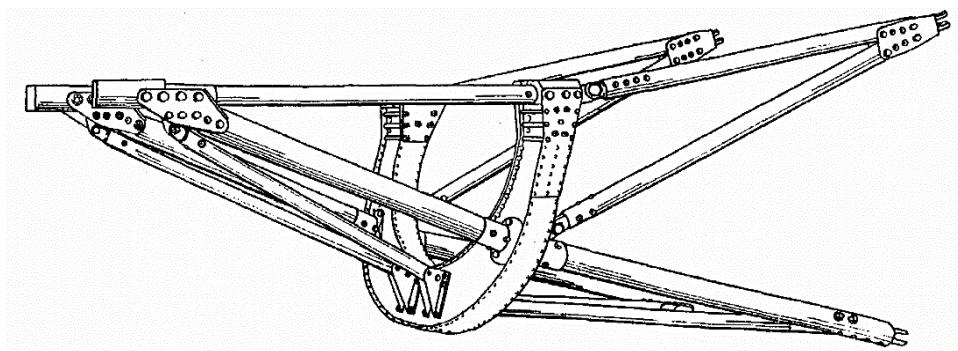


Figure 22: Engine mount

## Engine cowling

The engine is encased by an easily removable engine cowl, with cuts or hatches in the areas with access points for the engine refueling system. The order for dismantling the panels is as follows: top, side, then bottom of the hood. The hood is held in place by quarter-turn locks to the supporting elements, forming the shape of the bow. For checking lock positions, marks coinciding with the direction of the lock slot in the closed position can be found on the casing. During installation, you must first fix the rear edge of the panel, which is then moved towards the nose of the aircraft.

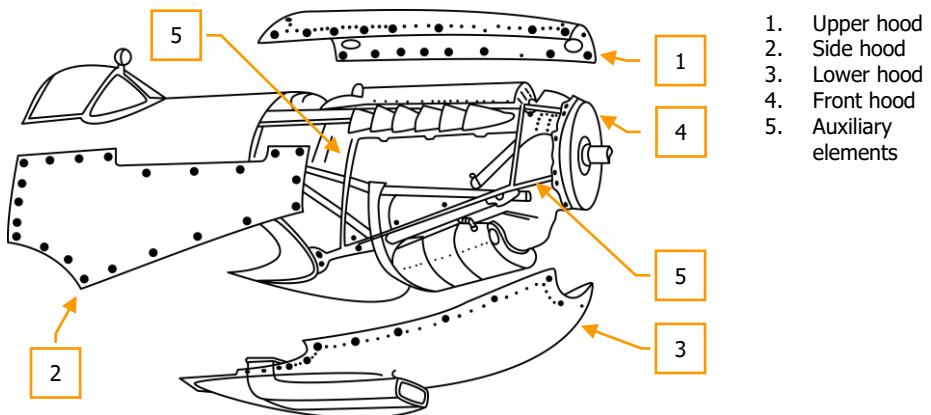


Figure 23: Engine cowling

## Engine management

The engine is managed with the throttle quadrant assembly.

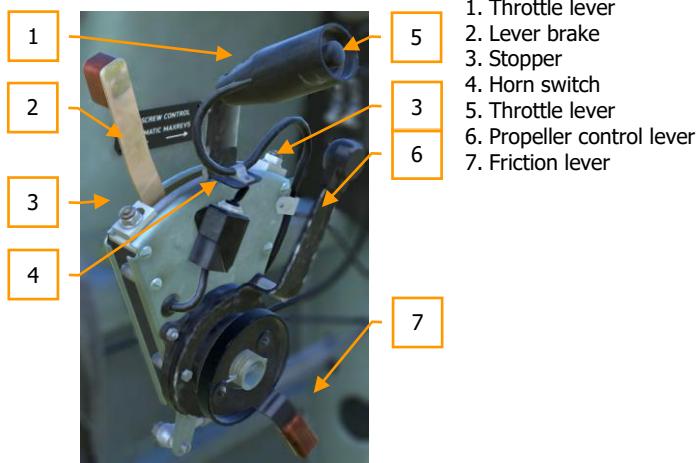
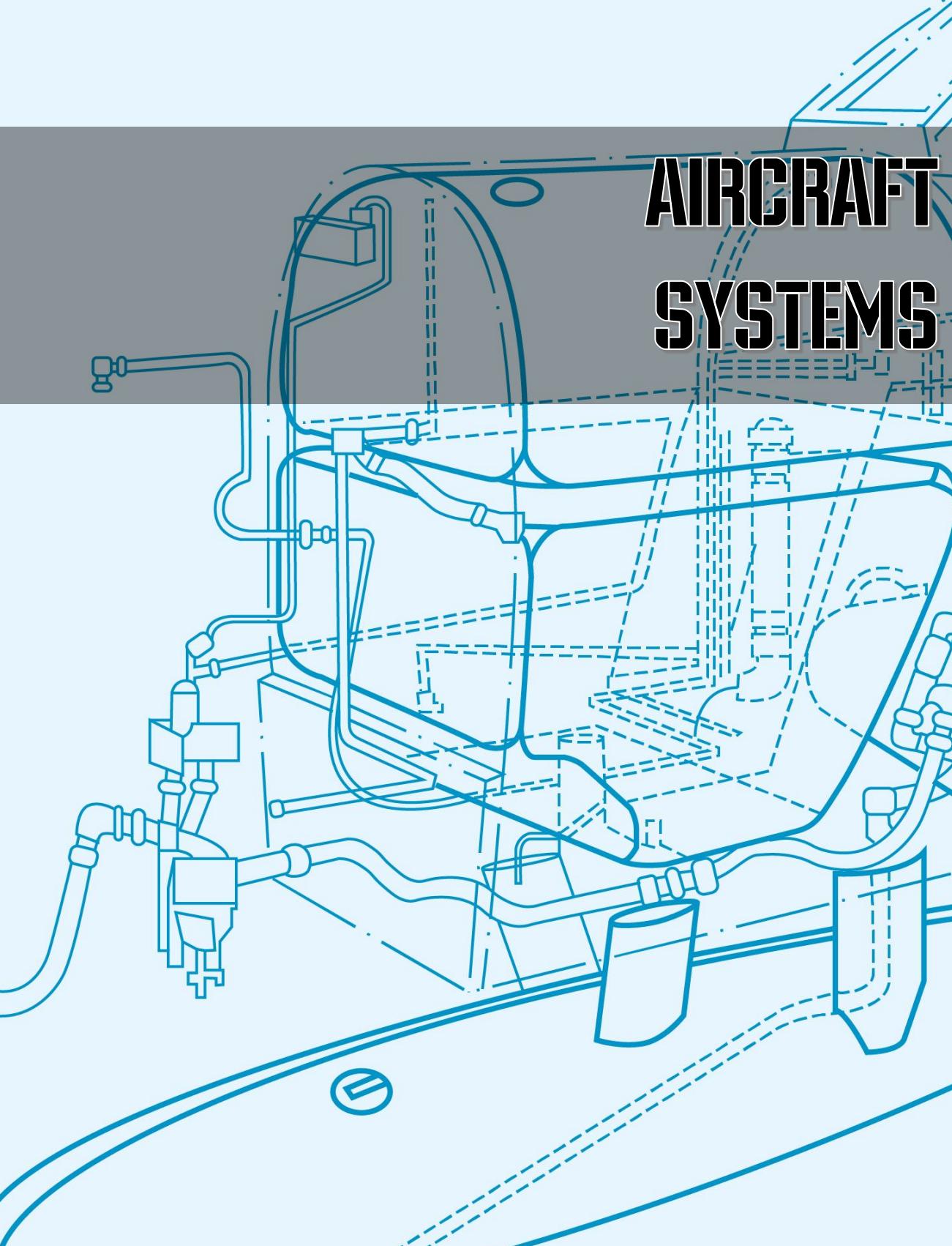


Figure 24: Throttle quadrant

# AIRCRAFT SYSTEMS



# AIRCRAFT SYSTEMS

## Aircraft control system

Control of the aircraft is performed by means of two separate command posts. For longitudinal, lateral and directional control on the plane, there are two independent systems - hand and foot/pedal control. The pilot's hands manipulate the elevator and ailerons, while foot pedals control the rudder. The ailerons, elevator and rudder are of metal construction. Both the rudder and elevators are cloth covered, while the cover of the ailerons and trimmer plates are made of an aluminum alloy.

The aircraft's elevators are horn balanced, while the rudders are weight balanced.

Depth of the cockpit and the pilot's elevated position led to designers rejecting the installation of a "pistol" type control stick. The aircraft is equipped handle, hinged top of "a steering" type. The handle is tilted at an angle of 11° from the vertical axis towards the pilot, deflection angle of the upper part is 41°.

The longitudinally-moving pedals have two platforms for the pilot's feet. The upper platform is used during intense maneuvering in combat.

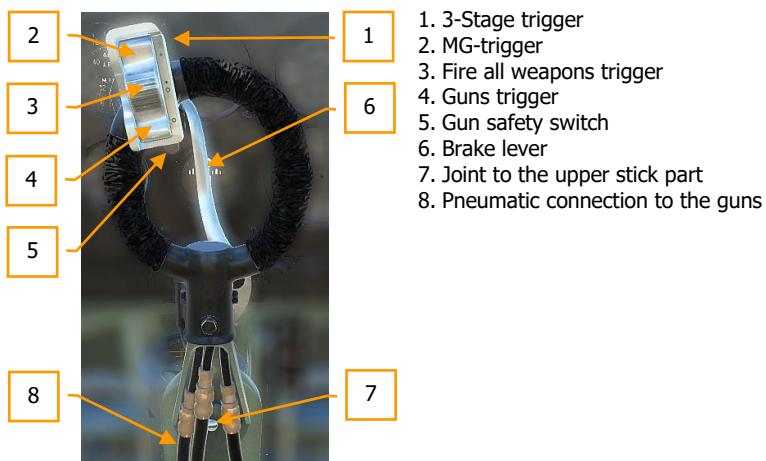
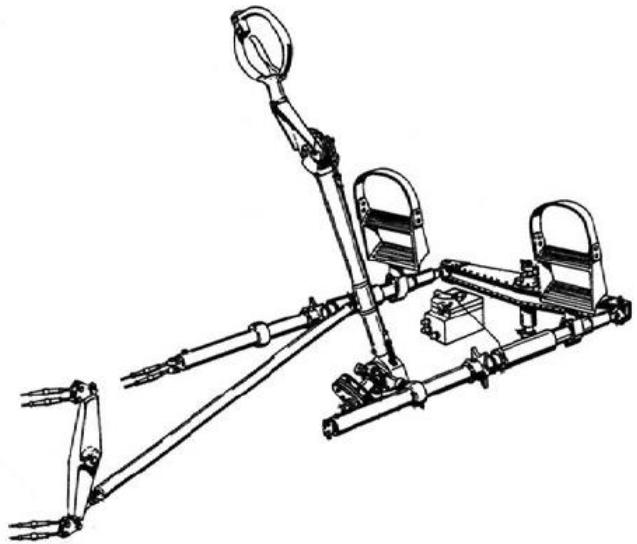


Figure 25: Control grip



**Figure 26: Aircraft flight control systems**

The transmission from the control systems is carried out by means of cables, rods and crossbeams.

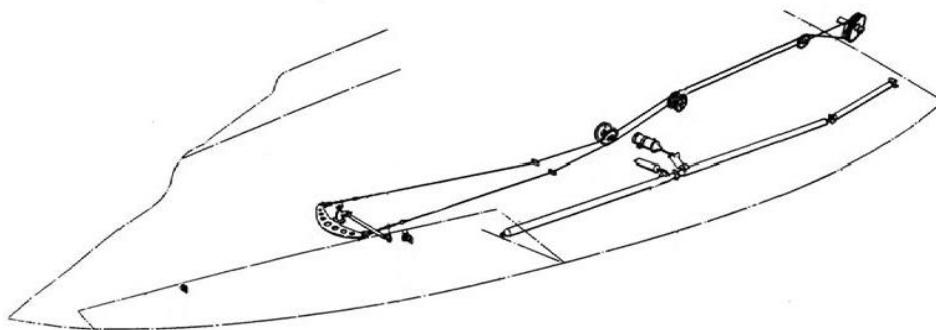


Figure 27: Aileron control system.



Figure 28: Tail-plane

### Ailerons

FRISE type ailerons of all-metal construction with 100% weight balancing. They are attached to the rear auxiliary spar. Balancing adjustment is performed by means of lead shim in the aileron sock tube. Adjustment of the lateral balancing of the aircraft is carried out on the ground by bending the trailing edge of the aileron.

Deflection angles:

- Up – 26°.
- Down – 18°.



**Figure 29: Ailerons**

### Rudder

Fastened to the tail fin at two hinges. It has a metal frame and fabric covering impregnated with varnish. Equipped with weight balancing. Early series saw rudders with a rounded top; later models were equipped with a wider rudder with a pointed top.

Deflection angles:

- Round rudder -  $28^\circ$ , measured by rib 6.
- Pointed rudder –  $28.5^\circ$  measured by rib 7.

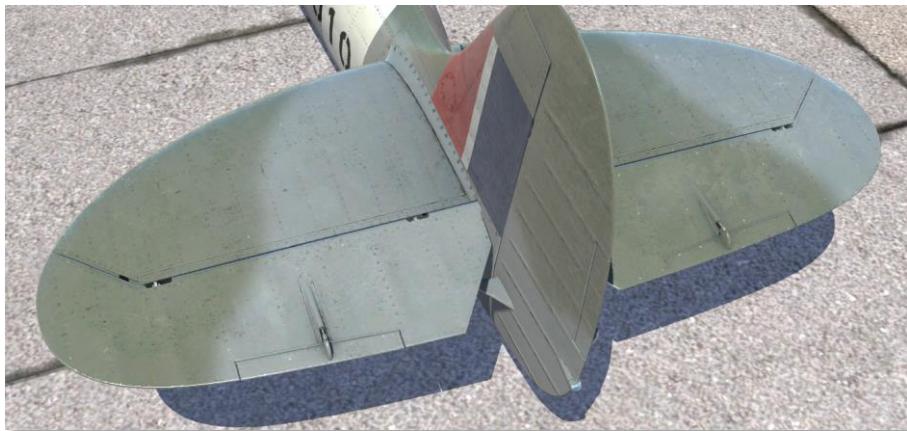
**Figure 30: Rudder and tail unit**

### Elevator

Fastened to the stabilizer, comprised of a single part. Has a metal frame and fabric covering impregnated with varnish. Equipped with horn balancing. Later series saw the installation of elevators with enlarged horn balancing.

Deflection angles:

- Up - 28°.
- Down - 23°.



**Figure 31: Elevator**

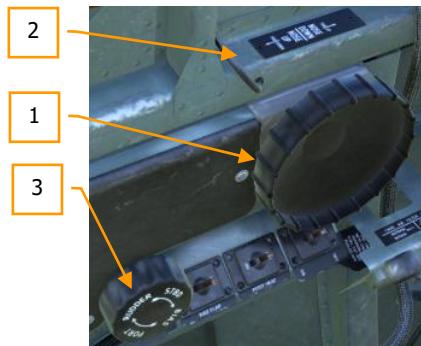
### Trimmers

To minimize pilot exertion on the stick and pedals, the aircraft's elevator and rudder are equipped with trimmers made of aluminum alloys.

The elevator trimmer is controlled by a large handwheel (30) on the left side of the cabin. On the left side of the dashboard is an indicator (24) showing the position of the trimmer relative to the elevator. The neutral position of elevator trim on the indicator is marked by 2 bars from the middle position towards "**NOSE UP**". Two full revolutions of the wheel are required to move the trimmer from the arrow's middle position to the extreme end.

The rudder trimmer is controlled by a small wheel (27) and has no position indicator. The aircraft has a tendency to yaw right upon clockwise rotation of the wheel. The rudder trimmer is of a flettner trimmer design, kinematically deflecting against the rotation of the rudder and has at the same time the option of manual control.

The direction of wheel rotation is indicated directly on the wheels, or close by on the plates.

**Figure 32: Trim controls**

Rudder trimmer deflection angles (for both rudder types):

- Left - 18°.
- Right - 5°.

Elevator trimmer deflection angles:

- Up - 20°.
- Down - 7°.

## Flaps

Four "SHRENK" type sectional flaps found in two portions on each plane: a main portion and a shorter inboard portion. Separation of the flaps is caused by a kink in the lower surface of the wing, by the rear edge at the plane of the wing's butt attachment to the fuselage. The flaps are attached to the auxiliary spar of the wing. Placed from the inner edge of the aileron to the wing root.

The flaps are controlled by a pneumatic system with a lever located at the top left of the dashboard. To deploy the flaps, the lever must be pulled down. In-flight retraction of the flaps is done by impact air pressure upon moving the lever to the upper position and by the force of the spring mechanism. On the ground, the flaps are retracted only by the force of the spring mechanism, mounted next to the release cylinder.

**Figure 33: Flaps switch**

The flaps have 2 positions - "**UP**" (retracted), and "**DOWN**" – fully deployed.

Flaps' deflection angles: 85° - 5°.



**Figure 34: Flaps wing indicator**

# Gear

<b>Main landing gear</b>	
Type	Retractable, cantilever
Track	5 foot 8 ½ inches (1,74 meter)
<b>Dampers</b>	
Shock-absorber struts	Vickers Oil-Pneumatic №91244/L, №91986
Air pressure (strut free)	465 lb/sq. In. (32,7 kg/cm <sup>2</sup> )
Wheels	"Dunlop" AH.2061
Covers	IJ.13 or IJ.17
Tubes	IJ.8 or IJ.9
Tyre pressure	57 lb/sq. In (4 kg/cm <sup>2</sup> )
or Shock-absorber struts	
Air pressure (strut free)	Oil-air "Vickers" №91244 380 lb/sq. In. (26,7 kg/cm <sup>2</sup> )
Wheels	"Dunlop" AH.10019
Covers	IJ.13 or IJ.17
Tubes	IJ.8 or IJ.9
Tyre pressure	54 lb/sq. In (3,8 kg/cm <sup>2</sup> )
<b>Note:</b> Strut No. 91244 is a spline type, and is only fitted when link type struts are not available.	
Brake	Pneumatic, "Dunlop"
<b>Tail wheel unit</b>	
Type	Non retractable
Shock-absorber strut	Oil-pneumatic "Vickers" №90356
Air pressure (strut free)	242 lb/sq. In (17 kg/cm <sup>2</sup> )
Wheel	"Dunlop" AH.2184/IX
Cover	TA.12 or TA.14
Tube	TA.2 or TA.3
Tyre pressure	47 lb/sq. In (3,3 kg/cm <sup>2</sup> )

A three-wheel undercarriage system with oil-air cushioning is installed on the aircraft. The system consists of two main cantilever-type struts and one non-retractable, moving tail wheel. The two main gears mounted in the wing panels are attached to the main wing spar. The tail wheel is mounted at the rear of the fuselage.

The undercarriage retracts along the wing span of the aircraft to the ends of the axis of the cantilevers. Retracted landing gears are covered by metal skirts, but not fully. The undercarriage in its retracted and deployed positions is fixed in place by a mechanical lock. There are mechanical, light, and (in earlier series) sound indicators of the landing gears' position.

The wheels are equipped with pneumatic brakes. The brake control lever is mounted on the "steering wheel" control stick of the aircraft while the differential brake system is connected to the foot pedals.

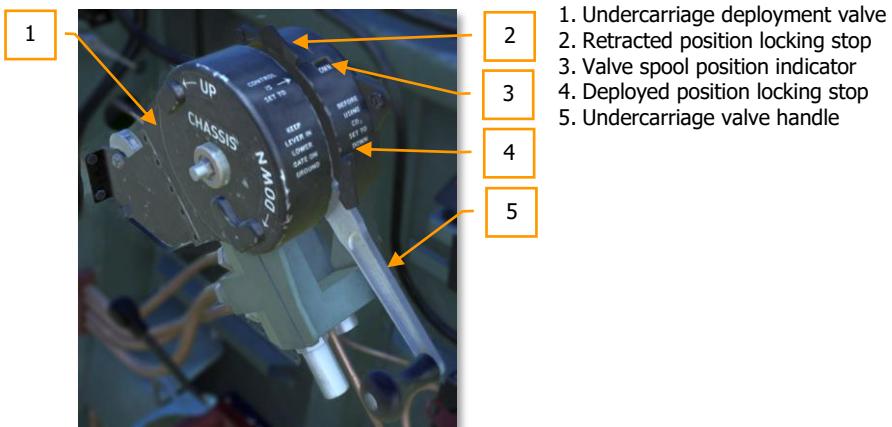
The narrow width of the track is at 5 feet 8.5 inches (0.153 wingspan) did not exclude the possibility of transverse swinging the aircraft during takeoff and landing. Due to the low height of the undercarriage, there was a possibility of the wingtip fairings breaking off, especially when landing the aircraft in field airstrips. The low rise of the main landing gears made the Spitfire prone to nosing over.

### Landing gear mechanism

The landing gear retraction system is hydraulically-powered. A pump mounted on the motor generates a fluid pressure that is passed onto the respective pistons in order to deploy or retract the landing gears.

The emergency landing gear deployment mechanism is pneumatic, driven by an onboard balloon filled with carbon dioxide.

Control of the gear deployment system is by the landing gear control lever (52) installed on the starboard side of the cabin.



**Figure 35: Gear controls**

## Strut locks

The struts are fixed by mechanical lock in both positions, for different clamps. The retracted position's clamp is installed in the shock absorber strut; The clamp for the deployed position attaches in the strut mounting rod of the gear deployment hydraulic lift mechanism. The locks are controlled by a lever with the help of ropes, turning into Gall chains by the lever and locks. The chains are draped over the sprockets, which ensure the rotation of the locking pin of lock from one position to another.

## Landing gear system operation

The landing gear lever (52) is located on the right side of the cabin.

Below is the procedure for retracting the landing gears:

1. Pull the lever back out of the gate and pause for a second or two at the extreme end of the slot.
2. Push the leader steadily and without pause forward to the up position. This rotates the down lock to the up position by means of chains and cables and directs the fluid to the up ends of the jacks.
3. When the undercarriage is locked up, the lever will spring into the forward gate under the action of a cut-out plunger in the control unit.

To deploy the undercarriage, the procedure for raising is reversed.

**CAUTION:** – Do not attempt to place the handle into the slots on your own, as this may lead to a cut-off of the hydraulic fluid system.

## Undercarriage indicators

### Indicator on the control unit

A mechanical indicator installed on the control unit displays the position of the lever in a small window with the words "DOWN", "UP", and "IDLE". Upon deployment of the gears, the window must display "DOWN", and upon retraction – "UP".

IDLE status is displayed when the system detects the handle being located in either slot. In the case of an inactive engine, the indicator may display DOWN while after engine startup the indicator must change status to IDLE; if the indicator continues to display DOWN, this indicates a potential malfunction of the hydraulic pump.

### Electrical visual indicator

An indicator panel installed on the left side of the dashboard has two translucent stencils with the words UP and down in red and green backgrounds respectively.

One of these two lights will be illuminated according to the position of the undercarriage – **UP** displays when the undercarriage is fully retracted and locked in position, **DOWN** when the gears are deployed and locked.

Each indicator is composed of two lights connected in parallel. There are shutters in place that cover the front part of the panel and dim the lights when flying at night.

The signalling system has three limit switches installed in the circuit. The first switch is activated when the undercarriage is in the retracted position (circuit "UP"), the second switch is triggered when the undercarriage is deployed (circuit "DOWN") and the third limit switch located in the lock housing and common to the two circuits is triggered when the locking pin is located in the clamp aperture.

The switch for the DOWN circuit is installed on the throttle quadrant and is activated by means of a striker on the throttle lever by pressing it forward. The switch must always be manually returned to the off position prior to parking the aircraft in order to avoid discharging the aircraft's batteries.

### Mechanical position indicator

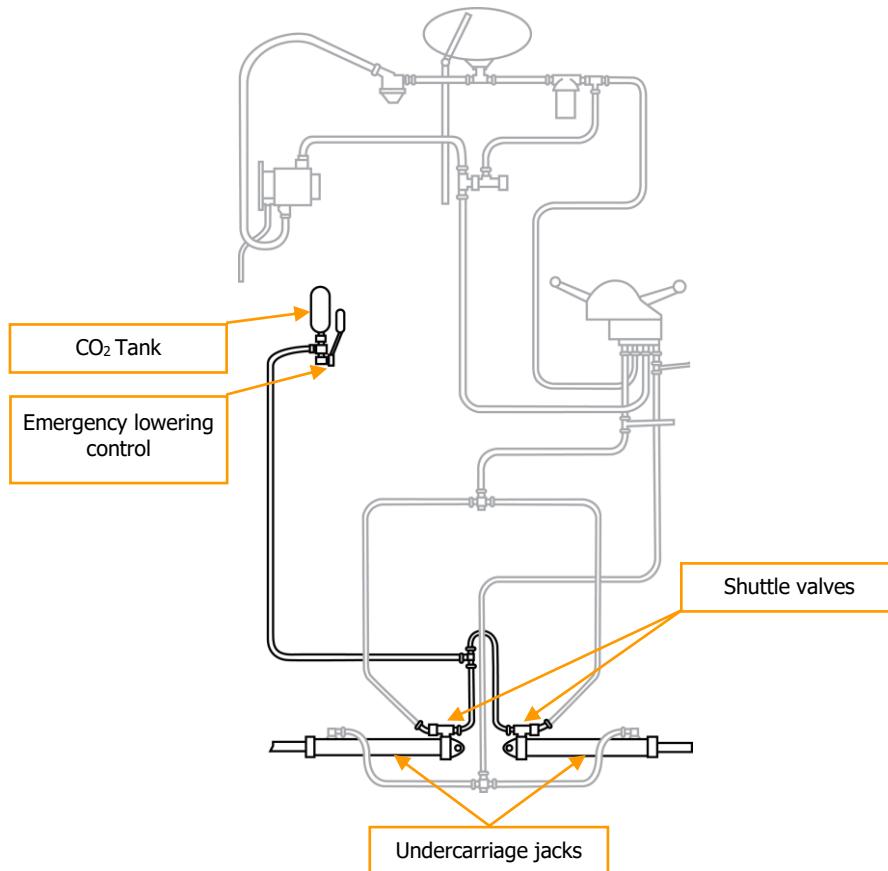
Installed on earlier models of the aircraft were mechanical indicators of the undercarriage position – essentially a rod, fitted to each undercarriage unit, that extends through the top surface of the aircraft wings. The rod (painted bright red) protrudes through the aircraft wings when the undercarriage is deployed, and are removed from view when the undercarriage is retracted.

### Warning horns

An auditory warning system was installed in the earlier models of the aircraft, and activates when upon detecting throttle is pulled all the way back while the undercarriage is in the retracted position. To deactivate the alarm, the pilot must push the throttle forward so that the striker on the throttle lever will depress the horn switch. Alternatively, the pilot may simply deploy the undercarriage.

## Emergency Gear extension system

In the event of hydraulic system failure, undercarriage deployment is performed by means of directing pressure from sealed high-pressure carbon dioxide cylinder into the undercarriage operating jacks. The cylinder is mounted on the right-hand side of the cockpit near the pilot's seat. The neck of the cylinder (containing 90g of carbon dioxide) is hermetically sealed, and has a red-painted lever (labeled "EMERGENCY ONLY") for emergency deployment. The lever is connected to a spring-loaded piston with a needle for puncturing the seal and delivering the gas into the undercarriage system. The lever is fitted with a thin copper wire seal as an additional safeguard against inadvertent use.



**Figure 36: Emergency gear deployment system**

The pipeline from the cylinder is divided by a tee and is connected to the hydraulic lines through the shuttle valve to the piston cavity of the hydraulic ram.

A shuttle valve is in place for disconnecting the hydraulic system should the pilot engage the emergency gear system. It is installed on the rear part of the hydraulic jack and has three openings: one leads to the hydraulic jack, the second for connection with the hydraulic line, and the third for connecting to the emergency system's gas cylinder. In normal operating conditions, a spring-loaded shuttle covers the valve leading to the carbon dioxide cylinder, allowing the hydraulic fluids to course freely along the pipeline. When the emergency system is activated, the pressure caused by the influx of carbon dioxide into the system forces the spring-loaded shuttle to its end, cutting off the hydraulic system from the

hydraulic jacks. Carbon dioxide is fed into the cavity of the piston lifts and forces the undercarriage into the deployed position.

### **Operation of the emergency system**

In case of hydraulic system failure and prior to engaging the emergency system the pilot must first ensure that the undercarriage selector lever is in the DOWN position. Afterwards, the pilot must push the emergency lowering level forward and downward. The angular travel of the emergency lever is about 100° for puncturing the seal of the cylinder. After this first step, a return spring and the gas pressure return the piston to its initial position, and the gas is fed into the hydraulic mechanism.

If the pilot fails to set the undercarriage selector level to the DOWN position, then upon activation of the emergency system, the undercarriage will fail to deploy. In this case, the pipeline feeding carbon dioxide to the undercarriage lifts must be depressurized by means of a crowbar.

After engaging the system no attempt must be made to return the lever to its original position until the cylinder is being replaced.

## HYDRAULIC SYSTEM

The hydraulic system is designed to power the undercarriage deployment system.

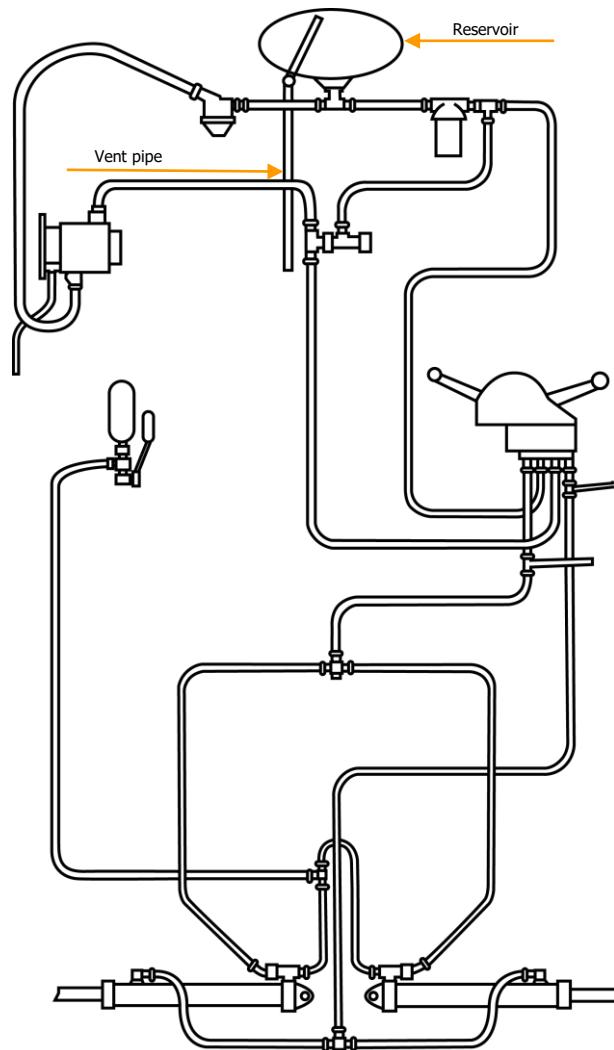


Figure 37: Hydraulic system

The source of pressure is a hydraulic pump mounted on the right side of the engine. Hydraulic fluid is supplied from a tank to the pump via an A.G.S. filter. The system uses the English Standard Oil D.T.D. 585, or a mix of 50% glycerol and 50% ethanol, with strength of not less than 78°. The volume of the hydraulic system is at 1.06 gallons (4.82 liters). After the pump, the hydraulic fluid is supplied through the safety valve to the undercarriage lever mounted on the right side of the cockpit. From the lever are pipelines connected to both cavities of the undercarriage lift mechanism. The undercarriage lever directs hydraulic fluid to the required cavity of the undercarriage mechanism depending on the desired operation: deployment or retraction. The drain line from the undercarriage crane delivers hydraulic fluid through a Vokes filter, the entrance to which is connected through a duct to a safety valve. Hydraulic fluid further flows back into the tank. The drain pipe from the tank passes on the right side of the frame and out the bottom along the plating.

