



Technical Education Branch,
Department of Education.

Technological Museum,
Sydney

A. R. Penfold, F.A.C.I., F.C.S., Curator.

The Aeronautical Work
of
Lawrence Hargrave

by
T. C. Roughley, B.Sc.

Bulletin No. 19.

Price, 1/-

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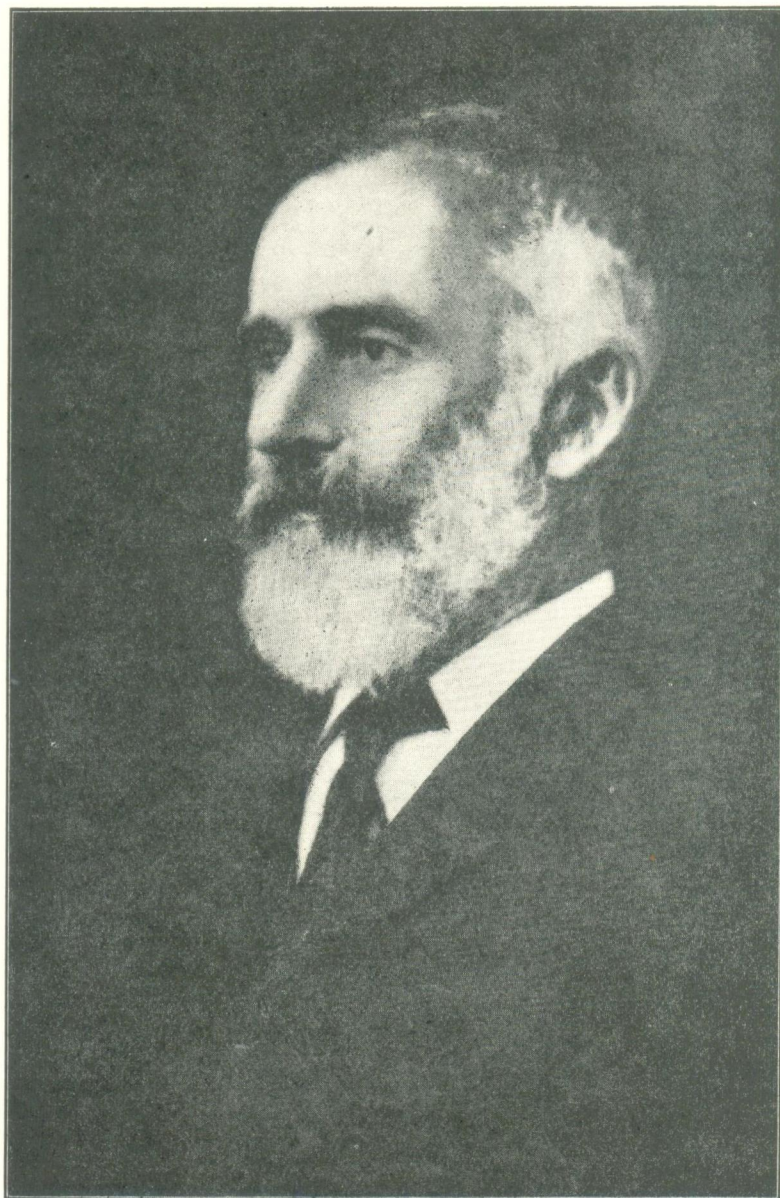
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Lawrence Hargrave.

PREFACE.

THIS pamphlet embodies, with very slight alterations, two articles published in the Technical Gazette of New South Wales; the first, dealing with Hargrave's experiments with monoplanes, appeared in Vol. 13, Part 2, 1923; the second, describing his experiments with curved surfaces and box-kites, appeared in Vol. 14, Part 1, 1924. Both were published under the title "Lawrence Hargrave—Australia's Pioneer in Aviation."

Since the date of the publication of these articles they have been much sought after, but during recent years no copies of the Gazettes in which they appeared have been available. In order to satisfy this demand the two articles are combined in the present form.

With the display of Hargrave's original monoplane models as a foundation, a splendid opportunity is afforded this Museum to illustrate the evolution of the aeroplane from the time when his first model was constructed in 1884 to the present day. And this is being done as fast as circumstances and our financial resources will permit.

