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Abstract. **The main theme of the work is using of electric energy for flight in the 19th century. The article contains information about the projects of airplanes and helicopters with electric engines, tests of electric dirigibles. The advantages and disadvantages of the electric motor as an aircraft propulsion system are shown in comparison with the engines of other types - the steam machine and the gasoline motor. There are also dates on the original ideas of Russian aviation inventors - A.N. Lodygin, N.A. Shishkov, V.A. Tatarinov.**

Keywords: helicopter, dirigible, airplane, electric engine

Attempts to construct motorized aircraft got started in the middle of the 19th century. The only type of engine that was available at the time was based on steam engine. This system, used in shipping and rail transport, was far too heavy for being of any practical use together with airplanes, helicopters, or even airships.

The discovery of electromagnetic induction rapidly advanced the further development of electrical engineering. A new type of power plant emerged - the electric motor. In 1838, the Russian physicist B.S. Jacobi conducted first experiments by using electric traction in a transport setting, equipping a vessel that carried 11 persons with 1 hp electric motor. The craft was able to cover short distances along the Neva river, even moving against the current. Later, more advanced models of electric motors with annular armatures and multi-section collectors appeared, improvements that ensured uniformity in the rotor movement. The greatest advances in this respect were made by the German firm Siemens.

One of the first who decided to use this new source of power together with aircraft was Russian inventor and electrical engineer A.N. Lodygin. In 1870, he sent a draft design of a helicopter − called "Electrolet" − to the Russian Minister of War. In a letter appended to the draft, Lodygin wrote:

"The experiments carried out by the Commission for use balloons in military affairs have given me the courage to turn to Your Excellency with a request to pay attention to the "Electrolet", an invention of mine. This aeronautical machine can move freely in various directions. Serving as a means of transporting cargo and people it can, at the same time, satisfy special military requirements as an offensive and defensive weapon. Having risen to a desired altitude, it is possible not only to safely monitor the actions of the enemy but also to destroy his combat and supply convoys by throwing explosive and incendiary shells from above: and all this without wasting any people for disarming the enemy ... I ask you to appoint a commission to consider this project, and to provide the means for building such a machine" [1].

"Electrolet" was to have a cylindrical body with a pointed bow and rounded rear based on a wooden frame covered with metal sheets. Atop there was a lifting screw, and at the back a rotary screw of a smaller diameter to create translational motion and control the direction of flight. The propellers were driven by a powerful electric motor via a transmission gear. To interrupt and close the current required for the rotational movement of the motor a mechanism was installed that Lodygin called the regulator. The power supply, apparently, was to come from batteries carried on board. According to the inventor, assuming an electric motor power of 300 hp, the total weight of the aircraft would be about eight tons. The power supply and weight of the 'Electrolet' were considered necessary to allow carrying a sufficient amount of ammunition.

Lodygin's project was rejected by the ministry, which recognized it as being impracticable. Lodygin, in turn, decided to offer it to France, which at that time was engaged in a war with Prussia. As he recalled: "I came to France with a proposal for a heavier-than-air flying machine. My project was approved by the National Defense Committee, and 50,000 francs were allocated; while all these preliminary actions progressed, however, France was lost the war. It had to sue for a truce, and then peace, and pay a billion to its adversary. As a consequence, the French government announced that a new flying machine was no longer needed: what is really needed for the country was money" [2]. That was the end of Lodygin's enterprise.

First practical steps regarding the use electricity for flying were taken in France together with the construction of airships during the 1880s.

In the fall of 1881, an International Electrical Exhibition was organized in Paris that demonstrated the manyfold applications of electricity with regard to medicine, entertainment, transport and in other areas. Suspended under the roof of the great exhibition hall

was a model aerostat constructed by Gaston and Albert Tissandier, both experienced and well-known aeronauts. The craft measured 3.5 m in length and had a diameter of 1.30 m. Filled with hydrogen, its lifting force was 2 kg. Installed at the lower part of the nacelle was a minuscule electric motor built by Parisian electrical engineer Gustave Trouvé; the contraption weighed just 220 grams. What made this motor unique was that some of its parts had been machined in the then revolutionary material aluminum.

This little motor was by a fixed shaft connected to a two-bladed propeller that was made of wood and textile; it turned at 6 revolutions per second. Energy for powering the motor was provided from two lead-acid batteries. Motor, batteries, hull and other equipment of the craft together weighed less than the lifting force of the balloon when filled with hydrogen (Fig. 1).

