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This Langley book has very good photographs of his work in 1894 and 1895 making a steam engine for his model airplane. Langley used a gasoline engine for his full sized airplane, the one that got caught in the catapult when being launched; thus crashing.

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There are later re-prints of this Smithsonian book. I have an original from 1909 and it is beautiful.

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SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE
VOLUME 27 NUMBER 3

LANGLEY MEMOIR ON MECHANICAL FLIGHT

PART I. 1887 TO 1896

BY

SAMUEL PIERPONT LANGLEY

EDITED BY CHARLES M. MANLY

PART II. 1897 TO 1903

BY

CHARLES M. MANLY

Assistant in Charge of Experiments

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The problem of generating steam was much more difficult and required a long and tedious series of experiments, which consumed the greater part of the year before any considerable degree of success had been attained. In the course of these experiments many unexpected difficulties were encountered, which necessitated the construction of special forms of apparatus, which will be described at the proper point. Numerous features of construction, which seemed to be of value when first conceived, but which proved useless when rigorously tested, will be noted here, whenever a knowledge of their valuelessness may seem to be of advantage to the reader.

The boiler was necessarily developed simultaneously with the development of the heating apparatus, and in the following pages, as far as possible, they will be treated together; but often for the sake of clearness and to avoid repetition, separate treatment will be necessary.

At the beginning of these experiments, there was much doubt as to whether alcohol or gasoline would be found most suitable for the immediate purpose. An alcohol burner had been used in connection with the earliest aerodrome, No. 0, but from the results obtained with it at that time, there seemed to be little reason to hope for success with it. It is to be premised that the problem, which at first seemed insoluble, was no less than to produce steam for something like 1 H. P. by a fire-grate, which should occupy only a few cubic inches (about the size of a clenched hand) and weigh but a few ounces. It had to be attacked, however, and as alcohol offered the great advantage of high calorific properties with freedom from all danger of explosion, it was at first used.

