

Outline of history and comparative analysis of internal combustion engines for flying models

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The article discusses the most important facts from the history of the development of miniature aircraft engines and carries out their comparative analysis. Already in the 1930s, the structural system characteristic of model engines was established, which has hardly changed to this day. The following sections compare the various types of engines: two-stroke and four-stroke engines, spark-ignition engines, glow plug engines, engines with a push-pull cylinder arrangement, radial and in-line engines. The comparisons of the parameters and operational indicators of such engines presented in the tables allowed for the assessment of the advantages and disadvantages of individual engines, making several observations and drawing some more general conclusions.

Key words: *internal combustion engines, model engines, history of model engines, comparative, flying models*

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1. Introduction

With the development of technology, more and more complex and expensive to build machines are created. In order to reduce the costs of manufacturing and testing prototypes, their smaller models are often built, on which it is possible to test various design and technological solutions. It was similar in aviation. The first flights were always associated with a high risk, which is why some designers decided to build smaller, unmanned prototypes. For them, sufficiently small power units were needed; initially, miniaturized steam engines were used, then internal combustion engines. Over time, with the development of aviation, the role of experimental models has decreased. However, they began to be used for hobby and recreational purposes [14].

The subject of model aircraft propulsion is extremely interesting, and unfortunately, over the last several decades it has been quite disregarded in domestic literature. The last monograph devoted entirely to modeling engines "Popularne mikrosilniki spalinowe" [17] was written over 40 years ago by W. Schier, a great mentor of Polish aviation modeling.

During the time of the People's Republic of Poland, new monographs in this field, which were created almost every few years, testified to the great interest in the subject of model engines. The first monograph after the war was published in 1946: "Silniki lotnicze do modeli latających" by W. Niementowski [8].

The subject of miniature aircraft engines for flying models certainly deserves a new study, mainly due to the use of new design concepts and the development of model engines that have taken place in recent years. This article attempts to conduct a comparative analysis of the most important design parameters and operational indicators of modern model engines and to assess the current level of their development.

2. The history of the development of model engines

The second half of the nineteenth century was a time of an intensive development of steam engines. Then, they were the main source of propulsion, except, of course, for

draft animals. With the advancement of steam engines, the need quickly arose to test various designs and construction concepts on scaled-down prototypes. It allowed to avoid significant costs of building expensive and complicated devices in real sizes.

For the first time a steam engine to drive an aircraft structure was used by an Englishman, John Stringfellow, in 1848, Fig. 1. The engine propelled a three-meter model, which made several successful jumps at a distance of less than 40 meters [18].

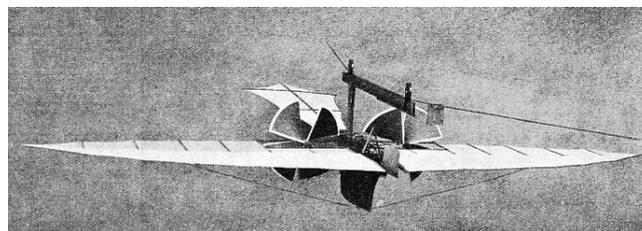


Fig. 1. John Stringfellow's airplane [41]

The steam engine of that time, however, was too heavy to be effectively used on a larger scale in aviation. Therefore, other solutions were sought. In the late 19th century, experiments were conducted with compressed air engines. The real breakthrough came with the development of internal combustion engines. In 1901, the first internal combustion miniature aircraft engine, designed by Samuel Pierpont Langley, was developed in the United States. Its power was 2 HP (about 1.5 kW) and allowed the flight of the model weighing 13.5 kg.

