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Jakub Pełczyński*
Poznań University of Technology
ul. Piotrowo 3, 60-965 Poznań, Poland
E-mail: jakub.pelczynski@doctorate.put.poznan.pl
https://orcid.org/0009-0004-0787-5616

Maciej Bajerlein
Poznań University of Technology
ul. Piotrowo 3, 60-965 Poznań, Poland
E-mail: maciej.bajerlein@put.poznan.pl
https://orcid.org/0000-0002-5908-1218

*(correspondent-author)

Outline of the history of the development of piston aircraft engines charging systems

Abstract. *The subject of the article is a review of the most important facts from the development of supercharging systems for piston aircraft engines from the beginnings of aviation to the present day, with particular emphasis on the period of dominance of piston engines in aviation, i.e. the first half of the 20th century. The work focuses on design solutions developed over the years that had a direct impact on engine operating indicators, altitude characteristic and therefore on aircraft performance. Moreover, in the first chapters it shows the reasons for using supercharging in aviation resulting from the unfavorable altitude characteristics of naturally aspirated engines, low-altitude engines or engines equipped with simple non-altitude superchargers systems. The aim of the article is to comprehensively outline the topic of supercharging piston aircraft engines, including, apart from the history of development, also its prospects. The text was prepared on the basis of literature and primarily on the basis of collected source material such as catalogues, archival publications and catalogue data sets. They allow not only to learn about the solutions used, but also to assess and analyze their impact on the engine's functionality. By learning about the altitude characteristics or operating indicators of an engine, it is possible to assess the usefulness of the design solutions used in its supercharging system. Such work requires not only the work of a historian who relies on source materials to learn about the past, but also the technical knowledge of an engineer who can interpret specific development trends in the construction of machines such as engines and their impact on their operating indicators. This approach allows not only to describe the past, but also to* *learn about development trends over the years. The analysis of historical constructions and operational indicators is often omitted in science because it requires working at the interface of two disciplines, both technical and historical. However, it is important for the development of the history of technology, because it concerns its central subject, i.e. the technical objects themselves.*

Keywords: *supercharging systems; piston aircraft engines; altitude characteristic; engine history*

Introduction.

The aim of this study is to demonstrate the relationship between the constant increase in operational indicators of aircraft piston engines and the use of superchargers in them and the continuous development of supercharging systems.

The first airplanes created at the turn of the 19th and 20th centuries were powered by quite simple piston engines and reached low flight altitudes, usually not exceeding several dozen meters above the ground (Pełczyński, 2023a). In recent years, however, before the outbreak of the First World War, airplanes became increasingly mature functional structures (Angle, 1921), not just sports toys or experimental projects (Lumsden, 1994). Increasing the power concentration of the propulsion units allowed to achieve higher flight ceilings, cruising speeds and range, but this resulted in the emergence of new, numerous construction and operational problems (Smith, 1986).

In aviation, turbosuperchargers and mechanical centrifugal superchargers are mainly used (Głowacki, 2017). The former can provide the most constant altitude characteristics, while maintaining high efficiency at any flight altitude. Their most serious disadvantage is significant thermal loads requiring the use of appropriate materials resistant to high exhaust gas temperatures. Mechanical superchargers are free of this defect. In order to ensure effective charging with a mechanical supercharger in the widest possible altitude range, much more complex systems of two-speed and two-stage superchargers are used than in the case with turbosuperchargers.

The development of aircraft engine supercharging systems had a large impact on operational indicators and the development of aviation in general, which will be presented in this article. Above all, however, it is a general overview, as it presents individual types of superchargers and the genesis of their development.

There are practically no publications solely on the history of the development of supercharging of piston aircraft engines. The subject is discussed in books that are generally about the history of aircraft engines, such as *The development of piston aero engines, from the Wrights brothers to microlights: a century of evolution and still a power to be reckoned with* by B. Gunston (1993), *Aircraft propulsion, a review of the evolution of aircraft piston engines* by C. F. Taylor (1971) or the works of H. Smith such as *A history of aircraft piston engines* (1986). The supercharging systems of specific companies or countries can be found in several publications, including *Allied aircraft piston engines of World War II* by G. White or *Rolls-Royce piston aero engines – a designer remembers* by A. A. Rubbra (1990). However, the most helpful in researching the subject are publications issued in the described era such as *The performance of a supercharged aero engine* by S. Hooker, H. Reed and A. Yarker (1941). The most important source in researching the history of aircraft engines is the *Jane's all of the world's aircraft* series. Each volume, usually published every two years, is a collection of catalog data for every aircraft and aircraft engine produced in the world. Up to 1920, the outstanding source for both engines and early supercharging systems is *Textbook of Aero Engines* by E. H. Sherbondy and G. D. Wardrop (1920).

For research on the development of the design or operational indicators of machines, which are also aircraft engines from an interdisciplinary perspective, based on knowledge from the field of technical sciences and historical sciences, the direct source is the construction itself and operational indicators. Thanks to their interpretation, it is possible to describe the history of development and development trends in a given field. Their knowledge may result from several primary sources. The first is the object itself and possible empirical studies performed on it; the second are source materials such as catalogs, operating instructions, manufacturers' publications, catalog collections, research reports and publications of research results; and the last source are studies and other publications from the period under study in which the necessary information can be found.