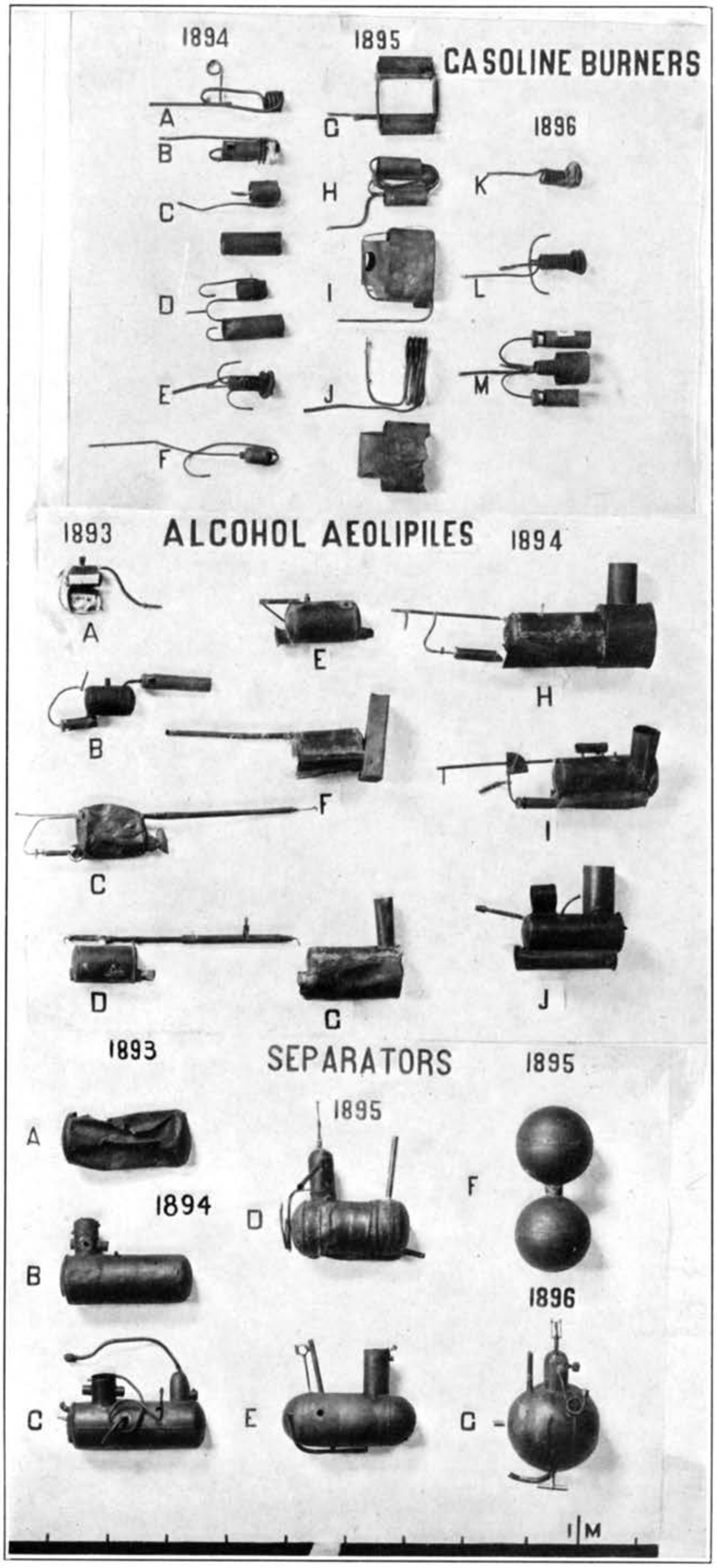
Early in 1893, it occurred to me to modify the burner so as to make it essentially an aeolipile, and in April of that year the first experimental aeolipile model shown at *A* (Plate 12) was made. It was very small and intended for the demonstration of a principle rather than for actual service, but the construction of this small aeolipile was an epoch in the history of the aerodrome. It furnished immensely more heat than anything that had preceded it, and weighed so little and worked so well that in May the aeolipile marked *B* was made. In this design two pipes were led from the upper portion of the cylinder, one to a large Bunsen burner which heated the boiler, the other to a small burner placed under the tank to vaporize the alcohol. This was followed by the one shown at *C*, wherein the heating burner was smaller and the gas pipe, leading to the main burner, larger.

Figures *D, E, F,* and *G* (Plate 12) were really continuations and improvements of the same idea. In *C* there was simply a tube or flue through the tank; in *F,* however, this tube discharged into a smoke-stack fastened to the end of the cylinder, while in *G* the flue turned upward within the tank itself and discharged into the short stack on top. The object of these changes was to increase the draft and heating power of the small flame, so that the gas would be more rapidly generated and a greater quantity be thus made available for use under the boiler in a unit of time. They were, however, though improvements in a construction which was itself a great advance, still inadequate to give out a sufficient amount of heat to meet the excessive demands of the required quantity of steam. The boilers in connection with which these aeolipiles were used must now be considered.