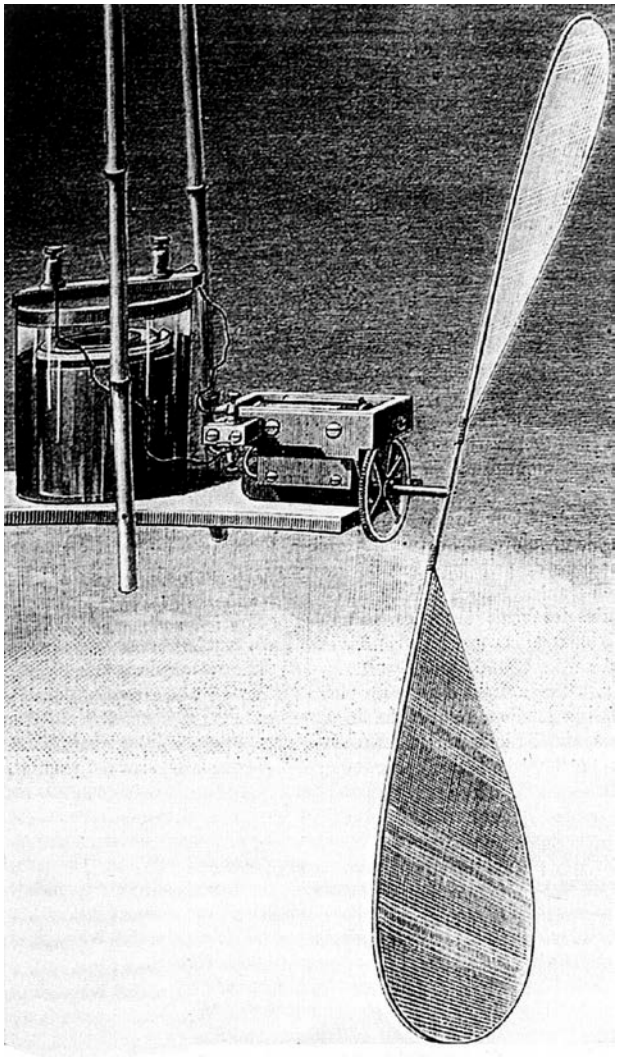

Fig. 1. Power plant of 1881 dirigible model

The little aerostat was demonstrated in full view of the public; it was tethered to a rope, which allowed towing it around like a circus horse. Astern was affixed a rudder, enabling the craft to move to the right or left. Throughout the exhibition, the aerostat was demonstrated twice each week.

Gaston Tissandier, meanwhile, had taken out a French patent − "New Application of Electricity to Aerial Navigation". In its specification he wrote: "Electric motors offer the following advantages: 1st) constant weight, meaning that the balloon stays balanced in the air; 2nd) absence of fire, which normally poses a considerable danger regarding envelopes filled with hydrogen; 3rd) the electric motor offers advantages together with easy starts and stops, and are marked by mechanical simplicity" [3].

Tissandier also founded a company with the intention to construct an aerostat of man-carrying capacity. During two years following the exhibition, Tissandier's team constructed an aerostat of 28 m in length. The nacelle of the craft consisted of a cage made of bamboo lashed together with ropes and copper wire covered with rubber; the floor was made of walnut planks covered by basketwork. The craft was equipped with a motor built by Siemens that weighed 54 kg. It was mounted on a wooden chassis and connected to propeller by special transmissions. Energy came from 24 heavy-duty dichromate potash batteries. The two-bladed pusher propeller was made of canvas/bamboo and turned at 180 rpm; it could be warped by pulling steel wires. The rudder was made of unvarnished silk stretched over a bamboo frame. The envelope weighed 170 kg, the motor and batteries 208 kg. Including the crew, the whole craft weighed 1,240 kg.

On October 8, 1883, the dirigible with the brothers Tissandier on board rose up into the sky at Auteuil southwest of Paris. The craft moved at a speed of some 10 km/h. It kept moving also against the wind, while rudder movements showed little effect. After 20 airborne minutes, the Tissandiers decided to land in a large field. There they left the craft inflated during the night that followed. A planned second ascent the following day was cut short, however: the cold of the night had led to a crystallization of the dichromate potassium in the ebonite reservoirs, causing the batteries, which were far from exhausted, to malfunction.