### **Hydraulic Tank**

The tank of the hydraulic system is secured with two clips to the fireproof bulkhead, on the top right. The filler neck of the tank is equipped with a gauze and dipstick filter. The level of hydraulic fluid in the reservoir is controlled by the dipstick.

### **Hydraulic Pump**

The **H Mk. IV** hydraulic pump is located on the right cylinder block and is driven by the engine distributor camshaft.

### **Safety Valve**

Placed on the front of the fireproof bulkhead - in the supply line from the pump to the undercarriage lever. In case of pressure increase in the supply line to  $1250 \pm 50$  lb/sq.in ( $87,88 \pm 3,52$  kg/sq.cm), the valve is activated and the liquid from the pump is discharged into the hydraulic tank, bypassing the undercarriage lever.

### **Undercarriage control unit**

The control unit consists of a quadrant housing the control lever and mechanism, and a body with three cylinders – one containing a piston, the other a centralizing spring, and the last, a cut-out plunger. The cylinder containing the piston contains angular grooves that communicate with four-pipe connections: the pressure inlet, the exhaust, and the retract/deploy lines to the undercarriage jacks.

The piston valve has a bore that directs hydraulic fluid from the pressure inlet into the drain line for deployment or retraction depending on the position of the piston in the cylinder. The piston valve is moved by the rod attached to an actuating lever (5) pivoted on a spindle in the quadrant. This lever (5) is driven by a crescent ring (7) which engages with the lever near the end of the movement of the control lever (9), to which it is attached.

Also attached by the lever (5) is the spring-loaded centralizing rod (6) which ensures that the piston (3) is in the idle position when fluid is flowing from the inlet to the exhaust. A spring-loaded pawl (18) is used in order to keep the piston in the UP or DOWN position against the action of the spring. The pawl engages into one of two notches in a ratchet (16) on the lever spindle when the control lever is pushed into the UP or DOWN position. The pawl is disengaged by a cam (17) mounted on the crescent ring (7) upon moving the control lever.

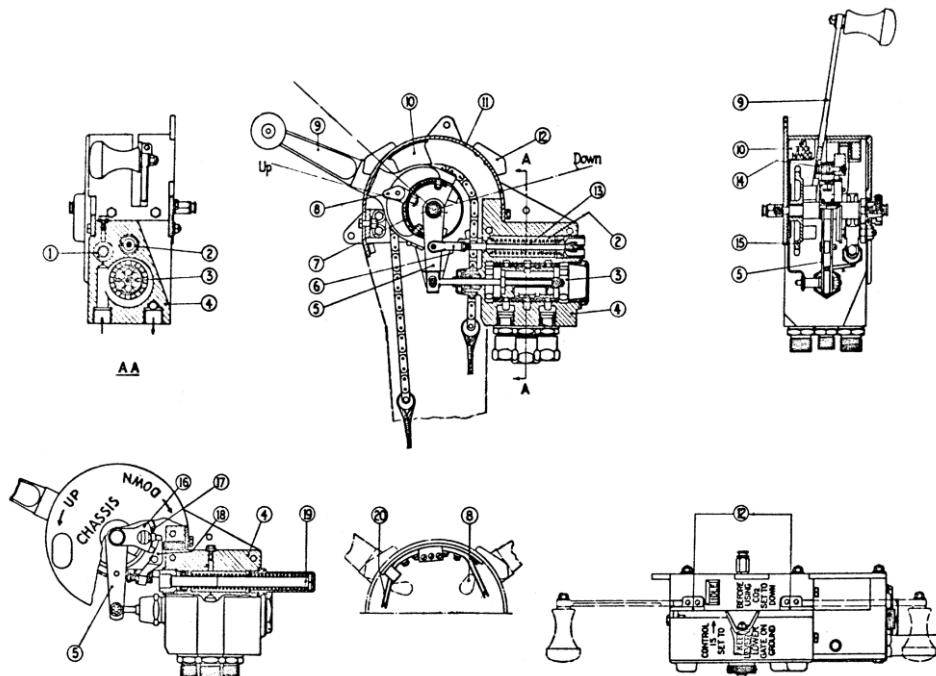
The pawl is also disengaged at the end of the undercarriage operation by fluid pressure building up in the unit and loading the cut-out plunger (19) which is forced along its cylinder to push the pawl out of engagement with the ratchet and allow the centralizing spring to return the piston to the idling position. The required hydraulic fluid pressure for operating the cut-off plunger is at  $1150 \pm 50$  lb/in<sup>2</sup> ( $80.85 \pm 3,52$  kgf/cm<sup>2</sup>).

Attached to the lever (5) is an indicator plate (10) which pivots on the same spindle and shows, through an opening in the quadrant, DOWN, IDLE, or UP, according to the position of the piston in the cylinder.

The control lever (9) is pivoted laterally on the crescent ring and loaded by a spring (14) which pushes the lever into the gate at each end of the slot when it is moved past the stops.

Also mounted on the spindle and operated by the control lever is a sprocket (15) carrying a chain to which are connected the cables operating the undercarriage locking pins, which engage in the strut. A backlash of 9° exists between the lever and the sprocket, so that the movement of the lever in and out of the gate does not affect the locking pins.

Mounted on the crescent ring (7) is a cam (8) which engages the electrical contacts (20) when the control lever is near the end of its travel in each direction; these contacts serve as a change-over switch for the RED and GREEN undercarriage indicators.



**Figure 38: Undercarriage control unit.**

## OPERATION OF THE CONTROL UNIT

When the hand lever is in the gate either at the UP or DOWN end of the quadrant, fluid from the engine-driven pump enters the control at the pressure inlet and passes straight through to the exhaust outlet back to the reservoir. In this condition, the system is idling (A).

In order to raise the undercarriage, the control lever must be moved  $9^\circ$  in a clockwise direction, laterally through the gate, and then in an anti-clockwise direction to the UP position on the quadrant; the time taken for the complete movement must be approximately one second. During these movements of the lever, the following movements of the piston take place:

1. *Initial  $9^\circ$  clockwise movement ("B"):*  
The valve piston is moved along the cylinder and is retained by the pawl engaging the top side of the ratchet centre tooth, thus closing the bypass circuit and diverting fluid under pressure to the DOWN sides of the jacks. Fluid from the UP sides of the jacks is exhausted through the cylinder and valve to the reservoir. As the undercarriage is already down, no movement can take place, but the pressure in the jacks relieves the locking pins of the weight of the undercarriage. The backlash between the control lever and the locking pin cables permits this  $9^\circ$  movement without affecting the locking pin.
2. *Passing through the gate:*  
The locking pins are unlocked.
3. *First  $9^\circ$  of counter-clockwise movement ("C"):*  
The backlash between the control lever and cables is taken up.
4. *Next  $132^\circ$  of counter-clockwise movement ("D"):*  
During the first part of this movement, the pawl is tripped by a cam and the piston is moved along the cylinder by the centralizing spring to the idling position. Relieved of the weight of the undercarriage the locking pins rotate freely from the DOWN position almost to the UP position.
5. *Final  $9^\circ$  of counter-clockwise movement ("F"):*  
The rotation of the locking pins is completed and, simultaneously, the valve piston is moved to the other end of the cylinder, in which position it is retained by the pawl engaging the underside of the ratchet centre tooth; thus the bypass circuit is closed again and fluid under pressure is diverted to the UP side of the jacks. Fluid from the down sides of the jacks is exhausted through the cylinder and valve to the reservoir. The fluid pressure during the raising of the undercarriage is approximately  $200 \text{ lb/in}^2$  ( $14 \text{ kgf/cm}^2$ ).
6. *End of counterclockwise movement ("G"):*  
On completion of the travel of the undercarriage, pressure in the system rises until it is sufficient to operate the cut-out, the plunger of which is housed in a chamber in communication with the pressure inlet to the valve. The cut-out spring is overcome and the projecting end of the cut-out plunger comes into contact with the setscrew in the pawl, disengages the ratchet, and permits the valve piston to move back to the idling position under the action of the centralizing spring.
7. *Final  $9^\circ$  of clockwise movement ("H"):*  
With the return of the valve to the idling position, the control lever simultaneously enters  $9^\circ$  into the gate, thus locking the pins. This final movement of the lever is automatic, but at the end of its counter-clockwise movement, the lever may be pushed by hand into the gate.

To lower the undercarriage, the hand lever must be moved to the DOWN position on the quadrant, the sequence of operations for raising the undercarriage being reversed.

## PNEUMATIC SYSTEM

The pneumatic system operates the wheel brakes, the Browning guns, Hispano guns, cine-camera, and flaps. Two storage cylinders are kept charged by an engine-driven compressor and from them the supply is led to the various units in the system, a diagram of which is shown below.

The engine-driven compressor, a HEYWOOD type SH.6/2, is mounted on the aft end of the engine's starboard cylinder block. The supply is led from the compressor through a regulator valve, type A.R.300-1, to an oil-and-water trap, type O.W.T./46, and thence to the containers. The oil-and-water trap is incorporated in the system to collect any oil or water mist from the air supplied to the container. The trap should be drained after every ten hours' flying.

The containers are mounted on the starboard side of the fuselage, directly behind the cockpit, and are connected to the system in series; when full, they contain air at a pressure of 300lb/in<sup>2</sup>. From the containers, air is led through a filter and then to a reducing valve (AHO 16402) which lowers the pressure to 140 lb/in<sup>2</sup> for the operation of the various units, listed below:

- Hispano guns reload mechanism.
- Hispano guns firing mechanism.
- Browning machineguns' firing, reloading, and safety mechanisms.
- Camera gun.
- Mk II brake differentials, located on the cockpit floor behind the control stick.
- Weapon fire buttons, located on the upper part of the control stick.
- Flap controls, located on the upper left part of the dashboard.

The system also has a valve for charging the pneumatic system that is located on the left side of the engine, access to which is through the refueling hatch of the engine oil tank.

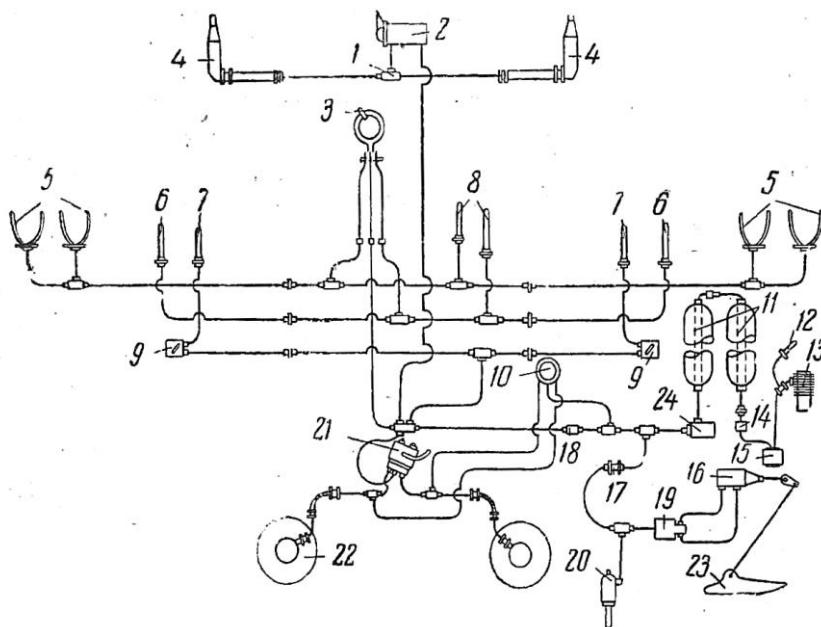


Figure 39: Pneumatic system

1. Cutoff valve
2. Flaps control valve
3. Weapon fire button
4. Flaps cylinder
5. Machinegun fire, safety mechanism, and reload
6. Cannon fire
7. Cannon reload
8. Cinegun
9. Cannon reload control valve
10. Three-pointer pressure gauge
11. Onboard air container
12. Onboard charging nozzle
13. Heywood compressor
14. Pressure reducer valve
15. Oil and mist separator
16. Radiator valve cylinder
17. Minimum pressure valve
18. Pressure reducer valve
19. Electromagnetic control valve for the radiator valve
20. Supercharger speed control cylinder
21. Brake differentials
22. Main landing gear wheel

- 
- 23. Radiator valve
  - 24. Air filter

### **Flap control valve**

Consists of a body housing a valve and two pipe connections. The body of the valve projects through the instrument panel and is fitted with a cap housing a control lever and spring-loaded plunger.

Movement of the lever DOWN depresses the plunger and valve and allows compressed air to flow through the valve to the operating unit. When the lever is raised to the UP position, the plunger moves under the action of the spring and allows the valve to close; at the same time, a hole in the plunger registers with a hole in the cap and allows the air in the operating unit to exhaust to the atmosphere.

### **Restrictor valve**

The T-piece, which connects the pipe from the flap control valve to the operating cylinders in the main planes, is fitted with a restrictor valve in the form of two discs with small orifices. The purpose of this valve is to prevent too violent a supply of air to the operating cylinders.

### **Flap jack**

The flap jack is mounted at its centre in bearings on the main plane structure. It contains a piston and rod the end of which is connected to the flap-operating lever. With the control lever in the DOWN position, compressed air enters the pipe connection at the end of the cylinder and forces out the piston to lower the flap. When the lever is moved to the UP position, the air is released to the atmosphere and the flap is raised by the slipstream, assisted by a spring-box.

### **Spring-box**

Used for retracting the flaps. This consists of a compression spring attached to a rod and enclosed in a cylinder pivoted on the main-plane rear spar outboard of the flap-operating cylinder. The rod is attached to a lever on the flap spar and the action of the spring is to raise the flap when the air is released from the operating cylinder.

### **Cine-camera**

The G42B cine-camera, mounted in the starboard plane, is operated by the pneumatic system, a lead being taken from the gun-firing pipe-line. Operation of the firing button on the control-column spade grip operates the camera continuously so long as the button is depressed. Connection between the air supply and the camera is by means of an electro-pneumatic switch.

### **Browning machineguns**

The machineguns in each plane obtain their supply of air from a pipeline connected to the firing button on the spade grip. The pipeline to each gun ends in a Y-piece, the arms being fitted with wing-nut connections from which flexible hoses lead to the fire-and-safe unit and bolt-unit on the gun.

### **Hispano guns**

The pneumatic reload and firing mechanisms of the Hispano cannons (connected to each other by flexible armored hoses) are connected to the same line as the trigger mechanism. Reloading the guns may be performed only on the ground.

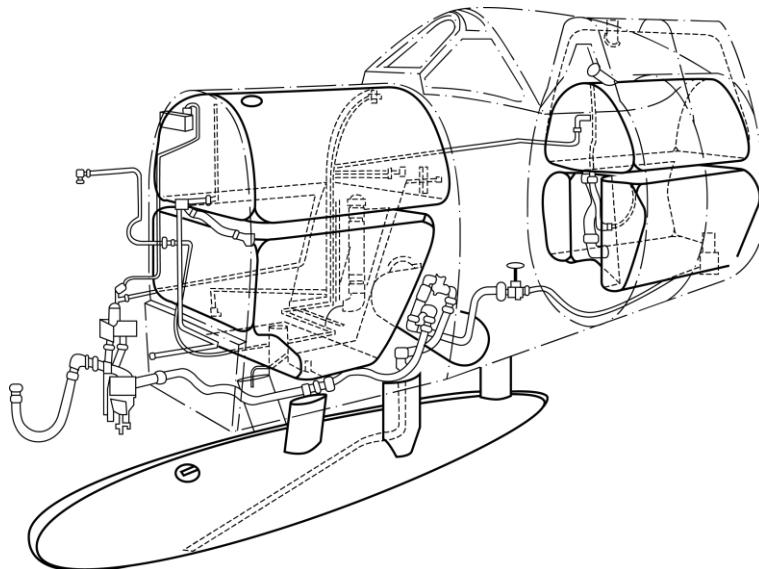
### Wheel brakes

The brake trigger located on the control stick (and connected to the valve by Bowden cable) opens the brake relay valve. Depending on the pressure applied to the trigger, the valve regulates the airflow to the brakes. The brake differential allows for regulation of the pressure in the brakes depending on pedal deflection. A triple pressure gauge on the lower left part of the instrument panel indicates the pressure at each wheel unit and the pressure in the container. Normal pressure is around 80-90 lb/in<sup>2</sup>.

## FUEL SYSTEM

The fuel system's main functions are the storage of the aircraft's onboard fuel supply as well as the circulation of fuel from the tanks and into the engine. The fuel system uses 100-octane fuel and obtains its supply from two banks mounted in the fuselage behind the fireproof bulkhead. One tank, of 37 gallons capacity, is mounted on the bottom of fuselage frames 6 and 7. The other, of 48 gallons capacity, is mounted above the lower tank on four brackets on the top longerons, and is protected by a sheet of armour covering the tank from behind the fireproof bulkhead. From above, the upper tank is covered by a removable panel which forms the top fairing of the fuselage. The two tanks are interconnected by a supply pipe. Ventilation is provided by two pipelines, both of which are installed in the forward-upper part of the upper fuel tank. One pipeline connects both lower and upper tanks, and the second passes through the rear wall of the upper fuel tank and leads out from under the fairing of the radiator located on the underside of the right wing.

Fuel from the upper tank flows on its own into the lower tank. From the cock on the lower tank, a pipe leads forward to an A.G.S. type filter on the forward side of the bulkhead. The outlet from the filter leads to the pump on the engine and then to the rear connection of a fuel cooler, mounted in the leading edge fillet of the port main plane. From the front connection on the cooler, the fuel passes to the pressure regulator and then to the carburetor. Air discharged from the separator is directed into the upper tank. When feeding fuel from external tanks, access to the air separator is shut off by a special valve in order to prevent the upper tank from overflowing. This valve is connected to the fuel intake valve of the external tanks.



**Figure 40: Fuel System Components on the Aircraft**

The above image shows the location of the fuel system components; depicted is a system with rear outboard fuel tanks and a 50-gallon (227L) cigar-shaped tank for Mk. IX and Mk.XIV aircraft.

In order to prevent fuel boiling at high altitudes in warm weather conditions, the fuel system is equipped with a fuel tank pressurizer system that switches on automatically at altitudes above 20000 feet. An aneroid valve feeds air, pressurized by a vacuum pump, into the fuel tanks. Pressurizing, however, impairs the self-sealing of the tanks and should be turned on only when the fuel pressure warning lamp lights up. In very warm weather at very high altitudes a rich cut may occur with the tanks pressurized, and pressure must then be turned off. The pressurizing cock is on the starboard side of the cockpit immediately below the instrument panel.

The default position of the pressurizer system is OFF, and must be turned ON only when a red warning light signalizes that the fuel pressure has dropped below 10lb/in<sup>2</sup>.

The control unit for the fuel pressurizer system is located under the right side of the instrument dashboard.

The valve for disabling fuel tank pressurization installed in the ventilation line of the fuel tanks allows for immediate disabling of fuel tank pressure in case of damage to the pipelines or fuel tanks, as the defensive properties of the lower tank suffer in case of excess pressure. The valve is located in the right wing fairing, and the control unit is located to the right and below the pilot's seat.

A hand wobble pump is mounted on the starboard side of the cockpit of early aircraft powered by a Merlin 66 engine. The pump draws its supply from the fuselage lower tank and delivers into the main fuel supply line at a point between the main fuel cock and the non-return valve. Designed to fill the aircraft's supply pipeline, drive pump and the carburetor before starting the engine. It can also be used as an emergency pump in case of drive pump failure. After exhausting the aircraft's external tanks, when switching to the main tank, it is necessary to pump gasoline into the engine by means of the manual pump until stable motor operation. A hand wobble pump, installed in the starboard side of the cabin behind the indicator light control switch, can be used to draw fuel from the bottom tank.

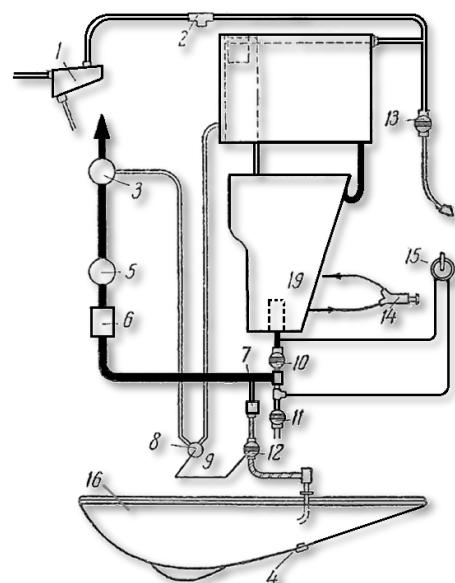
A Ki-gass type priming pump used to fill the engine cylinders and fuel lines with fuel before engine startup is located on the right side of the fuselage frame № 8. Gas from the bottom of lower tank flows through a line into the motor's suction nozzles under pressure created by the pump.

A Bendix-Stromberg injection type carburetor, in contrast to float-feed type carburetors, provides an uninterrupted supply of fuel into the engine while under negative Gs and while performing intense maneuvers.

Electric gasoline gauge, one sensor piece mounted in the lower tank. The gauge and power button are mounted at the bottom right of the instrument panel. The gauge measures the amount of petrol in the tank, but only when the button is pressed. The indicator has two scales: the lower scale is used for measuring gasoline while in flight, and the upper scale for use on the ground (when the aircraft is in its tricycle position).

A warning lamp is installed next to the gasoline gauge and is triggered when fuel pump pressure falls below 10 lb/in<sup>2</sup>. The lamp is powered by a circuit switch on the throttle quadrant.

Additional 30, 45, 90 or 170 gallons drop tanks may be fitted onto the aircraft for long-range flights. A separate valve controls the fuel supply from the drop tanks, and is located on the right side of the fuselage frame №9. The valve handle is located on the right side of the cockpit. The drop tank is jettisoned by an upward pull on the handle low down on the starboard side of the cockpit next to the drop tank cock lever. The handle cannot be operated until the cock lever is moved forward into the OFF position.



1. Vacuu system oil separator
2. Pressure control valve and vent
3. De-aerator on carburettor
4. Drain
5. Fuel pump
6. Filter
7. Non-return valves
8. Separator valve
9. Valve junction
10. Main fuel cock
11. Drain cock
12. Auxiliary fuel cock
13. Drain system valve
14. Priming pump
15. Hand wobble pump
16. 30 or 90 gallons drop tank
17. 47-gallon upper fuel tank
18. 38-gallon lower fuel tank

**Figure 41: Fuel feed system**

## OXYGEN SYSTEM

Oxygen is supplied to the pilot by a single oxygen tank with a capacity of 750 liters through an economizer. Oxygen from the cylinder (under high pressure: 1800 lbs/in<sup>2</sup>) enters the regulator equipped with a filter and pressure control valve that reduces the pressure of oxygen to about 40 lb/in<sup>2</sup>. The oxygen afterwards enters the economizer through an exit filter. Oxygen flows to the pilot's mask through a rubber tube coming from the economizer under the seat and attached to the right side of the cockpit.

The tank was placed in the rear part of the fuselage, between frames 16 and 17, on the right side above the datum longeron. The tank is attached to the frame with two quick-release clamps. The frame, in turn, is bolted and riveted to the frames and skin plating. If necessary, a second tank can be installed right between frames 18 and 19.

The economizer is mounted between frames 12 and 13 on the port side of the fuselage below the datum longeron.

The oxygen regulator Mk. XIA (VIIIA) is located on the top left side of the dashboard. An additional valve (39) is mounted on the right side of the cockpit.

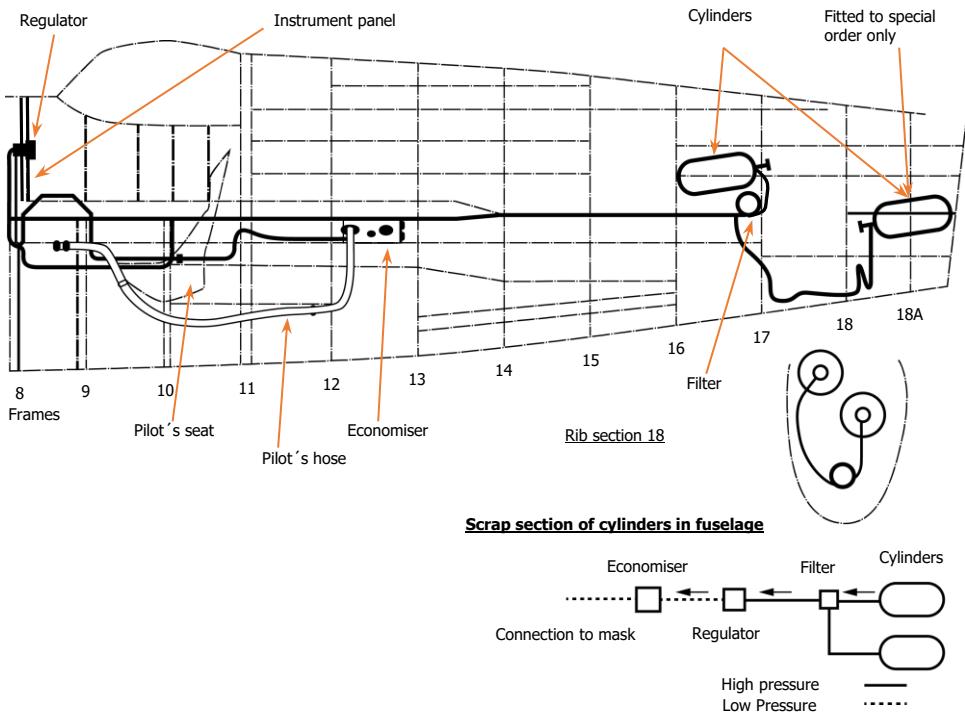


Figure 42: Oxygen system

# ELECTRICAL SYSTEM

The aircraft uses a 12-volt power supply circuit and a two-wire unshielded electrical power system. The sources of electric power are: 1.) the parallel connected generators, with wires leading from the aircraft motor, and 2.) a lead-acid battery.

The following aircraft components are the main consumers of electrical power:

1. Electric starter used for engine startup
2. Electric fuel gauge
3. Light and sound landing gear warning systems
4. Specialized and radio communications system
5. Heated pitot tubes
6. Night lighting equipment consisting of navigation lights, identification lights, cockpit lighting and gunsight illumination
7. Solenoid-operated oil-dilution valve

## Electrics

### Generator

The LX type generator is a four-terminal electric generator with shunted excitation. The generator's drive connection is sourced from the aircraft engine using a flexible coupling that protects the generator shaft from damage. The generator mounted on a special flange on the left side of the engine using four bolts. In-flight cooling of the generator is carried out by means of counter-airflow through the two pipes coming out of the cooling jacket: one for the air intake, and the other for exhaust. The switch is located on the upper right of the dashboard. A 60A fuse is in place to protect the generator against short-circuits and sudden overloads. The generator has the following characteristics:

- Power – 750W.
- Voltage – 13.5V.
- Current – 40A.
- Minimum RPM - 3500.
- Maximum RPM - 6000.

A red warning light labelled "POWER FAILURE" is in place for monitoring the operation of the electrical system, mounted on the left side of the cabin near the fuse box. The alarm is triggered when there is no battery power from the generator.

### Voltage Regulator Box

Non-contact "F" type voltage regulator. The regulator provides constancy in the range from 13 to 14.5V during changes in engine speed and varying generator loads within its operational capacity. The current limiter protects the generator from overloading. All parts of the regulator box are mounted on the baseplate which has a connecting block. The regulator is installed behind the seat headrest on frame 11.

### Minimum Relay

The minimum relay is responsible for the connection of the generator to the on-board network upon reaching the minimum voltage of 13-14V, and disconnection of the generator from the network during low speed or upon shutting down the aircraft motor. It is a separate unit and is mounted on the left side of the fuselage separated from the regulator box. Outside the relay cover, there are two sockets

for connecting a portable lamp or a voltmeter. Minimum relay serves as a safeguard from demagnetization of the generator, which is possible during parallel operation of the generator with the battery. During engine startup, as well as during flight in idling speeds when the generator does not output its maximum voltage due to the low RPM. The battery current tends to pass through the generator and force it to rotate by the electric motor. This phenomenon in shunt generators is accompanied by a change of polarity in the same direction of rotation, after which the generator ceases to operate as a Dynamo. In such cases, the minimum relay automatically switches off the generator of the common chain, the network load feeds off the current of the accumulator battery, and the generator starts to idle. As soon as the generator voltage returns to its normal values, the minimum relay will automatically activate the generator in order to power the system and charge the accumulator battery.

### **Accumulator battery**

On-board type "B" acid battery in an ebony monoblock. Has the following characteristics:

- Voltage – 12V.
- Capacity, 10-hour discharge - 40 A/h
- Capacity, 5-hour discharge - 27 A/h.
- Capacity, 1-hour discharge - 19 A/h.

The battery is installed in the fuselage between frames 17 and 18 on a wooden stand without a container and insulation. Output terminals of the battery is made in the form of tubes with thread, screwed onto which are coupling nuts fitted on special tips of the outlet wires.

### **Voltmeter**

A voltmeter showing the voltage of the generator from a scale of 0 - 20V is installed on the right side of the dashboard.

### **Filter Box**

A box of filters, consisting of six toroidal inductors and six capacitors, is included in the generator circuit in order to reduce interference to the radio receivers.

Mounted on the left of the subframe by the generator, and connected to it by wires in a shielding braid. The wires that extend from the box have no shielding.