Altitude Characteristics of Non-Charged Engines.

The power of piston engines decreases significantly with altitude above sea level. This was observed as early as 1909, when high-altitude flight tests began. The first research on the combustion of fuel in a cylinder at altitude was carried out at the National Bureau of Standards in the USA in 1918 (Taylor, 1971). The decrease in power with increasing flight altitude is similar for all piston engines without supercharging, because it does not depend on their construction, but only on the atmospheric parameters at a given ceiling, and especially on the air density, which decreases with increasing flight altitude. The figure below (Fig. 1) shows just such a decrease in engine power for standard atmosphere (ISA). The data are based on the information from the book "Stosowana mechanika lotu" (eng. "Applied flight mechanics") (Auzan, Bolkhovitinov, Kozlov, Kurickes, & Pysznov, 1938). Based on the book „Teoria silników lotniczych, podręcznik" (eng. "Theory of aircraft engines, textbook") (Worobiow, 1951), information for altitudes above 10,000 meters is given.

Effect of altitude on aircraft speed.

The decrease in air density with the flight ceiling also reduces the drag force. Therefore, often airplane at certain altitudes can reach higher flight speeds than at lower ones. For undercharged and non-high-altitude engines, the maximum speed usually decreases with a slight increase in flight altitude. It is possible that at low altitudes (e.g., up to about 3000 m) the velocity is constant, close to constant or slightly higher in relation to the velocity at sea level. It depends on many factors. For example, the efficiency of the propeller at a given altitude and the characteristics of the drag coefficient of the aircraft for a given Reynolds number. Knowing the parameters of the reference atmosphere, it is possible to derive a simplified dependence of the speed of an aircraft powered by a naturally aspirating engine on the flight altitude (Fig. 2).

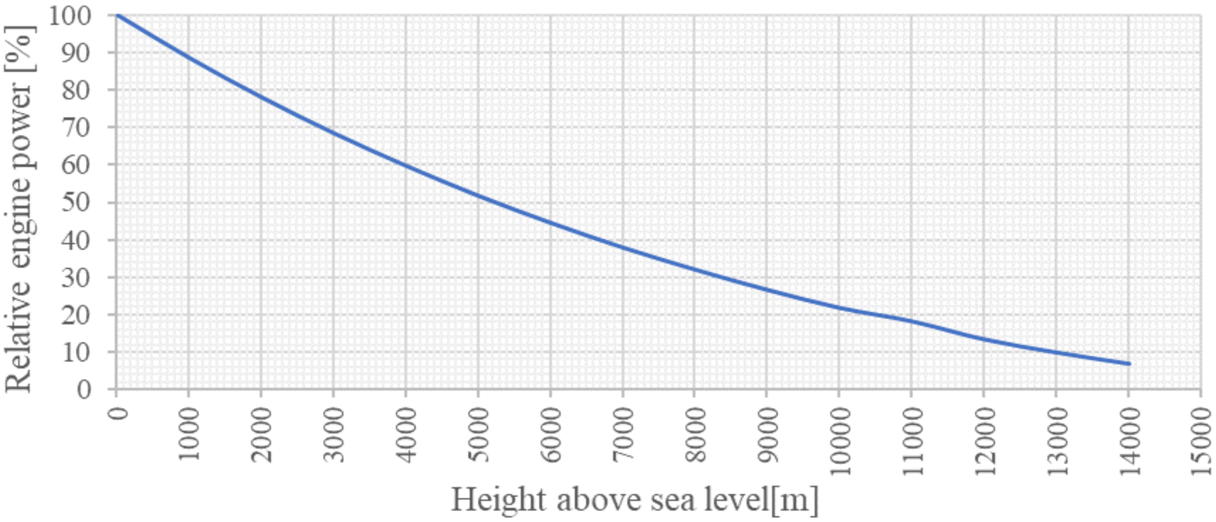

Figure 1. Reducing the relative power of the piston engine at altitude in [%], where 100% is the power at 0 meters (Author's source, based on the *Stosowana mechanika lotu* by A. K. Auzan, W. F. Bolkhovitinov, S. G. Kozlov, J. M. Kurickes and W. S. Pysznov (1938) and on the book *Teoria silników lotniczych, podręcznik* by P. Worobiow).