The aeroplane was not "invented" by any single experimenter; it gradually evolved as the result of the progressive efforts of many dauntless pioneers, some of whom lost their lives in the cause. There are already exhibited in the aeronautical section a model of an early Lilienthal glider (1892), the Wright Brothers' first biplane (1903), and a Bleriot monoplane (1911). Models of present-day aeroplanes serve to show how the most modern types evolved from these crude beginnings, and others now under construction are intended to fill in the many gaps which at present exist in the collection. Eventually, these models, arranged in sequence, will tell a connected story of the very beginnings of the aeroplane and its gradual development into the highly efficient machine of to-day.

Hargrave's monoplanes will remain for all time a tribute to his resource and ingenuity, but their influence on the achievement of dynamic flight is not to be compared with that of his box-kites. Unfortunately, Hargrave's box-kites went to Germany, but, through the good services of Mr. G. O. Ingledew, of Sydney, exact replicas of the most important of these are being constructed from the detailed plans published by Hargrave in the Journal and Proceedings of the Royal Society of New South Wales. These models in their materials, dimensions, and weights will correspond identically with Hargrave's originals; they will lack only the sentiment attaching to those constructed by his own hands. Some are already exhibited, and in a few months it is anticipated that all of the most important will be on view.

Under construction at the present time, also, is a Santos-Dumont biplane (1906), the first aeroplane to fly publicly, and this machine will show very clearly the importance of the Hargrave box-kite and the influence it had in aeronautical evolution, for it was essentially an arrangement of Hargrave kites placed side by side. When flying against the wind, it was found that an aeroplane of this design

was quite stable, but its stability was seriously affected in a side wind owing to the presence of the vertical surfaces. Improvement was effected by the removal of some of these, and eventually the whole of them were eliminated, leaving the upper and lower planes in essentially the same form as we see them to-day. The box-kite form of tail, however, persisted for a considerable time afterwards. Models of these machines will serve to illustrate this development very clearly.

The Wright Brothers' biplane followed a somewhat different line of evolution, and although these pioneers acknowledged their indebtedness to Hargrave, his direct influence in the development of their aeroplane is less apparent. The Wright biplane can, however, be clearly traced back to the gliders of Lilienthal, the great German pioneer of gliding flight, who, beginning his experiments with monoplanes, later constructed biplane gliders, and it was the failure of one of these which caused his death in 1896. Lilienthal's work was taken up by Pilcher in England, and Chanute in America, the former concentrating on monoplane, and the latter on biplane, gliders, and then the Wright Brothers entered the field at a time when the internal combustion engine had attained a degree of efficiency which adapted it to use in an aeroplane. The first aeroplane to fly was therefore a biplane glider fitted with an internal combustion engine.

The aeronautical exhibits of this Museum are being planned to tell this story with the aid of accurate scale models, and in doing this we feel that we are paying but a small tribute to the wonderful pioneering efforts of Lawrence Hargrave, who to some extent at least made the telling of the story possible.

Lawrence Hargrave was born in England in 1850; he was the son of John Fletcher Hargrave, who practised at the equity bar in London until 1856, when he came to Australia. He was soon afterwards made a New South Wales district court judge, and in 1865 a judge of the supreme court. Lawrence remained in England to continue his education, and came to Australia in 1866 (at the age of 16). He was first apprenticed to an engineering firm, and was later an assistant at the Sydney Observatory. During his work at the Observatory his attention was directed to the study of air currents; this led him to ponder over the problem of flight, and fired him with an ambition to solve the problem of human flight. This he decided to make his life's work. From 1884 to 1892 he experimented with monoplane models constructed of a framework of light wood and tissue-paper, and from 1892 till 1909, when his last paper on aeronautics appeared, he concentrated his attention on box-kites and curved surfaces.

Toward the end of his life Hargrave took up the study of early Australian exploration, and made public some deductions from personal observation that failed to secure approval from more experienced historians. He died at Sydney on 6th July, 1915, at the age of 65, but he had lived to receive the thanks and the admiration of the greatest pioneer aviators.

T. C. ROUGHLEY.

July 10, 1933.

The Aeronautical Work of Lawrence Hargrave.