### **Airfield electrical power**

The aircraft has two special sockets for use in airfields, connecting the onboard power circuit to a ground-based source. One socket is mounted on the subframe frame on the right side of the motor. The main purpose of this socket is to supply power to the starter. The second outlet is located on the left side of the fuselage on frame 11 behind the seat frame, in the wing fairing. The main purpose of this socket is to supply power to the radio equipment for use during ground checks. Insertion of the airfield power source plug is accompanied by a rotation of the socket caps, which disconnects the negative side of the accumulator battery from the network.

### **Power grid**

The aircraft uses a two-wire power grid, the entirety of which is laid out without metal screens, except for the portion of the circuit that goes from the generator to the filter box. Protection of electrical installations is provided by fuses located in three blocks of the closed type. A set of spare fuses can be found inside each block on the inside of the cover. The units are installed along the port side of the cabin. The covers are marked with the number of fuses (according to the circuit diagrams) and the name of the aircraft components protected by these fuses. Each circuit is initially identified by a number corresponding to its fuse number. This is in the form of adhesive tape wrapped round each end of the

cable. Where the circuit splits up, higher numbers are used as shown by the wiring key. Polarity is identified by means of the basic colour of the tape. The appropriate colour is represented on the diagrams with a letter after the circuit number, e.g. R = Red, and B = Blue. When black cables are installed, service colours are indicated by plain tape attached to the cable, e.g. Yellow for electrical service, blue for engine service, red for radio service. Distribution boxes are installed in the places where aircraft sockets as well as branching wires can be found. The boxes are marked as: T. B. 1 T. B. 2 T. B. 3, etc. in the diagrams. On the inside of the cover to the fusebox is a table showing the key to the wirings.

## Consumers

- Starter
- Gear warning systems
- Gunsight
- Cine-camera
- Bomb fuses and release
- Navigation lights
- Identification lights
- Cockpit lighting
- Heated pitot tubes
- Solenoid-operated oil-dilution valve

In-depth descriptions of the aforementioned components can be found in their respective sections.

An illustration of the electrical system can be found below.

### Starter motor

The starter motor is fitted to the starboard side of the engine and a boost coil is mounted on the starboard side of the fireproof bulkhead. These are controlled by two push-switches mounted in the centre of the instrument panel, connection to the starter motor being made through a magnetic relay, fixed on the engine mounting. The main magneto switches are mounted on the port bottom of the instrument panel. The ignition system's starting coil is installed on the fireproof bulkhead, on the right. Current is supplied to the starter motor from the accumulator, or alternatively by an external accumulator which can be connected through a socket mounted on the starboard engine bearer.

Insertion of the airfield power source plug is accompanied by a rotation of the socket caps, which disconnects the negative side of the accumulator battery from the network. The sockets have differing diameters: for positive conductors a larger socket is used; for negative conductors, smaller sockets are in place.

Control of the booster coil is provided by the buttons on the dashboard to the right of the starter button.

For protection against accidental pressing, the two buttons are protected by spring-loaded caps.

A 10A fuse is in place for the protection of the relay circuit and the trigger coil.

Starter activation time should not exceed 10 seconds, after which a break of 10 - 15 seconds becomes necessary.

Upon activation the starter consumes a current equal to 250 - 275A.

Engine startup should usually be performed using a ground-based power source (i.e. the airfield batteries.)

## Magneto

Two magnetos (B.T.H C6SE-12S or the Rotax NSE12-4) are installed on the motor.

The magneto is a unit which combines an electric power generator and transformer with a distributor for high-voltage circuits. It consists of a rotor magnet, the armature, the primary and secondary windings of the transformer, circuit breaker, condenser, distributor plate and ignition governor. The magneto rotor is a permanent magnet which is the source of magnetic energy. An alternating magnetic flux is created in the transformer core upon rotor winding, resulting in an electromotive force in the windings of the transformer. Breaker contact closure to the ground fault results in a primary current at low voltage in the primary winding of the transformer. At that moment, when the force of the current reaches its maximum value, the rotating cam of the breaker turns the breaker lever around its axis and the breaker contacts open very quickly. There is also a rupture of the primary current and a sharp change in magnetic flux in the transformer core. A capacitor connected in parallel to the contacts of the breaker reduces the arcing between them; this contributes to a drastic change in magnetic flux, while preventing burning of the contacts.

Upon a change in magnetic flux, a high-voltage current occurs in the secondary winding of the transformer. This current is supplied from the main contact via the high-voltage terminal through the distributor plate and distributor brush to the generator electrode, from which it passes on through generator electrodes of the distributor plate by wires towards the core electrodes of the spark engine. The high-voltage current flows to the spark of the cylinder in which by this time a flash should occur. Between the central and outermost electrodes of the spark plug is a spark gap. The high-voltage current penetrates the gap between the electrodes and an electric spark passes between the electrodes, igniting the compressed working mixture in the combustion chamber. The ignition governor is a normal centrifugal regulator.

The rotor magnet of the magneto is connected to the crankshaft by gears and therefore only rotates during engine operation. Gear ratio of the magneto drive is 1.5: 1. When the motor shaft rotates, sparks are supplied in the correct sequence to the cylinders.

## Rotax N.I.K A/M Booster coil

Magnetos are not suitable for engine startup, so the engine is mounted with an booster coil, which operates from battery power or a ground-based source. The booster coil is not a power source, but a transformer which turns a low-voltage direct current into a high-voltage pulsating current. (15000-18000 V)

# Radio Equipment

## Radio communication equipment

The aircraft is equipped with an A.R.I. 1063 type HF radio. The T. R. 1196A transceiver is configured at four specific frequencies for use with airborne two-way communication between aircraft and ground services. Frequency switching is done by means of a Type-4 remote, installed on the left side of the cockpit. Frequency interval of the radio station: 100 - 156 MHz. The radio range between the aircraft and ground-based command posts depends on the altitude:

Altitude, Feet	Range, Miles
1000	30
3000	70
5000	80
10000	120
15000	150
20000	180

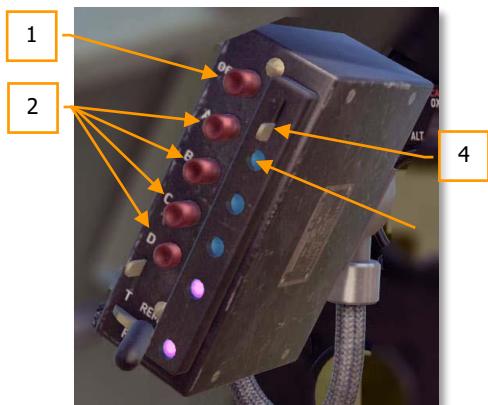
The T.R.1196A radio consists of the following: Type 22 (10R/23) transmitter; Type 25 (10P/11) receiver, contained in one case. Accessories of the HF radio: Type 104 (10K/238) 12V power supply, Type 4 control panel, wire antenna, Type 359 headset jack.

The transceiver is mounted on four anti-vibrating studs to a bracket on the starboard side of the fuselage between the 14th and 15th frames. The power supply is mounted beneath the transceiver. An access hatch to the radio kit is located on the left side of the fuselage for ease of maintenance. The control panel is mounted on the bracket on the left side of the cockpit. The control panel has buttons for frequency switching, the off button, mode selector, and the rheostat for illumination of the lamps of the selected frequency. The headset connector is placed on the right side of the cockpit behind the 10th frame. The wire antenna is attached to the mast mounted in the upper part of the fuselage on the frame 12 and leading to the insulator on the tail fin.

## Radio System Control Box

The "Type 4" (110J / 71) control box is designed for switching between radio channels when conducting two-way radio communications. The radio station has 4 preset channels for this purpose. Channel selection is performed by using the channel selection buttons, labeled with the letters A, B, C and D on the faceplate panel. Next to each button is a light signal which highlights selected channel. Included are light filters for dulling the glow for dusk and night flights. Turn off the radio by pressing the OFF button in the upper part of the front of the console. At the bottom of the panel is a mode toggle switch labeled "T-R-REM". This switch sets the three modes of operation:

- T - Transceive
- R - Receive
- REM - Remote



1. Radio system power switch
2. Channel selector switches
3. Selected station light
4. Light filter slider
5. Mode toggle switch
6. Mode toggle switch locking pin.

**Figure 43: Radio control box**

## IFF System

The aircraft is equipped with an A.R.I. 5025 type identification transponder system (IFF - Identification Friend or Foe). The transponder consists of: an R.3067 receiver, mounted behind the radio station, Type 90 and Type 89 switching units, Type B control panel, a Type 90 whip antenna. Control of the transponder is by means of a Type F switch that activates the transponder, and a Type D switch that controls the transmission of distress signals, and two push buttons that activates the detonator. The control panel is mounted on the starboard side of the cockpit just forward of frame 10. The detonator must be actuated when forced to land in enemy territory by simultaneously pressing both buttons. An accident sensor is in place for automatic self-destruction of the IFF unit upon detection of high shock loads. The antenna of the transponder, pin type 90, is mounted on the lower surface of the right wing.

## Navigation Equipment

The aircraft's navigation equipment consists of the P.8.M (6A/726) magnet compass installed on the central part of the aircraft dashboard's lower section, as well as the Mk.1A (6A/1298) gyroscope on the instrument panel for blind flying. The main part of the compass is a magnetic compass system, which bears the name of the compass rose. The compass rose, a sensitive element consisting of a system of magnets, antennae, damping wires, a compass cap, centre-pin and hollow float, which reduces the weight of the compass rose in the liquid. The axes of the magnets are parallel to the grid ring axis 0 ° -180 °, called the axis of the compass rose. Analogous poles are aligned in one direction. The compass rose pin rests on a cup of solid stone (sapphire, agate), set into the compass column and the cap. Inside the compass bowl (which is an aluminum vessel hermetically-sealed by a glass lid) is the column that serves as a support for the compass rose. Under the glass is the Lubber Line - a thin wire, against is set the compass rose. This line serve as index for determining the course. The compass bowl holds liquid for dampening the compass rose oscillations. The compass bowl is joined to a membrane made of corrugated thin brass. The membrane section is used to compensate for changes in fluid volume due to changes in temperature. Attached below the compass bowl is a corrector unit to compensate for the semicircle deviation 6A / 6B or 1032/1752. The compass bowl is filled with alcohol solution. Two

deviation cards are installed in the middle of the lower part of the dashboard: to the left is the compass for use with a suspended fuselage tank, while the right one is for use without an external tank.

The gyroscope does not automatically indicate course and instead indicates the deviation from any given course, measured by the magnetic compass P8.

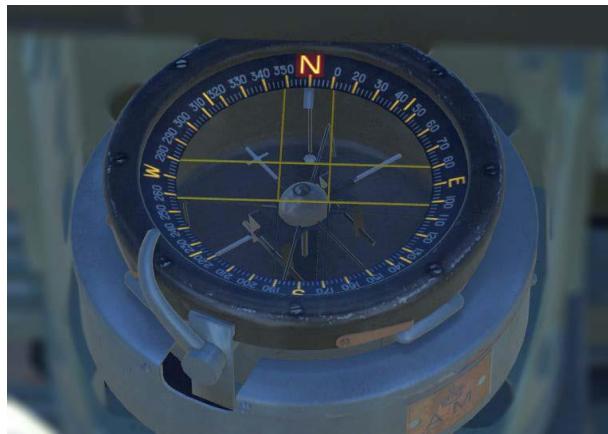


Figure 44: P.8.M Compass

## Lighting Equipment

The lighting equipment of the aircraft consists of navigation lights, recognition lights, cabin lighting and landing lights.

### Navigation Lights

The switch controlling the navigation lamps is mounted on the port side of the cockpit. The 20W port and starboard wingtip lamps are fitted with a dome-shaped metal cover which secures a coloured glass screen firmly to the lamp body. The 10W tail lamp is inserted into a holder let into the trailing edge of the rudder and is covered by a streamlined screwed-on dome.

### Identification lights

The downward identification lamp is designated for use in communications with ground crews; while the upper lamp is used for communication between aircraft.

Control of the identification lights is performed through a special actuator (Type C), located on the starboard side of the cabin. It consists of two switches, the left switch for lower, right for the top light and Morse code. Each switch has three fixed positions: "STEADY" is for indefinite lighting, "OFF" is for off, and "MORSE" is used for transmissions in Morse code.



**Figure 45: Morse key**

The Morse key is adjustable by turning the small ring in the upper left corner of the switch. The position of the ring is fixed with a special latch, which is included in the corresponding neck ring.

Power consumption of the identification lamps: lower lamp: 35W, upper lamp: 16W.

The holder of the upper lamp is located on the bracket, mounted on the top of the fuselage from the inside. Present on the fuselage is a slit, which is closed off by a cap in a streamlined shape, made of transparent Plexiglas.

The downward facing lamp has a reflector, and has a frosted lamp. A cut, covered with orange Plexiglass, is made on the underside of the fuselage for the downward facing lamp. If necessary, the plexiglass may be changed to red or green.

### Landing lights

Landing lights were demounted. Installed on Spitfire IX aircraft.

### Cabin lighting

Two cockpit lamps are fitted, one on each side of the cockpit. The lamp on the starboard side is so mounted that it can be moved vertically up or down; the lamp on the port side, mounted on a universal bracket, can be extended and turned to suit the instrument panel. Both lamps are shielded to prevent glare and are controlled by the dimmer switches, Type A, mounted in the centre of the instrument panel.

## Auxillary Equipment

### Flare launcher

A Plessey six-shot signal launcher is installed in the upper rear part of the fuselage between frames 16 and 17. Fires 1.5 inch flares when the handle is pulled. After firing, the handle returns to its place. The selector is located above the firing handle. The control for this unit is mounted on frame 10 on the port side. Rocket launcher is armed through the opening on the right side of the fuselage between the 17th and 18 frames. The cutout in the skin plating under the launcher's muzzle is sealed with percale before takeoff.

### De-icing system

For cleaning the windscreens of frost, a de-icing system is installed. The system consists of a tank containing a mixture of distilled water and ethylene glycol in equal quantities, a pump and needle valve for regulating the flow of liquid, an ON/OFF cock, and pipes leading to a diffuser from which the liquid is sprayed upwards over the outside of the front panel of the windscreens. A pipe also leads from the control cock to the pipe between the tank and the pump to allow any excess liquid in the pump to be returned to the tank when the cock is OFF. The tank, pump, and cock are all on the starboard side of the cockpit.

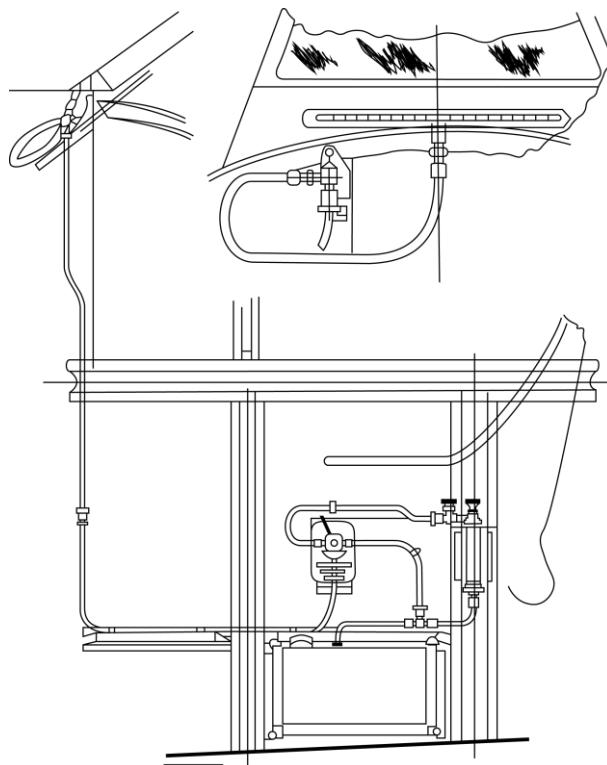


Figure 46: Windscreen de-icing system.

### Heated Pitot tube

The heating element of the Pitot tube uses 115W and is controlled by a switch mounted on the port side of the cockpit between frames 9 and 10. To avoid undue discharge of the accumulator, and to prevent breaking down the insulation under excess heat, the element should be switched off upon landing.

# COCKPIT



# COCKPIT

The cockpit includes the aircraft and engine controls, the instrument panel, instruments and equipment on both sides (with bar arms) and additional equipment mounted on the rear wall of the cockpit. See below for a detailed picture of the cockpit.



Figure 47: Spitfire cockpit

## Front panel

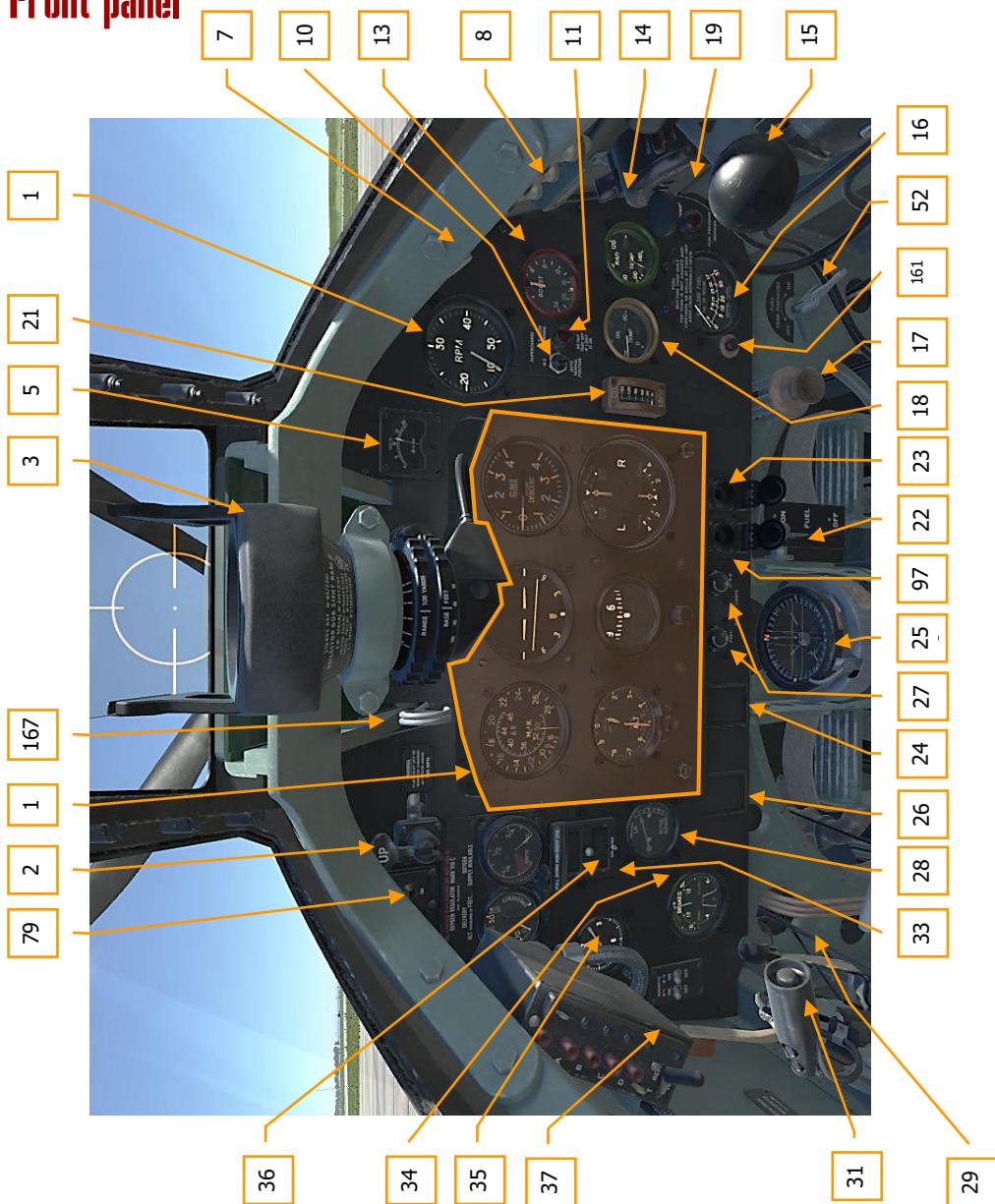


Figure 48: Spitfire instruments

1. Blind-flying panel
2. Flap control valve
3. Mk II Gyroscopic gunsight.
4. Gunsight connector assembly.
5. Voltage meter.
6. Tachometer.
7. Cockpit air vent.
8. Spare lightbulbs for gunsight illumination.
10. Supercharger speed toggle switch
11. Supercharger second speed activation light
13. Boost gauge.
14. Coolant fluid thermometer
15. Manual fuel pump.
16. Fuel gauge.
17. Primer pump (a).
18. Engine oil thermometer.
19. Fuel pressure signal light.
21. Engine oil pressure indicator.
22. Fuel cock handle.
23. Engine starter switch.
24. Compass deviation card.
25. Magnetic compass.
26. Secondary compass deviation card
27. Cockpit lighting rheostat.
28. Elevator trim indicator.
29. Three-pointer air pressure indicator.
31. Magneto toggle switches.
33. Undercarriage warning system.
34. Oxygen regulator.
35. Oxygen flow indicator.
36. Oxygen pressure gauge.
37. Radio system control box
52. Tank pressurization cut-in valve.
79. Nav-light switch.
97. Booster coil button.
161. Fuel gauge button.
166. Bomb jettison.
167. Gunsight light filter handle

## Instrument Dashboard

The instrument dashboard has 2 parts. The central part made of an aluminum alloy 3mm thick contains the basic flight control and navigation instruments. The blind-flying panel is mounted on three cushioned supports in order to reduce potential damage to the equipment. On the right side of the dashboard are the instruments for managing the power plant while located on the left are the control devices for the aircraft's auxiliary systems. At the bottom is the compass set, the main fuel valve, the priming syringe, and fuel tank pressurization valve.



**Figure 49: Instrument dashboard**

## Blind-flying Panel

The late-model 6A/760 standard instrument panel for blind flight is installed on the aircraft.



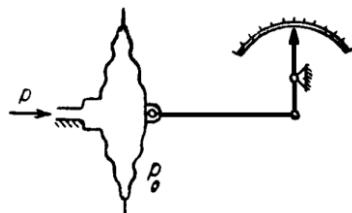
**Figure 50,: Blind-flying panel (late model)**

On the blind-flight instrument panel are the following flight and navigation instruments:

### Mk.IXF (6A/587) Airspeed Indicator

Used for measuring the airspeed of the aircraft in flight. Airspeed is the speed of the aircraft relative to the air. The airspeed indicator is built on the principle of measuring the various aerodynamic pressures (forces of oncoming air flow resistance per unit area of the moving body in it) in flight. An advanced pitot tube consisting of two metal tubes, static and dynamic, are used as the instrument of measurement. The tubes are connected to their respective measuring chambers. The elastic metal chamber Vidi is used as the dynamic chamber, while the static chamber is the internal cavity of the instrument. Total pressure is created in the dynamic chamber, while the static chamber creates only static pressure. Equal static pressure in both chambers is balanced, and the Vidi chamber will either expand (in case of increasing flight speed) or compress (when decreasing speed) depending only on the dynamic pressure. Movement of the box through the transmission mechanisms of the arm system are then transmitted to the meter needle. The housing is hermetically sealed. The device communicates with the Pitot tube via two outlet fittings to be connected to the static and dynamic pipelines. When the aircraft is parked on the ground, the pitot tube is covered, which prevents it from clogging. The meter has a dual concentric scale tared in miles per hour. Readings on the outer scale are in the range of 60

miles per hour to 280 miles per hour, then from 280 to 480 miles per hour on the internal scale. Graduation is at 5 miles per hour for both scales.



**Figure 51: Schematic diagram of the airspeed indicator**



**Figure 52: Airspeed indicator**

### Mk.1B (GA/1519) Artificial Horizon

Designed to determine the position of the aircraft relative to the horizontal plane during blind flight. The artificial horizon is an important instrument of blind flight, since it makes it possible to keep the horizontal position of the aircraft without actually seeing the Earth. Indications of the artificial horizon are inertialess and have no delay. The artificial horizon responds instantly to changes in flight angle and does not wobble during accelerations that accompany the flight.

The action of the artificial horizon is based on the properties of a gyroscope with three degrees of freedom, the axis of which is adjusted by means of pendulum correction.

On the front of the device there is a black screen with a horizontal line, covered with a luminous mass representing the horizon. The silhouette of the aircraft is fixed and clearly reproduces the actual position of the plane, as if flying away from the observer, relative to the Earth's horizon. The angle between the silhouette of an airplane and the horizontal line is the absolute lateral roll of the aircraft. The distance between the center and the characteristic silhouette is proportional to the absolute longitudinal roll of the aircraft. Markers for the roll angles can be found at the bottom of the device.



**Figure 53: Artificial horizon**

### Mk. 1A(6A/942) Vertical Speed Indicator

Designed to indicate changes in altitude rate, i.e. the rate of ascent or descent. The vertical speed indicator's readings are essential to the pilot at all stages of flight. To perform horizontal flight is necessary to maintain a constant height, but altimeter readings may vary markedly in cases of sufficiently large (by a few tens of meters) changes in altitude. The indicator, being a sufficiently sensitive instrument, responds to minor changes in rates of climb or descent, thus making it possible to keep the plane fully horizontal. When performing a gliding descent, a dive, or climb, the vertical speed indicator also helps to quickly establish the desired mode of ascent or descent.

The instrument's principle of operation is based on the measurement of relative pressure in an enclosed space communicating with the atmosphere by means of a capillary tube (see illustration).

In horizontal flight, the pressure in the box and Vidi housing unit are atmospheric. Moreover, the Widi box does not feel any pressure difference, and the arrow thus remains at zero.

Atmospheric pressure decreases upon ascent. Air from the instrument starts to go through a capillary tube. The capillary has a smaller diameter, so that the pressure inside the device does not have time to catch up with the atmosphere. The pressure inside the housing is greater than the atmospheric pressure in the Widi box at an amount proportional to speed recovery. Under the influence of the difference in pressure, the Vidi box shrinks and moves the arrow upwards from zero. The external pressure stops changing once the aircraft ceases its ascent; the pressure inside the box is equalized with the atmospheric pressure, and the arrow is returned to zero.

Upon descent the pressure inside the box is increased, and the pressure inside the housing is left behind by an amount proportional to the speed reduction. Under this pressure difference the Vidi box expands and moves the arrow downwards from zero.

These indications may experience a delay due to the fact that the flight mode change may take some time (usually a few seconds) to establish a pressure difference inside and outside the chamber.

The arrow must remain at zero during horizontal flight.

The scale is graduated from 0 to 4000 ft / min. The scale intervals are at 200 ft / min.

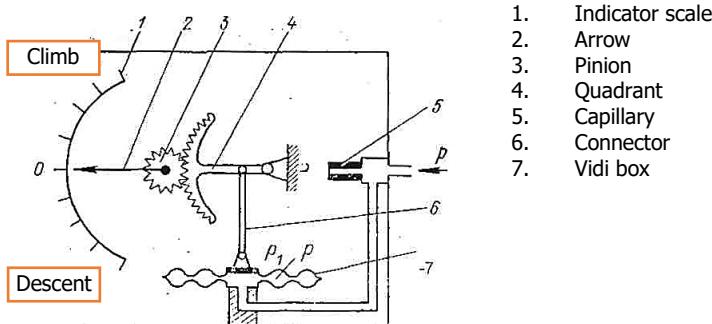


Figure 54: Schematic diagram of the vertical speed indicator



Figure 55: Vertical speed indicator

**Mk. XIVA (6A/685) Altimeter**

Designed to determine the barometric altitude of flight on the principle of measuring the static pressure of the air surrounding the aircraft. Air pressure drops the higher an aircraft is located above sea level.

The altimeter is a metal barometer, an elastic element is aneroid box. The box is placed in a sealed housing, which communicates with the pitot tube static chamber. The external air pressure on the box is compensated for by the resilience of the membranes. The deflection of the center of the barometric cell box is greatest near the ground and decreases as it rises in altitude: that is, decreasing external pressures. The movement of the center of the membrane is transmitted to the indicator arrow by the transmission mechanism.

The housing is sealed and communicates with the pitot tube's static chamber. The same pathway for the airspeed indicator is used to connect both static chamber and barometer housing.

The altimeter has three arrows. The units for each direction are indicated on the dial of the altimeter near its tip.

The long narrow arrow indicates altitude in hundreds of feet, while the shorter broad arrow shows it in thousands of feet. The short narrow arrow indicates altitude in tens of thousands of feet.

The altimeter is fitted with a mechanism for setting barometric pressure. Rotating the knob moves the pressure range in the window of the dial. When setting the altimeter barometric scale to match that of the atmosphere on the day of flight, small errors of no more than 3 divisions of the scale are allowable.



**Figure 56: Altimeter**

### Mk.IA (GA/129B) Flight Gyroscope

Designed to help the pilot maintain a specified course for the aircraft and perform turns at desired angles. The gyroscope is built on the principle of a gyroscope with gymbaling freedom; the rotor gyro axis is horizontal.

The gyroscope does not automatically indicate course and instead indicates deviation from the given course measured by the P8 magnetic compass installed in the middle lower section of the dashboard. To this end, the gyroscope range can be set by the pilot to any readout with the help of a special caging mechanism installed on the bottom of the device. After every 10-15 minutes of flight, the readings are cross-checked with the compass and, if necessary, are corrected by the mechanism. The need for adjustment is due to the fact that the readings accumulate errors over time (up to  $2^\circ \sim 3^\circ$  after 10-15 min.). As such, the gyroscope is used in combination with the magnetic compass.

The gyroscope readings, as well as those of the artificial horizon are inertialess and do not have any delays. Because of this, the gyroscope is used in blind flight.

The front wall of the instrument casing has a circular window, hermetically sealed by a glass panel. Behind the glass is a round dial with a square notch and heading indicator. The compass rose of the gyro is visible through the window; it is divided from 0 to  $360^\circ$  with divisions every  $5^\circ$ . Digitization of the rose is made every  $30^\circ$ , and the numbers are written without zeros, i.e. the inscription "9" indicates  $90^\circ$  and so on. Divisions and compass card numbers, as well as the course indicator are all covered with a luminous mass. Under the window is a knob that serves to set the desired indication on the course indicator and also functions as a locking device when the device is turned off.

Like all gyroscopic instruments, the gyroscope is sensitive to defects in the power system or in the hermiticity of the instrument casing. When the vacuum is disturbed, the gyro tracking is disrupted and its stability is lost. The gyroscope is also prone to errors when piloting. When turning with a large cross

roll axis, the instrument's vertical frame tilts at an angle equal to the absolute roll of the aircraft. This results in an error in determining the course by an order of 4 °.

When performing acrobatic flight, as well as when landing and taxiing, the pilot must push the knob in order to prevent premature deterioration of the device. The gyro allows for longitudinal and transverse rolls of no more than 55°. If they are exceeded, the pilot must push the knob and then re-input the desired values.