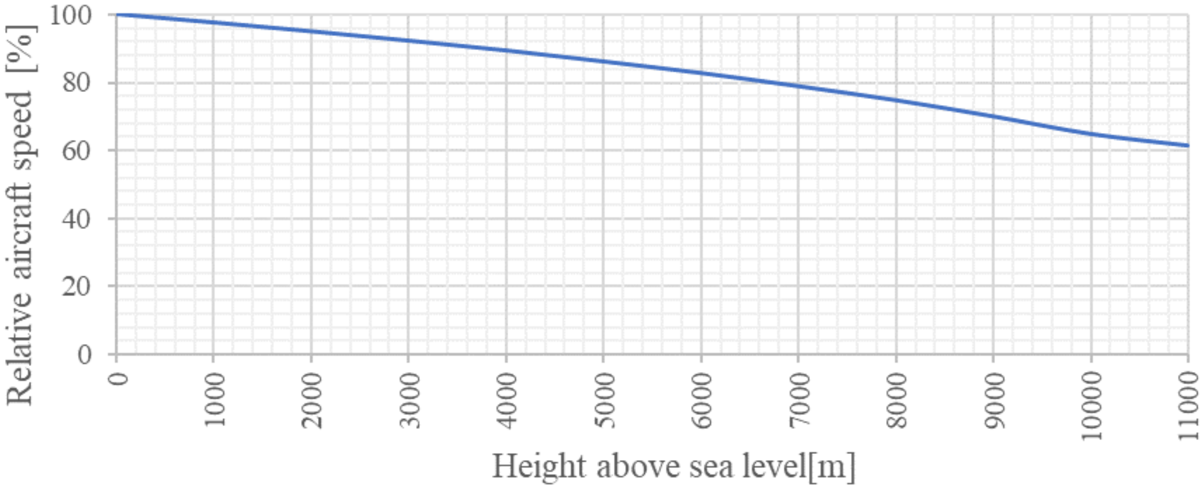

Figure 2. Simplified speed characteristics of an aircraft powered by an undercharged piston engine in [%], where 100% is the aircraft speed at sea level. The figure only includes flights in the troposphere (Author's source, based on the *Stosowana mechanika lotu* by A. K. Auzan, W. F. Bolkhovitinov, S. G. Kozlov, J. M. Kurickes and W. S. Pysznov (1938) and on the book *Teoria silników lotniczych, podręcznik* by P. Worobiow).

In order for the aircraft to climb to a higher altitude, sufficient speed is necessary to maintain lift in the thinned air, which is more difficult to achieve with the decreasing engine power. It is widely known that the lift depends on squared speed according to the formula (1).

$$F_z = \frac{1}{2} \cdot c_z \cdot \rho \cdot S \cdot v^2 \, , \qquad (1)$$

where: F_z – the lift force; c_z – the lift coefficient at the desired angle of attack, Mach number and Reynolds number; ρ – density of air; S – wing surface; v – flight speed (Staszek, 1983).

The thrust of the propeller-engine assembly for a propeller selected for operation in at sea level conditions decreases with altitude due to insufficient engine power. Choosing a propeller with a specific height in mind, in turn, causes an excess of power below this height, which will be too large for the propeller to fully use it. The best solution is to use a propeller with variable blade pitch. This allows it to be adjusted to the flight parameters. The change of pitch can be controlled by the pilot or automatic, regulated by the constant speed controller. It allows not only to set the propeller blades in several positions (usually two), but also to smoothly change the propeller pitch (Worobiow, 1951).

Early Attempts to Solve the Problem of High-Altitude Flights and the Genesis of Aircraft Engine Supercharging Systems.

The first supercharged aircraft engine was built in 1910. It was a two-stroke Murray-Willat equipped with a simple fan that compressed the fuel-air mixture before entering the cylinders (Angle, 1921). It allowed for flight at an altitude of 5,200 meters (Wisłocki, 2023). The second known aircraft engine equipped with a supercharger was built in Japan by Captain Kumazo Hino in 1911. According to the design, it was supposed to achieve a power of 30 hp (22 kW), but in practice only 18 hp (13 kW) was achieved. Probably the same engine was installed in a plane from 1915. However, it managed to increase its power to 25 hp (18 kW). Initially, historians believed, based on photographs, that the engine had four cylinders. However, it turned out that two of them were piston superchargers increasing the air pressure at the inlet to the cylinders (McCutcheon, 2022).

Due to the fact that the first superchargers were only in the experimental phase, the issue of high-altitude flights during World War I was tried to be solved in several ways. In Great Britain, Rolls-Royce used a manually controlled altitude corrector in the carburetors of its engines, which was to ensure the maintenance of a constant composition of the air-fuel mixture.

In Germany, Maybach (Hoffman, 2021) and then BMW designed engines that were supposed to operate at a certain altitude (Sherbondy, Wardrop, 1920). Their entire structure was designed for atmospheric parameters at an altitude of 5,000 meters. However, this did not mean that they were unaffected by the altitude of the flight. In fact, these engines were able to achieve much more power on the ground, but this threatened to damage them due to too significant loads. Therefore, planes equipped with them could not take off with the throttle fully open. Then, in order to fly with maximum power, the pilot could open the throttle while climbing. Too much fuel would result in too high pressures in the cylinders and thus loads on the crank system. The engine maintained the same power throughout, up to the design altitude. After exceeding it, it began to decrease, as in any other engine (Rubbra, 1990).

These problems related to the to the decreasing power of piston aircraft engines needed to be solved. Aa early as 1914, Swiss engineer A. J. Buchi proposed the construction of an aircraft turbosupercharger that would allow air to be compressed at higher flight altitudes in order to preserve engine power. Unfortunately, at that time, the construction of a usable turbocharger was impossible, mainly due to the resistance of materials to high temperatures. During the First World War, many studies and trials were carried out. However, they did not go beyond the phase of laboratory experiments (Taylor, 1971).

More advanced work was carried out on mechanically driven superchargers. The British company Royal Aircraft Factory, in cooperation with Armstrong-Siddley, installed a centrifugal supercharger for a radial engine in 1916. Ultimately, however, it was not suitable for production due to high vibrations. Later, the Royal Aircraft Factory also conducted research on turbochargers (Taylor, 1971). In 1918, the French experimental Rateau turbosupercharger was tested on the R.A.F. 4d engine. The tests were carried out on the R.E.8 aircraft (Lumsden, 1994).