Soon after, the first "large" aircraft with a combustion engine was built [9]. Therefore, miniature engines began to lose their relevance. However, they quickly found a new application in aviation modeling. Initially, they were smaller and simplified versions of "large" four-stroke aircraft engines. Compressed air drive has been experimented with. A simple rubber drive was invented, which is used to this day in the simplest aircraft models. The first model engine with a classic design, similar to modern engines, was made

in 1934 in the USA; It was called Brown “Junior”, Fig. 2. It was a two-stroke, single-cylinder, spark-ignition engine, also called gasoline engine in modeling terminology because of the fuel it burns. It had a displacement of 9.72 cm^3 . It reached the power of 0.25 HP (approx. 0.2 kW) and the maximum speed of 6000 rpm. Currently, engines of this size can have nearly 10 times the power and 2-3 times the maximum speed. Nevertheless, at that time the Brown “Junior” engine was a breakthrough design and for those times – very modern.



Fig. 2. Engine Brown “Junior” [25]

The main problem in spark ignition engines was the considerable weight of the ignition system, especially the battery. The Swiss managed to solve this problem in 1940. They created a compression-ignition engine for model airplanes with the same layout as previously built model engines, i.e. the so-called self-ignition engine. It sucked in a fuel-air mixture from the carburetor, similar to spark ignition engines. The Swiss dubbed the new engine “Dyna 1”. It had a displacement of 2.04cc. It reached the power of 0.09 HP (approx. 0.07 kW) and the maximum speed of 7500 rpm [17].

After the end of World War II, self-ignition engines spread throughout Europe, almost completely replacing spark-ignition engines by the end of the 1950s [13].

The construction of the self-ignition engine offered many possibilities that were impossible to achieve with gasoline engines. Very small engines were built, even below 1 cm^3 of cylinder capacity, which – if they had a heavy ignition system with a spark plug – would not have any practical application [15]. A model powered by such a small motor would not be able to lift the battery.

Over the years, the modeling engines have been improved more and more. New, better and better flushing systems began to be used in two-stroke engines. A good example is the 1.8cc “Elfin 1.8” engine. It reached the power of 0.11 HP (about 0.8 kW) and the volumetric power ratio of 61 HP/dm^3 (45 kW/dm^3), which was much more than in the analogous spark ignition engines of that time. Such engines were also built in Poland. An example can be the famous “Jaskółka” Fig. 3 [14].



Fig. 3. Polish self-ignition engine “Jaskółka” with a capacity of 2.5 cm^3 [26]

Despite the popularity of self-ignition engines in Europe, they never became widespread in the USA. Gasoline engines were constantly improved there, achieving a power ratio of over 100 KM/dm^3 (76 kW/dm^3), higher than most of the then engines [17]. Still, an unsolved problem was the considerable weight of the ignition system, especially the battery [22].

The breakthrough for American modeling was the invention of the glow plug by Roy Arden. He used it for the first time in his “Arden .09” engine. The model automatic engine with glow plug ignition, also referred to as a glow engine, which he created had the same structure as the rest of the model engines [14]. The only difference was the glow plug, which does not need to be permanently connected to the power source, but only during start-up. Therefore, the battery that powers it does not have to be on board an airplane model. It only needs to be connected to the plug on the ground when starting the engine, before take-off [6].

For some time, the development of model engines was different in America and Europe. Spark ignition engines in the USA were replaced by compression ignition glow engines, and in Europe by compression ignition self-ignition engines [14].

In the 1950s, further development of model drives showed the superiority of glow engines in terms of the power achieved. However, in Europe, self-ignition engines were already very common. They also burned less fuel. Glow engines slowly began to appear on the European market in the second half of the 1950s, but they were fully ousted only several dozen years later, Fig. 4.



Fig. 4. Modern ASP S52A glow engine [29]

The 1950s and 1960s were a period in which the so far built sub-square [1] engines with a large piston stroke, larger than the cylinder diameter, were more and more often replaced by engines with the same stroke as the diameter or with a stroke greater than the diameter, i.e. square motors. The stroke-to-diameter ratio is usually only slightly less than one, although in the 1960s experiments were conducted on motors with a very small ratio of these sizes. An example is the Soviet self-ignition engine by engineer Blinov, where this value was 0.27 [14].