Figure 57: Gyroscope

### Mk.IB (6A/1302) Bank Angle and Sideslip Indicator

Designed to display aircraft rotation around the vertical axis of the aircraft and the presence of sideslip. Turning in conjunction with the magnetic compass improves the accuracy of piloting in a straight line, as the arrow of the bank indicator more quickly and accurately responds to aircraft deviation from the straight line compared to the magnetic compass. The combination of the bank indicator with the sideslip indicator allows you to correctly turn at a given speed.

The action of the bank indicator is based on the properties of the gyroscope with two degrees of freedom. The gyro axis direction coincides with that of the longitudinal axis of the aircraft. The damper in the bank indicator is intended to minimize arrow swinging. If there was no damper, even the slightest yaw input would cause the arrow to swing so wildly that it would be impossible to fly the aircraft using the readings from the instrument.

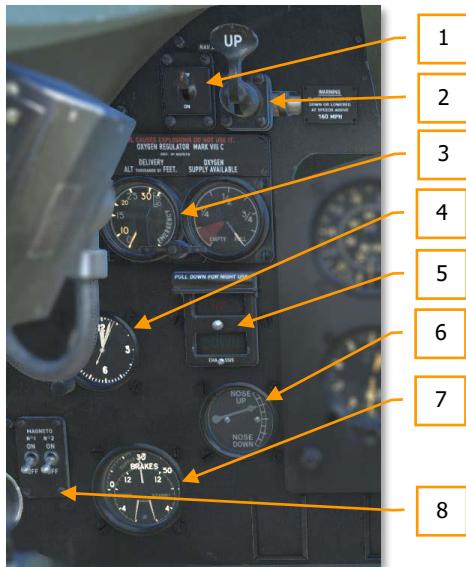
The sideslip indicator is based on the principle of a pendulum.



**Figure 58: Sideslip indicator**

## Dashboard Left Side

The left side of the dashboard contains the following:



**Figure 59: Dashboard left side**

1. Navigation light control switch (5C/543)
2. Flaps control valve (SHT 6/34959)
3. Oxygen unit Mk.VIIIC (6D/513)
4. Onboard clock Mk.IV (106A/322)
5. Undercarriage position indicator (SHT 54/30036)
6. Elevator trimming tab position indicator(SHT 9/30034)
7. Three-arrow manometer Mk.IC (6A/1754)
8. Magneto control switch (5C/548)

### Navigation light control switch (5C/543)

Toggle switch connected to the topside, tail and wing navigation lights.

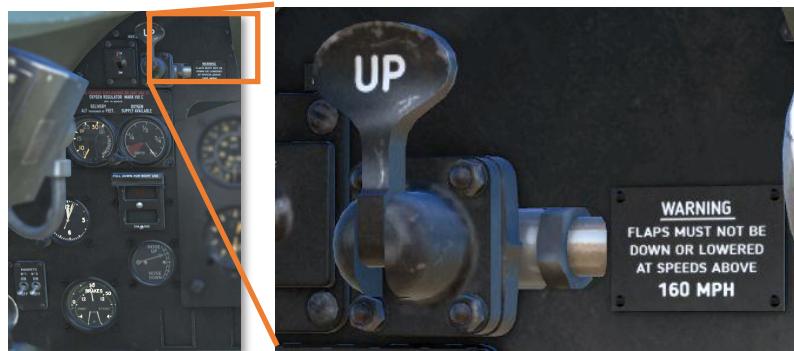


Figure 60: Navigation light control switch

### Flaps Control Valve (SHT 6/34959)

Construction of the valve and operational scheme are discussed in detail in the flap valve section.

The flaps are retracted when the valve is in the upper position. In the lower position, they will be deployed. There is no intermediate position for the switch. Flaps deploy at an angle of 85°. A plaque is mounted near the valve with a reminder for the pilot that the maximum allowable flight speed with deployed flaps is at 160 miles/hour.



**Figure 61: Flaps control valve**

### Mk.VIIC (6D/513) Oxygen Unit

The oxygen unit is used to control the flow of oxygen from the onboard tank into the pilot's oxygen mask. The pressure gauges installed on the front surface are used to indicate to the pilot the amount of oxygen available in the tank. A second manometer - the oxygen flow indicator - monitors the correct supply of the required quantity of oxygen in the pilot's mask depending on flight altitude. The principle of operation of the oxygen flow indicator is based on the use of the high-speed jet of oxygen pressure directed to the blade of the instrument arrow. The deviation of the blades (arrows) is determined by according to the scale of the altimeter, which corresponds to a certain required amount of oxygen. If the altitude shown by the flow indicator matches the actual flight altitude, it can be assumed that the device is working properly.

A pressure reducing valve is installed between the pressure gauges. Oxygen from the onboard oxygen tank is supplied through the economizer unit, and then through a flexible hose to the pilot mask.



**Figure 62: Oxygen unit**

## Mk.IV (106A/322) Aviation Watch

The watch is designed to display the current time in hours, minutes and seconds. Has a crown at the bottom of the device. The pendulum is used as the operating principle. The construction is of a common spring pendulum clock with a round-balancer. Power reserve is good for 8 days.

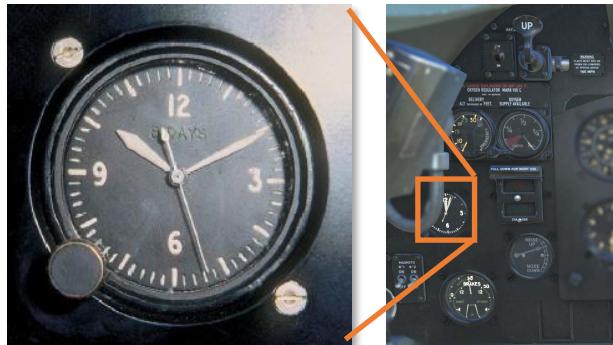


Figure 63: Watch

## Undercarriage Position Indicator (SHT 54/30036)

Designated to indicate the position of the undercarriage. The corresponding annunciation panel lights up when the undercarriage is retracted (stencil "UP") or deployed (stencil "Down"). At the top of the display is a shutter to dim the illumination for night operations. The circuit alarm for the released position has a switch which opens the circuit when the aircraft is parked. The switch is located on the motor control column. When you move the throttle forward, the switch is activated and the deployed position chain is powered up. After taxiing and switching off the motor, this switch must also be set to off manually in order to prevent needless battery discharge.



Figure 64: Undercarriage Position Indicator

### Elevator trimming tab position indicator (SHT 9/30034)

It serves to visually indicate to the pilot the position of the elevator trim tab. The arrow in the upper end of the scale indicates that the trimmer deflected upward, and vice versa.



**Figure 65: Elevator trimming position indicator**

### Three-Pointer Air Pressure Gauge (GA/1754)

Control device for the serviceability of the pneumatic system. A three-arrow indicators combines, in one device: the pneumatic pressure in the aircraft pneumatic system and in the wheel air brakes. In general, three dial scales are present: pressure in the pneumatic system from 0 to 600 pounds per inch<sup>2</sup>, manometers left and right brakes - from 0 to 130 pounds per inch<sup>2</sup>. The scales are arranged in such a way that under normal measured values the arrows form a figure that facilitates the monitoring of the instrument; there is no need to read the measurement of each arrow, thus this allows the pilot to evaluate the state of the system only by the arrangement of the arrows.

The upper part of the scale is intended to control the pressure of compressed air, the lower left and right scales indicate the air pressure in the wheel brakes. At the top of the gauge indicator is an indicator marking the maximum allowable pressure in the pneumatic system.



**Figure 66: Air pressure gauge**

### Magneto Control Switch (5C/548)

The magneto is a magnetoelectric machine that converts mechanical energy into electrical energy. In some gasoline internal combustion engines where the battery is not used, the magneto provides an electric current pulse to the spark plugs. In airplanes, each cylinder typically has two spark plugs that are connected to a single magneto. This design creates a redundancy in case of failure of one of the magnetos and two sparks provide a more complete and efficient combustion of the fuel mixture.



Figure 67: Magneto switches

## Dashboard Right Side

On the right side of the dashboard are the power plant control devices, fuel gauge, voltmeter, as well as the signal lights controlling the supercharger and fuel system.

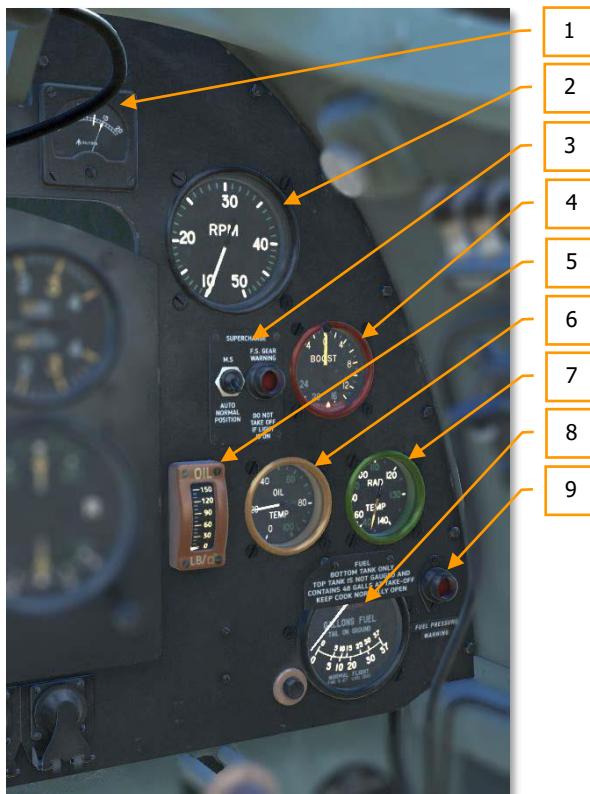


Figure 68: Dashboard right side

1. Voltmeter (5U/1636)
2. Tachometer Mk.IX G (6A/1191)
3. Supercharger control panel (SHT183/35134)
4. Boost gauge Mk.IIIL (6A/1427)
5. Oil pressure indicator Mk.XIV (6A/570)
6. Oil temperature indicator Mk.IA (6A/1094)
7. Coolant temperature indicator Mk.VIII (6A/1100)
8. Fuel gauge Mk.IV (6A/704)
9. Fuel pressure warning light (5C/1069)

### Voltmeter (5U/1636)

Designed to measure and display the voltage of the aircraft's on-board electrical network. The DC electrical measuring instrument is based on the occurrence in the moving arrow torque under the influence of a direct current. The angle of deflection of the arrow depends on the current strength, which in turn depends on the applied voltage. Grading scale is 0-20 V. The normal voltage value of the system is 12 V. For convenience, a mark is placed at 12 V.

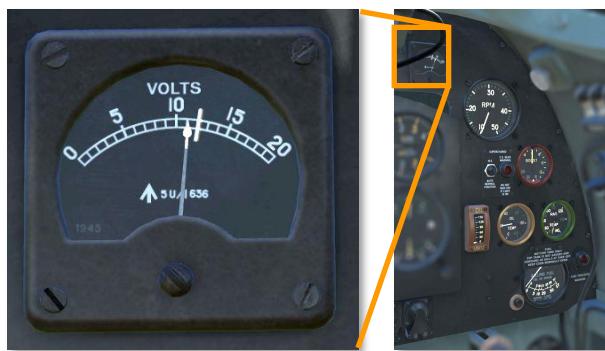


Figure 69: Voltmeter

### Mk.IX G (6A/1191) Tachometer

The tachometer is used to determine the rotational speed of the main engine shaft (crankshaft). Speed is determined by the number of revolutions per unit of time, usually a minute. The tachometer indicates the rotation speed of the main shaft at any time and quickly responds to any kind of change to this speed. Using the readings of a tachometer, the pilot sets the engine to maintain the RPM required for the given mode of flight.

Tachometer is of a centrifugal type, built on the principle of measuring the centrifugal force developed by the rotating load. The flexible shaft transmits the rotation axis of the tachometer from the fitting camshaft of the left cylinder. The instrument scale has divisions from 1000 to 5000 RPM. The two extremes of zero are discarded. The smaller notches represent increments of 100 RPM. The instrument parts are also covered with a luminous mass.



**Figure 70: Tachometer**

### Supercharger control panel [35134-1B3]

The panel includes a selector switch between the supercharger speeds and a pilot light. The supercharger performs its gear-switch automatically based on the signal from the altitude sensor mounted behind the cockpit. However, the pilot can forcibly switch the supercharger back to the first speed. The switch has two positions:

- AUTO NORMAL POSITION – automatic gear-shifting
- M.S. – forced shift to first speed.

The pilot alarm lamp is colored red and is designated as "F.S. GEAR WARNING." This warns the pilot that the supercharger is currently operating at the second speed. If this alarm is active prior to take-off, take-off must be stopped immediately in order to identify the cause and remedy the problem.



**Figure 71: Supercharger control panel**

### Boost Gauge [GA/1427]

To maintain the power of the aircraft engines, it is necessary to ensure that the weight ratio between the air pumped into the cylinders and fuel is at approximately 13: 1. This means that the weight units

of air must be 13 times greater than the same fuel unit. The weight of the same volume of air is directly proportional to air density. With an increase in flight altitude and a decrease in the air density, the required proportion also decreases and with it, the power of the engine is reduced. Maintaining normal proportions by reducing the amount of fuel while maintaining engine power is impossible, as the overall weight of the mixture is reduced. Engine power is significantly reduced as altitude increases: at an altitude of 5000m engine power is approximately half of what it would be at ground level. In order to maintain engine power at high altitudes, a supercharger is installed on the engine. The supercharger captures the fuel mixture from the carburetor and pumps it into the suction pipes of the engine, increasing the pressure there and thus the density of the mixture. The pressure in the suction pipe depends on the supercharger speed and the flight altitude. At every moment while in flight, the pilot should be able to control the amount of pressure or, equivalently, the amount of boost. To measure the pressure in the intake pipe of the engine unit is an instrument called the vacuum pressure gauge, or the supercharger boost gauge. The pressure gauge operates on the principle of a diaphragm with a metal gauge box and measures the pressure increase compared to atmospheric. When the engine is not running, the pressure in the intake pipe is equal to atmospheric pressure: thus, the pointer will be at 0. The notches on the scale represent increments of 1 lb/in<sup>2</sup>. These numbers indicate the difference between the absolute pressure after the supercharger and the atmospheric pressure in lb/in<sup>2</sup>.



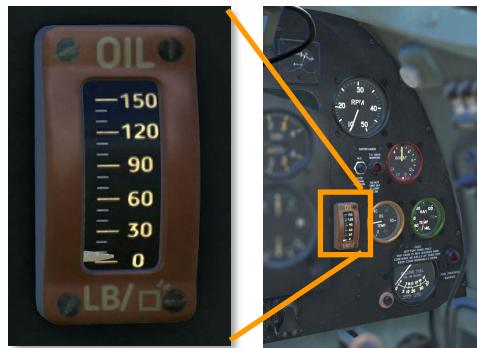
Figure 72: Boost gauge

#### Mk.XIV (6A/57D) Oil Pressure Indicator

The uninterrupted circulation of oil depends on the pressure difference between the oil line and the crankcase. This difference is measured by the oil manometer. This gauge controls the uninterrupted flow of lubrication and warns the pilot about faults in the lubrication system. This instrument is a differential pressure gauge with a Bourdon spring. The instrument housing is not hermetically sealed because the pressure difference between ambient air pressure surrounding the device and the oil sump is negligible compared with the measured oil pressure. Oil pressure is measured by a special receiver, which is installed in the trunk. Pressure is fed into the receiver housing and is perceived bellows, the inner cavity of which is connected to a manometer by means of connecting tubes.

Oil pressure is received by a special receiver installed in the trunk. Pressure is fed into the receiver housing and is received by a bellow valve, the inner cavity of which is connected to a manometer by means of connecting tubes.

The bellow valve, capillary tube and Bourdon tube are filled with toluene. The receiver and gauge are welded together by a connection tube and are integral. Toluene does not change its viscosity and does not freeze at low temperatures. The measurement range is between 0-150 lb/in<sup>2</sup>. The instrument notches has divisions from 0 to 150 lb/in<sup>2</sup>. The value of the smallest notch is in increments of 10 lb/in<sup>2</sup>. The figures, the notches, as well as the end of the arrow are covered with a luminous mass.



**Figure 73: Oil pressure indicator**

### Mk.IA (6A/1094) Oil Temperature Indicator

Engine operation produces a great amount of heat, and engine overheating lowers the limit of elasticity of the metal. As a result, parts may become deformed.

The heat temperature of the engine with its cooling liquid is determined indirectly by measuring the heat of the coolant, as the fluid continuously washes the cylinder wall and receives its temperature. With an increase in engine heat, the temperature of the liquid also rises. The temperature of the oil and coolant are measured by steam-powered thermometers which control the engine's heat and the quality of the lubricant, and also warn the pilot of potential overheating.

The basis of operation of these steam thermometers are on the measurement of changes in pressure of the saturated vapors from fluids with a low boiling point. If such a liquid placed is in a closed space and heated to its boiling point, the liquid will be converted into steam. The amount of steam will then increase the vapor pressure in the enclosed space. At a certain pressure value, further vaporization ceases and equilibrium occurs. The space above the liquid in which no further evaporation of the liquid occurs is called saturated. The vapours themselves are also called saturated. With a further increase in temperature, liquid evaporation resumes until again the space is saturated with vapor, but at a higher pressure. Each value of the measured temperature corresponds to a specific vapor pressure. This property of the saturated vapor is used to measure temperature.

The steam thermometer indicator consists of a receiver, the connecting pipe, and the manometer. The receiver is in the form of a closed metal container filled with a boiling liquid. The space above the liquid surface communicates with the interior of the Bourdon tube by means of a conduit. The receiver is immersed in an environment the temperature of which must be measured. With an increase to the measured temperature, vapor pressure increases, the Bourdon tube flexes and moves the arrow indicating the measured temperature. When the measured temperature decreases, part of the vapor is condensed and the pressure is reduced, which causes a reverse movement of the arrow.

The measurement range is from 0-100° C. The value of the smallest notch is 5° C. All markers and indicators are coated with a luminous mass.



**Figure 74: Oil temperature indicator**

#### **Mk.VIII (GA/1100) Coolant Temperature Gauge**

Similar in construction to the steam thermometer that measures the temperature of the oil.

Measurement range from 40-140 ° C. The value of the smallest notches are 5° C. All markers and indicators are covered with a luminous mass.



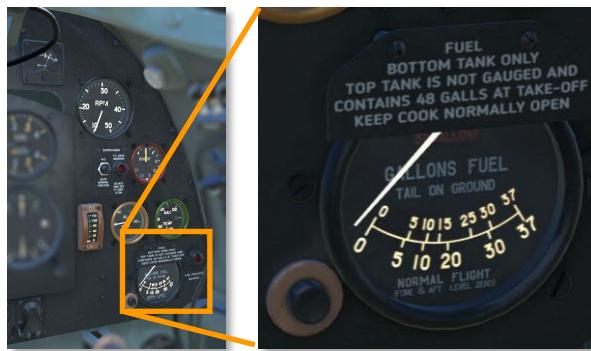
**Figure 75: Coolant temperature gauge**

#### **Mk.IV (GA/704) Fuel Gauge**

The fuel gauge is the instrument that informs the pilot of the amount of fuel present in the tanks of aircraft. Aircraft flight duration is determined by the amount of fuel, therefore, it is necessary to be aware at all times of how much fuel is remaining. The aircraft fuel system has a float gasoline gauge that measures only the amount of fuel in the bottom tank.

The main component of the gasoline float gauge is a floatpiece which rests on the fuel surface in the tank. Upon changes to the fuel level the floatpiece follows the level and with the help of the transmission mechanism moves the indicator to match the remaining fuel levels. The gasoline gauge is powered electrically by DC in transmitting its data to the cabin.

The fuel gauge indicator is an electromagnetic type electrical measuring instrument. The basis of its operation is the exertion of the magnetic fields of the stationary coil with a current onto the stationary armature made from a soft metal. The scale on the gasoline gauge is two-part. The upper scale is used to measure the amount of fuel on while on the ground, when the aircraft is in its three-point position. The bottom scale is used for the measurement of fuel in flight. The maximum value is equal to the volume of the lower tank: 37 gallons. To check fuel level you must press the button (5CW / 4187) from the bottom left of the indicator in order to power the gasoline gauge from the onboard power network.

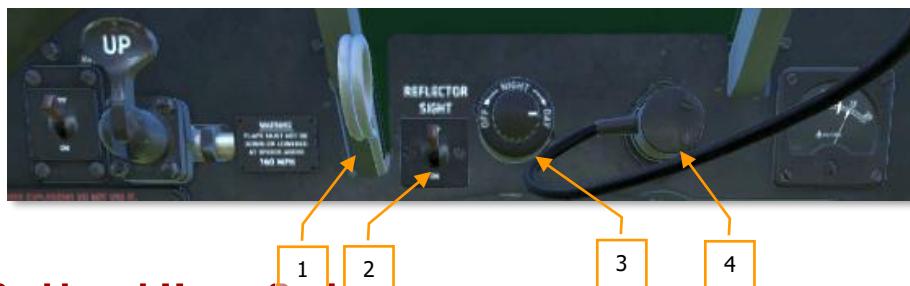


**Figure 76: Fuel gauge**

### Fuel Pressure Warning Light

To the left of the gasoline gauge is a lamp switch that triggers upon a drop in pressure (below 10lb/in<sup>2</sup>) from the gasoline pump. The circuits of the fuel pressure sensor are powered by the circuit powering the undercarriage warning lights, and is also controlled by a switch on the column of the engine control levers.



**Figure 77: Fuel pressure warning light**

## Dashboard Upper Section

### 1. Collimator gunsight optical filter

In conditions of very bright illumination an optical filter is used for aiming convenience. To install the filter in front of the reflector, pull the ring, which moves the light filter over the crosshairs.

### 2. Collimator sight tumbler

A separate switch is installed for activating the gunsight.

### 3. Collimator gunsight artificial illumination rheostat switch

The brightness of the gunsight illumination is controlled by this rheostat switch.

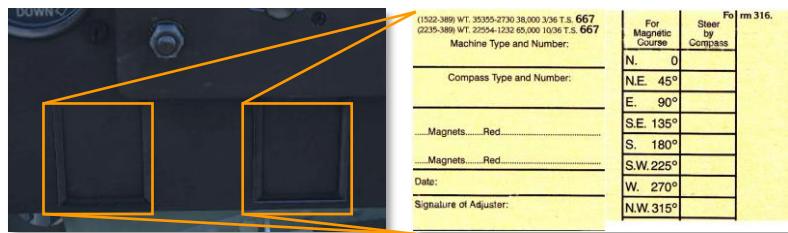
### 4. Collimator gunsight connector assembly

A connector assembly is installed on the dashboard for connecting the collimator gunsight to the aircraft's onboard power supply.

## Dashboard Lower Section

### Deviation Report Cards

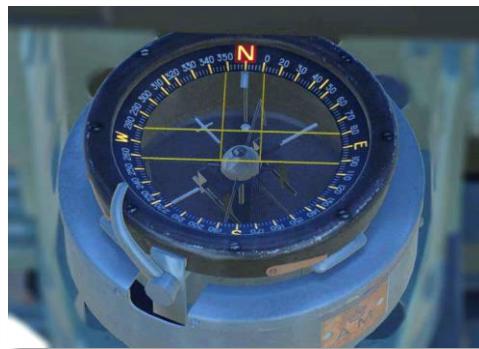
Installed are two holders for cards indicating the deviation of the magnetic compass, both for flights with and without external tanks.



**Figure 78: Front and back sides**

### P.8.M (6A/726) Compass

A magnetic compass is mounted on a special bracket on the lower middle part of the dashboard.



**Figure 79: Compass**

### Cabin Illumination Rheostat

For cabin lighting in low-light conditions. Both sides of the cockpit have two floodlight lamps. Turning on the lamps and setting their brightness is controlled by two rheostats on the lower part of the dashboard.



Figure 80: Cabin Illumination panel

### Startup Buttons

Power must be supplied to the starter coil and electric starter in order to start the motor. The bottom of the dashboard has two buttons for this purpose. To prevent unintentional pressing, the buttons are equipped with spring-loaded lids.

The left button is for the boost coil, while the right button controls the electric starter.

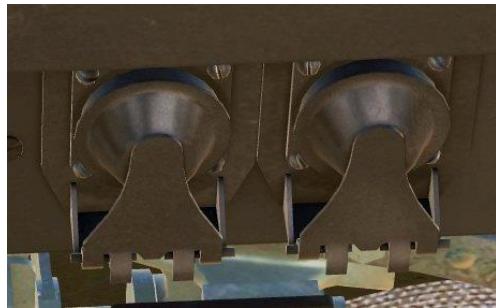


Figure 81: Startup buttons

### Main Fuel Valve

The main fuel valve is mounted to the right of the compass. This valve shuts off the flow of petrol from the tank to the engine dispensing pump.



**Figure 82: Main fuel valve**

### Engine primer pump

To facilitate starting the engine, the fuel system is equipped with a priming syringe to feed gas directly from the bottom of the tank into the inlet pipe of the engine.



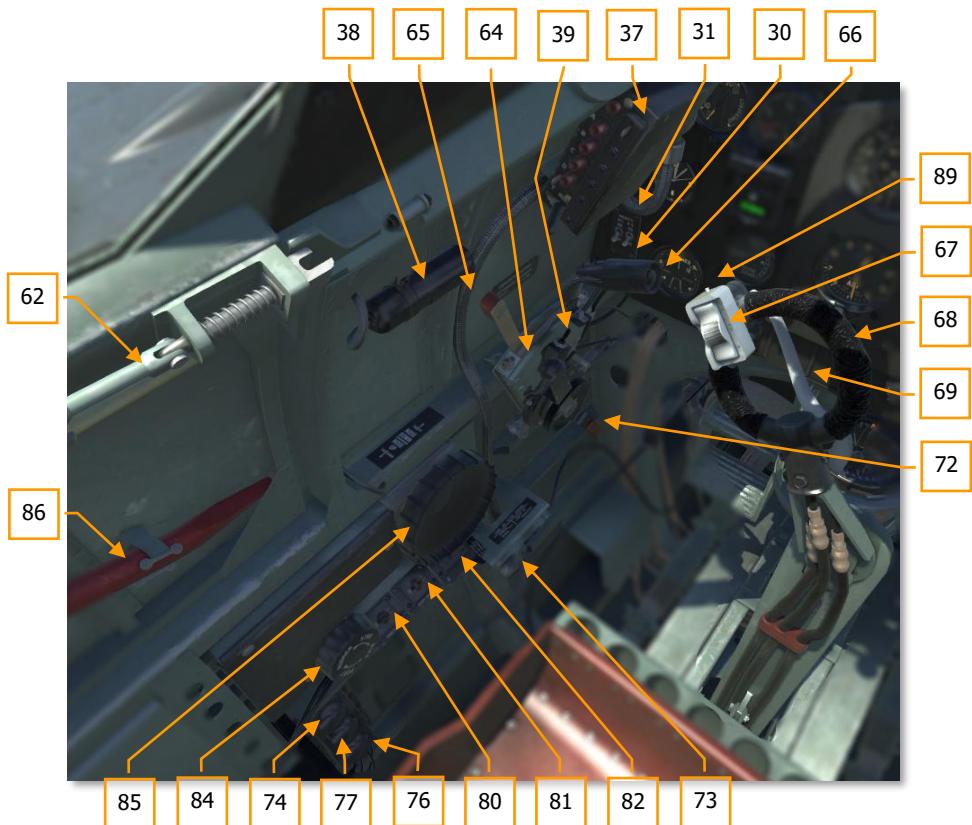
**Figure 83: Engine primer pump**

### Fuel Tank Pressure Valve

The bottom right side of the dashboard holds the fuel tank pressure valve. Normal position is "OFF". Tank pressure must be turned on when the fuel low pressure alarm is active.



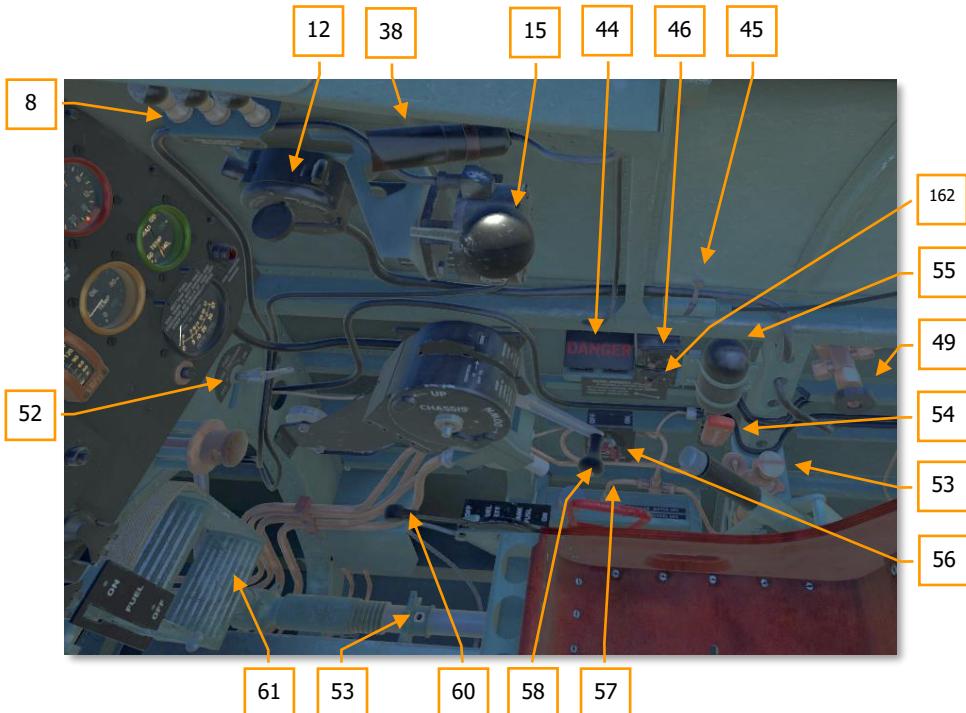
**Figure 84: Fuel tank pressure valve**

**LEFT SIDE**

- 30. Throttle Control
- 31. Ignition Switches
- 37. Radio Control Unit
- 38. Cockpit Floodlight
- 62. Cockpit Door Handle
- 63. Camera Gun Indicator Wedge Plate
- 64. Propeller Control
- 65. Fuel Cut-Off Control
- 66. Bomb Release Push-Button
- 67. Gun Firing Push-Button
- 68. Control Column
- 69. Brake Lever
- 70. Camera Push-Button
- 72. Throttle Control Friction Adjuster
- 73. Air Intake Control
- 74. Oli Dilution Push-Button
- 75. Fuel Pump Ammeter Test Socket
- 76. Radation Flap Test Push-Button

- 77. Supercharger Test Push-Button
- 78. Fuel Pump Test Push-Button
- 80. Pressure Head Heater Switch
- 81. Camera Gun Master Switch
- 82. Fuel Pump Switch
- 83. Generator Failure Lamp
- 84. Rudder Tab Control
- 85. Elevator Tab Control
- 86. Hood Jettisoning Crow-Bar
- 89. Gun Firing Safety Catch

## RIGHT SIDE



- 8. Reflector Spare Lights
- 12. Signalling Switch Box
- 15. Hand Wobble Pump
- 38. Cockpit Floodlight
- 39. Beam Approach Master Switch
- 42. Control Lock Attachment Lug
- 43. Oxygen Supply Tube
- 44. I.F.F Radio Push-Buttons
- 45. Harness Release Controll
- 46. I.F.F. Radio Master Switch
- 47. Incendiary Bomb
- 48. Clothing Heater Plug
- 49. Oxygen Supply Cock
- 50. Control Locking Gear (Stowed)
- 51. Microphone / Telephone Socket
- 52. Fuel Pressuring Cock
- 53. Windscreen De-Icing Pump Plunger
- 54. Undercarriage Emergency Control Lever
- 55. Undercarriage Emergency Carbon Dioxide Cylinder
- 56. Undercarriage Emergency Carbon Dioxide Cylinder
- 57. Undercarriage Emergency Carbon Dioxide Cylinder
- 58. Undercarriage Emergency Carbon Dioxide Cylinder
- 60. Undercarriage Emergency Carbon Dioxide Cylinder
- 61. Undercarriage Emergency Carbon Dioxide Cylinder

- |   |  |
|---|--|
| 56. Windscreen De-Icing Fluid Cock<br>57. Drop Tank Jettison Handle<br>58. Undercarriage Control Lever<br>59. Rudder Pedal Adjustment Wheel | 60. Drop Tank Fuel Cock Control Lever<br>61. Rudder Pedal<br>162. I.F.F. Radio Distress Switch |
|---|--|

# FLIGHT PERFORMANCE



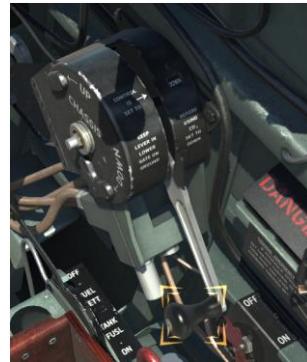
## Pre-Flight Checks

Ensure the following:

- The stop valve lever must be in the rear (closed) position.