The creation and development of turbosuperchargers.

After the end of World War I, work on mechanical superchargers and turbosuperchargers was intensified (Wisłocki, 2023). In 1918, the US Army Air Force Aircraft Engineering Division commissioned General Electric to design a turbocharger. The experimental model was tested in the Liberty engine (National Air and Space Museum, n.d.a), first on a dynamometer, the same year, and then in flight in 1919. The Le Pere airplane with a turbocharged Liberty engine achieved successive altitude records in 1920, 1921 and 1922. Nevertheless, the drive not adapted to the supercharger from the very beginning, turned out to be very prone to failure. For example, while breaking the record in 1920, one of the connecting rods in the engine broke (Taylor, 1971).

A much more serious disadvantage, however, was that the turbine itself was significantly overheating, which led to damage to its blades. This problem was finally brought to attention in 1922 and soon resolved. The turbine casing was mounted so that it was exposed and could be cooled by the air flowing around the airplane. On this basis, General Electric built many successful turbochargers in the 1920s, 1930s and during World War II (Taylor, 1971).

During World War II, two types of General Electric turbochargers were produced: Type B and Type C. The first one was design for engines with power from 801 to

1400 hp (from 589 to 1029 kW), and the second one for engines from 1801 to 2200 hp (from 1324 kW to 1618 kW). Their construction was similar. The single-stage centrifugal turbine powered a single-stage centrifugal supercharger. Turbine rotational speed was 22,000 rpm. Turbochargers were designed so that the engine could achive the same power at any altitude within a certain specific range. To ensure this, an exhaust gas venting was used. Only during the flight at the maximum altitude, the entire exhaust gas flow directed to the turbine (White, 1995).

In the 1930s and 1940s, only one turbocharged engine was produced and applied in practice outside the United States. It was a self-ignition, two-stroke Junkers Jumo 207 engine (Wisniewski, 2013), which was a high-altitude version of the Jumo 205 engine (National Air and Space Museum, n.d.b). Moreover, very advanced tests were carried out in the USSR, but probably no turbocharged engine was used except for experimental flights (Kotelnikov, 2005). Additionally, trials were conducted in Japan (Goodwin & Starkings, 2017), France and the United Kingdom.

Development of Mechanical Superchargers.

However, mechanically driven superchargers turned out to be much more common than turbosuperchargers. However, the first successful aviation mechanical supercharger was developed later than the first successful aviation turbochargers. In 1925, the Curtiss and Wright companies built their experimental, prototype mechanical superchargers. In 1926, they were first successfully used in Jaguar car engines, and in 1927 in the Pratt and Whitney Wasp aircraft engine. It was a Roots supercharger and was designed by NACA (National Advisory Committee for Aeronautics). It was one of the few successful applications of Roots superchargers in aviation, which were quickly replaced by centrifugal superchargers. In 1927, Lieutenant Champion of the United States Navy, flying a plane equipped with a supercharged Wasp engine, broke another altitude record (Taylor, 1971). Simpler construction and lower thermal loads allowed for the widespread use and continuous improvement of the construction of mechanical superchargers. The economic factor was also important here, as turbochargers were much more expensive.

An example of the development of mechanical supercharging can be Rolls Royce Merlin engine. Initially, it was equipped with a single-stage, two-speed Farman supercharger. Subsequent versions of Merlin had a two-stage and two-speed supercharger. The compression ratio was 9.49:1. Due to high temperatures, the supercharger in most versions had a separate cooling system that used water with glycol (Rubbra, 1990).

The use of two-speed and two-stage compressors allows for approximation of the height characteristics of the supercharged engine to the characteristics of the turbocharged engine (Hooker, Reed, & Yarker, 1941).

In engines with two-stage superchargers, the second stage is usually switched on only at a certain altitude to improve the altitude characteristics of the engine. Single-stage superchargers and the first stages of two-stage superchargers in high-altitude engines achieve compression ratios between 5:1 and 9.5:1. However, there were greater values. An example is the German Daimler Benz DB 601 engine from the Second World War, equipped with a single-stage mechanical supercharger with a compression ratio of 10.47:1. Most two-stage supercharger static pressure ranges from 7:1 to 11:1 (Jones, 1995).

Altitude Characteristics of Supercharged Engines.

The development of aircraft engines supercharging has had a positive impact on the use of other advantages and applications for superchargers. In addition to improving the altitude characteristics of the engines, they allowed to increase the parameters of all piston engines. In airplanes, superchargers turned out to be useful not only for high-altitude flights, but also in order to increase engine power during take-off, flight or air combat (Douglas, 2022).

The advantages of aircraft superchargers are best reflected in the altitude characteristics of the engines. The chart (Fig. 3) shows the characteristics of the Rolls-Royce Merlin engine at different altitudes with two types of supercharging and without supercharging (Gunston, 1993).