In the 1960s, the so-called multi-range engines, i.e. with the possibility of changing the rotational speed, and not, as before, without such a possibility. In order to ensure the maximum simplification of construction, initially efforts were made to solve their operation in various unusual ways. Experiment with adjusting the engine speed only by changing the position of the needle valve (needle) of the carburetor. For some time, a popular solution was to use a special, simple, controlled shutter of the outlet opening in the cylinder. By exposing the exhaust port, the exhaust gases from the cylinder were allowed to flow out normally, and by obstructing their outflow. Eventually, development of rotary damper carburetors began. Thus, at the end of the 20th century, multi-range engines with a rotary throttle in the carburetor almost completely replaced those without the possibility of rotational speed control [17].

Interesting solutions tested in the 1960s were Wankel engines, i.e. engines with a rotating piston. Despite their short-lived popularity, they did not enter into wider use for a long time. An example can be the Polish "SW-92" engine designed by MSc. J. Fałęcki from the Institute of Aviation in Warsaw. Its structure, together with executive and assembly drawings, is presented by W. Schier in the book „Miniaturowe silniki spalinowe” from 1967 [14].

By the end of the 20th century, self-ignition engines were practically out of use. Currently, virtually no one produces them. There are only rare exceptions to the solutions offered as "retro engines". Very small self-ignition engines for particularly small model aircraft are also appearing in the USA. In recent years, however, spark ignition engines have become widespread. They are designed for large aircraft models where the weight of the ignition system is of little importance. This is possible because currently used nickel or lithium batteries are much lighter than those used in the past. Therefore, no such engines are produced with displacements of less than 10 cm³. The main advantage of spark ignition engines is the low price of gasoline that drives them in relation to methanol-based fuels used in glow engines. Currently, almost all engines with a cylinder capacity exceeding 20-30 cm³ are built as spark ignition engines, Fig. 5 [6].

Nowadays, very large, multi-cylinder model engines are also built, the power of which can exceed 20 HP (approx. 15 kW). Such engines are usually built in a system with push-pull pistons (the so-called boxer), less often in an in-line configuration.

Four-stroke engines are also being built. They have less power and a lower maximum speed than two-stroke engines, but they are considered more exclusive, and the sound they make is extremely beautiful. Manufacturers

often advertise the sounds of their engines. Four-stroke radial engines and sometimes also four-stroke in-line engines are considered extremely exclusive. They are valued primarily for their aesthetic qualities. They can also be used in mock-ups of airplanes that actually had radial engines. Thanks to this, instead of inserting a mock-up of a radial engine into the engine cover, you can place a real engine there, which powers the model during flight [21].



Fig. 5. O.S.Gasoline spark ignition engine MAX GT60 [33]

3. Comparative analysis of two-stroke and four-stroke engines

Nowadays, the vast majority of aircraft engines for flying models are built as two-stroke engines, Fig. 6, Fig. 7. They have a simpler and cheaper structure than four-stroke engines and have greater power [10]. The only technical advantage of four-stroke engines is that they burn less fuel. Fuel injection and power stroke occur every second revolution of the crankshaft. Valves opened at appropriate moments prevent the formation of such large losses of the mixture during injection, as in two-stroke engines, in which, during the rinsing process, part of the mixture escapes along with the exhaust gases through the outlet port [2]. Nevertheless, with such small displacements, the difference in the fuel used is so small that the difference in the price of the fuel used is negligible in relation to the difference in the price of the engines. Therefore, four-stroke engines (Fig. 8) in modeling will probably never fully replace two-stroke engines [12].