Part I.

Experiments with Monoplanes.

Introduction.

THE majority of Australians have probably never heard of Lawrence Hargrave. Of those who have, many possess but a vague idea of the man and his work. There are some who will say that he invented the aeroplane; others, that he was a crank obsessed with the idea that he had solved the problem of flight; while there are others, again, who endeavour to discount his work entirely. Few, indeed, are possessed of an accurate knowledge of Hargrave's real position in the history of aviation.

It may be stated at once that Hargrave did not invent the aeroplane; he was not a crank, but he probably did as much to bring about the accomplishment of dynamic flight as any other single individual. He did the pioneer work.

The aeroplane evolved from the accumulated efforts of many dauntless workers. No single individual can be said to have invented it. The Wright Brothers in America were the first to fly, but the machine in which they flew embodied the ideas of many workers before them. It was the work of such men as Hargrave, Lilienthal, Pilcher, Chanute and others which made this flight possible.

The following sketch is intended to convey a brief account of Hargrave's experiments, from their inception in 1884 till 1909, when his last published work on aviation appeared. The whole of the information is taken from the Proceedings of the Royal Society of New South Wales, to which Hargrave communicated his discoveries, freely and openly, as soon as they were made. Had he patented the whole of his inventions, there is little doubt that he would have benefited very materially, but this he ever refused to do, in spite of the continued exhortations of his friends. He was possessed of sufficient means to keep him in such comfort as he desired, and the love of his work was more to him, and brought him greater real enjoyment than all the wealth in the world. Hargrave's attitude of mind is expressed in a statement he made in 1890. "The writer thinks the act of invention to be a sort of inspiration, and a pleasure that the individual does not seek to be rewarded for undergoing; it is followed by a greedy sensation or wish to obtain money from others without giving an equivalent. . . . Inventors will always invent; they cannot help it, and you cannot stop them; and a patentee is nothing but a legal robber."

Hargrave published to the world his discoveries, others often seized and patented them. Perhaps this was the cause of his last remark. He was afraid a patent would restrict the use of the invention, whereas he wanted every worker in the field of aviation to use his ideas freely, and, if possible, to improve on them.

Thus, and thus only, would the most rapid strides be made towards the common goal. Hargrave cared little who was the fortunate one to actually fly first, so long as it was accomplished. The objective of his life's work was, first, to discover the secret of dynamic flight, and, second, to freely assist others in its achievement. The progress of civilisation demanded aerial transport, the individual did not matter.

Theory of Flapping Wings.

The first paper read by Hargrave before the Royal Society of New South Wales was entitled, "The Trochoidal Plane." This was a theoretical discussion of the movements of animals such as worms, slugs, jellyfish, and fishes, and the motion of ocean waves, and led naturally to the study of the flight of birds. Even at this time Hargrave appears to have anticipated the successful results of his experiments for he stated that "The trochoidal action of fins, muscles, and legs seemed so plain

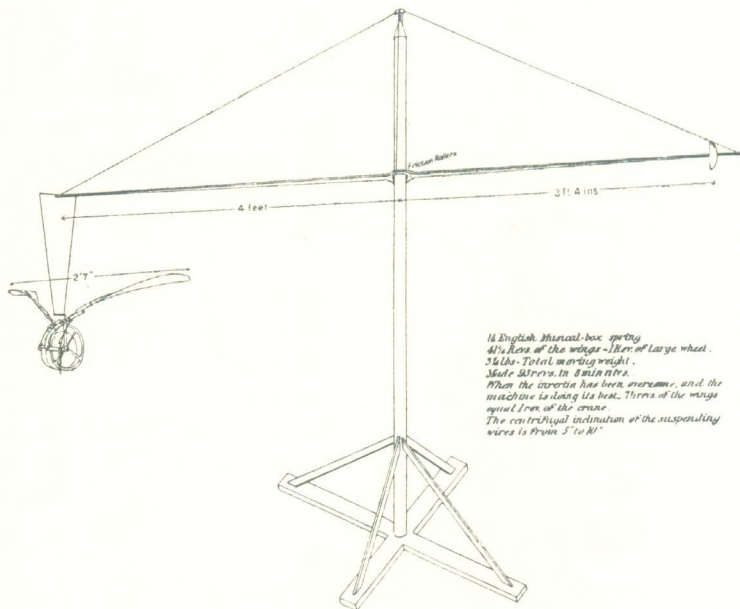


Fig. 1. Oar-shaped Wings driven by Clockwork. 1884.

that I could not help being led to theorise on the action of wings in flight; I say theorise simply because I have not a flying machine to show you, but the chain of evidence seems so complete, that I have no doubt it will soon be accomplished without the aid of the screw or gas-bag."