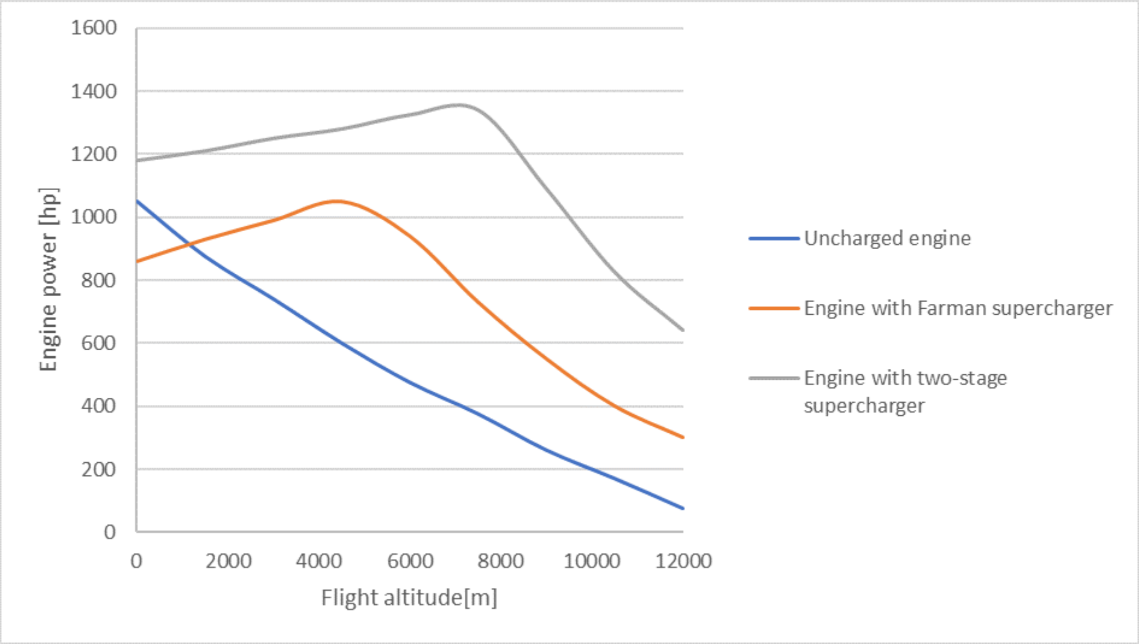

Figure 3. Altitude characteristics of Rolls-Royce Merlin engines in several versions (based on *Rolls-Royce piston aero engines – a designer remembers* by A. A. Rubbra (1990)).

At an altitude of 10,000 m without supercharging it reaches only 200 hp, with a Farman supercharger twice as much, and with a two-stage supercharger as much as 800 hp.

The main problem of mechanical superchargers is the decrease in efficiency with flight altitude. At an altitude of 10,000 meters, it may require up to 30% of the engine power for its propulsion. To prevent this, high-altitude superchargers use complex two-speed and multi-stage systems. Nevertheless, when they exceed the nominal height at which they reach the maximum pressure, their efficiency decreases. Ground-level superchargers have a simpler construction and their task is to supply air under increased pressure, especially at low flight altitudes (Kostia, 1953).

Mechanically driven superchargers are driven from the engine crankshaft, mostly by means of a gear transmission. Belt or chain transmissions, popular in cars, are not used. The superchargers are always centrifugal, although early attempts were made to use Roots systems. Turbochargers are driven by a centrifugal or, less commonly, axial turbine (Balicki, Kawalec, Pągowski, Szczeciński, J., & Szczeciński, S., 2005).

Turbocharger turbines use the difference in exhaust gas and air pressure. At higher altitudes, this difference becomes greater, making turbosuperchargers more efficient at high altitudes than mechanically driven superchargers.

Supercharging and the Fuel System.

Engines with one carburetor have the supercharger located behind the carburetor (sometimes turbochargers may also be located in front of it). The flow of the fuel-air mixture through the supercharger ensures a fairly high degree of mixture evaporation and, importantly, its high homogeneity. The disadvantage of this solution is that the carburetor must be additionally heated to protect it against icing (Balicki, Kawalec, Pągowski, Szczeciński, J., & Szczeciński, S., 2005).

Multi-carburetor engines cannot have a supercharger behind the carburetor, because in such a case there would have to be a separate supercharger for each carburetor. Therefore, it is located in front of the carburetors. This ensures very good evaporation of fuel. In order to obtain the same boost pressure as in the case of a carburetor located in front of the supercharger, less power is needed to drive the mechanical supercharger or less pressure of the exhaust gas feeding the turbocharger turbine. Thanks to this, losses resulting from throttling the exhaust gas flow are smaller. A significant disadvantage of this solution may be uneven air supply to individual engine carburetors, resulting from turbulent flow downstream of the supercharger and upstream of the carburetors. In addition to the flow turbulence caused by the operation of the supercharger, vortices are also formed inside the flow channels, primarily at joints, seals and unevenness of internal surfaces. For this reason, this should be taken into account when designing intake ducts (Wisłocki, 1991).

The use of direct injection instead of a carburetor (Welshans, 2013) allows for more free design of the charging system. Nevertheless, a significant amount of a aircraft engines are equipped with carburetors.

Charge Air Cooling.

In the 1930s, the development of supercharging systems forced the development of effective charge air cooling systems (Wisłocki, 2023). To reduce the risk of accelerated ignition, coolers were used through which air from the supercharger flowed. The simplest solution was to provide external air flow around the radiator.

However, it is usually more effective to use a liquid as a cooling agent (Wisłocki, 1991).