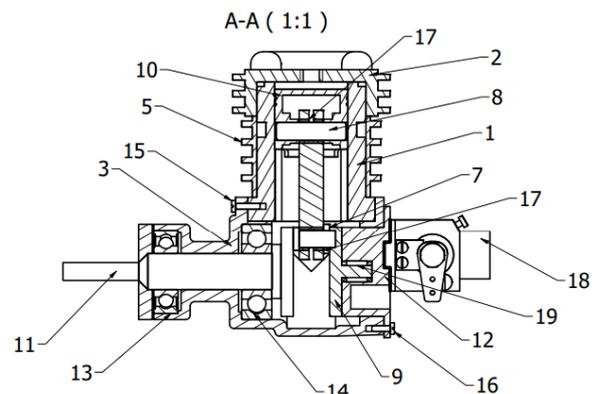


Fig. 6. Cross-section of a typical two-stroke glow engine, fragment of the assembly drawing [12]



Fig. 7. ASP 180 AR two-stroke glow ignition engine [29]



Fig. 8. The Saito FA-125 A four-stroke glow-ignition engine [36]

The only real advantage of 4-stroke engines is their clear sound when operating. It is especially appreciated by modellers. In models of real aircrafts, it allows not only to match the original appearance, but also in terms of the sounds that the plane makes during the flight. Four-stroke engines are considered more elegant and exclusive than ordinary two-stroke engines [11].

As can be seen from the comparison in Table 1 and 2, the power of two-stroke engines is much greater than the power of four-stroke engines. Two-stroke engines with small and medium displacements also have significantly higher maximum speeds. In four-stroke engines, however, they do not change significantly with increasing displacement, while in two-stroke engines they decrease significantly. Thus, large four-stroke engines (from about 15 ccm) often have higher RPMs than similarly sized two-stroke engines.

The main parameters by which two-stroke and four-stroke engines can be compared are the maximum speed and power. These are also the basic parameters provided by the producers. Tables 1 and 2 provide lists of engines for two selected cylinder capacities. Only the glow engines were selected for comparison as they are the most popular.

The unit power of two-stroke engines decreases with the displacement, and in four-stroke engines it remains unchanged. Nevertheless, for typical displacements used in single-cylinder model aircraft engines, its value is always higher for two-stroke engines.

Two-stroke engines with small displacement can generate very high power in relation to their displacement. An example is ASP 12A with a capacity of 1.94 cm³, for which this ratio is as much as 309 KM/dm³ (about 228 kW/dm³) [11].

Table 1. Glow engines with a displacement of approximately 10 cm³ [27, 28, 30, 32, 35, 38-40, 42]

Two-stroke engines	Maximum rotational speed [rpm]	Power [hp (kW)]	Specific power [KM/dm ³]	Four-stroke engines	Maximum rotational speed [rpm]	Power [hp (kW)]	Specific power [KM/dm ³]
MAX-55AX	17,000	1.68 (1.24)	188	O.S. MAX FSa-56II	13,000	0.99 (0.73)	106
ASP S61A	17,500	2.19 (1.61)	229	Saito FA-62B	11,000	1.01 (0.74)	101
MAX-65AX	12,000	1.73 (1.27)	163	ASP FS61AR	11,500	1.14 (0.84)	114
Super Tigre G-61 Ring	16,500	1.80 (1.32)	180	O.S. MAX FS-62V	11,000	1.08 (0.79)	107
Average	15,750	1.85 (1.36)	190	Average	11,625	1.06 (0.78)	107

Table 2. Glow engines with a displacement of approximately 20 cm³ [27, 28, 30, 32, 35, 38-40, 42]

Two-stroke engines	Maximum rotational speed [rpm]	Power [hp (kW)]	Specific power [KM/dm ³]	Four-stroke engines	Maximum rotational speed [rpm]	Power [hp (kW)]	Specific power [KM/dm ³]
MAX-120AX Ring	9600	3.06 (2.25)	153	O.S. MAX FS-120SII	12,000	2.07 (1.52)	104
ASP 120AR	9600	3.60 (2.65)	180	ASP FS-120AR	11,500	2.13 (1.57)	107
Moki M140 RC	13,000	3.90 (2.87)	173	Saito FA-125a	11,000	2.22 (1.63)	108
Average	10,730	3.52 (2.59)	169	Average	11,500	2.14 (1.57)	106