The Tissandiers, not distracted by any such mishaps, continued to improve their electrically powered dirigible. On 26 September 1884, the craft took to the skies again. With an improved rudder installed, it stayed airborne for one whole hour. Gaston Tissandier wrote:

"We took-off at 4:20 in the late afternoon, followed by thunderous applause and enthusiastic

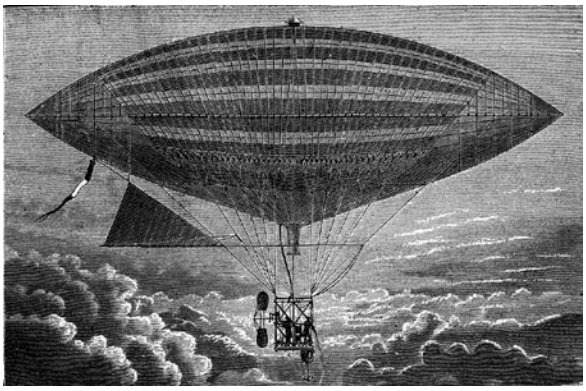

Fig. 2. Tissandier' dirigible

exclamations from the crowd gathered below. At an altitude of around 400 m, we were caught by a fairly strong northeasterly current, and I immediately started the engine. At first, the balloon continued to follow along, but then, obeying the rudder, it took another course, making a semicircle and moving against the wind. We felt a fresh breeze blowing right into our faces, and we fought, quite successfully, with the oncoming airflow. The wind speed was equal to 3 m/sec, and the speed of our balloon reached almost 4 m/sec. We continued like that for more than 10 minutes" [4] (Fig. 2).

Still, being unable to go against stronger headwinds, Gaston Tissandier had to land the craft close to the Servon forest in the Paris region.

The Tissandiers were not the only ones to design an electrically powered dirigible. Only some weeks earlier, on 9 August 1884, a second cigar-shaped aerostat had taken to the skies powered by what today is called a flow battery − electrical energy is thereby created by pumping chlorine from one chamber to another one containing zinc, generating power for the motor. The creators of this craft were Charles Renard, head of Central Establishment of Military Aerostation at Meudon, and his fellow officer Arthur Krebs.

Work with constructing the final version of the battery, which had a capacity of 44kg/hp, had started in early 1883. The electric motor, constructed by Krebs, had a rotor with two crowns and eight electromagnets and supplied on average by eight contact brushes. The whole apparatus weighed 88 kg and generated 8.5 hp. Affixed to the side of the craft's gondola, a steering wheel controlled the power of the batteries by pushing the zinc cathodes in and out of the batteries. (Fig. 3).

On 9 August 1884, Renard & Krebs' dirigible "La France" took to the air at Meudon. Its path continued overhead a farm at Villacoublay, then made a controlled return to Meudon. This was the world's first closed-circuit flight. It lasted for 23 min along a circuit of 8 km, giving "La France" an impressive speed of 19,8 km/h. On seven flights carried out in 1884 and 1885, "La France" returned five times to its starting point.

Despite this success, Renard realized the many limitations of lighter-than-air, battery-based, and electrically-powered dirigibles. For the coming 20 years of his life, he would move away from electricity as a source of power, concentrating his research on more efficient gasoline engines.

The flights of dirigibles powered by electric engines, and also Siemens' successful work with electric trains at that time, aroused the interest among writers of science fiction concerning flying machines powered by electricity. In his novel "Robur the Conqueror", Jules Verne introduced a giant electric helicopter, the "Albatross", letting it have the shape of a ship. The vessel moved through the air by 37 lifting and two pulling propellers at a speed of 200 km/h [5].

Concurrently, many projects of flying machines with electric motors were launched. Most, though, were technically poorly designed, and therefore differed little from the works of the science fiction community.

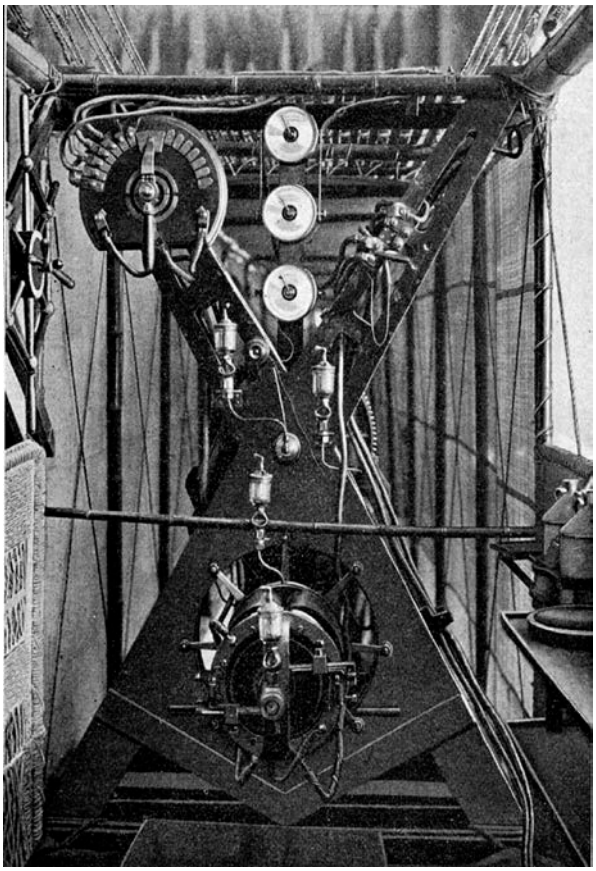

Fig. 3. Electric power plant of the dirigible "La France"