The outbreak of World War II led to the search for solutions that would allow for a more effective increase in power concentration (Bridgman, 1944). In order to be able a short-term increase in boost pressure during air combat, it was necessary to use more efficient cooling systems than those used so far. For this purpose, the phenomenon in which a liquid absorbs part of the thermal energy from the surroundings during evaporation was used (Wisłocki, 1991). The simplest solution was to use water injection into the charge air. It was used in American Allison, Wright and Pratt & Whitney engines (White, 1995) as well as British Rolls-Royce and Napier (Lumsden, 1994). Experiments on water injection were also conducted in the USSR (Kotelnikov, 2005). This solution allows for a short-term increase in engine power. Due to the extra weight of the liquid, it is not possible to use it as a way to cool the charge air for a long periods of time. Moreover, water causes corrosion of engine parts and causes it to wear out faster.

In Germany, water injection was used only in a few types of drives, such as Junkers Jumo 213A and BMW 323R (Bridgman & Gunston, 2001). Due to the greater risk of corrosion, engines equipped with it were inspected every 50 hours of operation. Water injection with methanol was used much more often (Fig. 4, Table 1), as MW 50 (Methanol-Wasser 50%, containing 49.5% water, 50% methanol, 0.5% anti-corrosion agent) or MW 30 (Methanol-Wasser Wasser 30%, containing 69.5% water, 30% methanol and 0.5% anti-corrosion agent).

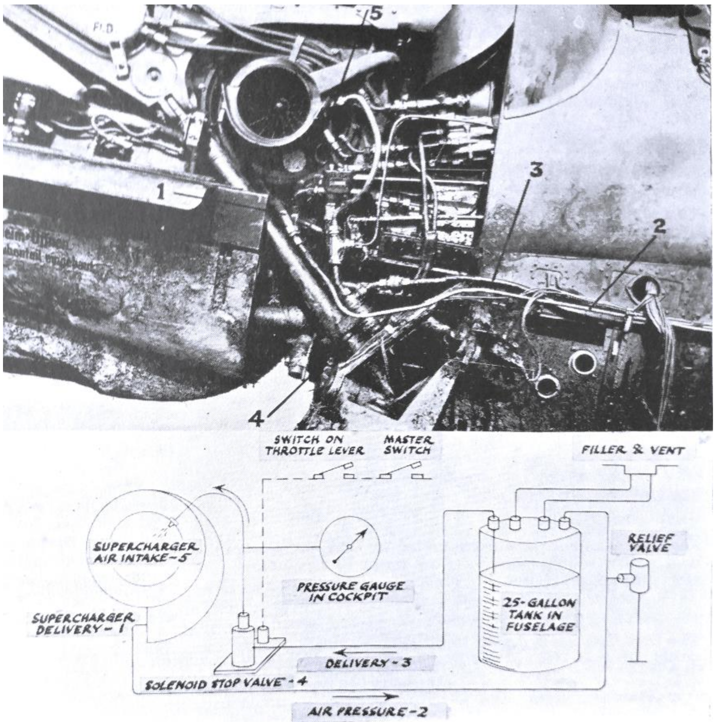

Figure 4. View and diagram of the MW 50 injection system in the Daimler-Benz DB 605 engine in the Messerschmitt BF 109 aircraft (Bridgman, 1970).

Table 1. The influence of MW 50 injection on the power of the Daimler-Benz DB 603L engine and the maximum speed of the Focke-Wulf Ta 152B aircraft powered by it (based on table from *Jane's all the world's aircraft 1945, collector's edition* by Bridgman (1994)).

Engine type	Ceiling [m]	Power [hp]	Power with MW 50 [hp]	Airplane speed [km/h]	Speed with MW 50 [km/h]
DB 603L	0	1,800	2,100	546	578
DB 603L	11,300	-	-	706	-
DB 603L	10,500	-	-	-	745
DB 603L	9,000	1,450	1,750	-	-
DB 603E	0	1,800	2,250	550	595
DB 603E	8,200	-	-	671	-
DB 603E	6,800	-	-	-	698
DB 603E	5,500	1,630	1,900	-	-

This allowed for a significant increase in engine power at low and medium altitudes (Fig. 5). Alternatively, in systems adapted to inject water with methanol, it was possible to use water with ethanol (49.5% water, 50% ethanol, 0.5% anti-corrosion agent) (Bridgman, 1945). In some American engines, such as the Allison V-1710 and at the end of the war also in British ones, water injection was replaced with water-methanol injection, just like in German engines (Lumsden, 1994; Connors, 2010).

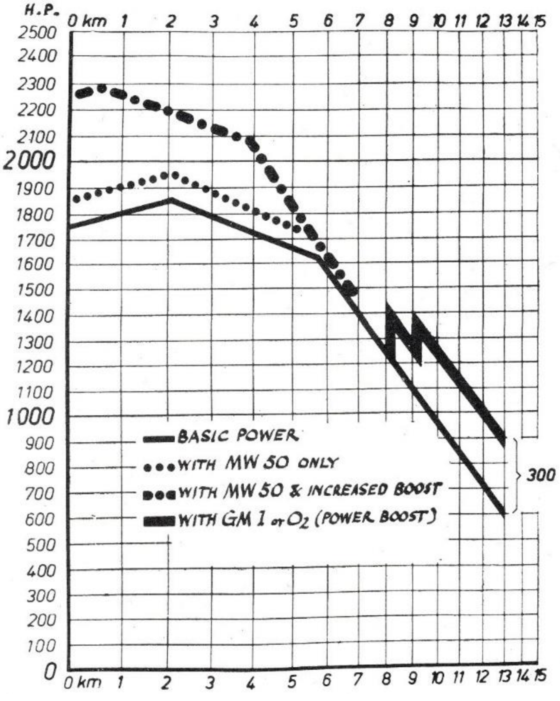

Figure 5. Altitude characteristics of an example German engine without injection, with MW 50 injection, with MW 50 injection and increased charging pressure, and with GM 1 or pure oxygen injection (Bridgman, 1970).