4. Comparative analysis of glow and spark ignition engines

Currently, most of the engines for models produced are compression ignition engines with a glow plug. It is exactly the opposite of aero engines for propulsion of "large" aircraft, where compression ignition engines are a minority [5]. However, more and more often engines with a cylinder capacity exceeding 10–15 cm³ are built with spark ignition, Fig. 9. At the beginning of the history of engines for model aircraft, only spark ignition engines were produced [14]. Their main disadvantage was the weight of the ignition system, especially the battery. Currently used nickel or lithium batteries are much lighter than those used in the past, so their weight in larger models with spark ignition engines is not a problem [6]. The use of a glow plug allows the construction of very small engines for small models. The glow plug needs to be connected to the power source only during start-up, therefore the battery does not have to be on board the model. The construction of spark ignition and glow engines is practically no different. The only significant difference, apart from the ignition system, is the compression ratio – in glow engines it is higher [17].

Spark ignition engines burn ordinary gasoline, which can be obtained, for example, at a gas station. That is why they are also called gasoline engines in modeling. Fuel for glow engines is much more expensive. Its main ingredient is methanol. Usually it also contains nitromethane, which increases the calorific value of the fuel. Usually its content is significant, it can reach even 30–40% of the total volume of the fuel consisting of pure methanol. Such fuel is produced especially for incandescent engines. Fuel with

a composition of 70% methanol and 30% nitromethane has a calorific value of about 25% greater than that of pure methanol [16]. You can buy it only in stores and modeling wholesalers, which makes it much more expensive than gasoline. This is the main reason why gasoline engines are used, not just glow ones.



Fig. 9. Spark ignition engine O.S. MAX GT15 [29]

As in the case of the comparison of two-stroke and four-stroke engines, Tables 3, 4 and 5 contain lists of engines for selected cylinder volumes, giving the power and maximum rotational speed of these engines.

Table 3. Engines with a displacement of approximately 15 cm³ [27, 28, 30, 32, 35, 38-40, 42]

Glow engines	Maximum rotational speed [rpm]	Power [KM (kW)]	Specific power [KM/dm ³]	Spark ignition engines	Maximum rotational speed [rpm]	Power [KM (kW)]	Specific power [KM/dm ³]
Super Tigre G-90 Ring	16,000	2.5 (1.84)	170	O.S. MAX GT15	15,000	2.47 (1.82)	165
ASP S91A	18,000	2.8 (2.06)	187	RCGF 15cc	15,000	2.4 (1.77)	160
MAX-95AX RING	16,000	2.86 (2.1)	184	ngh GT17	9000	2.1 (1.54)	124
Average	16,700	2.72 (2.0)	180	Average	13,000	2.32 (1.71)	150

Table 4. Engines with a displacement of approximately 20 cm³ [27, 28, 30, 32, 35, 38-40, 42]

Glow engines	Maximum rotational speed [rpm]	Power [KM (kW)]	Specific power [KM/dm ³]	Spark ignition engines	Maximum rotational speed [rpm]	Power [KM (kW)]	Specific power [KM/dm ³]
MAX-120AX Ring	9600	3.06 (2.25)	153	DLE20	9000	2.5 (1.84)	125
ASP 120AR	9600	3.6 (2.65)	180	RCGF 20cc	10,500	2.8 (2.06)	140
Moki M 140 RC	13,000	3.9 (2.87)	173	Valley View 20cc	9000	2.5 (1.84)	125
Average	10,600	3.45 (2.54)	169	Average	9500	2.6 (1.91)	130

Table 5. Engines with a displacement of approximately 30 cm³ [27, 28, 30, 32, 35, 38-40, 42]