- The undercarriage valve lever must be located in the rear (release) position, while the emergency release lever must be locked in the upright position.



- the external fuel tank valves must be in the OFF (closed) position.



- the fuel cock handle must be in the off position.



- Ensure that all flight instruments are properly connected (joystick, pedals, etc.) to their respective functions. Begin with a test of the rudder pedals – look to the tail section of the aircraft and ensure proper deflection of the rudder to the left and right of the aircraft. Use the designated keypresses or axes: **[Num4]** or **[Num6]** to look backwards, **[Z]** or **[X]** (or the rudder axes) for controlling the rudder. Next, test the function of the flight stick Y axis. Completely push the stick all the way to the end, then pull in the same manner. Next, check the ailerons – Observe the right aileron and move the stick left and right. Then do the same while observing the left aileron.

- Both magneto switches must be in the OFF position



- fuel tank booster valves must be in the OFF position



- air pressure in the pneumatic system according to the three-arrow gauge must display a pressure of no less than 250lb/in<sup>2</sup> where a full load displays 300 lb/in<sup>2</sup>.



- Altimeter fixed at 0. To do this, place the cursor over the highlighted regulator and adjust with the mouse wheel.



- The flaps must be working. Place the flaps lever in the down (deployed) position; to do so, press **[F]** or the left mouse button with the cursors on the highlighted lever. Look to the left and right of the aircraft and ensure that both mechanical indicators located on the aircraft wings have deployed. Then return the flaps lever to the up (retracted) position and ensure that the mechanical indicators have returned to their original position.



- Ensure proper operation of the movable part of the canopy – **[LCtrl+C]** shuts the canopy, while **[LShift+C]** opens it. Check whether there is dirt on the Plexiglas, and whether the emergency release bolts are shut.
- Move the throttle handle forward until the visual warning system located on the motor control column activates. Press **[Num+]** or push the throttle forward.



- At the same time, make sure that 1. the undercarriage status light shows a green light and "DOWN" on the inscription. 2. the fuel pressure warning light is red. Once the warning systems have been tested, return the throttle to its initial position by pressing **[Num-]** or by pulling the throttle.



- Check the quantity of fuel on the tanks. Press the button on the gauge and observe the arrow. Release the button after checking.



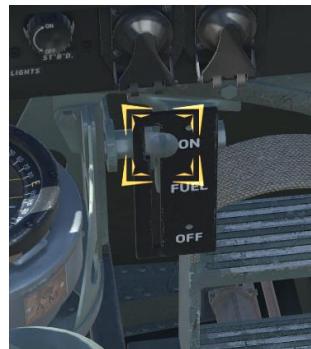
The aircraft is now ready for engine startup.

To startup the engine, perform the following procedures:

- Depress the brakes, so that the aircraft remains in place during engine startup. Place the mouse cursor over the highlighted section of the control stick and roll the mouse wheel.



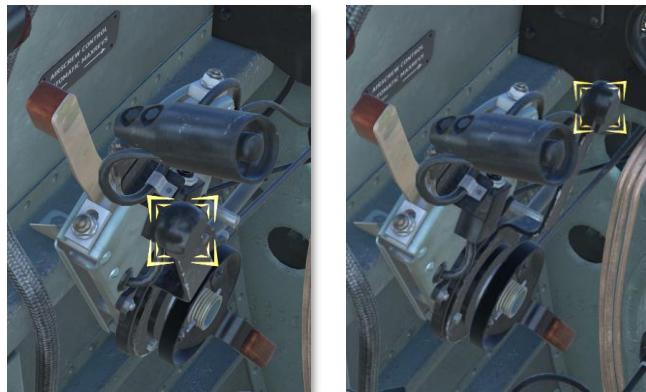
- Place the fuel cock handle in the ON position. Left-click on the highlighted handle or press **[T]**.



- Move the throttle forward by 10-12mm starting from the rearmost position. Press **[Num+]** or push the throttle of your joystick system.



- Set the pitch lever to its frontmost position. Press **[PageUp]** or move the throttle axis.



- Move the dust filter lever to the frontmost position (FILTER IN OPERATION). Press **[H]** on the keyboard or click the highlighted lever.



- Turn the handle of the primer pump. Hover your mouse over the highlighted section and roll the mouse wheel. Then perform the required number of complete movements by the primer pump in order to fill the engine. To do this, press and hold **[Insert]** or the left-mouse button with the cursor on the highlighted section. The following table shows the number of complete movements to be performed by the piston pump depending on the outside temperature:

Outside air temperature, °C	+30°	+20°	+10	0°	-10° ~ - 20°
Number of complete movements	2 - 3	4	5	5 - 6	Up to 15



- Create fuel pressure using the wobble pump (9-10 pumps) until the warning light begins to flash. Press **[LCtrl+Insert]** or click the highlighted section in the cockpit.



- Switch on both magnetos by placing their switches in the ON position. **[LShift+End]** and **[RShift+End]**, or click on the highlighted switches in the cockpit.

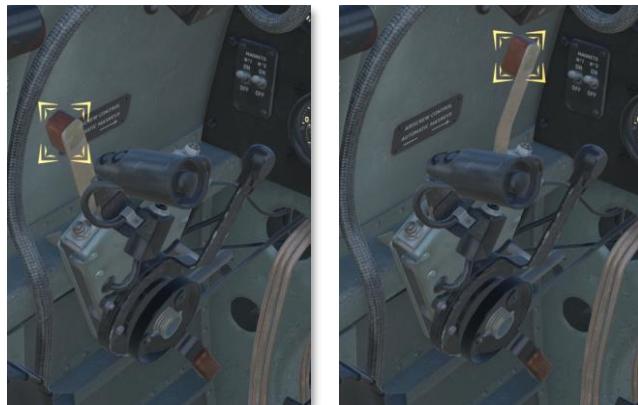


- Pull back the protective caps on the starter and booster coil buttons by clicking on the highlighted elements.



- Simultaneously press the starter and booster coils: the keybinds are **[Home]** and **[Delete]** respectively. After the first spark in the motor, move the stop valve lever forward

by pressing **[M]** on the keyboard or by clicking it with the mouse. Then release the starter and booster coil buttons.



- If motor startup fails, pull back the stop valve lever and repeat the process beginning from engine filling.



## Engine warmup

- After successful engine startup, pull back the idle cut.off control to its rearmost position.



- Ensure that the oil pressure is within 60-120ft/in<sup>2</sup>.



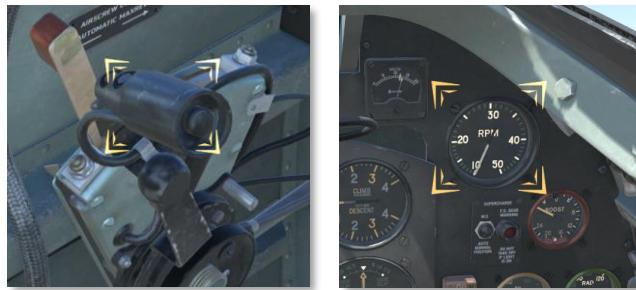
- Return the protective caps of the starter and booster coil buttons by clicking on them.



- Turn the handle of the primer pump by highlighting it with the cursor and rolling the mouse wheel.



- Set the throttle to the position corresponding to 1000-1200 RPM according to the tachometer.



- Continue to warm the engine at an RPM of 1000-1200 until the oil temperature reaches 20°C and the coolant fluid temperature reaches 60°C (shown by the left and right instruments respectively)



## Engine runup

During engine runup, double check the control instruments, which must show the following figures:

Basic modes of operation of the Merlin 66 engine, with 100 octane fuel									
Basic data	Mode	Takeoff		Combat		Nominal		Cruising	
		I spd.	II spd.	I spd.	II spd.	I spd.	II spd.	I spd.	II spd.
Horsepower	1325	-	-	1680*	1440	1310	1135	985	865
				1750**	1630	1410	1315	1095	1030
RPM	3000	-	-	3000	3000	2850	2850	2650	2650
Boost lb/in <sup>2</sup>	+12	-	-	+18	+18	+12	+12	+7	+7
	mm Mercury			1690	1690	1380	1380	1120	1120
Altitude limits in m. (w/o ram air flow)	305	-	-	1680	4960	2750	5800	3660	6330
Time for uninterrupted operation, in minutes	5	-	-	5	5	60	60	Unltd	unltd

\* - Data for sea level

\*\* - Data on approximate altitudes.

23. Using the throttle lever, set a boost pressure of 4 lb/in<sup>2</sup> and check the ff.:

- 1.) Activation of the second speed compressor, for which the compressor speed selector switch located on the dashboard must be set to "AUTO" (automatic gear shifting,) and click on the button for testing the activation of the compressor second speed, located on the left side of the pilot's seat.

The signal lamps on the dashboard serves as confirmation of successful activation of the compressor second speed.

**NOTE.** Before activation of second speed, first ensure that the pressure of the pneumatic system has not fallen below 150 lb/in<sup>2</sup>.

- 1.) Operation of the propeller regulator. To do so, move the pitch lever from its frontmost position to the rear position, reducing the RPM to 250-300. Afterwards, push the lever to its frontmost position, which should return the RPM to its full value.

- 2.) Operation of the automatic temperature regulator for the cooling fluid and oil. To do so, push the control button of the radiator grates. Opening of the radiator valves tunnels must be controlled by the technician located near the aircraft.
- 3.) Using the throttle, set a pressure of 9lb/in<sup>2</sup>, and by alternately switching off the magnetos ensure proper operation of the ignition system by checking for a decrease in RPM and by ear. Decrease in RPM with one working magneto, compared to the RPM when both are active, must not exceed 100RPM.
- 4.) Check engine response and motor operation on takeoff mode: set the pressure to 12lb/in<sup>2</sup> over 2-3 seconds using the throttle at an RPM of 3000.
- 5.) When testing the motor, ensure the ff:
  - Completely pull on the stick.
  - Hold on to the aircraft's tail with a weight of about 2 people.
  - Do not allow an increase in coolant temperature beyond 120°C and oil temperature beyond 85°C.
  - Take note whether the electric generator is working (check the voltmeter arrows) and test the radio equipment for 2-way communication.

## Take-Off and climb

### Taxiing

1. Prior to taxiing, ensure that all instruments are working and double-check the position of the levers and handles.
  - Coolant temperature between 60° C - 120° C.
  - Oil temperature between 20° C - 80° C.
  - Pitch lever in the position corresponding to the takeoff mode. (fully up front)
  - External tank valves shut off.
  - Main fuel tank valves on.
  - Undercarriage lever in the DOWN position.
  - Pneumatic system air pressure no less than 220 lb/in<sup>2</sup>.
  - Weapon safeties engaged.
  - Radio systems turned on and tuned into the assigned frequencies.
2. Buckle up!
3. Give the command to remove the wheel pads. Upon receiving confirmation, begin taxiing.
4. Double-check proper brake operation during taxi. Upon completely depressing the brakes and pulling on the stick, the aircraft must remain in place even with the motor working (with an RPM up to 1800)
5. For best view of the surrounding area, raise the pilot seat and open the canopy.

### **NOTE**

1. *Fast taxiing on uneven terrain is dangerous. Due to the narrow track of the aircraft undercarriage, when one wheel hits an uneven surface, the aircraft may come into contact with the ground.*
2. *Minimize engine work and shorten taxi time when working in hot weather as the engine may quickly overheat.*
3. *Taxiing on soft ground without an escort on the tail of the aircraft is prohibited.*
4. *The stick must be completely pulled back during taxiing.*

## Before takeoff

- 1.) Before taking off, once more check if all systems are normal: check instruments and their readings. Check the position of the following:
  - i. Elevator trimmers neutral, rudder trimmers 7-8 mm to the right to counteract the aircraft's tendency to yaw left.
  - ii. Main fuel valves in the on position.
  - iii. External fuel tank valves shut off.
  - iv. Fuel boost valve in the OFF position.
  - v. Pitch lever fully forward.
  - vi. Flaps lever in the UP position (retracted)
- 2.) Apply breaks and increase RPM.
- 3.) Check for debris on the runway, and check surroundings.

## Takeoff

- 1.) Throttle up until a boost value of 8-12 lb/in<sup>2</sup> is achieved depending on the aircraft load and the airfield condition. Depending on the acceleration, begin to release the stick in order to raise the tail for takeoff position. Compensate for the aircraft's tendency to yaw left by yawing right and try to keep takeoff path as straight as possible.

Liftoff occurs at 90-95mph IAS.

- 2.) To avoid aircraft ballooning and the consequent loss of speed, do not immediately attempt a climb after liftoff, but follow the runway just above the ground until an IAS of 140mph is achieved, after which the pilot may begin to climb and retract the undercarriage.
- 3.) To raise the undercarriage, first pull back the undercarriage control lever and take it out of the slot, and then push it into the forward position and press it against the board. Leave the lever in this position and watch the signal lights. As soon as the undercarriage begins to retract, the green light goes out and lights up red when the undercarriage is fully retracted and locked in place. The undercarriage lever shuts off automatically - the lever drops into the upper groove and the hydraulic valve in the quadrant on the undercarriage lever will show the position of "IDLE" (neutral). In addition, when retracting the undercarriage, the pilot will hear the wheels settling in the wings.

If the undercarriage does not retract, repeat the process and hold it in the front position. Deployed and unlocked landing gears slow down the aircraft and may lead to engine overheat.  
**NOTE.** After retracting the undercarriage, it is necessary to turn out the anti-dust filter.

## Climbing

1. To achieve maximum rate of climb, pilots may make use of maximum power ( $P_k=12 \text{ lb/in}^2$ ,  $n=2850 \text{ RPM}$ ). In extreme situations even combat mode may be used ( $P_k=18 \text{ lb/in}^2$ ,  $n=3000 \text{ RPM}$ ), but for no longer than 5 minutes.

2. In all cases where maximum rate of climb is not required, climbing may be performed with a pressure 7lb/in<sup>2</sup> and 2650RPM. Doing so conserves fuel and increases total flight range.
3. Refer to the following table for the most efficient speeds for climbing at certain altitudes:

Altitude	Speed	
From (ft)	To (ft)	mph
<b>0</b>	12000	185
<b>12000</b>	15000	180
<b>15000</b>	20000	170
<b>20000</b>	25000	160
<b>25000</b>	30000	150
<b>30000</b>	33000	140
<b>33000</b>	37000	130
<b>37000</b>	40000	120
<b>40000</b>	-	110

4. While climbing, ensure that the temperatures for coolant and oil do not exceed 125° and 90° C respectively.
5. Control of the radiator grates is automatic depending on the coolant temperature. The grates open at temperatures above 115°C. In case of system failure, the grates may be opened by pressing the button located on the left side of the pilot seat.
6. Supercharger 2<sup>nd</sup> speed engages automatically at 13500-14000 ft while climbing. While descending, the supercharger returns to 1<sup>st</sup> speed past 12500 ft.
7. If it is necessary to use 1<sup>st</sup> speed past 13500-14000 ft, set the dashboard switch to MS.
8. Fuel boost valve must be set to off. Switch on only in response to the red light signaling a loss of fuel pressure (lower than 10lb/in<sup>2</sup>)
9. Rules for using the fuel tanks:  
Startup, motor warmup, takeoff: Use main tanks. Switch fuel feed to use external tanks only at altitudes above 2000ft (600m) and only when external tanks are in place.
10. Before dropping external tanks that have not been fully exhausted, first connect the main fuel tanks, then release.
11. If the external tanks have no fuel remaining, or if it has been jettisoned, ensure that the valve for the external tanks is completely shut off. If they are not completely closed, the system will be fed air and may lead to interruptions in the motor operation.
12. Periodically check remaining fuel levels while in flight by pushing the fuel gauge button. The gauge will begin to show remaining levels only after it begins feeding off the lower tank.

### Preparing weapons systems for use in flight

13. Remove the weapon safeties by moving it from left to right. A pin will come out of the upper part of the trigger system that signifies weapons readiness.
14. Regulate the sight glow intensity by using the rheostat located under the gunsight on the dashboard. The rheostat has three positions – OFF, NIGHT, and DAY.

### In-flight radio system testing

15. While in flight, periodically hail the ground stations to check if the radio is working.
16. In case of loss of contact between the ground station, continue to hail and receive until restoration of communications according to the schedule approved by the chief of communications.

## Level flight

1. Circling flight may be performed at indicated airspeeds no less than 150mph without external tanks, and no less than 175mph with external tanks.
2. Operational flights, rebasing, patrol flights, loitering at target areas, flights in reserve regiments (with the exception of aerobatics and air combat training) must be performed under the economic regimes.
3. When switching flight modes to reduce airspeed, perform these steps in the following order:
  - Set the required (reduced) airspeed with the throttle lever.
  - Set the specified RPM with the pitch lever.
  - If the aircraft experiences a reduction in airspeed, then achieve the required airspeed by means of the throttle lever.
4. When switching flight modes to increase airspeed, perform these steps in the following order:
  - Set the specified RPM with the pitch lever.
  - Using the throttle lever, set the boost to the required airspeed. Take care not to exceed the boost settings conforming to the chosen flight mode.
5. In order to achieve maximum speeds (for use during enemy contact, pursuit, air combat, and retreat) the motor must be set to operate at the nominal or combat modes of flight (depending on the circumstances.) To do so, first set the RPM, followed by the boost settings corresponding to the chosen mode of flight.

***NOTE. Motor operation in combat mode is permitted for periods no longer than 5 minutes.***

***Additionally, the oil and cooling fluid temperatures must not be allowed to exceed limits.***

6. The aircraft is easily balanced by trimmers on the entire diapason of horizontal flight. An aircraft properly configured may be left to fly uninterrupted without pilot intervention.
7. A complete loss of speed during horizontal flight on an aircraft with normal weight and throttled-down engine will happen under the following conditions:
  - when gears and flaps are retracted – at 85mph IAS.
  - when gears and flaps are deployed – at 75mph IAS.

<b>Distance and duration of flight under different modes</b> (without external tanks) $G_n=3392\text{ KG}$ , $V_{top}=392\text{ L}$							
Flight mode	Altitude	IAS	RPM	Fuel consumption		Until tanks are emptied	
	ft	mph		L/km	L/hr	Distance of horizontal flight, km	Duration of horizontal flight, H:MIN
Distance, maximum speed	21600 6600	256 410	2570	0.52	295	595	1:03
Distance, relative maximum speed	16400 5000	245 394	2360	0.475	237	685	1:22
Maximum distance	3280 1000	187 300	1800	0.395	125	880	2:46

## Weapons control

- Control of the guns is by means of the pneumatic system and the triggers installed on the control sticks.
- Both cannons and machineguns can be fired separately from each other or simultaneously. Pressing the upper part of the trigger opens fire from the machineguns; the lower part for cannons; and the middle part for simultaneous fire from both weapon types.
- Reloading of the weapons systems may be performed only on the ground.
- Weapons fire must be in short, controlled bursts: 10-15 rounds per burst from the machineguns, and 3-5 rounds per burst from the cannons.

## Emergency canopy jettison

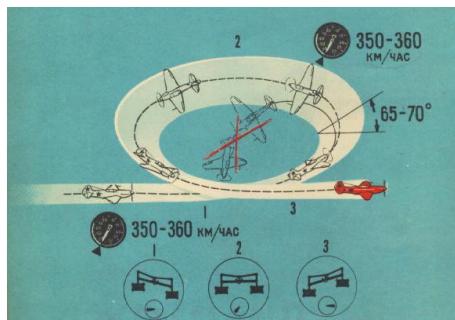
During emergency escape from the aircraft, the canopy may be jettisoned by means of the emergency jettison lever: pull the rubber balloon located on the upper part of the canopy forward and then down, then push the lower part of the canopy with your elbows. In extreme situations, use the crowbar that is kept on the inner side of the doors.

# Flying

1. Aerobatics and stalls may be performed only on an aircraft with no external tanks attached.
2. Before performing aerobatic manoeuvres, first balance the aircraft by its trimmers at an IAS of 200mph.
3. Performing aerobic manoeuvres must be done with smooth movements of the control platforms. Sharp, sudden movements may lead to excessive Gs and as such are not permitted.
4. Banking turns and acceleration upon entering combat, loops, immelmans and hammerheads may be performed at maximum continuous power ( $P_k=12 \text{ lb/in}^2$ ,  $n=2850 \text{ RPM}$ .) In special cases, when circumstances demand the absolute maximum capabilities of the aircraft's motor, pilots may switch to the motor's combat mode for periods of no longer than 5 minutes. ( $P_k=18 \text{ lb/in}^2$ ,  $n=2850 \text{ RPM}$ ) During vertical maneuvers, keep in mind that the airspeed figures indicated on the instruments will give distorted (low) figures.

## Banking turns

1. The most advantageous speed for such turns with a bank angle of 65-70° is 185mph IAS at nominal engine operation. At the same time, the minimum time for a banking turn at an altitude of 3000 feet is at 17-18 seconds.
2. The plane performs turns steadily and can easily shift from one turn to another. On the left-hand turn the aircraft has a slight tendency to lower the nose, and vice versa.
3. When you drag the handle to turn, the aircraft will shake a little and start to slide on the wing. In this case, release the handle slightly: the sliding will stop and the plane will continue to turn.

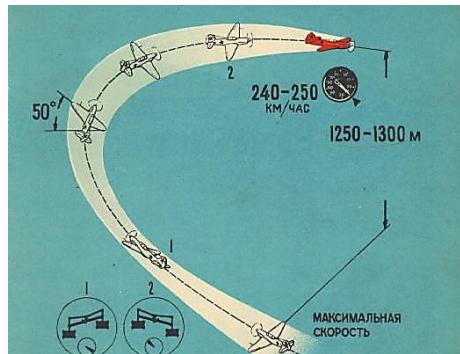


## Chandelle

1. To perform a chandelle, the motor must be set to maximum continuous power, and airspeed pushed to its maximum (at altitudes of 21000 feet above ground – 310mph IAS) after which the control stick must be smoothly pulled back and in the desired direction,

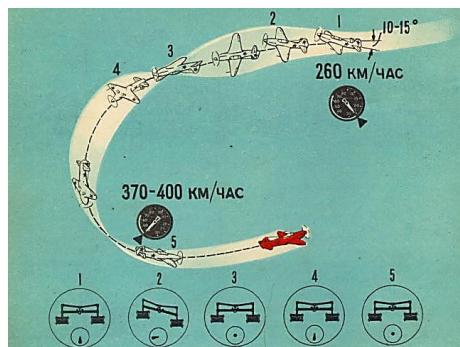
combined with rudder movement in the same direction. This sets the aircraft to climb in an upward spiral with a roll up to 50°.

2. Complete the manoeuvre at an IAS of 140-150mph while the motor is running at maximum power. The aircraft will have gained 1900 feet of altitude.
3. Performing this manoeuvre with excessive bank will cause the aircraft to quickly lose speed and gain less altitude from the manoeuvre.



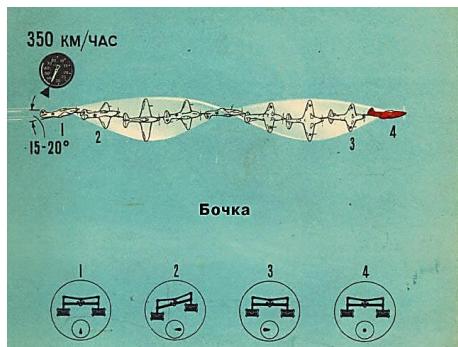
### Split S

1. Split S' are performed at speeds of 150mph IAS. In 2-3 seconds, smoothly move the stick in the desired direction at about 3/4s of its maximum reach, and the corresponding rudder by about 1/2 of its maximum reach.
2. At about 20-30° to aircraft inversion, interrupt the roll by placing both control platforms in their neutral position.
3. Once the aircraft has stopped rolling, reduce throttle and slightly pull on the stick to manoeuvre the aircraft into a dive.
4. After gaining 220-230 mph IAS, smoothly manoeuvre the aircraft back to horizontal flight. Take care not to overload the aircraft.
5. If, after the Split S, another vertical manoeuvre is required, then the acceleration that takes place while diving must be done at an angle of no more than 40° relative to the horizon, followed by a gradual decrease in the angle.
6. The aircraft loses 1300-1400 feet after performing this manoeuvre.



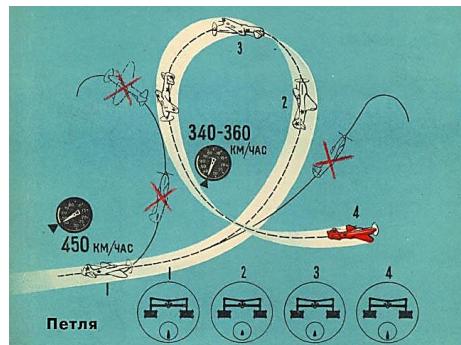
## Barrel roll

1. Barrel rolls are performed at speeds of 160-170 mph IAS, and the aircraft must be trimmed for horizontal flight beforehand. The aircraft must have a pitch-up angle of 10-15°; after ensuring this, smoothly and simultaneously push the stick and rudders by  $\frac{1}{2}$  of their maximum reach in the desired direction. Cease rolling at about 10-20° until the horizontal position by returning the stick and rudder to their neutral positions. This manoeuvre, performed ideally, takes 5-6 seconds.
2. The technique for performing a barrel roll is identical regardless of direction, but barrel rolling to the right must be done more energetically.
3. Excessive movement of the stick, insignificant pulls upon entry will lead to a significant increase in roll speed and shaking in the aircraft.



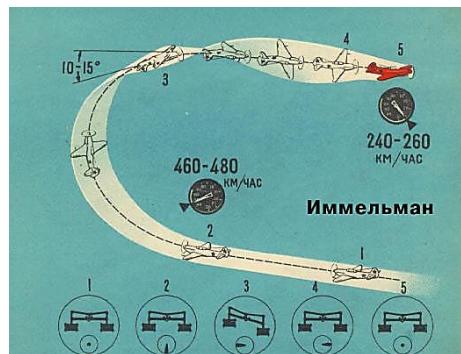
## Loop

1. Loops are performed at speeds of 230-240 mph IAS. Prior to performing the manoeuvre, account for acceleration such that the aircraft reaches the required airspeed prior to pitching up. Smoothly pull the stick towards you to initiate climbing, and maintain this position until the aircraft begins to dive at the end of the manoeuvre.
2. As the aircraft enters the dive, lower throttle and slowly begin to release the control stick in order to build up acceleration.
3. Upon reaching 220-230 mph IAS, manoeuvre the aircraft out of the dive.
4. The control stick must be pulled back during the climbing part of the manoeuvre, otherwise the aircraft will lose speed and fall on its wing or back. Correct execution yields an altitude gain of 400-500 feet.



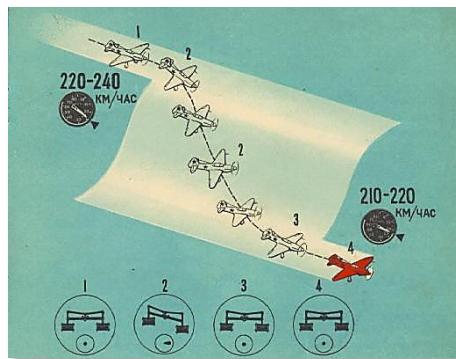
### Immelmann

To perform an Immelmann, it is necessary to accelerate the aircraft to a speed of 250-260 mph. The first half of the Immelman is performed in the same manner as the first half of the loop. When approaching the apex of the manoeuvre, when the aircraft is in an inverted position and the horizon appears in the middle of the glare shield, smoothly push both control surfaces toward the desired rotation. At 10-15° to the horizontal position, return both stick and rudder to neutral. Normal speed on exit should be at least 140 mph. The aircraft gains 1700-1800 feet after an Immelman.



### Sideslip

The plane glides steadily with a roll up to 40 ° (with the landing gear and flaps); speed of entry being 130mph, exit at no less than 120 mph. To exit from sideslip, correct with ailerons and set the normal glide angle. Maintain flight direction with rudders.

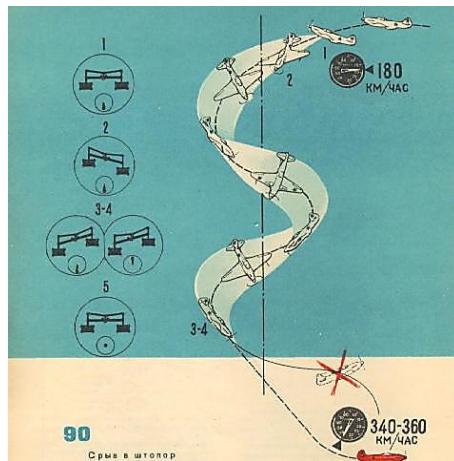


## Stalls

Induced tailspins are permitted for training: only up to two turns from a height of no less than 10,000 feet.