Some versions of the Daimler-Benz DB 601, Junkers Jumo 213 and BMW 801 engines use nitrous-oxide injection. The official name of this system is "ha-ha" or "laughing gas". The designation is GM 1. The gas injected under high pressure was in the form of a liquid, which then evaporated in the charge air. In addition to its cooling properties, nitrous-oxide acted as an oxidizer, which allowed for a higher oxygen content in the cylinder during combustion and meant an increase in engine power at high altitudes (Fig. 5) (Bridgman, 1970).

The BMW 801D engine uses gasoline injection into the charge air. By evaporating, it also allowed the charging air to cool. With the increase in the charging pressure, this allowed for an increase in the maximum power from 1730 hp (1272 kW) to 1870 hp (1375 kW) (Bridgman, 1996).

Unconventional Charging Systems.

The last method of charging aircraft engines introduced into operation was created at the turn of the 1930s and 1940s. It involved recovering power from exhaust gases by the turbine and transmitting it to the crankshaft. Such a solution is referred to as a turbo-compound. The system usually worked with a mechanical supercharger, but there were also engines that were also equipped with a turbocharger. For the first time, such a supercharging method was used in the Rolls-Royce Crecy (Nahum, Foster-Pegg, & Birch, 2013). It was a two-stroke engine in an in-line system (Rubbra, 1990). Many consider it to be the peak example of the development of piston aircraft propulsion (Pełczyński, 2023b).

The most famous engine with such solution is probably the Wright Turbo-Cyclone R-3350, which was equipped with a two-speed mechanically driven centrifugal supercharger. In addition, three turbines were connected via a gear to a shaft to which they transmitted the recovered power. Turbo-Cyclone engines were used in the recent large piston engine-powered passenger aircraft, such as the Douglas DC-7 and the Lokheed Super Constellation (Taylor, 1971). The second well-known example is the Pratt and Whitney R-4360 in a four-row radial system, which turned out to be even better than the aforementioned Wright engines. In some versions it was equipped with a turbo-compound, turbocharger and mechanical supercharger (Connors, 2010). It became the power plant for large military aircraft such as the Convair B-36 Peacemaker bomber.

An interesting engine exploiting the described solution was also the British two-stroke, self-ignition Napier Nomad (Gunston, 1998). The engine, although very interesting, was not a success due to the growing popularity of turbine engines, with which it could no longer compete.

A properly designed engine exhaust system allows exhaust gases to be directed rearward in order to obtain additional thrust. An example would be the Rolls-Royce Merlin, in which it was possible to increase the thrust of the propulsion system by approximately 670 N. Estimated for such a system, during a flight at a speed of approximately 480 km/h, one pound of force, i.e. 4.45 N, is equivalent to additional

1 hp in the engine, assuming a propeller efficiency of 80%. This means that the obtained thrust corresponds to a power of approximately 188 hp (Nahum, Foster-Pegg, & Birch, 2013). At the end of World War II, Rolls-Royce conducted research on developing the concept of using exhaust gases to create additional thrust. According to the first, simplest version, the exhaust gases were to go into a channel through which air flowed. The exhaust gases increased the mass flow in the channel and their energy. Thanks to this, a certain thrust was created. There were several versions of this solution, designed as a straight channel or additionally connected to a mechanical supercharger or turbocharger. A further development was the afterburning of exhaust gases in the channel, which would additionally increase thrust (Nahum, Foster-Pegg, & Birch, 2013).

The solution was provided for the Rolls-Royce Crecy engine. In 1942, a project was created to use it in the Supermarine Spitfire airplane. According to calculations, taking into account the thrust of the exhaust gas, the maximum speed would be 792 km/h. The airplane with the Rolls-Royce Griffon engine produced at that time was able to reach 665 km/h (later versions with the Griffon engine reached approximately 730 km/h) (Nahum, Foster-Pegg, & Birch, 2013).

In 1943, the concept of using Crecy engines in the De Havilland Mosquito aircraft was also created. Ultimately, it turned out that it was impossible to use the full capabilities of the engine in both the Spitfire and Mosquito airplane due to the risk of easily exceeding the maximum permissible speed. For this reason, the decision was made to use the Crecy engine in the more durable airframe of the North America P-51 Mustang airplane. According to calculations, it could achieve a maximum speed of approximately 965 km/h (Nahum, Foster-Pegg, & Birch, 2013).

Similar research has been carried out by Pratt and Whitney since 1946 in the R-4360 engine. The exhaust gases coming out of the cylinders powered an additional turbojet engine. Through channels from the exhaust valves, exhaust gases moved to the combustion chamber, into which fresh air, compressed with a separate compressor, entered. Behind the combustion chamber there was a turbine that powered the jet engine's supercharger and transferred some of the energy to the piston engine's crankshaft. Exhaust gases from the turbojet engine provided additional thrust (Connors, 2010)

Current Development of Supercharging of Piston Aircraft Engines.