Glow engines	Maximum rotational speed [rpm]	Power [KM (kW)]	Specific power [KM/dm ³]	Spark ignition engines	Maximum rotational speed [rpm]	Power [KM (kW)]	Specific power [KM/dm ³]
Moki M 180 RC	12,000	4.1 (3.02)	138	MVVS 30 IFS/ICU-L	9500	4.1 (3.02)	137
ASP 180 AR	10,000	6.0 (4.41)	201	DLE30	8500	3.7 (2.72)	123
Average	11,000	5.05 (3.71)	170	average	9000	3.9 (2.87)	130

As can be seen from the presented comparisons, glow engines are usually more powerful than spark ignition engines. The maximum speed is similar, although in glow engines it is usually slightly higher than in spark ignition engines. The unit power of glow engines is much greater than those of spark ignition engines. For both types of engines, it decreases as the displacement increases. It should be noted that the comparisons were made for extreme values. A displacement of 15 cm³ is perfectly normal for glow engines, while for gasoline engines it is almost the lower limit, below which they are usually no longer built. There are only a few types of smaller displacement engines. 20cm³ glow engines are much rarer than spark ignition engines of this size. 30cm³ engines are very rarely built as glow engines. Here, the glow engines with the largest value of cylinder capacities and the spark ignition engines for the smallest were compared.

The smallest glow engines have very high maximum rotational speeds. An example would be the ASP AP. 061 A Wasp engine, with a rotational speed of 25,000 rpm. This engine has a displacement of 1 cm³. Building a spark ignition engine of this size would be possible, but it would be practically pointless, as its applicability would be significantly limited by the considerable weight of the ignition system [11].

5. Engines with push-pull cylinder arrangement

The largest modeling engines are those with a push-pull cylinder arrangement, also known popularly as boxers, Fig. 10. The largest of them exceed the volume of 300 cm³, reaching a power of 40 HP (approx. 30 kW) or more. Usually they are not smaller than 20–25 cm³, i.e. about 10 cm³ per cylinder.

There are several reasons why boxer engines are built. First of all, the capacity of a single cylinder cannot be increased without limit. It would be difficult to fit in the fuselage of an aircraft or in the engine nacelle, and the large and protruding cylinder would be a significant drag in flight [19]. In many models of real airplanes, a single cylinder protruding beyond the fuselage would spoil the silhouette of the model [21], especially in airplanes that also originally had a boxer engine. Engines with a push-pull cylinder arrangement are also characterized by the lowest vibrations during operation. Vibrations from opposite cylinder can cancel out partially.

Due to the fact that boxer engines usually have large displacement volumes, the vast majority of them are spark-ignited. Glow plug ignition engines are also built, usually

then also four stroke. Their displacement volumes do not exceed 60 cm³, i.e. up to 30 cm³ per cylinder. However, they are quite rare exclusive products, in which the aesthetic values and the sound they produce outweigh the practical ones; similar to the single cylinder four-stroke engines. Pull-push cylinder arrangement engines are usually built for high horsepower, and therefore have a two-stroke cycle.



Fig. 10. Two-stroke gasoline boxer engine RCGF 70cc T [34]

Engines with a push-pull arrangement of cylinders always have at least one pair of cylinders located opposite to each other [4]. The axis of one of them is slightly shifted back to the axis of the other, which is due to the location of the connecting rods on the crankshaft. Each pair has a common crankcase and carburetor. The pistons in a pair simultaneously execute the same power stroke. As a result, the boxer engines are characterized by low vibrations during operation and good balance. Single boxer engines (i.e. with one pair of cylinders) or double boxer engines (i.e. with two pairs of cylinders) are built. Engines with three pairs of cylinders are much less common.

It is difficult to compare engines with a push-pull cylinder arrangement and single cylinder engines, as few designs have similar displacements. Table 6 presents a simplified comparison of several; push-pull (boxer) engines with single-cylinder engines of the same displacement.