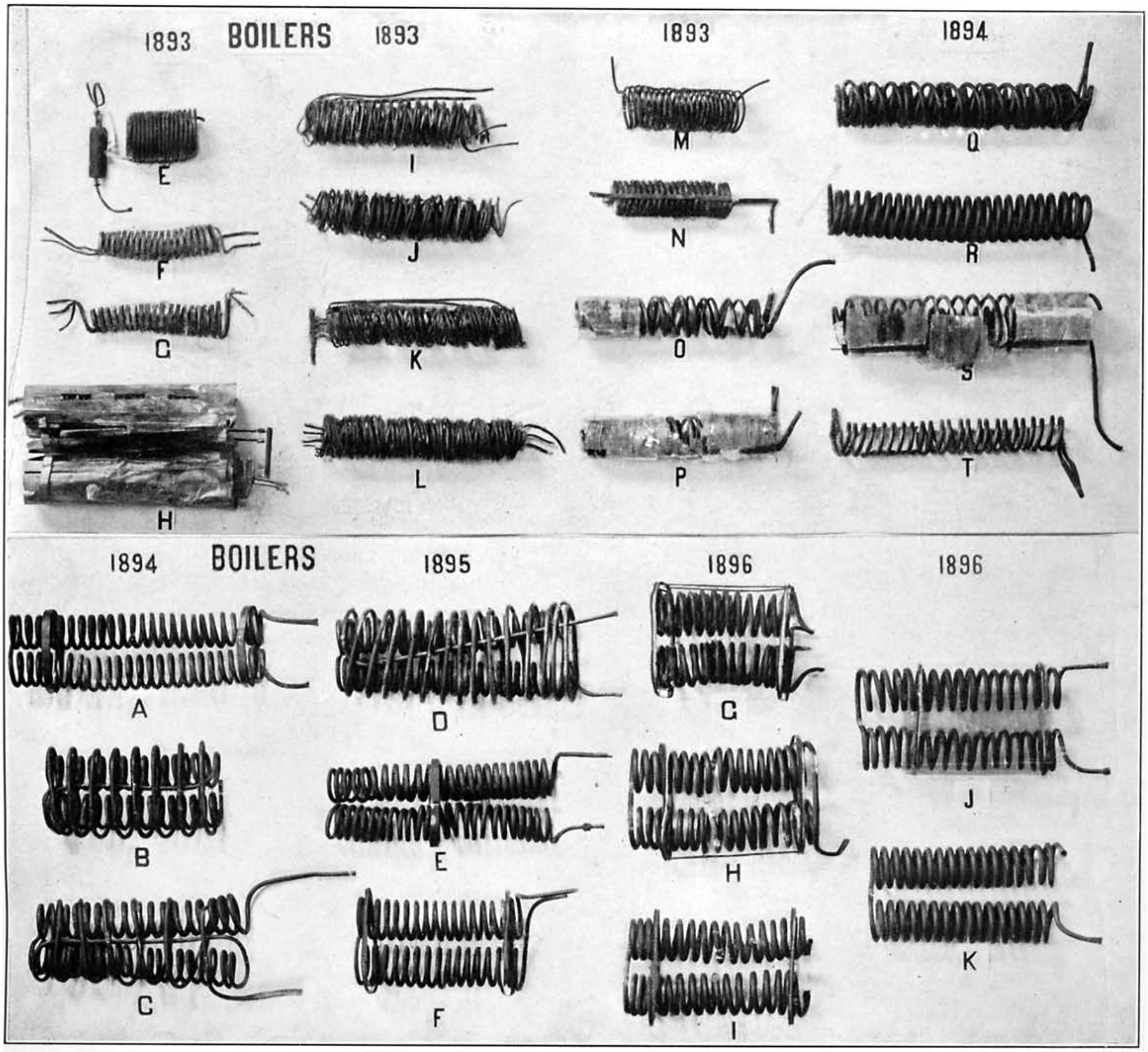
The first boiler *E* (Plate 13) made during this year was a double-coil boiler of the Serpollet type, formed of 19 feet of copper tubing having an internal diameter of about $\frac{1}{8}$ inch. Attached to the boiler was a small vertical drum, from the top of which steam was led to the engine, a pipe from the bottom leading to the pump. This boiler was tested in April with an alcohol heater, the pump in this trial being worked by hand. This apparatus developed a steam pressure varying from 25 to 75 pounds, which caused the engines to drive a 60 cm. propeller of 1.25 pitch-ratio 565 revolutions per minute. The greatest difficulty was experienced in securing a sufficient and uniform circulation in the boiler coils. The action in the present case was extremely irregular, as the pressure sometimes rose to 150 pounds, driving the engines at a dangerous speed and bending the eccentric rod, while at other times it would fall so low that the engines stopped completely.

As the pump used in this trial had proved so unsatisfactory and unreliable, it was replaced by a reservoir of water having an air-chamber charged to 10 atmospheres, the flow from which could apparently be regulated with the greatest nicety by a needle valve at the point of egress; but for some reason its performance was unsatisfactory and remained so after weeks of experiment.