Currently, most piston aircraft engines are not designed for high-altitude flights above 4,000 meters. For this reason, a significant part of currently produced aircraft engines are not equipped with superchargers. There is a tendency to use supercharging to ensure the highest possible pressure at sea level, which is intended to improve engine performance, among others, during takeoff (Walentynowicz, 2011).

Increasingly frequent use of direct fuel injection (Walentynowicz, 2021) allows for greater charging pressure at low altitudes. The reason is the lower risk of knocking combustion. In recent times, it has been possible to notice the abandonment of mechanically driven superchargers to turbochargers. Mechanical superchargers are still produced for older engine types and a few new ones. Therefore, their use is becoming less frequent.

Due to the currently slower development of aircraft piston engines than automotive engines, it will be more and more common to encounter the transfer of certain solutions typical of automotive drives to aircraft engines (Pełczyński, 2025).

Conclusions.

At the beginning of the 20th century, in order for airplanes to fly at higher and increasing altitudes, it became a problem to develop an appropriate propulsion system that would allow maintaining adequate power within the required altitude range. Three methods have been developed to achieve this. The first, historic method, is to design an engine designed to operate in the air density prevailing at the assumed altitude. This solution is described primarily in source materials from before World War II (Sherbondy & Wardrop, 1920) The second one is to ensure proper height adjustment of the carburetor, which allows to maintain an appropriate excess air ratio. The third, most effective way is to ensure the highest possible mass of air entering the engine cylinders, despite the decreasing air density with the flight altitude. This is accomplished using superchargers.

Turbochargers were the first to appear in aviation. They allow to maintain the most constant altitude characteristics. In addition, their efficiency increases with height. Initially, the main problem was the resistance of the materials used to the exhaust gas temperature (Pełczyński, 2023b).

Mechanically driven superchargers in aviation initially became much more popular than turbochargers. These were almost exclusively flow superchargers. It was easier to build a gearbox for a mechanical flow supercharger than for a sufficiently durable turbine. It is much more difficult to obtain achieve pressure with a mechanical supercharger over the widest possible range of altitudes. For this reason, complex two-speed or two-stage systems were used. Moreover, the efficiency of the mechanical supercharger decreases with increasing flight altitude. Since World War II, there has been a slow process of abandoning mechanical superchargers in favor of turbochargers.

From the second half of the 1940s and 1950s, piston aircraft engines were replaced by turbine engines in most of their applications (Opara, 2006). For this reason, most aircraft piston engines are currently designed for flights at low altitudes of up to 3,000–4,000 meters and therefore only some of them are supercharged. These are usually turbochargers or mechanical superchargers in older types of engines still in production (Smith, 1986). An example is the Asz-62IR engine, which is a licensed version of the Wright R-1820 engine from 1931. It is currently produced by WSK "PZL-Kalisz" (Kotelnikov, 2005).

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Якуб Пельчинський
Познанський технологічний університет, Польща

Мачей Байерлейн
Познанський технологічний університет, Польща

Огляд історії розвитку систем наддуву поршневих авіаційних двигунів

Анотація. *Предметом статті є огляд найважливіших фактів з історії розвитку систем наддуву поршневих авіаційних двигунів – від зародження авіації до сьогодення, з особливим акцентом на період домінування поршневих двигунів в авіації, тобто першу половину XX століття. У роботі зосереджено увагу на конструктивних рішеннях, які були розроблені протягом років і мали безпосередній вплив на експлуатаційні показники двигунів, висотні характеристики, а отже, й на льотно-технічні характеристики літаків. У перших розділах також висвітлюються причини використання наддуву в авіації, що випливають з несприятливих висотних характеристик атмосферних двигунів, двигунів малої висоти або двигунів, оснащених простими системами не висотного наддуву. Метою статті є всебічне окреслення теми наддуву поршневих авіаційних двигунів, включаючи не лише історію розвитку, а й перспективи цієї технології. Публікацію підготовлено на основі літератури, а передусім – на основі зібраного джерельного матеріалу, такого як каталоги, архівні публікації та каталогові бази даних. Вони дозволяють не лише ознайомитися із реалізованими рішеннями, але й оцінити та проаналізувати їх* *вплив на функціональність двигуна. Знання висотних характеристик чи експлуатаційних показників двигуна дає змогу оцінити доцільність впроваджених конструктивних рішень у його системі наддуву. Подібна робота вимагає не лише історичних досліджень, що спираються на джерела, а й технічних знань інженера, здатного інтерпретувати конкретні тенденції розвитку конструкцій машин, зокрема двигунів, та їх вплив на експлуатаційні показники. Такий підхід дозволяє не лише описати минуле, а й виявити тенденції розвитку протягом років. Аналіз історичних конструкцій і експлуатаційних показників часто ігнорується в науці, оскільки вимагає роботи на стику двох дисциплін – технічної та історичної. Проте він є важливим для розвитку історії техніки, оскільки стосується її центрального об'єкта – технічних засобів.*

Ключові слова: *системи наддуву; поршневі авіаційні двигуни; висотна характеристика; історія двигунів*

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