Table 6. Comparison of basic indicators for single-cylinder and boxer engines with comparable displacements [27, 28, 30, 32, 35, 38-40, 42]

	20 cm ³		30 cm ³		40 cm ³		60 cm ³	
	Single-cylinder engine	Boxer						
Name	RCGF 20cc	RCGF 20ccT	DLE 30	RCGF 30ccT	Zenoah 38 cm	DLE 40	O.S. MAX GT60	DLE 60
Power [KM (kW)]	2.8 (2.06)	2.8 (2.06)	3.7 (2.72)	3.7 (2.72)	2.64 (1.94)	4.8 (3.53)	6.0 (4.41)	7.0 (5.15)
Maximum rotational speed [rpm]	10,500	8600	8500	8500	9500	8500	8000	8500
Mass [g]	798	920	1140	1145	1623	1450	1400	1950

From the list in Table 6, it can be concluded that the maximum rotational speeds of the engines with the push-pull cylinder arrangement and the single-cylinder engines do not differ significantly. But you can see some difference in the achieved power. The boxer engines have a displacement similar to that of single-cylinder engines in the region of 30 cm³. In engines with a displacement of 40 cm³, there is already a significant difference in favor of the boxer engines. It should also be noted that the boxer engines are usually heavier than single-cylinder engines [11].

6. Radial engines

Radial engines (Fig. 11) in modeling are used to a fairly limited extent, as they are among the most expensive reciprocating model engines. They are considered the most exclusive. Therefore, they are only built as four-stroke. Radial engines do not match the performance of engines with a similarly sized push-pull cylinder arrangement. Their use is limited primarily to models where appearance matters. An example of this is models of real aircrafts where a real radial engine adds authenticity compared to a single-cylinder or boxer engine, often hidden or integrated into a model of a radial engine.

The smallest of the model radial engines have several dozen cm³ of displacement, the largest ones can even be up to 400 cm³. Together with the engines with the push-pull cylinder arrangement, they are among the largest model engines. They can be built with both glow and spark ignition.



Fig. 11. 7-cylinder Evolution Radial 260cc engine [37]

In a radial engine, connecting rods with pistons are placed radially around the crankshaft [23]. To avoid resonance of inertia forces, their number is always odd. 3-cylinder, 5-cylinder, 7-cylinder and 9-cylinder engines are built. In “real” aviation, there are engines with a greater number of cylinders, in a double or even quadruple radial system [23]. In modeling, however, motors in a multiple radial system do not exist.

Table 7 presents an illustrative comparison of spark-ignition radial engines with two-stroke boxer engines, also with spark ignition. Due to the relatively small number of model radial engine types produced, the list is simplified, as in the case of boxer engines.

On the basis of the quoted list, the following conclusions can be drawn: above all, radial engines are inferior in all respects to engines with an push-pull cylinder arrangement. Therefore, in terms of performance, the boxer engines are much more profitable as large model engines. Radial engines are always inferior to them in terms of power, usually also in terms of maximum speed and weight.

7. In-line engines

In-line engines (Fig. 12) are rarely used in modeling; there are very few designs of such engines. Two-stroke in-line engines may be an alternative to push-pull cylinder engines in airplanes which require a narrow fuselage for some reason. An example can be models of real airplanes, which in fact also had an in-line engine [21]. The four-stroke in-line engines are more exclusive. By using such engines in models of real aeroplanes, you also get pure sound, more like the original engine used in a real, original airplane.



Fig. 12. MVVS 116 iL two-cylinder two-stroke in-line engine [31]

Table 7. Comparison of basic indicators for radial and boxer engines with comparable displacements [27, 28, 30, 32, 35, 38-40, 42]

	Ca. 20 cm ³		Ca. 60 cm ³		Ca. 125 cm ³		Ca. 180 cm ³	
	Radial engine	Boxer	Radial engine	Boxer	Radial engine	Boxer	Radial engine	Boxer
Name	Saito FG-19R3	RCGF 20cc TWIN	Saito FG-60R3	DLE60	UMS 5-125cc	DLA 128	UMS 5-180cc	DLA 180
Power [KM(kW)]	1.5 (1.1)	2.8 (2.06)	4.5 (3.31)	7.0 (5.15)	8.0 (5.88)	13.0 (9.56)	10.9 (8.02)	18.5 (13.61)
Maximum rotational speed [rpm]	10,000	8600	7000	8500	6000	6600	5500	6200
Number of cylinders	3	2	3	2	5	4	5	2
Mass [g]	950	920	1850	1950	3900	3780	4700	4130