To exit a tailspin, push rudder to maximum in the opposite direction of the tailspin while pulling on the stick.

Once the aircraft ceases to spin, set rudders to neutral, and after gaining an airspeed of 150mph on a dive manoeuvre the aircraft back to horizontal flight.



## Diving

1. Before entering a dive, first trim the aircraft for horizontal flight at an IAS of 280mph.
2. Diving may be performed from any position with an engine RPM of no more than 2850, throttle set to no less than 1/3. The values for RPM and boost must not exceed the maximum permitted values under combat mode.
3. The aircraft descends steadily from any angle.

4. 450mph IAS is the maximum airspeed for diving, while the maximum RPM is 3150 over 20 seconds.
5. Exit the dive by smoothly pulling the stick. Sharp pulls may lead to excessive Gs, which in turn may cause the pilot to lose consciousness, or even lead to catastrophic damage to the airframe.
6. The total loss of altitude on a dive is 5000 ft, with a max airspeed of 450mph IAS



## Landing

### Preparing for landing

1. Engage the safeties for the weapon triggers. Ensure that:
  - Pitch lever is set to low pitch. (frontmost position)
  - second supercharger speed is off (red light off)
  - gauges show an internal pressure of 220 lb/in<sup>2</sup> in the air system and 800 lb/in<sup>2</sup> in the brake system.
2. Open the canopy.

### Normal gear deployment

1. Deploy gears at a speed of 150-160mph IAS before the third turn.  
Prior to deploying the landing gears:
  - 1) For 2-3 seconds hold the undercarriage lever in its frontmost position to relieve the locks.
  - 2) Sharply pull the lever to its rearmost position and leave it there. The lever will automatically lock into the gap as the undercarriage locks in place in the deployed position. The hydraulic valve indicator will once again show IDLE.
  - 3) If there is resistance when attempting to pull the lever backwards, then repeat step 1, but this time hold the lever for longer (3-5 seconds.) In this case, provide additional relief to the locks by reducing airspeed to 120-130 mph and lowering the RPM to 1200-1800, or by briefly and energetically nosing down.
  - 4) Once the green undercarriage signal lights are shown, double-check undercarriage deployment and locking.

## Emergency undercarriage deployment

If the hydraulic system fails after all the steps above have been taken, pilots are authorized to use the emergency undercarriage deployment system.

- Pull the gear deployment handle down.
- break the seal and place the emergency handle in the frontmost position.
- ensure that the undercarriage has deployed successfully.

## Gliding descent

1. Straight gliding descent with retracted undercarriage and flaps is performed at a speed of 100-120 mph IAS; with deployed gear and flaps, 100-110 mph IAS.
2. Avoid overcooling the engine. On lengthy gliding descents, raise the engine RPM to 2400-2500 for 5-6 seconds every 3-4 minutes.
3. Reliable motor acceleration is guaranteed when the coolant temperature is not lower than 60° C and oil temperature is not lower than 20° C.
4. Turning before landing approach must be done at a speed of 150mph IAS. (assuming final approach is started at an altitude of no lower than 500ft)
5. Deploy flaps at a speed no greater than 160mph by pulling the flap deploy handle downwards.
6. Check instruments to ensure that the flaps have indeed deployed successfully.
7. **NOTE.** *In case of pneumatic system malfunction and a loss of pressure (below 120 lb/in<sup>2</sup>), perform the landing with retracted flaps, setting aside compressed air for the brakes.*
8. After flaps deployment, smoothly pull the stick to reduce speed to 100-110 mph IAS, which is the normal gliding speed.

## Go-around

If forced to go-around:

- Smoothly push throttle to maximum.
- retract the undercarriage (flying with a deployed undercarriage can cause an overheat of the coolant) and begin a climb.
- at an altitude of no lower than 300 ft and at a speed of 130mph IAS: retract flaps.

## Landing

1. When landing with deployed flaps, flare at an altitude of 6-7 meters; when flaps are retracted, this must be done at 5-6 meters. Complete touchdown at 0.25m-0.5m.
2. For touchdown on all three points, do not completely pull back on the stick.
3. After touchdown, periodically depress the brake trigger. Avoid braking sharply when the aircraft may potentially nose over – begin braking only when the stick is fully pulled back.
4. After your ground speed is under control, retract the flaps by returning the handle to the UP position.
5. Observe the runway and proceed to taxiing.

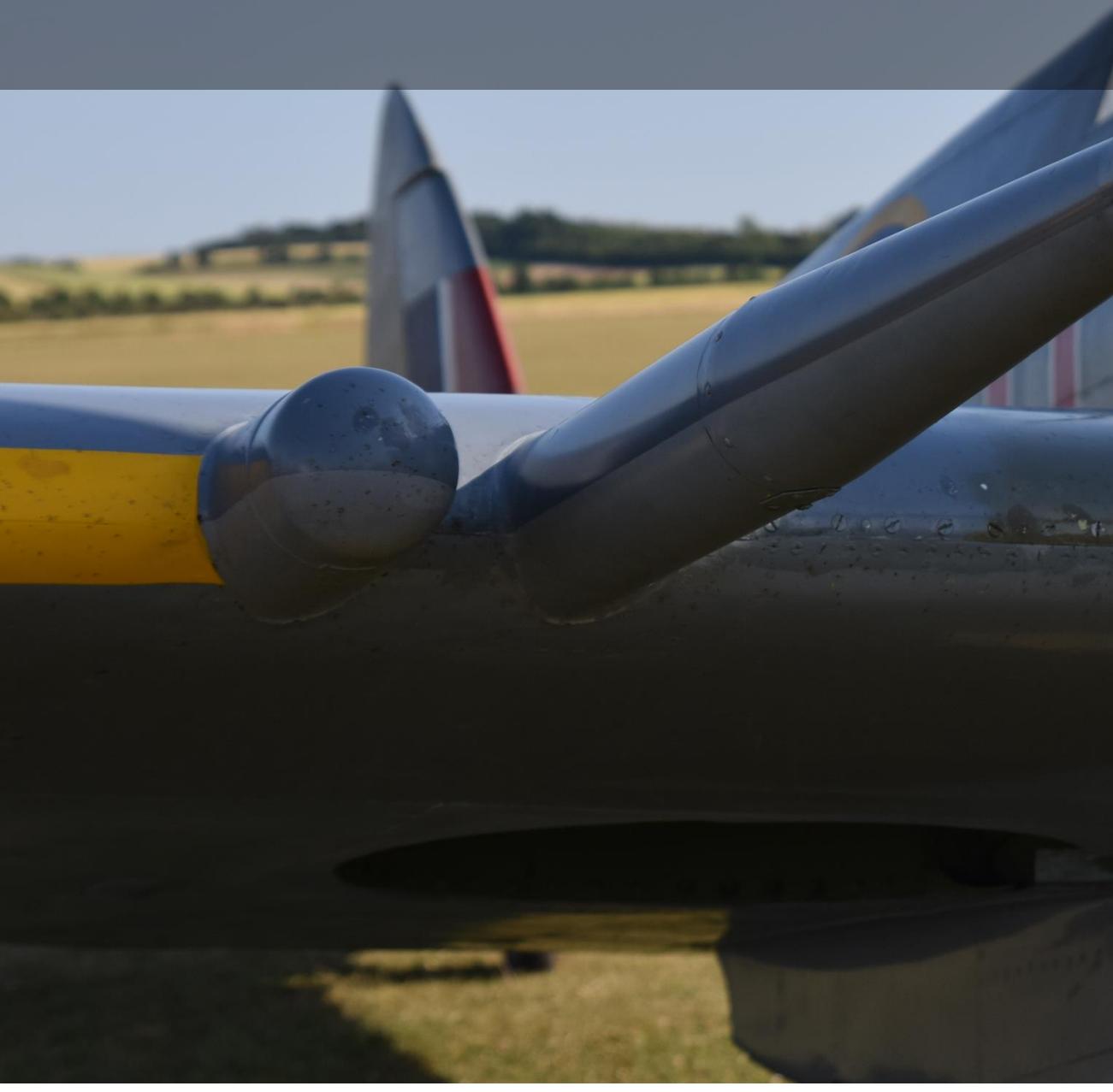
## After taxiing

1. Cool the engine by letting it run for 2-3 minutes at an RPM of 800-1000.
2. Stop the motor by pulling the shutdown lever from its frontmost position all the way back to the slot, then smoothly push the throttle forward.
3. After motor shutdown, shutoff ignition and close the fuel valve.
4. Shutoff all electrical systems.

## After flight

Inform the mechanic of any in-flight issues with the aircraft that need resolving.

# WEAPONS



## Armament

The plane is armed with machine-guns and cannons and also has the ability to carry three bombs on three hardpoints – one on the center-line and one beneath each wing.

### Cannons

The aircraft's cannon-type armament consists of two 20-mm Hispano Mk. II guns, each with an ammunition capacity of 120 rounds. The cannons are supplemented with four additional .303 calibre (7.69mm) Browning machineguns, with an individual ammunition capacity of 350 rounds.

These guns are mounted in the aircraft's wings on special mounts.

Trajectory calculation is performed with the help of the reflector sight mounted in on a bracket above the instrument panel. Weapons fire is controlled by a pneumatic valve controlled by a button mounted on the aircraft control stick.

Compressed air enters the air system of the cylinder that is charged during operation of the motor compressor. Fire management is carried out by means of the trigger.

1. Depressing the upper part of the trigger fires the machine guns.
2. Depressing the lower part of the trigger fires the cannons.
3. Depressing the middle part of the trigger discharges both weapons at once.

There is a lever located below the trigger. When turned to the left, the trigger safety mechanism is engaged; when turned to the right, the safety is disengaged.

Reloading the guns is performed only on the ground. The cannons have a pneumatic reloading system, while the machineguns are loaded by means of a special cable.

Pneumatically loading the cannons is by means of a special valve, installed in the gun compartments, located at the rear-right section for the left plane, and rear-left for the right plane.

In order to reload the right plane cannon, the valve lever must be depressed, while the left plane lever must be pulled upwards. The pneumatic loading system is powered by a special tank with a pressure of 250-300 lb/in<sup>2</sup>.

Before takeoff, cuts in the skin under the guns must always be sealed with fabric lining. The cannon barrels also must be covered (when on the ground.)

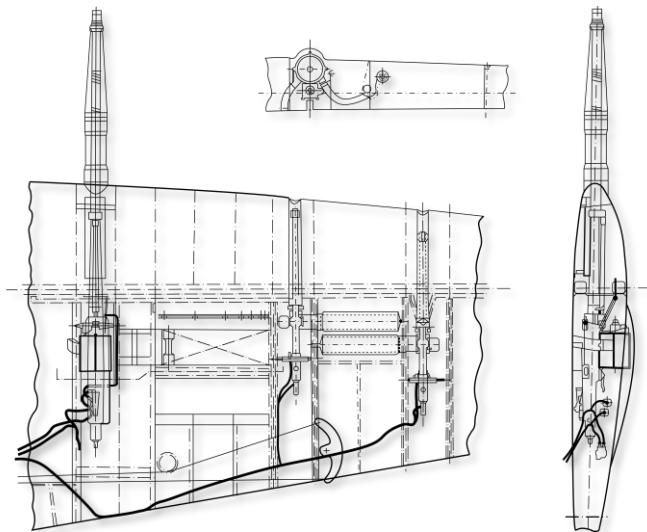
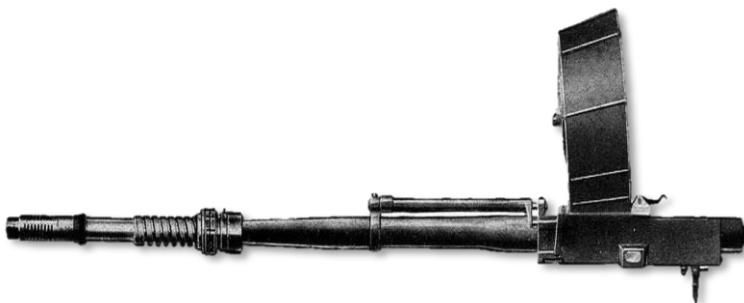


Figure 86: 303in and 20mm Gun Installation

## "HISPANO" Mk. II Gun

### Development History

The UK, on the eve of World War II, saw the beginning of a program for the development of cannon-armed fighter aircraft, and license was acquired for the manufacturing of French HS.404 guns. This choice (which proved to be in the French weapon smiths' favour) was not made immediately: the possibility of acquiring a license for the Swiss Oerlikon guns was considered at first. In 1936, a demonstration of a working prototype of the HS.404 was set up in Paris. The demonstrations proved the superiority of the French weapon over the Oerlikon: while the dimensions and weight were similar, the French cannon proved to be capable of faster and more destructive fire. As a result, the French gun was adopted by the Royal Air Force under the designation Hispano Mk.I. Nevertheless, it took a considerable amount of time to acquire permission for purchasing the license, to settle all the necessary formalities, to setup the Hispano company branch in Grahams (the British Manufacturing And Research Company - BMARCO), to translate all the drawings from millimeters to inches, to setup production facilities, to test and fine-tune gun prototypes, and then to eliminate all the difficulties associated with the installation of the guns in aircraft wings.



**Figure 87: HS.404 cannon with 60-round drum magazine**

For this reason, the Hispano guns were not able to play a significant role in the Battle of Britain. Only in 1940 did the British begin to install Hispano cannons on their aircraft - first on their Westland Whirlwind heavy fighters, and later on the Bristol Type 156 Beaufighters (sometimes referred to simply as "Bo"). Thus, Royal Air Force planes found a new, powerful cannon armament at their disposal.

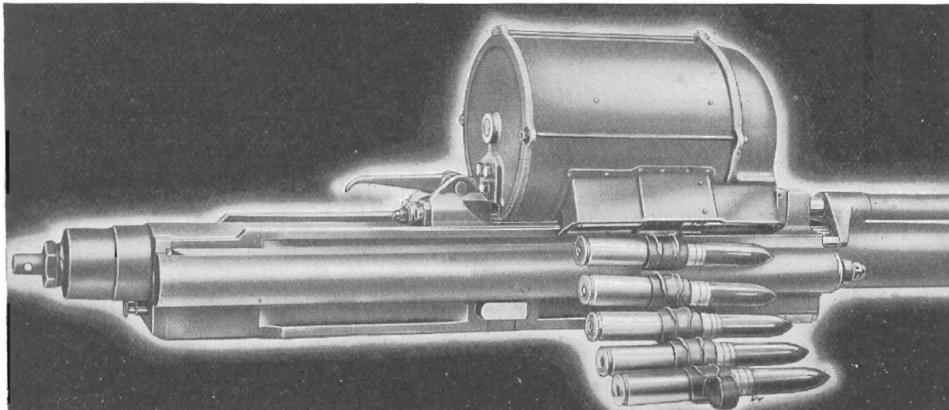
Meanwhile, during the Battle of Britain, it became apparent that batteries of 8 rifle-calibre guns - the traditional armament of fighter aircraft at the time - was completely inadequate, and the main weapon on fighters should be automatic cannons.

Air-to-air combat experience on Beaufighters, which were used in part as night fighters, once again stressed the need for a belt-feed mechanism for automatic cannons. On such fighters, the task of reloading the cannons was delegated to the radar operator, and under conditions of total darkness while in a manoeuvring aircraft, one had to change heavy 60-round drum magazines relying on practically nothing more than touch. Trial attempts were made at installing cannons in the wings of Hurricane and Spitfire fighters, which resulted in several new problems: when performing energetic maneuvers the cannons tended to jam, and worked very unreliably in general. June 1940 saw the participation of the first (and only) squadron, the 19th squadron, flying cannon-equipped Spitfire Mk.IB aircraft. Each plane carried a pair of Hispano Mk.I cannons. The results of this proved to be truly catastrophic - the cannons jammed with such frequency, and oftentimes after the very first shot, that the pilots immediately demanded that their aircraft be replaced with the usual machinegun-equipped models.

The issue stems from the fact that the cannons were initially designed for installation on the engine - fixed to a massive, strong and rigid cylinder crankcase. To even dream of such stability from wing mounts would have been practically impossible. In addition, the guns had to be installed side-by-side in order to make room for the drum magazines inside of the wings, which proved to be yet another reason for failure. Achieving failproof performance of the guns required significant time investment for ironing out these issues, and consequently, the top brass of the British air force began to doubt the feasibility of cannons on fighter aircraft, while the war ministry released specifications for the development of new fighter aircraft equipped with 12 machine guns.

However, the gun design was quickly finalized and the belt-feed mechanism developed by Martin-Backer was implemented into the design. The modified gun came into service, seeing use on aircraft of the Royal Air Force and Navy from 1941 onwards under the designation Hispano Mk.II. Instead of 8 Browning machine guns, 4 such cannons were mounted on Hurricane fighters and on some

modifications of the Spitfire that were designed mainly for tropical and hot climates. Most Spitfire aircraft only saw 2 cannons alongside 4 rifle-caliber machine guns or 2 heavy machineguns.



**Figure 88: Belt-fed Hispano Mk.II cannon**

The ammunition also needed improvements. The fuse of standard high-explosive shells proved to be too sensitive, which meant that they would far too often detonate upon contact with the target aircraft's armor plating, and not in the more vulnerable elements of the airframe, which would have been more desirable. Tests showed that in many cases the full-metal shells which had no explosive charge dealt significantly more damage onto enemy aircraft. In 1941, the new high-explosive shells with a delayed-action fuse were created, as well as high-explosive incendiary projectiles. Full-metal rounds were also used along the HE shells until the development of new armor-piercing incendiary rounds. These new rounds were composed of a body of high-explosive shells filled with an SR379 incendiary component (the composition of which was: aluminum-magnesium alloy - 47%, barium nitrate - 50%, paraffin - 3%), but had no fuse - only a full-metal tip. Starting from 1942 the standard combat loadout for Hispano guns consisted equally of HE and incendiary AP shells, alternating 2 after 2 or 1 after 1.

## Description

The automatic cannon operates under a mixed-type system.

The pressure of powder gases discharged through the hole in the barrel to the piston rod provides the force for unlocking the gate after the shot is fired. The shutter dropping to the rear position is due to pressurized gas to the bottom of the sleeve, like a weapon with blowback. Because of this principle of automation it is not possible to equip the gun with a synchronizer for firing through the propeller.

## Cannon Specifications

1. Caliber .... 20 mm.
2. Total length... 2565 mm (with recoil reducer), 2413.4 mm (with flash hider)
3. Barrel length ... 1708 mm.
4. Gun weight, with front-mount unit... 53.75 kg.
5. Ammunition capacity ... 20x110, practice shells, HE, HE-Incendiary, AP Incendiary.
6. Individual shell weight ... 0.255 kg.
7. Rate of Fire ... 570 - 620 RPM.
8. Muzzle velocity ... 853.4 m/s.
9. Rifling grooves... 9.

The cannons are installed in the wing compartment between the 8th and 9th ribs. The front mount is made on the front edge of the wing and consists of two eccentrics with the help of which gun convergence is regulated. The rear mount allows the gun to take any position, set by the front mount during zeroing. To ensure that the feeder mechanism remains fixed in place during weapon fire, a rod is mounted between the spar and the ammo drum.

The cannon is belt-fed, with the ammo belts coming from a box.

The ammunition compartments are located between ribs 10 and 13 behind the main spar. The compartment can hold 120 rounds; the bottom panel and the top hinged cover are made of a duralumin sheet with a thickness of 10 S.W.G (3.251 mm.). The front wall has a thickness of 6 mm to shield the ammunition. Structurally there are 2 compartments in the detachable part of the wing, but only the frontal compartment is used for housing ammunition. Spent casings are ejected through slits in the skin of the lower surface.

## Ammunition

The cartridge consists of a fuse, projectile, powder charge, the casing and the capsule. For a more durable connection of the projectile with the shell casing, the casing neck is rolled after the shell is inserted. It is also for this purpose that there exists a groove on the belt part of the round. The casing without a flange, extruded with a hole in the bottom under the capsule installation. After installation, the capsule is fixed in place by annular punching. At the capsule joint and the bottom of the shell casing is a purple varnish. On the body of the round is a lead belt made of copper. №253 instant action fuses are present on all rounds, save for the armor piercing rounds (which have steel tips) and practice rounds. Oerlikon type modified fuses (№254 Mark IV) are approved for use as an alternative.

The powder charge used is pyroxylin gunpowder. Tetryl serves as the explosive material for the corresponding ammunition types.

The following ammunition types saw production for the Hispano gun:

**Ball** - Practice shell. It is a hollow shell, the bottom of which is closed off by a disc to prevent the penetration of gas in the shell. Painted in black or blue.

**Tracer** - Tracer round. The body of the shell is fused with a burning composition, which is ignited by the propellant gases. Burning time - 3.5 seconds. Painted black and is marked with the letter T in red, or by a red stripe on the head.

**A.P.** - armor-piercing, used against armored targets and aircraft armor. The shell has no inner content, its sharp tip has a plastic cap. Later modifications of the projectile without the cap and possess inert gear or armor-piercing core. Painted in black, with the nose of the projectile in white.

**A.P./T** (Day/Night) - armor-piercing tracer day / night. Made of armor-piercing steel, without a plastic cap and laced with tracer content for day or night use. Painted in black, with the tip of the projectile in white; the leading belt has a white or green band.

**H.E.I.** - the projectile contains a cartridge of incendiary substances and a cartridge of explosive material. Both are separated by a seal of waxed cloth. Upon impact, the fuse triggers the explosive component, which triggers the incendiary component providing high enough temperatures for igniting fuel. The lower part of the projectile is colored in red, the upper part in dark yellow. Fuse tip is green.

**S.A.P/I** – Semi-armor-piercing incendiary shell. This ammunition type is designed for penetrating armored fuel tanks of target aircraft. The body shell is similar projectile H.E.I. with the cartridge of incendiary material or explosive cartridge and fuse, and a steel projectile nose. Painted in red, the

head of the projectile is painted in white. Penetrative properties of the projectile are inferior to armor-piercing (A.P.) rounds.



Figure 89: Ammunition types

#### **High-explosive, incendiary projectile (H.E.I.).**

Designed to destroy targets by means of fragmentation and explosive force, as well as to ignite gasoline in unarmored fuel tanks. The shell is equipped with a direct action fuse head, which detonates the shell upon impact with even the thinnest obstacle (such as aircraft skin) and at a distance of no more than 10 cm beyond a barrier. Detonation inflicts a ragged hole in the second, and sometimes in the first barrier with a diameter of 40 cm, greatly amplifying the fragmentation effect.

In addition to its strong fragmentation and explosive action, the round is also designed to ignite petrol in fuel tanks. The shell contains 7 grams of tetryl and 4.3 grams of the S.R.379 incendiary compound.

#### **Semi-armor piercing Incendiary (S.A.P/I).**

Intended for use against aircraft, lightly armored and other such targets where an incendiary effect is desirable. High-explosive incendiary shells are used in tandem in order to amplify the effects of this ammo type.

Three versions of this ammunition were produced, Mk.1Z, Mk.2Z and Mk.3Z. The construction of these shells are identical, with the exception of the detonators, which are designed to ignite the incendiary component.

Mk.1Z and Mk.2Z rounds weigh 266 g.

Mk.3Z ammunition weighs about 265 grams and has a standard sleeve and shell. The projectile is a steel hull, the nose section of which has an internal groove for the steel tip. Before installing the tip, R.D.1248 adhesive or R.D.1229 sealant is applied on the groove and the adjacent surfaces. The tip is fixed in place by center-punching after the projectile assembly. The bottom of the shell is welded to the body. The interior of the shell is filled with incendiary composition and the plastic housing of the detonator. 2 discs, one made of tinned brass and the other of cloth, are located between the detonator and the tip. A ZY detonator is installed in the shell, weighing approximately 0.39 grams. This detonator is similar to the one installed in the fuse head of the D.A. N9917 Mk.1.

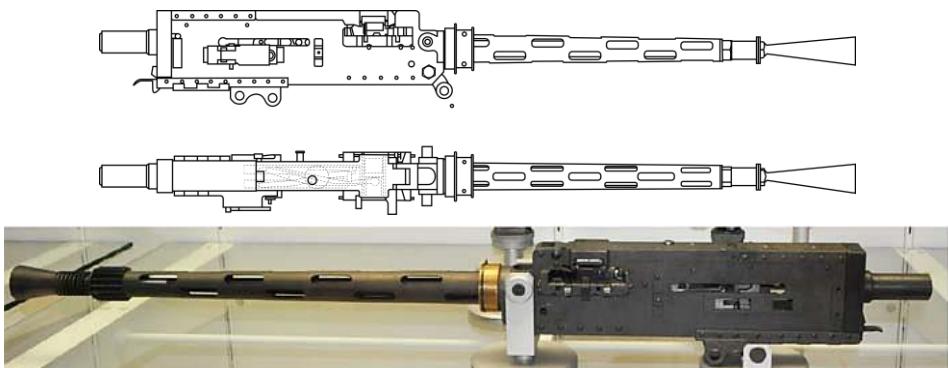
The round's incendiary composition is comprised of three cartridges of the incendiary compound S.R.379, each weighing about 3 grams, separated from the detonator by a paper disc.

All three versions are capable of piercing armor plates with a thickness of 20 mm at a distance of 200 meters at an angle of 90 °, while igniting the petrol located behind the armor.

## "COLT BROWNING" Machine gun

### Development History

By the mid-30s, the RAF leadership suddenly realized that in the realm of aircraft-mounted small arms English technology was hopelessly behind the rest of the major powers. Unsurprisingly, thus began a panicked search for an adequate replacement for the machinegun stock left over from the 10-20-ies.



**Figure 90: "Browning 0.303" Mark II" Machineguns**

The mid-20s saw the first shipments of the new American-designed Browning M1919 machineguns. The efforts of the American engineers are deserving of praise; hoping to reach the British market, the

Colt designers, with great difficulty, were able to adapt their machine gun design to the English .303 round. The issue was that the regular rimless American .30-06 Springfield munition differed too greatly from the English rimmed cartridge, and a thorough rework of the extractor was required in order to ensure the safe disposal of empty cartridges from the chamber. During the process of this adaptation in 1925, Armstrong Whitworth & Co. Ltd. purchased six guns for prototype evaluation. Slow tests of the Browning M1919 were held in England until 1931. When the news came from the United States about the completion of an improved aircraft version of the .30 Browning M2-AN, an additional four units were purchased immediately and arrived just in time.

In 1934, Great Britain held competitive testing of the new prototypes for aircraft machineguns, with the main contenders being the Browning .30 M2 AN, M1919, the English Vickers-J (Vickers Central Action) - the last of the Vickers machinegun family, with technical information being difficult to come by, as the only known fact about it was that its maximum rate of fire could reach 1250RPM. Also participating were the French Darne, Dutch Madsen and Hungarian Gebauer Motorgeppuska 1926/31.Minta GKM machineguns. The Hungarian Gebauer was deemed to be too complex technologically despite its superior 2000RPM, and the French Darne was deemed too unreliable. The technical characteristics of the Vickers-J failed to make any impression on the testers. The Dutch Madsen was also rejected, as it was deemed too costly to produce.

2 models made it to the final stages: the American Browning M2 AN and the Vickers-K. The .30 caliber Browning M2 AN light machine gun saw significant modifications to the original prototype, the M1919 HMG, which was meant for infantry use. Not only was the calibre changed from 7.62mm to the English .303, but the gun also saw significant modifications to its automatic fire mechanism. The testing process showed that the British-made cartridges equipped with cordite striking a heated chamber after a continuous burst of 100 shots had a tendency to spontaneously ignite. It was an unpleasant side-effect of all automatic firing mechanisms operating on the basis of the locked breech system: that is, when in between bursts, the next cartridge loads into the chamber and locked the breech. But in the case of American cartridges that used powdered pyroxylin (less sensitive to heat,) spontaneous ignition was a rare occurrence. When using the same principle of an open breech, the round enters the chamber only upon depressing the trigger. Because of the British-made cartridges, the gun had to be readapted for operation under the open breech system. At the same time, due to the introduction of a delayed impact mechanism into construction, designers managed to retain the machine gun's ability for synchronized fire, which has always been a problem with open breech systems. However, despite all efforts, Browning managed to finish its English version only in 1939. Nevertheless, spontaneous ignition remained a frequent occurrence when using incendiary ammunitions with the reworked gun.

### **History of the .303 cartridge**

The history of this famous round, officially entered into active service in 20 February of 1889, began when the English army adopted the Lee-Metford rifle in 1888. The prototype for this round was the 7.5mm Swedish "Schmidt-Rubin" with a protruding rim.

The cartridge was widespread in Canada and other parts of the British Empire. Though the army planned to replace it with a more modern round in 1908, it remained in service in the UK until 1957, when it was replaced by the 7.62x51mm NATO cartridge.

The cartridge was equipped with a smoked powder until 1892, and until 1902, the cartridge had a bullet with a spherical apex, and a copper-nickel alloy sheath.

The 1st Hague Conference in 1899 saw the adoption of the "Declaration concerning expanding bullets," resulting in bullets being designed with pointed tips and full-metal jackets - the so-called Spitzer type.

In 1910, the spherical bullets were finally replaced by Spitzer types; the coating material was also changed, with steel coated with red brass being used in production. The cartridge was manufactured in many countries and is still widely used in hunting.

During the First World War, British factories alone produced 7,000,000,000 .303 rounds.

In addition to colour-coding, model numbers/codes were also engraved on the bottom of the shell casng. All bullets of classifications I to VI had a spherical apex: they are extremely rare and are not provided in the table. Type II, III, IV and V bullets belong to the expanding munitions type, and were developed by English army captain Berie Clay (who served in India in the Dumdum Arsenal.)

Type VII bullets were basic to use. The relatively low weight of these bullets despite their significant length was achieved by using a core of aluminum or bakelite in the bullet tip, with the remaining parts filled with lead. This design better stabilizes the bullet in flight and amplifies the tumbling effect upon striking the target, maximizing stopping power. The bullet had a nominal muzzle velocity of 2,440 feet per second (743.7 m/s) and the rotation velocity was about 175 800 rpm. Flight speed and rotation speed significantly decreased, but even past 800 meters the bullet speed remained supersonic. Bullets flying past could be clearly heard.

At ranges over 300 yards (274.3 meters) the trajectory of tracer rounds differed significantly from the trajectory of heavy rounds - it rapidly lost altitude. Due to this, pilots who would correct their fire based on the tracers would often miss.

The deficit of special munitions led to the widespread use of conventional ammunition. Machineguns were loaded with belts filled with conventional, armor-piercing, incendiary, tracer and incendiary ammunition. until the production of special cartridges sped up. By 1942 standard loadouts were already equipped with armor-piercing and incendiary (B Mk.VI) cartridges. The cartridges in the belt were usually of the same type. To remind the pilot of depleting ammunition, 5 tracer rounds were placed before the last 50 rounds.