The most unusual technical proposals put forward in this respect include the projects by two Russians, Shishkov (1882) and Tatarinov (1891), with regard to electrically powered airplanes.

N.A. Shishkov suggested abandoning the use of heavy batteries carried on board, instead getting energy from the ground by using a movable contact: “News in foreign magazines about the gradual, but at the same time continuous spread of Siemens’ electric trains, and also about Tissandier’s experiments with a balloon having an engine running on electricity received from Fauré-batteries, led me to the following thoughts, the essence of which I will try to outline below. ... I suppose the possibility of constructing a flying machine, consisting of a light boat, placed in the longitudinal axis of a large plane (wing. – D.S.) and equipped with an electric motor connected by a long wire with a telegraph wire on ground stretched along poles. The idea is obviously that strong machines (electric generators - D.S.) send currents along a designated wire connecting stations A and B, and the engine, placed in the craft afloat, receives this current through a connecting wire in exactly the same way as a Siemens motor" [6]. Shishkov called his project the “Air Railroad”.

A major feature V.A. Tatarinov’s project was that the aircraft had no propeller. The thrust force was to be created by electric fan that injected air into a special bag installed under the wing having a horizontal slot in the back. Controlling the craft, according to the inventor, was done by changing the position of the passenger nacelle relative to the wing [7].

Another project in this same direction, an electrically powered helicopter designed by the Austrian engineer W. Kress, was far more realistic. In 1873 he began to study the properties of a lifting propeller. In the mid-1890s, Kress received an order from the military to build a tethered helicopter to replace the military’s captive observation balloons. The electric current, thereby, was to be transmitted upwards through a cable from the ground. An electric motor with a capacity of 20 hp and weighing about 200 kg was ordered from Siemens.

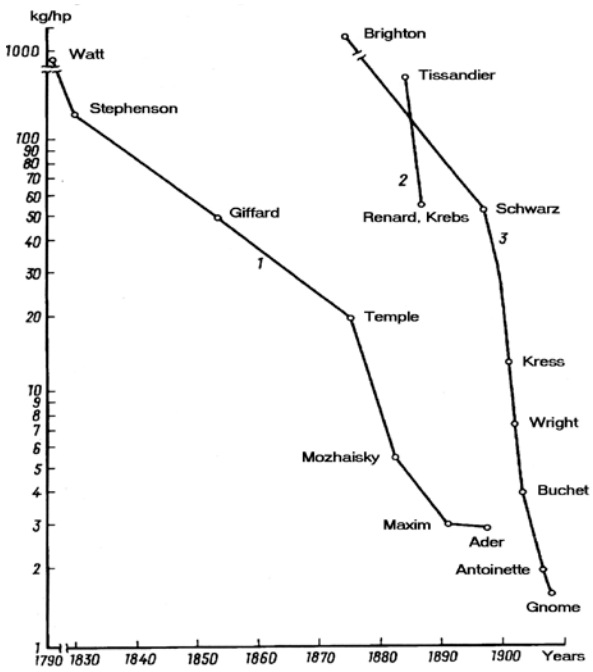

Fig. 4. Ratio weight to power of steam engines (1), electric engines (2) and gasoline engines (3)

However, in 1898, when the craft was partially finished, the military stopped funding the project, being unsure of its success [8]. Kress, in turn, started to construct an airplane powered by an internal combustion engine.

By the turn of the 20th century, electrically powered aircraft, which require carrying heavy batteries on board, came out of fashion. This, of course, is mainly due to the successful development of a new type of power plant – the gasoline-based internal combustion engine. Under the direct influence of the automotive industry the development of gasoline engines moved rapidly forward − pre-compression of the combustible mixture, float carburetors, improved ignition systems and other innovations made it possible to significantly reduce the dimensions and weight of engines while, at the same time, increasing their reliability and efficiency (Fig. 4). Soon, the internal combustion engine became the sole type of power plant used in aircraft.

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