Table 8. Comparison of basic indicators for in-line and two-stroke boxer engines with comparable displacements [27, 28, 30, 32, 35, 38-40, 42]

	60 cm ³		100 cm ³		116 cm ³	
	In-line engine	Boxer	In-line engine	Boxer	In-line engine	Boxer
Name	Moki G 360 RC	DLE60	DA-100I	DA-100L	DLA160i2	MVVS 116NS IRS
Power [KM (kW)]	7.3 (5.37)	7.0 (5.15)	–	9.8 (7.21)	13.0 (9.56)	11.0 (8.09)
Maximum rotational speed [rpm]	11,000	8500	6800	6800	6500	7500
Number of cylinders	2	2	2	2	2	2
Mass [g]	2450	1950	3450	2800	3744	3310

Table 9. Comparison of basic indicators for in-line and four-stroke boxer engines with comparable displacements [27, 28, 30, 32, 35, 38-40, 42]

	60 cm ³		85 cm ³	
	In-line engine	Boxer	In-line engine	Boxer
Name	ngh GF60i2	Saito FG-61TS	ROTO 85 FSI	ROTO 85 FS-NG
Power [KM (kW)]	6.3 (4.63)	–	–	–
Maximum rotational speed [rpm]	7500	7400	5800	–
Number of cylinders	2	2	2	2
Mass [g]	2940	2090	3000	2790

The pistons in an in-line engine are arranged in a row, one after the other on the crankshaft. “Large” in-line engines may have cylinders arranged in two or more rows. This happens only in the largest engines, which are no longer being built [7]. In modeling engines, however, such a solution has never been used.

The vast majority of in-line miniature aircraft engines for flying models are built with spark ignition. There are only a few designs of compression-ignition in-line engines.

Table 8 shows a simple comparison of the spark ignition two-stroke in-line engines with the push-pull cylinder two-stroke engines, also with spark ignition. The second list in Table 9 concerns four-stroke spark ignition engines.

Due to the small number of produced types of in-line engines, it is difficult to make a meaningful comparison. In addition, rarely used engine types have little data available. However, on the basis of the quoted summaries, several conclusions can be drawn. Inline and boxer engines have similar values of operational indicators. The main difference is the much greater weight of the inline engines. As a result, the use of in-line engines in modeling is unprofitable, except when it is absolutely necessary to keep a narrow fuselage.

8. Summary and conclusions

This article presents a comparative analysis of the construction of model aircraft engines. This required supple-

menting the information in relation to the last monographs entirely devoted to this issue from forty years ago. During this time, a lot of changes took place in the technique of miniature motors.

Currently, the modeling market is dominated by glow engines and large, more and more perfect spark ignition engines. Self-ignition engines are practically no longer used. Small internal combustion engines have been largely replaced by brushless (induction) electric motors [6]. In the past, even small engines with a displacement of 0.5 cm³ were produced. Motors with such small capacities turn out to be heavier than electric motors of similar power together with the battery.

Model making is constantly evolving, and there are still many people in Poland who deal with it. Unfortunately, currently no one in Poland produces piston model engines. Although there is a company near Poznań that produces turbojet engines for models, they are not the most popular propulsion for model aircraft and do not fit into the subject of this study.

In the Czech Republic, however, model making is developing very intensively. Particular attention can be paid to excellent Czech gasoline engines from companies such as MVVS or ZDZ. Their products far surpass most other motors.

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Jakub Pełczyński, Eng. – Faculty of Civil and Transport Engineering, Poznan University of Technology, Poland.
e-mail: jakubpelczynski-1999@wp.pl