A one-second volley of 4 machine guns had a burst mass of 900 grams at a rate of 20 rounds per second and muzzle velocity of about 740 m/s. The guns had ammunition enough for 13 seconds of continuous fire.

During the Royal Air Force' testing of armor piercing .303 and 7.92mm (German) rounds, it was discovered that both ammunition types had similar problems with penetration. The tests were carried out on the rear section fuselage of a Blenheim bomber at a distance of 200 yards (180 meters.) The armor protection of the rear gunner was a steel sheet with 4 mm thickness. The plate was at an angle of 60° to the line of fire. The results were disappointing. Only 33% of the discharged bullets managed to reach the armor plates, the other bullets were scattered or even got stuck in the design elements. Only 6% of the bullets pierced the armor. Incidentally, the results of the German munitions were much worse, placing at 23% and 1% respectively.

The characteristics of the incendiary ammunition are also not much different. Test fire against the sealed fuel tanks of a Blenheim bomber at a distance of 200 yards (180 meters) from behind showed that the ignition capabilities of the Buckingham B Mk.IV incendiary tracer cartridge were equal between both types of ammunition. The tank was ignited by one of the 10 hits.

The B. Mk VI De Wilde Incendiary cartridge (which was named after a Belgian inventor, but was in fact completely redesigned by Major C. Aubrey Dixon), which contained 0.5 grams of the incendiary composition SR365 (containing a mixture of barium nitrate, which was ignited on target impact) proved to be twice as effective, requiring only one hit out of five to ignite fuel.



Figure 91: B. Mk VI "De Wilde" Incendiary Round

Production of the De Wilde rounds began in June 1940 and saw field testing during the evacuation of Dunkirk. Pilots liked the increased potency of the rounds, coupled with visual confirmation of hits on target.

### Description

The machine gun's operation is based on the principle of using the recoil with short barrel movements. Each instance of recoil moves the barrel backwards by a short distance. This movement unlocks the gate, knocking it backwards, while the return spring pushes it back. During this backward movement the breech extracts the spent case from the chamber as well the next the next cartridge from the belt. Then, the spring pushes the breech and barrel back into position, chambering the next round, locking the barrel and readying the gun for the next shot.

### Technical characteristics.

1. Caliber .... 0.303 inches.
2. Total length ... 3 ft 8.5 in (1130 mm) (with flash hider)
3. Barrel length ... 2 ft. (609.6 mm).
4. Weight ... 21 lb 14 oz (9.922 kg).
5. Ammunition ... All types: Mk. VII S.A.A.
6. Cartridge weight ... 22.9 ~ 25.45g.
7. Loading mechanism ... Belt-fed.
8. Rate of fire... 1150 RPM.
9. Muzzle velocity ... 743.7 m/s.
10. Barrel grooves... 5.
11. Ammo capacity ... 250 rounds per gun.

The machine guns are mounted in the wing compartments between ribs 13 and 14, 16 and 17 respectively.

Gun mounts allow for adjustments to the vertical and horizontal convergence.

The guns are belt-fed, with the belt coming from a box. The boxes are installed in bays between the 14th and 16th ribs. The front compartment houses the ammo box for the internal gun, while the rear houses the ammo of the outer gun. Access to the compartments is by an easily removable hatch on the lower surface of the wing.

Spent belts and cartridge cases are ejected through slits in the skin of the lower surface.

### Ammo Types

**0.303 Ball Mk. VII** - cartridge with a heavy bullet. Bullet consists of a steel plated nickel silver shell and core (core nose of aluminum, the rest of the lead). Brass sleeve. The primer consists of a red-brass cap, percussion composition and a foil coating with lacquer. The projectile is secured to the casing by circular-punching. Primer composed of nitroglycerin-based tubular non-graphite gunpowder. Used against enemy infantry and aircraft.

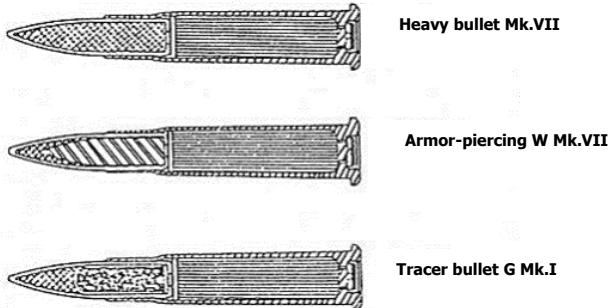
**0.303 Armor Piercing W Mk. VII** - cartridge with armor-piercing bullet. Bullet consists of a steel plated nickel silver sheath and a lead jacket and armor-piercing steel core. Brass sleeve. The primer composition with a percussion composition of mercury fulminate and potassium chlorate. Propellant composed of nitroglycerin plate powder. Used against lightly armored vehicles, armored cars, trains, etc.

**0.303 Tracer G Mk. I** - cartridge with a tracer round. Bullet consists of a steel plated nickel silver shell red-brass cup with tracer composition of white fire and lead core. Brass sleeve. The primer consists of a red-brass cap, percussion composition, foil coating, lacquered outside. It is secured in the case by circular punching. The propellant is tubular nitroglycerin powder (cordite).

Used for fire correction. In daytime, the tracer is visible only as a small bright spot from the bottom of the bullet.

**0.303 Incendiary B Mk. IV** - cartridge with an incendiary (phosphorous) round. The bullet is composed of nickel silver plated steel shell with an opening on the pointed end, filled with quick-melting alloy, cupronickel cylinder with a lead core and grooves on the surface for the passage of phosphorus that fills the tip of the bullet. Brass casing. The primer consists of a red-brass cap, percussion composition, foil coating, lacquered outside. It is secured to the casing by circular punching. Propellant - smokeless pyroxylin coated plate powder.

Used to ignite flammable materials and parts such as fuel tanks, etc.



**Figure 92: .303 rounds, cross section**

These cartridges were improved throughout the war and saw a few modifications. The very last modification of the G Mk VIII tracer cartridge was put into service in 1945; of the W Mk 1Z armor-piercing rounds in 1945; and the B Mk VII incendiary rounds in 1942.

#### **General Characteristics**

Total length – 76.7mm

Casing length – 56.1mm

Bullet diameter – 7.9mm

Diameter from cartridge neck – 8.54 mm

Case diameter, from rim – 11.65 mm

Rim diameter – 13.44 mm

Bullet weight - 11.13 g onwards

Cartridge weight – 22.9 ~ 25.45 g.

Muzzle velocity - approx. 743.7 m/s

#### Cartridge colour coding

Bullet model	Bottom Markings	Capsule Colour	Notes
Mark VII (Z)	VII	Violet	1910 onwards
Mark VIII Z	--	Violet	For machineguns
G Mark I (Z)	G	Red	Tracer, 500m
PG Mark I (Z)	PGI	--	For training use. Cyan paint on base
G Mark II	G	Red	Tracer, 900m
G Mark III	G	Red	Tracer, 750m. Naval use
G Mark IV (Z)	G	Red	Daytime tracer, 500m. Airforce use. White tip.
G Mark V (Z)	G	Red	Night tracer, 500m. Airforce use. White tip.
G Mark VI (VII, VIII) (Z)	G	Red	Similar to the G Mark II, used together with the G Mark IV. Tracer, 500m.
W Mark I (Z)	W	Green	Armor piercing, green tip
B Mark III	B	Blue	Dull-tipped incendiary round, Buckingham type
B Mark IV(Z)	--	--	Staged incendiary ammunition for use against observation balloons
B Mark VI	--	--	Incendiary ammunition, steel ball on tip, threaded plug on base
B Mark VII (Z)	--	--	Incendiary, narrowed to the base
O Mark I (II)	O	Black	For target designation. Black tip
O Mark III	O	Black	Same as above. Bullet charged from base(?)

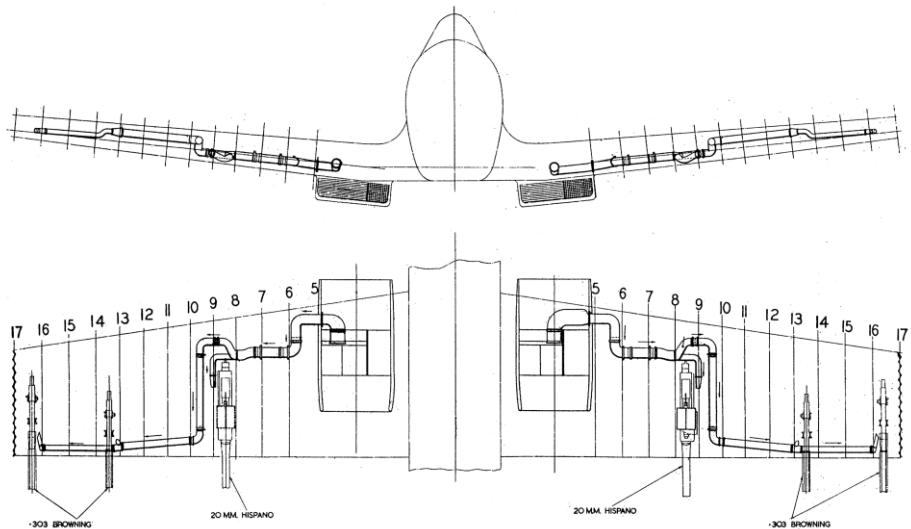
The letter Z in cartridge designations indicate that smokeless pyroxyle graphite plate-powder is used instead of cordite.



**Figure 93: Cordite strands..**

## Weapons heating

Often, on early versions of aircraft, weapons malfunctioned due to frozen lubricant on the moving parts. To ensure trouble-free operation of weapons, aircraft began to use heating systems for their weaponry. Hot air for heating is taken past the cooling radiators is sent to the machine-gun compartments by pipelines. The heating system is automated and requires no input from the pilot.



**Figure 94: Weapons heating system**

## Bombs

Some aircraft were modified to be able to mount bombs under the detachable wing sections between ribs 8 and 10. Each hardpoint is fastened to the 9th rib into two nodes using the quick-removable points. Front mount of the hardpoint was located behind the main spar cap, with the rear unit at a distance of 9 inches from the frontal one. On the left side of the cockpit by the 10th bulkhead are the fuse control units. On the cockpit left side by the 10th partition is the control set for the bomb fuses. Bomb release is performed by means of a button at the end of the throttle grip. There is also a mechanical release on the left side of the throttle.

## Aiming

### Gunsight – General Characteristics

A Mk.II (8B / 2361) aircraft collimator sight is installed on the dashboard of the aircraft. It consists of two parts:

- Optical viewfinder (collimator)
- rangefinder

The optical system consists of the reticle, a lens, a reflector, and a light filter. The reticle has a ring, as well as a point at the center of two short vertical and two long horizontal strokes. The reticle is etched on an opaque plane-layer lens. The bottom of the reticle is illuminated by an electric lightbulb. The rays pass through the lens reticle and fall on the reflector glass, which is installed at an angle of 45 ° to the optical axis of the system. The reflector reflects the rays from the light source at an angle of 90 ° in the direction of the observer, who sees the image of the glowing reticle as if it was focused at infinity.

The gunsight rangefinder consists of two cams, the horizontal lines of the reticle, two scales and two handwheels.

The rangefinder mechanism provides a change in the interval between the visible image of the horizontal lines of the gunsight reticle. This interval is variable and is the basis for measuring the distance to the target. The value of the interval between the lines of the visible image of the sight grid depends on the angle of rotation of the range handwheel (upper) and from the target base handwheel (lower). Rotate the upper handwheel manipulates the upper scale, called the range scale, while the lower hand manipulates the lower scale, called the base scale (target size). The range scale is calibrated in hundreds of yards, and the base scale - in feet.



Range scale						
In hundreds of yards	1	2	3	4	5	6
<b>Yards</b>	100	200	300	400	500	600
<b>Meters</b>	91,4	182,8	274,2	365,6	457	548,4

Base scale						
Feet	40	50	60	70	80	90
<b>Meters</b>	12,2	15,2	18,3	21,3	24,4	27,4
						30,5

## Gunsight – Specifications

1. Reticle ring diameter – angular values:  
 - In degrees                     $6^\circ 44'$   
 - In thousandths              118
2. Reticle rings radius - angular values:  
 - In degrees                     $3^\circ 22'$   
 - In thousandths              59
3. When shooting, this ring corresponds for allowance at an aspect of 2/4 and target speed of 322 km/h.
4. At target aspect of 1/4, target speed should be 644 km/h

## Aiming method adopted by the Air Force in England

In the RAF, lead angle is determined by the magnitude of the angular velocity of the target relative to the aircraft that is opening fire. This speed is sometimes called the transverse velocity.

Acquisition of such a firing solution requires the pilot to determine the target lateral speed by eye. By using the reticle ring as a yardstick, the shooter may take into account the relative lead angle at any transverse speed of the target. Thus it is necessary to know the aspect and direction of the target's relative increase. We must remember that, taking into account the English target leading technique, the target relative direction line should be passing through the reticle center, and not the continuation of the longitudinal axis of the aircraft.

## Aiming method adopted by the USSR Red Air Force

The Mk.II sight has one ring with a radius of 59 thousandths. Soviet Air Force sights have 2 rings:

- large, with a radius of 105 thousandths
- small, with a radius of 70 thousandths

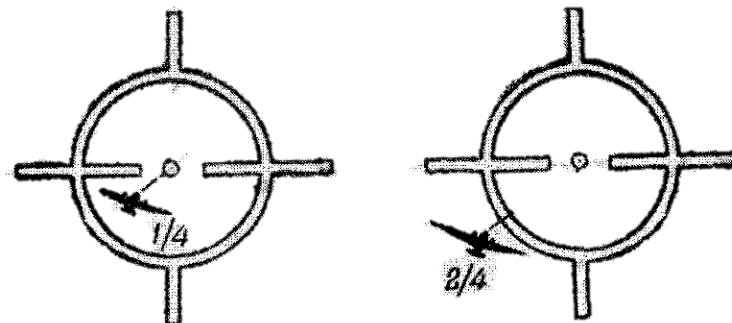
A 2/4 aspect and the following target speeds are taken into consideration using the rings.

- For the large ring, target speed of 600 km/h
- For the small ring, 400 km/h

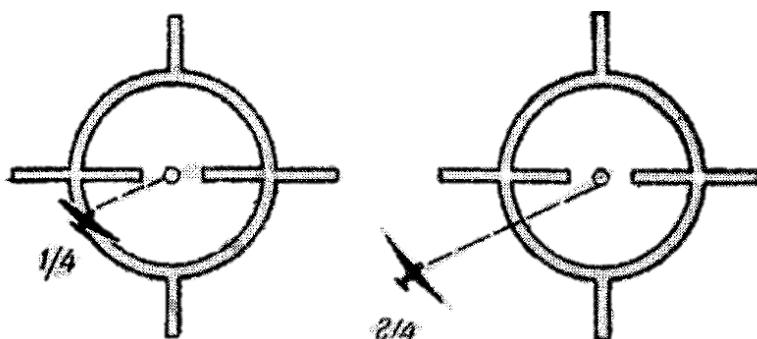
The large ring is used for targeting enemy fighters, while the smaller ring is used for enemy bombers.

A comparison of these data shows that weapon fire using the Mk.II sight against enemy bombers at an aspect of 2/4, we must take lead for 1/7 greater than the radius of the ring; when firing at enemy fighters with a 1/4 aspect, we must take lead for 1/8 less than the radius of the ring.

In all cases, the continuation of the longitudinal axis of the target aircraft must pass through the center of the ring.



**Figure 95: Aiming at a bomber with an airspeed of 400kph. Different aspects**



**Figure 96:  
Aiming at fighter aircraft with a speed of 600kph. Different aspects**

### Determining target distance

The rangefinder device assists the pilot in determining the correct range from which he may begin to open fire. Distance is not measured during fire. Such use of the rangefinder allows the pilot to enter a correction on the gunsight using the range scale and the scale base (target size) knobs either before flight or during approach on target. In the process of rapprochement with the purpose of the pilot follows the apparent target size. When target size becomes equal to the space between the horizontal lines of the reticle, target range will be equal to the set target distance. At this point, the pilot should begin to open fire, taking into account target lead in accordance with the target aspect and aircraft type.

## Testing the gunsight

1. Ensure that the gunsight is fixed in place and is not loose.
2. Turn on the gunsight backlight tumbler. Enter the rheostat and check gunsight illumination.
3. Set the propeller blades with a cross vertically to match the scratches on the spinner and hood. Check alignment of the optical axis of the sight with the cross on the propeller blades.
4. Remove the rheostat and turn off gunsight illumination.

## Changing the lightbulbs

To replace the bulb, press the button and remove the bulb holder. The lamp, having a cartridge with a bayonet lock, is removed and replaced with a new one. The bulb should be inserted with the amalgamated part down

# RADIO COMMUNICATIONS



# RADIO COMMANDS

Two modes of conducting radio communication are present in the simulator:

- Simplified
- Realistic

The player may select one of these modes in the settings menu of the game by checking or unchecking the box for «Easy Communication» under the GAMEPLAY tab. If this option is disabled, in-game radio communication will be set to realistic by default. The selected mode also determines the keybindings used to bring down the radio menu.

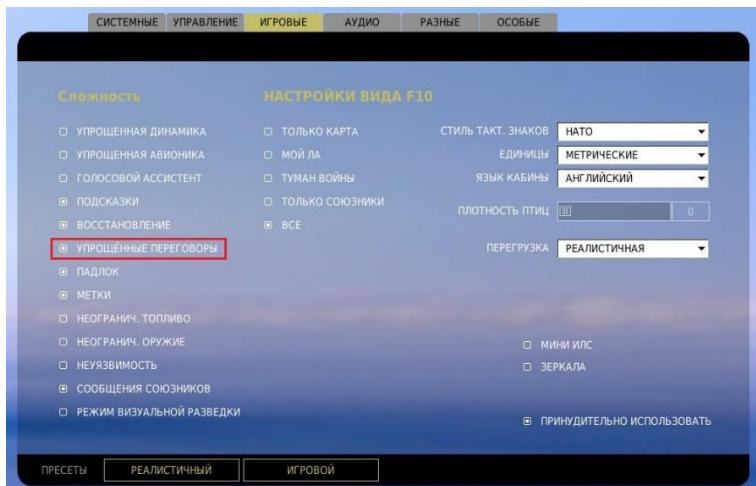


Figure 97: GAMEPLAY tab in the settings menu

All available radio commands and messages are transmitted and received through the onboard radio station, which must be set to a common frequency for it to work. If this requirement is not met, then the intended recipient will not be able to receive the transmission.

In real life, VHF radio communication is stable only within line of sight. The simulator also has built-in algorithms for calculating distance and the radio shadowing caused by the terrain horizon. A necessary condition for the transmission of messages or commands is line of sight to the recipient as well as a distance of not more than 100~150 km. In such cases where the recipient is located beyond this distance, or line of sight is obscured by terrain, the message will not be received. Because the TR1196 radio is limited to 4 preset radio channels, you can maintain radio communication only with contacts whose radios are tuned to your frequency. The frequencies of the radio channels are set by the mission creator in the mission editor.

## Simplified Radio Communication

The radio communications window is accessed by a press of the **[\\]** backslash key (this is for US keyboards, other language keyboards may vary). After the command selection the radio or interphone will be selected (if required) and tuned (if required) automatically. The **[\\]** key will close radio command menu, if open.

When the radio menu is displayed, recipients are color-coded as follows:

- Recipients on which at least one of the radios is tuned to are colored white.
- Recipients on which at least one of the radios can be tuned to but is not currently on the correct frequency are colored gray.
- Recipients that cannot be contacted due to range or terrain masking / earth curvature are colored black.

Each will also have their modulation / frequency listed. When you select a recipient, the appropriate radio will automatically be tuned to communicate with the selected recipient.

When Easy Communications mode is enabled, the following 'quick' command shortcuts are also available:

- **[LWIN + U]** Request AWACS vector to home plate.
- **[LWIN + G]** Command flight to attack ground targets.
- **[LWIN + D]** Command flight to attack air defense targets.
- **[LWIN + W]** Command flight to cover me.
- **[LWIN + E]** Command flight to proceed with the mission and return to base.
- **[LWIN + R]** Command flight to proceed with the mission and rejoin.
- **[LWIN + T]** Command flight to open/close the formation.
- **[LWIN + Y]** Command flight to rejoin the formation.

## Realistic Radio Communication

When playing with realistic radio comms enabled, access to the radio menu is done by pushing the PTT (Push To Talk) button **[RAlt + \\]** located on the throttle.

When recipients are displayed, there is no color-coding of availability and no listing of their modulation / frequency. This is the more realistic play mode and requires you to know the correct modulation / frequencies for each recipient and you must manually enter the frequencies on the correct radio.

## Radio Communications Window

Top Level Recipient List:

If using "Easy Communications", recipients not present in the mission will not be listed.

**F1. Wingman...**

**F2. Flight...**

**F3. Second Element...**

**F5. ATCs...**

**F8. Ground Crew...****F10. Other...****F12. Exit**

Hotkeys will also be available to directly issue any command in the structure. These can be found in Input Options.

To exit radio communications, you can also press the ESC key.

## **F1 Wingman**

Upon selecting F1 Wingman from the main radio communications window, you have the option to select the basic type of message you wish to send to your number 2 wingman. These are:

**F1. Navigation...****F2. Engage...****F3. Engage with...****F4. Maneuvers...****F5. Rejoin Formation****F11. Previous Menu****F12. Exit**

### **F1 Navigation...**

The Navigation options allow you to direct where your wingman will fly to.

**F1. Anchor Here.** Your wingman will orbit at its current location until you issue a Rejoin command.

**F2. Return to base.** Your wingman will return to and land at the airbase designated in the flight plan.

**F11. Previous Menu****F12. Exit**

## **F2 Engage...**

The Engage options allow you to direct your wingman to attack a specific type of target. After issuing the order, the wingman will attempt to locate the specified target type and attack it.

**F1. Engage Ground Targets.** Wingman will attack any enemy ground unit it can locate.

**F2. Engage Armor.** Wingman will attack any tanks, infantry fighting vehicles, and armored personnel carriers it can locate.

**F3. Engage Artillery.** Wingman will attack any tube artillery or multiple rocket launchers that it can locate.

**F4. Engage Air Defenses.** Wingman will attack any enemy anti-aircraft artillery and surface to air missile units that it can locate.

**F5. Engage Utility Vehicles.** Wingman will attack all supply, transport, fuel, power generation, command and control, and engineering units it can locate.

**F6. Engage Infantry.** Wingman will attack hostile infantry units. Note that the infantry units are very difficult to detect unless they are moving or firing weapons.

**F7. Engage Ships.** Wingman will engage enemy surface combatants. Note that most naval targets are heavily armed and pose a heavy threat to the Spitfire.

**F8. Engage Bandits.** Wingman will engage any enemy fixed-wing and rotary-wing aircraft it can locate.

**F11. Previous Menu**

**F12. Exit**

## F3 Engage With...

Whereas the F2 Engage command allows you to give basic orders for your wingman to attack a target type, the F3 Engage With set of commands not only allows you to determine target type, but also the direction of attack and what weapon type to use. This is done in a tiered manner by first selecting target type, then weapon type, and finally the attack heading. The wingman will then attempt to locate targets of the specified type and attack them according to your specified weapon and attacking heading. While the F2 Engage options are fast to issue, the F3 Engage With options provide much greater control.

**Target Type.** These options mirror those of the F2 Engage orders and allow you to determine the type of ground target you want your wingman to engage.

**F1. Engage Ground Targets.** Wingman will attack any enemy ground unit it can locate.

**F2. Engage Armor.** Wingman will attack any tanks, infantry fighting vehicles, and armored personnel carriers it can locate.

**F3. Engage Artillery.** Wingman will attack any tube artillery or multiple rocket launchers that it can locate.

**F4. Engage Air Defenses.** Wingman will attack enemy anti-aircraft artillery and surface to air missile units that it can locate.

**F5. Engage Utility Vehicles.** Wingman will attack all supply, transport, fuel, power generation, command and control, and engineering units it can locate.

**F6. Engage Infantry.** Wingman will attack hostile infantry units. Note that the infantry units are very difficult to detect unless they are moving or firing weapons.

**F7. Engage Ships.** Wingman will engage enemy surface combatants. Note that most naval targets are heavily armed and pose a heavy threat to the Spitfire.

**Weapon Type.** Once you have selected the target type, you will be given a list of weapon types that you want your wingman to engage the target with. These include:

**F2. Unguided Bomb...**

**F4. Rocket...**

**F6. Gun...**

**Attack Heading.** After you've selected the weapon type for your wingman to use, the third and final step is to determine the attack heading that you wish your wingman to use. This can be useful to help it avoid overflying enemy defenses. The options include:

**F1. Default.** Wingman will use the most direct heading to attack the target.

**F2. North.** Wingman will attack the target from south to north.

**F3. South.** Wingman will attack the target from north to south.

**F4. East.** Wingman will attack the target from west to east.

**F5. West.** Wingman will attack the target from east to west.

## F4 Maneuvers...

Although your wingman will generally do a good job of knowing when and how to maneuver, there may be times when you want to give him/her a very specific maneuvering order. This could be in response to a threat (fire from enemy anti-air defences or fighter aircraft) or to better set up an attack.

- F1. Break Right.** This command will order your wingman to make a maximum-G break to the right.
- F2. Break Left.** This command will order your wingman to make a maximum-G break to the left.
- F3. Break High.** This command will order your wingman to make a maximum-G break high.
- F4. Break Low.** This command will order your wingman to make a maximum-G break low.
- F7. Clear Right.** Your wingman will perform a 360-degree turn to the right of the current flight path while searching for targets.
- F8. Clear Left.** Your wingman will perform a 360-degree turn to the left of the current flight path while searching for targets.
- F9. Pump.** Your wingman will perform a 180-degree turn from its current heading and fly 18km. Once reached, it will turn 180-degrees back to the original heading.

## F5 Rejoin Formation

Issuing this command will instruct your wingman to cease its current task and rejoin formation with you.

### F2 Flight

Upon selecting F2 Flight from the main radio communications window, you have the option to select the basic type of message you wish to send. These are:

- F1. Navigation...**
- F2. Engage...**
- F3. Engage with...**
- F4. Maneuvers...**
- F5. Formation**
- F6. Rejoin Formation**
- F11. Previous Menu**
- F12. Exit**

## F1 Navigation...

The Navigation options allow you to direct your flight where to fly to.

- F1. Anchor Here**
- F2. Return to base**
- F11. Previous Menu**

**F12. Exit**

These commands mirror those of the Wingman Navigation commands, but apply to all flight members.

## F2 Engage...

The Engage options allow you to direct your flight to attack a specific type of target. After issuing the order, the flight will attempt to locate the specified target type and attack it.

**F1. Engage Ground Target****F2. Engage Armor****F3. Engage Artillery****F4. Engage Air Defenses****F5. Engage Utility Vehicles****F6. Engage Infantry****F7. Engage Ships****F8. Engage Bandits****F11. Previous Menu****F12. Exit**

These commands mirror those of the Wingman Navigation commands, but apply to all flight members.

## F3 Engage With...

These commands mirror those of the Wingman Engage With commands, but apply to all flight members. These commands work the same as the Wingman Engage With Commands described above.

## F4 Maneuvers...

**F1. Break Right****F2. Break Left****F3. Break High****F4. Break Low****F7. Clear Right****F8. Clear Left****F9. Pump****F11. Previous Menu****F12. Exit**

These commands mirror those of the Wingman Maneuvers commands, but apply to all flight members.

## F5 Formation

From the Formation menu, you can select the formation that the flight will fly in relation to you as the flight leader.

- F1. Go Line Abreast**
- F2. Go Trail**
- F3. Go Wedge**
- F4. Go Echelon Right**
- F5. Go Echelon Left**
- F6. Go Finger Four**
- F7. Go Spread Four**
- F8. Open Formation**
- F9. Close Formation**
- F11. Previous Menu**
- F12. Exit**

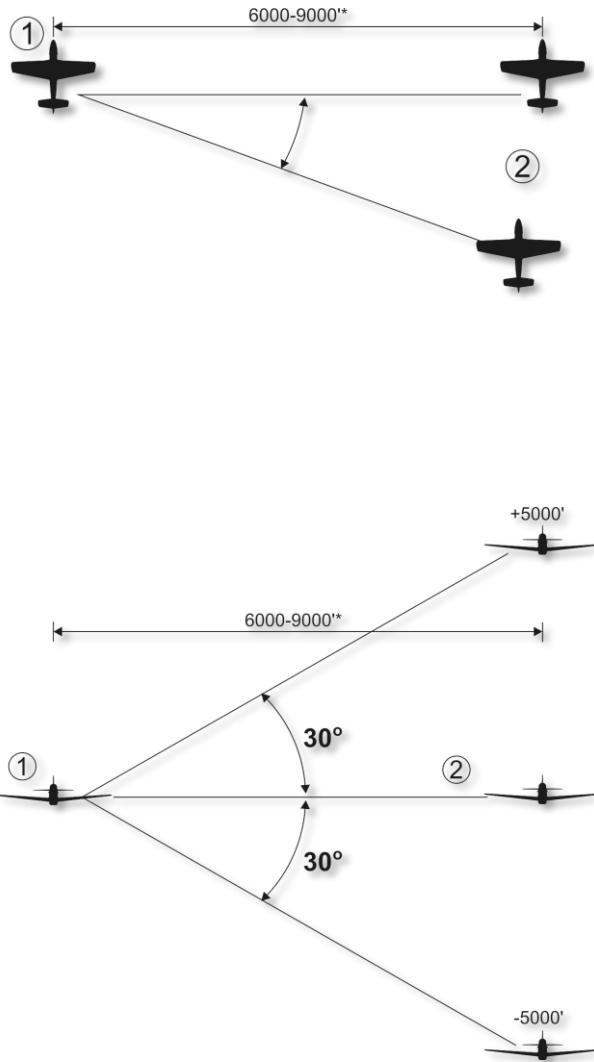


Figure 98: F1 Go Line Abreast



**Figure 99: F2 Go Trail**

Position may be modified within a 1500-4000m envelope by flight lead.