There was used in connection with this device the double-coil boiler shown at *F* (Plate 13) which was made of tubes flattened so as to be nearly capillary. The idea of this was to obtain a larger heating surface and a smaller volume of



BURNERS, AEOLIPILES, AND SEPARATORS



BOILERS OF AERODROMES

water, so that by proper regulation at the needle valve, just that quantity would be delivered which could be converted into steam in its passage through the coils, and be ready for use in the engines as it left the boiler at the farther extremity. The results obtained from this were an improvement over those from the original coil, and a third set of coils (*G*, in Plate 13) was made. This boiler consisted of three flattened tubes superposed one over another.

These two boilers were tried by placing them in a charcoal fire and turning on an alcohol blast, while water from a reservoir under constant air pressure was forced through them past a pin valve. The result was that the two-stranded coil supplied steam at from 10 to 40 pounds pressure to run the engines at about 400 revolutions per minute. The pressure rose steadily for about 40 seconds and then suddenly fell away, though the coils were red-hot, and neither the water nor the alcohol was exhausted—apparently because of the irregularity of the supply of water, due to the time taken by it after passing the valve to fill the considerable space intervening between that point and the boiler.

An attempt was made to overcome this difficulty by putting a stop-cock directly in front of the boiler so that the water, while still under the control of the needle valve, could be turned in at once; the alcohol blast was also arranged to be turned on or off at pleasure, and provision was made, by taking out the end of the flue inclosing the boiler, to provide for an increased air supply. With this arrangement a flame eight or nine inches long was obtained, but a test showed that not more than 25 grammes of water per minute passed through the tubes, which was not enough.

Further tests with these boilers were so far satisfactory as to show that with the flattened-tube Serpollet boiler, comprising from 60 to 80 feet of tubing, from 80 to 100 pounds pressure of steam could be maintained, but not steadily. As there were difficulties in flattening the tubes to make a boiler of this sort, a compromise was effected in the construction of the one shown at *H* (Plate 13), which was made of light copper tubes 5 mm. in diameter, laid up in three lengths of 6 metres each. The ends of these coils were so attached to each other that the water entering at one end of the smallest coil would pass through it and then enter the middle coil, whence it passed through the third or outer coil. Two sets of these coils were made and placed in the thin sheathings shown in the photograph. Repeated experiments with these boilers demonstrated that the pressure did not rise high enough in proportion to the heat applied, and that even the pressures obtained were irregular and untrustworthy. The principal difficulty still lay in maintaining an active and uniform circulation through the coils, and for this purpose the water reservoir under constant air pressure had proved itself inadequate. This pointed to a return to the use of the force pump, the construction of which had hitherto presented so many special difficulties that it had been temporarily abandoned.

A further difficulty experienced in the use of these boilers had been that of obtaining *dry* steam for the engines, as during the early experiments the steam had been delivered directly into the engines from the boiler coils. But in August the writer devised a chamber, known as the "separator," where it had an opportunity to separate from the water and issue as dry steam, or at least approximately dry steam. This was an arrangement familiar in principle to steam engineers under another form, but it was one of the many things which, in the ignorance of steam engineering the writer has already freely admitted, he had to reinvent for himself.

At about the same time, a new pump was designed to drive the water from the bottom of the separator, which served the double purpose of steam drum and reservoir, into the coils. This pump had a diameter of 4.8 cm., and was run at 180 strokes per minute.

The result of the first experiments with these improvements demonstrated that, within certain limits, the amount of water evaporated is proportional to the circulation, and in this boiler the circulation was still the thing that was at fault. Finally, the results of the experiments with the two-stranded, triple-coil boiler may be summed up in the statement that it was possible to maintain a pressure of 80 pounds, and that with it the engines could be made to develop from 0.3 to 0.4 H. P. at best. It weighed 650 grammes (1.43 pounds) without the asbestos jacket.

About this time the writer had the good fortune to secure the temporary services of Dr. Carl Barus, an accomplished physicist, with whose aid a great variety of boilers were experimented on.