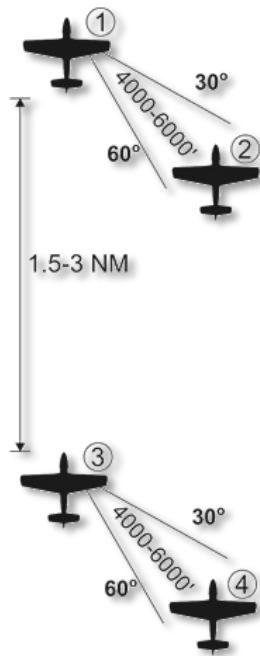
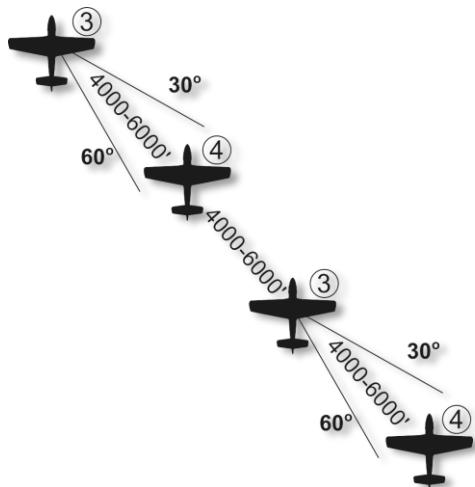
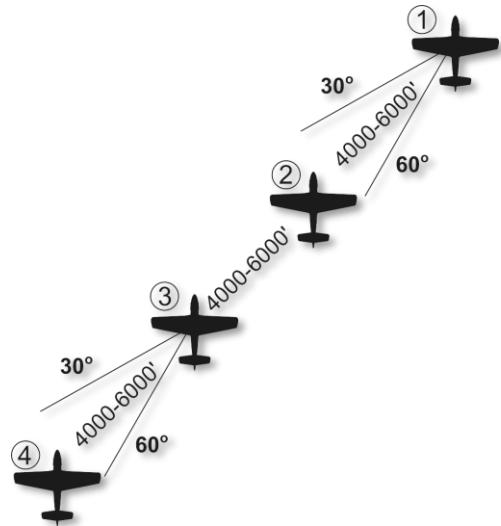
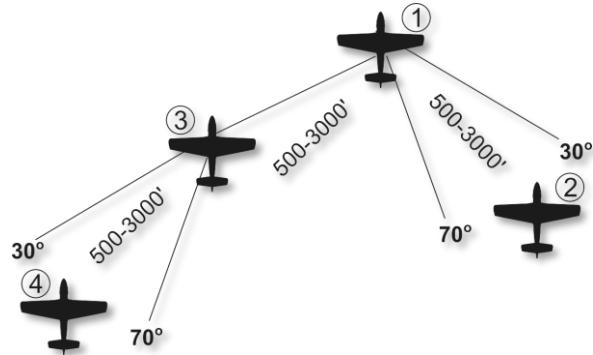


Figure 100: F3 Go Wedge



**Figure 101: F4 Go Echelon Right****Figure 102: F5 Go Echelon Left****Figure 103: F6 Go Finger Four**

Position may be modified within a 1500-4000m envelope by flight lead.

**Figure 104: F7 Go Spread Four**

Position may be modified within a 1500-4000m envelope by flight lead.

**F9. Close formation.** Decrease the distance between each aircraft in the current formation.

## F6 Rejoin Formation

Issuing this command will instruct your flight to cease their current task and rejoin formation with you.

## F3 Second Element

Upon selecting F3 Second Element from the main radio communications window, you have the option to select the basic type of message you wish to send to the second element of your flight. The second element consists of flight members 3 and 4 with number 3 being the element lead. When issuing a command to Second Element, number 3 and 4 carry out the order jointly. These commands are:

- F1. Navigation...**
- F2. Engage...**
- F3. Engage with...**
- F4. Maneuvers...**
- F5. Rejoin Formation**
- F6. Out**
- F11. Previous Menu**
- F12. Exit**

### F1 Navigation...

The Navigation options allow you to direct your second element where to fly to.

- F1. Anchor Here**
- F2. Return to base**
- F11. Previous Menu**
- F12. Exit**

These commands mirror those of the Wingman Navigation commands, but apply to the second element.

## F2 Engage...

The Engage options allow you to direct your second element to attack a specific type of target. After issuing the order, the wingman will attempt to locate the specified target type and attack it.

- F1. Engage Ground Target**
- F2. Engage Armor**
- F3. Engage Artillery**
- F4. Engage Air Defenses**
- F5. Engage Utility Vehicles**
- F6. Engage Infantry**
- F7. Engage Ships**
- F8. Engage Bandits**
- F11. Previous Menu**
- F12. Exit**

These commands mirror those of the Wingman Maneuvers commands, but apply to the second element.

## F3 Engage with...

These commands mirror those of the Wingman Maneuvers commands, but apply to the second element.

## F4 Maneuvers...

Although your second element will generally do a good job of knowing when and how to maneuver, there may be times when you want to give him/her a very specific maneuvering order. This could be in response to a threat like an incoming SAM, or to better set up an attack.

- F1. Break Right**
- F2. Break Left**
- F3. Break High**
- F4. Break Low**
- F7. Clear Right**
- F8. Clear Left**
- F9. Pump**
- F11. Previous Menu**
- F12. Exit**

These commands mirror those of the Wingman Maneuvers commands, but apply to the second element.

## F5 Rejoin Formation

Issuing this command will instruct your second element to cease its current task and rejoin formation with you.

## Flight Member Responses

After sending a radio message to any of your flight members, you will have one of two responses:

**Flight number of responder (2, 3, or 4), acknowledged.** When a flight member will carry out the order, it will respond with its flight number and add "acknowledged."

**(Flight member number) unable.** When a flight member cannot carry out the order, it will respond with its flight number following by "unable". For example: "2, unable"

## F5 Air Traffic Controller (ATC)

This group of radio commands relating to communication and simultaneous action with the Air Traffic Controller (ATC) includes a menu for requests for permission for engine startup, taxiing, takeoff and return to base.

The menu is called down by using the following keypresses: **[\\] Commands [F5] ATC...**

The Air Traffic Control (ATC) system of this simulation is context sensitive to the location of your aircraft: on the parking ramp or runway/airborne. A necessary condition for the functioning of the ATC is the presence of certain surface facilities that are associated with it. For example, in order to transmit a response to player requests, the airfield control tower must be undamaged.

### Parking Ramp Start

Before you can communicate with ATC/Ground Control to get permission to start your engine, you first need to have your VHF AM radio up and running.

With the radio now operating, press **[\\]** or **[RALT + \\]** to bring up the radio menu and then press F1 "Request Engine Start".

If you have wingmen, they will also now start their engine.

After the aircraft has been started and configured, select **[F1]** "Request taxi to runway". Once you receive permission, you can taxi to the "hold short" area of the taxiway - the area on the taxiway just short of entering the runway.

If you have wingmen, they will also now taxi to the runway.

When at the hold short area, press **[\\]** or **[RALT + \\]** and **[F1]** "Request takeoff". When permission is granted, you can taxi on to the runway and takeoff.

## Air Start and Landing

If you are not starting from the parking ramp, you can access ATC by pressing the **[\\]** or **[RALT + \\]** key. Upon doing so, you can select **[F5]** "ATCs".

If you are using "Easy Communications", a list of airfield ATCs will be shown along with their contact frequencies. Select the airfield ATC you wish to contact. If not using Easy Communications, you will first need to manually set the frequency used by the desired airfield.

Once the airfield ATC is selected, you can either send them an "Inbound" message to indicate that you intend to land there, or an "I'm lost" message that will result in the ATC providing you guidance to reach the airfield.

- When you select "Inbound", the ATC will respond with the following information:
- Heading to fly to reach landing initial point.
- Range to landing initial point.
- The QFE, or atmospheric pressure at the airfield elevation.
- Which runway to land on.

Upon approach to the descent starting point (from the 5KM border), the ATC will transmit "(callsign,) you are cleared to land." After this message, the pilot must respond with "Request Landing." If the pilot does not intend to land at the airfield, they must respond with "Abort landing."

If the runway is clear, the ATC then gives permission and reports the runway heading as well as the direction and speed of wind near the earth. If the runway is occupied, the ATC will prohibit the landing and give instructions for a go-around. «Request Azimuth» – sends the ATC a request for navigational assistance.

"Request Azimuth" transmits to the automatic airfield directional radio in case of a loss of orientation while in flight.

In reality, "Request Azimuth" is served in case of a loss of orientation in flight upon failure of the aircraft's navigation equipment, or while flying in adverse weather conditions or at night. This request is received by the automatic direction finder (ADF) at the airport, after which the operator of the ARP transmits a direct course to the airport.

In-game, in case of loss of orientation, a player may "request azimuth", which will be answered with a direct course to the nearest airfield. Approach the airport by flying this heading.

If you choose to land and are on the glide path, make a second request for landing permission. If the runway is free, the control tower gives permission and informs the pilot on the direction and speed of wind.

After landing, taxi to the parking area and shut down the aircraft.

## F6 Ground Crews

After landing at a friendly airfield and taxiing to a parking ramp, you can communicate with the ground crew for rearming and refueling by pressing the F6 option to display the Ground Crew menu.

The command list for ground personnel includes the menu for editing the aircraft loadout and fuel load, as well as for selecting the aircraft power source.

# KEYBINDINGS



# KEYBINDINGS

<b>AIRCRAFT CONTROL</b>	
Flaps (toggle)	[F]
Flaps EXTEND	[LShift - F]
Flaps RETRACT	[LCtrl - F]
Flight BANK LEFT	[Left]
Flight BANK RIGHT	[Right]
Flight NOSE DOWN	[Up]
Flight NOSE UP	[Down]
Flight RUDDER LEFT	[Z]
Flight RUDDER LEFT 1NOTCH	[RShift - ,]
Flight RUDDER RIGHT	[X]
Flight RUDDER RIGHT	[RShift - /]
Trim Elevator NOSE DOWN	[RCtrl - ;]
Trim Elevator NOSE UP	[RCtrl - .]
Trim Rudder LEFT	[RCtrl - ,]
Trim Rudder RIGHT	[RCtrl - /]
Trim Elevator (analog)	
Trim Rudder (analog)	

<b>ENGINE CONTROL</b>	
Booster Coil	[Delete]
Booster Coil Button Cover (toggle)	[LShift-Delete]
Booster Coil Button Cover CLOSE	
Booster Coil Button Cover OPEN	
Carburettor Air Filter (toggle)	[H]
Carburettor Air Filter OFF	[LCtrl-H]
Carburettor Air Filter ON	[LShift-H]
Drop Tank Fuel Cock (toggle)	
Drop Tank Fuel Cock OFF	
Drop Tank Fuel Cock ON	
Engine RPM DECREASE	[PageDown]
Engine RPM INCREASE	[PageUp]
Fuel Pump (toggle)	[0]
Fuel Pump OFF	[LCtrl - 0]
Fuel Pump ON	[LShift - 0]
Magneto No. 1 (toggle)	[LShift - End]
Magneto No. 1 OFF	

Magneto No. 1 ON	
Magneto No. 2 (toggle)	[RShift - End]
Magneto No. 2 OFF	
Magneto No. 2 ON	
Main Fuel Cock (toggle)	[T]
Main Fuel Cock OFF	[LCtrl - T]
Main Fuel Cock ON	[LShift - T]
Mixture Control (toggle)	[M]
Mixture Control IDLE CUT-OFF	[LShift - M]
Mixture Control RUN	[LCtrl - M]
Oil Dilution	
Oil Dilution Button Cover (toggle)	
Oil Dilution Button Cover CLOSE	
Oil Dilution Button Cover OPEN	
Operate Wobble Type Fuel Pump	[LCtrl-Insert]
Primer	[Insert]
Primer Lock (toggle)	[LShift-Insert]
Radiator Test	
Radiator Test Button Cover (toggle)	
Radiator Test Button Cover CLOSE	
Radiator Test Button Cover OPEN	
Starter	[Home]
Starter Button Cover (toggle)	[LShift-Home]
Starter Button Cover CLOSE	
Starter Button Cover OPEN	
Supercharger Mode (toggle)	[RShift -S]
Supercharger Mode AUTO	
Supercharger Mode M.S.	
Supercharger Test	
Supercharger Test Button Cover (toggle)	
Supercharger Test Button Cover CLOSE	

Supercharger Test Button	
Cover OPEN	
Throttle DECREASE	[Num-]
Throttle INCREASE	[Num+]
Engine RPM (analog)	
Throttle (analog)	

<b>AIRCRAFT CONTROL STICK</b>	
Fire Cannons	[RAlt - Space]
Fire Machineguns	[Space]
Fire Machineguns and Cannons	
Guns Safety Lever (toggle)	[LShift-Space]
Wheel Brakes	[W]
Wheel Brakes DECREASE	
Wheel Brakes INCREASE	
Wheel Brakes (analog)	

<b>AIRCRAFT SYSTEMS</b>	
Bailout	[LCtrl-E]
Canopy (toggle)	
Canopy CLOSE	[LCtrl-C]
Canopy OPEN	[LShift-C]
Door (toggle)	
Door CLOSE	
Door OPEN	
Drop Bombs	[RShift-Space]
Fuel Tank Pressure (toggle)	
Fuel Tank Pressure OFF	
Fuel Tank Pressure ON	
Jettison Canopy	[LCtrl-LShift-C]
Jettison Drop Tank	[LCtrl-LShift-T]
Oxygen Valve (toggle)	
Oxygen Valve CLOSE	
Oxygen Valve OPEN	
Pitot Heating (toggle)	[P]
Pitot Heating OFF	[LCtrl-P]
Pitot Heating ON	[LShift-P]
Radiator (toggle)	[A]
Radiator AUTO	[LCtrl-A]
Radiator OPEN	[LShift-A]
U/C Indicator (toggle)	

U/C Indicator OFF	
U/C Indicator ON	
Undercarriage (toggle)	[G]
Undercarriage DOWN	
Undercarriage Emergency Release	[LCtrl-LShift-G]
Undercarriage UP	
Widscreen De-Icing (toggle)	[LAlt-P]
Widscreen De-Icing OFF	[LAlt-LCtrl-P]
Widscreen De-Icing ON	[LAlt-LShift-P]

**INSTRUMENT DASHBOARD**

Altimeter Set Pressure DECREASE	
Altimeter Set Pressure INCREASE	
Clock Winding/Adjust (toggle)	[RShift-Q]
Clock Winding/Adjust ADJUST	
Clock Winding/Adjust DECREASE	[RCtrl-Q]
Clock Winding/Adjust INCREASE	[RAlt-Q]
Clock Winding/Adjust WINDING	
Compass Course DECREASE	[RAlt-C]
Compass Course INCREASE	[RCtrl-C]
Directional Gyro Course DECREASE	
Directional Gyro Course INCREASE	
Nav. Lights (toggle)	[U]
Nav. Lights OFF	[LCtrl-U]
Nav. Lights ON	[LShift-U]
Show Fuel Contents	
U/C Indicator Blind (toggle)	
U/C Indicator Blind DRAW	
U/C Indicator Blind RAISE	
Altimeter Pressure Set (analog)	
Compass Course (analog)	
Gun Sight Base DECREASE	[LCtrl-O]
Gun Sight Base INCREASE	[LShift-O]
Gun Sight Range DECREASE	[RCtrl-O]
Gun Sight Range INCREASE	[RShift-O]

Gun Sight Tint Screen (toggle)	
Gun Sight Tint Screen DRAW	
Gun Sight Tint Screen HIDE	
Gun Sight Base (analog)	
Gun Sight Range (analog)	

<b>VHF RADIO</b>	
Radio Channel A	[LCtrl-1]
Radio Channel B	[LCtrl-2]
Radio Channel C	[LCtrl-3]
Radio Channel D	[LCtrl-4]
Radio Lights Dimmer BRIGHT	
Radio Lights Dimmer DIM	
Radio Mode R	[LCtrl-5]
Radio Mode REM	[LShift-5]
Radio Mode T	[LAlt-5]
Radio Mode Switch Locking Lever T.LOCK	[LAlt-LCtrl-5]
Radio Mode Switch Locking Lever UNLOCK	
Radio Power OFF	[LCtrl - `]

<b>COMMUNICATIONS EQUIPMENT</b>	
ID Downward Lamp (next mode)	
ID Downward Lamp (prev. mode)	
ID Downward Lamp MORSE	
ID Downward Lamp OFF	
ID Downward Lamp STEADY	
ID Operate Morse Key	
ID Upward Lamp (next mode)	
ID Upward Lamp (prev. mode)	
ID Upward Lamp MORSE	
ID Upward Lamp OFF	

ID Upward Lamp STEADY

RESPONDER	
I.F.F. Circuit B (toggle)	
I.F.F. Circuit B OFF	
I.F.F. Circuit B ON	
I.F.F. Circuit D (toggle)	
I.F.F. Circuit D OFF	
I.F.F. Circuit D ON	
I.F.F. Cover (toggle)	
I.F.F. Cover CLOSE	
I.F.F. Cover OPEN	
I.F.F. Detonate Button 1	
I.F.F. Detonate Button 2	

RADIO COMMANDS	
COMM Communication menu	[\\]
COMM Push to talk	[RAlt-\\]
COMM Switch dialog	[RShift-\\]
COMM Switch to main menu	[RCtrl-\\]
COMM Ask AWACS home airbase (easy communication)	[LWin-U]
COMM Attack Air Defenses (easy communication)	[LWin-D]
COMM Attack Ground Targets (easy communication)	[LWin-G]
COMM Attack my target (easy communication)	[LWin-Q]
COMM Cover me (easy communication)	[LWin-W]
COMM Dispatch wingmen - complete mission and RTB (easy communication)	[LWin-E]
COMM Dispatch wingmen - complete mission and rejoin (easy communication)	[LWin-R]
COMM Join up formation (easy communication only)	[LWin-Y]
COMM Toggle formation (easy communication)	[LWin-T]

<b>CABIN ILLUMINATION</b>	
LH Dashboard Lamp Brightness DECREASE	[LCtrl-N]
LH Dashboard Lamp Brightness INCREASE	[LShift-N]
RH Dashboard Lamp Brightness DECREASE	[RCtrl-N]
RH Dashboard Lamp Brightness INCREASE	[RShift-N]
LH Dashboard Lamp Brightness (analog)	
RH Dashboard Lamp Brightness (analog)	

<b>KNEEBOARD</b>	
Kneeboard Next Page	[{}]
Kneeboard ON/OFF	[RShift-K]
Kneeboard Previous Page	[{}]
Kneeboard current position mark point	[RCtrl-K]
Kneeboard glance view	[K]

# Developers

## EAGLE DYNAMICS

### Directors

Nick Grey	Project Director, Director of The Fighter Collection
Igor Tishin	Project Director, Director of Eagle Dynamics (Russia)
Andrei Chizh	Programming Assistant, QA Manager, Producer, Technical Documentation
Sergei Gerasev	Project Manager
Alexander Babichev	Project Manager
Matt "Wags" Wagner	Producer, Business Development
Matthias "Groove" Techmanski	Producer, Localization Management

### Programmers

Dmitry Baikov	Systems, Multiplayer, Sound Engine
Ilya Belov	Graphic Interface, Maps, Input Interfaces
Maksim Zelensky	Aircraft, Aircraft AI, Flight and Damage Models
Andrey Kovalenko	Aircraft AI, Weaponry
Alexander Oykin	Avionics and Aircraft Systems
Yevgeny Podyachev	Plugins and Assembly
Timur Ivanov	Graphics and Effects
Oleg "Olgerd" Tischenko	Avionics
Vladimir Feofanov	Flight Models, Aircraft AI
Konstantin Tarakanov	Graphic Interface, Mission Editor
Yevgeny Gribovich	Avionics
Dmitry Robustov	Landscape
Yevgeny Panov	AI
Mikhail Yershov	AI
Alexei Sayenko	Graphics
Alexei Militov	Effects
Grigory Manukyan	Graphics
Roman "Made Dragon" Deniskin	Aircraft Systems and Flight Models

### Ground Vehicles Division

Roman "Dr.Iex" Podvoysky	Combined Arms
--------------------------	---------------

Alexander "SFINX" Kurbatov

Vehicles and Ships

Pavel Khamlov

Vehicles and Ships

## Designers

Pavel "DGambo" Sidorov

Lead Designer

Alexander "Skylark" Drannikov

Graphics and Graphical Interfaces, Aircraft

Timur Tsygankov

Aircraft, Vehicles, Ships, Weapon Models

Yevgeny "GK" Khizhnyak

Aircraft and Vehicles

Konstantin Kuznetsov

Sound Director

Sergei "tama" Ashuyko

Buildings and Landscape

Andrei "LISA" Reshetko

Persons

Maxim Lysov

Aircraft

Igor Piskunov

2D Designer

Yuri Starov

Aircraft

Alexandra Alexeeva

2D Designer

## Sound

Konstantin "btd" Kuznetsov

Sound Director, Composer

## OTK

Valery "USSR\_Rik" Khomenok

Lead Tester

Ivan "Frogfoot" Makarov

Tester

Alexander "BillyCrusher" Bilievsky

Tester

Nikita "Nim" Oprudelenkov

Tester

Oleg "Dzen" Fedorenko

Tester

## Scientific Support

Dmitry "Yo-Yo" Moskalenko

Mathematical Models: Dynamics, Systems, and Ballistics

## Localization Department

Alexei "Mode" Chistyakov

Localization

Elena Pryanichnikova

Translation

Jzan Lo

Translation

## IT and Customer Support

Konstantin "Const" Borovik

System and Network Administrator, Web and Forums

Andrei Filin

Systems and Network Administrator, Customer Support

Konstantin "MotorEAST" Kharin  
Alena Yurikovskaya

Customer Support  
Customer Support

## **Training Missions**

Sergei Goretsky

## **Additional Skins**

Mbendi1  
=RAF= Ваттель  
CHSubZero  
Golani79  
Jponti  
JST  
KIZIR\_77  
Ovenmit  
Reflected  
Snowsniper

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## **German Localization**

Hardy "I./ZG15\_FALKE" Bauer  
Sebastian "Lino\_Germany" Benner  
Charly "Nirvi" Kramer  
Marcel "EagleEye" Kruger  
Daniel "Luigi Gorgonzola" Atencio Psille  
Matthias "Groove" Techmanski  
Special Thanks:  
Erich "ViperVJG73" Schwarz  
Werner "derelor" Siedenburg

## **French Localization**

Gilles "Maraudeur" Annee  
Clement "Azrayen" Bakes  
Gaetan "ameleon33" Delaporte  
Guillaume "Bad CRC" Gaillet  
Julien "Psycho" Gras

Cedric "Cedaway" Lemercier

## Czech Localization

Honza Lehky

### Testers

Christopher "Mustang" Wood  
Danny "Stuka" Vanvelthoven  
Darrell "AlphaOneSix" Swoap  
Dmitry "Laiynas" Koshelev  
Erich "ViperVJG73" Schwarz  
Jeff "Grimes" Szorc  
Jurgen "lion737" Dorn  
Kairat "Kairat" Yaksbaev  
Martin „Smudge“ Smith  
Matt "mdosio" Dosio  
Matthias "Groove" Techmanski  
Norm "SiThSpAwN" Loewen  
Peter "Weta43" McAllister  
Raul "Furia" Ortiz de Urbina  
Roberto "Vibora" Seoane Penas  
Scott "BIGNEWY" Newnham  
Sergei "eekz" Goretsky  
Vadim "Wadim" Ischuk  
Valery "=FV=BlackDragon" Manasyan  
Viktor "vic702" Kravchuk  
William "SkateZilla" Belmont

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(tf_Wraithweave)	Alberto Loro	Alper Mat	andrey112
[3rd]KaTZe	ALBERTO MARTIN	Alvio Costantini	Andrii
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a_korolev[at]pochta.ru	Alejandro	Amos Giesbrecht	Andy Toropkin
Aapef	Alejandro Montero	Amraam	Andy Wall
Aaron Fess	Aleksander Yatsenko	Anatoly Yakubov	Andy Wishart
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Craig Martin	Alex G	Andreas Schmidt	Ant Paul
Adam Jasiewicz	Alex Hitrov	Andreas Tibud	Antal Bokor
Adam Navis	Alex Huber	Andreas Wagner	Anthony
Adam Schneider	Alex Hughes	AndreasDitte	Anthony Echavarria
Adam Tomczyński	Alex Ip	Andrej Babis	anthony milner
Admir Nevesinjac	Alex Murphy	Andrej Jesenik	Anthony Portier
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Adrian Cretu	Alex6511	Andrew	Anthony Wheeler
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Afly	ALEXANDER ALEKSEEV	Andrew Bartlett	Levesque
Aginor Chuain	Alexander Barenberg	Andrew Blinkin	Anton Golubenko
Agnar Dahl	Alexander Borisov	Andrew Broadfoot	Anton Grasyuk
Aidan Jabs	Alexander Gebhardt	Andrew Dean	Anton Krug
airyy[at]163.com	Alexander Orevkov	Andrew Deng	Anton Ottavi
Aivaras Staniulis	Alexander Vasilyev	Andrew Devine	antonello
Aki Holopainen	Alexander Zhavoronkov	Andrew Fenn	antonio dasilva
Akin	Alexandr Marishenkov	Andrew Garst	Antonio Manuel Ortiz
Aksel Sandsmark	Alexandr Petak	Andrew Gibbons	Seguel
Borgersen	Alexandre Jacquin	Andrew Heimbuch	Antonio Ordóñez de Paz
Aku Kotkavuo	Alexandre Pigeon	Andrew Hickman	Antonyuk Dmitry
Aladrius	Alexey	Andrew Jennings	Antti Kalliomäki
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Alan Dougall	Alexey Polovets	Andrew Olson	Antvan
	Alexey_K	Andrew Paull	ANV
	AlexPX	Andrew Rolfe	Anže Blatnik
	ALFA_49	Andrew Scarr	Apex
	Alfonso Garcia Martinez	Andrew Smith	apollo01
	alfred demauro	Andrew Stotzer	Aquila
	Alfredo Laredo	Andrew Suhren	Aram
	Alistair Stuart	Andrew Thomson	Aries The Destroyer

Arjuna	Bo Henriksen	bzan77[at]hotmail.com	Chris West
armrha[at]gmail.com	Bob Bent	Caldur	Chris Wuest
Arnel Hadzic	Bob Denhaar	Caleb E. Farris	Christelle JESTIN
Arto Rajajärvi	Bob Evans	Caleb Keen	Christer Arkemyr
Arto S.	Bob Petrone	callsignalpha	Christian
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Dalminar	David Pajnic	Dver	Fabiano Carlos Alves do Nascimento
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Dan Lake	David Rilstone	EAF51_Walty	Federico Delfanti
Dan Padnos	David Ross Smith	EagleTigerSix	Fedorenko Oleg
Daniel	David Savina	Eamonn McArdle	fedorlev90[at]gmail.com
Daniel Beltran Gonzalez	david say	Ed Curtis	m
Daniel Boontje	David Schroeder	Edward A. Dawrs	Felix Felixsson
Daniel Gestl	David Setchell	Edward Billington-Cliff	felix heine
Daniel Groll	David Southall	Edwin Szekely	Felix Mueller
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Darryl Chupp	Demon	Enrique Alvarado	Florian Voß
Dave Pettit	Denis Kaplin	Eoghan Curtin	Flying Colander
Dave Webster	Denis P	Erastos	folomeshkin[at]gmail.com
David	Denis Winters	Erdem Ucarkus	m
David	Dennis Ejstrup	Eric	Force_Majeure
David Abreu	Derek Barnes	Eric Anderson	Ford Wesner
David Belvin	Derek Guiliiano	Eric Dickerson	Francesco Kasta
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Fred de Jong	Gleb Ivanovsky	Helio Wakasugui	Isaac Titcomb
Fred Golden	Glen Reed	Helldiver	Isidro Rios
Fred Schuit	Glenn Lilley	HellToupee	ismailaytekarlsan[at]gm
Frederic GEDEON	Goat Yoda	Hemul	ail.com
Fredrik Silfverduk	gor7811[at]hotmail.com	Hen Shukrun	Istvan Takacs
Fredrik Sjöborg	Goran Skoko	Hendrik Berger	Ivan
Friedrich Plank	Göran Wikman	Henning	Ivan Čavlek
FSXFlight	Gordon McSephney	Henning Leister	Ivan Fedotov
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Gene Bivol	Guillaume Houdayer	ian d	James Cleeter
Geoffrey Lessel	GUMAR	Ian Dahlke	James D Brown
Geofray	gunter113[at]yandex.ru	Ian Hughes	James dietz
George Bellos	Gunther Mueller	Ian Jones	James Faraca
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javierlarrosa	Joen	Jose Manuel	Karen Kurpiewski
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Jazzerman	Johan Waldemarsson	Josef Eberl	Karl "Light" Akkerman
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jean-baptiste mouillet	Johannes Mueller-	Joseph Noe	karl bullard
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Jens Langanke	John J.	Josse Aertsen	Ken Cleary

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Ken Peterson	Kyle	Maarten Schild	Mark Shepheard
kenneth	Kyle Fulton	Magistr	Mark Trenda
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Kev	Larry Jones	makabda	Markus Narweleit
Kevin Beswick	Larry Lade	Makoto Hakozaiki	Markus Nist
Kevin Francis	Lars Lie	malczar[at]wp.pl	Markus Ronkainen
Kevin Watts	Lasse Nystuen Moen	Manuel	Markus Wohlgenannt
Kevin Witt	Lasse-Pekka Toivanen	Manuel Maria Alfaro	marly fabien
Keyser	Lassi Miettunen	Gomez	Martim Avelino Geller
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Kim Johnstuen Rokling	Leandro Medina de	Marc	Martin Eriya
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Koz Myk	Lorenzo Manzoni	Mark David Cleminson	Matt Crawford
kozeban[at]mail.ru	Louie Hallie	mark downer	Matt Fisher
kpax	lowellsil	Mark Duckett	Matt Huston
Kristian Wall	Luis Manuel Carrasco	Mark Fisher	Matt Olney
Kristofer Crecco	Buiza	Mark Gordon Cochrane	Matt Parkinson
krms83[at]gmail.com	Luis Miguel Lopes	Mark Hickey	Matt Renfro
Krueger	Lukas Erlacher	Mark Jedrzejczak	Matt Styles
Kruglik Svetlana	Lukas Vok	Mark Linnemann	Matthew
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Matthew Wohlford	Mick Alden	Nicholas Prosser	Oskar Hansson
Matthias Kober	Miguel Angel González	Nicholas Wagner	outsorsing[at]yandex.ru
Matthias Lütke-Wenning	Domingo	Nick	Owe Cronwall
Matthijs	Miguel Arias	Nick Walsh	P A KAFKAS
Mattia Garuti	Miguel Coca	Nick Wright	PA_Hector
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MgFF	Mikko Pulkkinen	Niels Hille Ris Lambers	Pasi Yliuntinen
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michael	Milan Šimundža	Niklas Nordgren	Patrick Barnhill
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Michael Sprauve	Nacho	Oleg Belenko	Pavel Bozhenkov
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Michael Turner	NATALYA DOLZHENKO	Oliver Bennett	Pavel Osipov
michael waite	Nathaniel Williams	Oliver Hooton	Pavel Škoda

Paweł Sokolowski	Rafał Szekalski	Robert Elliott	Ross Martin
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peter winship	Ricardo Madeira	Rodrigo Mejía	Sami Juntunen
Petter Lausund	Ricardo Nuñez	roeemalis[at]gmail.com	Sami Luukkonen
PH	Richard	Roger Buchser	Samuel
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Phil Barker	Richard Hickerson	Roger Ringstead	Samuel Morrissey
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