The next form of boiler tested was that shown at *N* (Plate 13), made on a system of coils in parallel, of which there were twenty complete turns. In the first test it generated but 20 pounds of steam, because the flame refused to work in the colder coils. The work of this boiler was very unsatisfactory, and it was only with the greatest difficulty that more than ten pounds pressure could be maintained. There was trouble, too, with the circulation, in that when the flame was in full play the pump seemed to meet an almost solid resistance, so that it could not be made to do its work.

A new boiler was accordingly made, consisting of three coils of four strands each. With this the pump worked easily, but whereas it was expected to get 120 pounds pressure, the best that could be obtained was 70 pounds. The outer coil was then stripped off, and a trial made in which everything ran smoothly and the pressure mounted momentarily to 90 pounds. After some adjustment, a mean pressure of 80 pounds was obtained, giving 730 revolutions of the engine per minute, with an indicated horse-power of 0.32.

It was shown in this work that, within certain limits, steam is generated most rapidly when it is used most rapidly, so that two engines could be used almost as well as one, the reason apparently being that the rapid circulation increased the steam generating power of the boiler, and that the engines worked best at about 80 pounds. It was also found that a larger tubing was better than the small, weight for weight, this fact being due to the greater ease with which circulation could be maintained, since fewer coils were necessary in order to obtain the same external heating surface. The pressure in the coils and the separator was also much more nearly equalized. The result was that the boiler temporarily approved was one made of tubing 6.35 mm. (0.25 inch) in diameter, bent into a two-coil, two-stranded boiler, having sixteen complete turns for each strand in each coil. The total weight was 560 grammes (1.23 pounds) with a total heating surface of 1300 sq. cm. (1.4 sq. ft.).

The separator used in the experiments made during August and September was of a form in which the water was forced below a series of partitions that prevented it from following the steam over into the cylinders of the engines. It weighed 410 grammes (0.9 pound) and was most conveniently worked with 700 grammes (1.54 pounds) of water. The boiler and separator together weighed 970 grammes (2.1 pounds).

A new separator was, however, designed, which was horizontal instead of vertical, as it was intended that it should be placed just below the midrod. Another form, devised for constructional reasons, consisted of a cylinder in which a pump was imbedded. Heretofore the pump used had been single-acting, but it was now proposed to make a double-acting pump. Upon testing this apparatus, it was found that when using an aeolipile, it took 150 grammes of alcohol to evaporate 600 grammes of water. It was evident that the latter was used very wastefully, so that the thermal efficiency of the engine was not over one per cent; but it was also evident that, under the necessity of sacrificing everything to lightness, this waste was largely inevitable.

About the middle of October, another boiler (O, Plate 13) was made, which consisted of two coils wound in right and left hand screw-threads, one fitting loosely over the other, so as to make a cylindrical lattice-work 32 cm. (12.6 in.) long. Each coil contained two strands of copper tube 0.3 mm. thick, and weighing 54 grammes to the metre (0.036 pound to the foot). The inner coil had a diameter of 5.63 cm. (2.22 in.), with nine turns of tube to the strand, the two strands making a length of 319 cm. (10.5 feet) for the coil. The outer coil had a mean diameter of 6.88 cm. (2.71 in.) and a length of 388 cm. (12.7 feet) for the two strands. The total length of the two coils was, therefore, 707 cm. (23.2 feet), with a heating surface of about 1415 sq. cm. (1.52 sq. ft.) and a total weight of 382 grammes (0.84 pound).

The results obtained with this boiler were so far satisfactory as to show that, under the most favorable conditions, when air was supplied in unlimited quantities and there were no disturbing currents to put out or interfere with the work of the burners, steam could be supplied at a sufficient pressure to run the engines. It was realized, however, that the conditions in flight would be very different, and that in order to protect the apparatus from the wind, some sort of protecting covering would have to be devised, which would of itself introduce new difficulties in providing the burners with a proper and uniform draft.

The hull, as at first constructed, consisted of a cylindrical sheathing open in front, through the rear end of which the boiler and aeolipile projected inward,