The flapping motion of the wings of birds formed the basis of the means of propulsion in all Hargrave's earlier work, and, although at this meeting of the Society no actual flying machine was shown, there were exhibited several models which incorporated this idea. Chief of these was a pair of oar-shaped wings suspended from a horizontal rod rotating round a vertical support (Fig. 1). A musical-box spring was used as the motive power to flap the wings. It was found that ninety-three

revolutions round the vertical axis were made in eight minutes, and when the inertia had been overcome, and the machine was doing its best, seven and a half flaps of the wings were sufficient to complete the circle.

Having demonstrated that the mechanical action of flapping wings was capable of readily propelling a body through the air, Hargrave began the construction of models of flying machines in an endeavour to discover the secret of sustaining surfaces requisite to maintain equilibrium in flight.

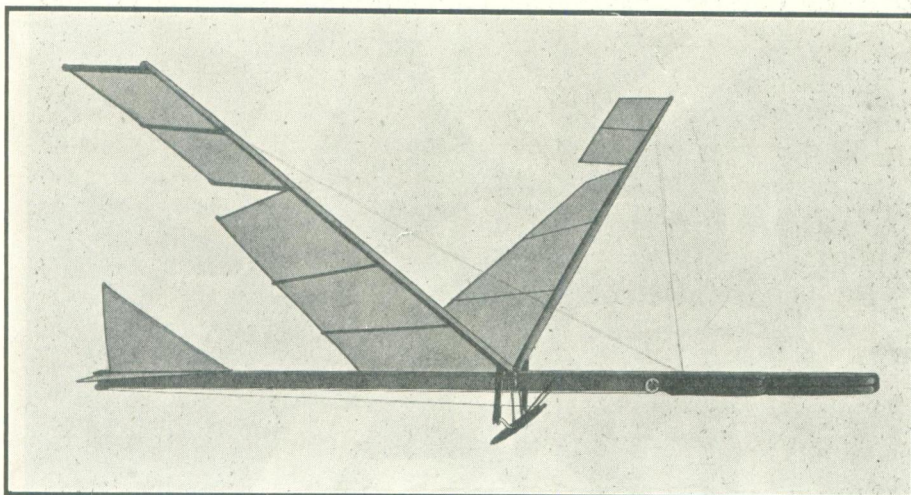


Fig. 2. An early flapping-wing model (probably 1885) with wings in two sections, a vertical fin, and fixed tail-planes. The motive power was rubber-bands in tension.

The Earliest Monoplanes.

Between August, 1884, and June, 1885, when Hargrave's second paper, entitled "Notes on Flying Machines," was read before the Royal Society, he experimented with nearly fifty models with such success that he stated, "Experimenting with nearly fifty models has resulted in these that I hope to show you supporting themselves and moving horizontally in such a way that if the motion is not that used by birds, it is at all events very like it." Several of these models are shown in Fig. 3. Clockwork, which had previously provided the motive power, was now discarded in favour of rubber bands, which, in proportion to their weight, were found to transmit more power.

In this paper also Hargrave incorporated diagrams demonstrating how air, compressed into spherical or spindle-shaped steel vessels, could be made to drive a direct-acting single-cylinder oscillating engine for the purpose of flapping the wings. He persevered with rubber bands, however, for some considerable time afterwards.

Rubber Bands as Motive Power.

The general arrangement of the parts of a typical rubber-band driven machine with which Hargrave was experimenting at this time may be seen in Fig. 4. This model was exhibited on 2nd December, 1885. It had a wing spread of 7 feet 2 inches; the length of the body and head was 6 feet $1\frac{1}{2}$ inches; the total weight

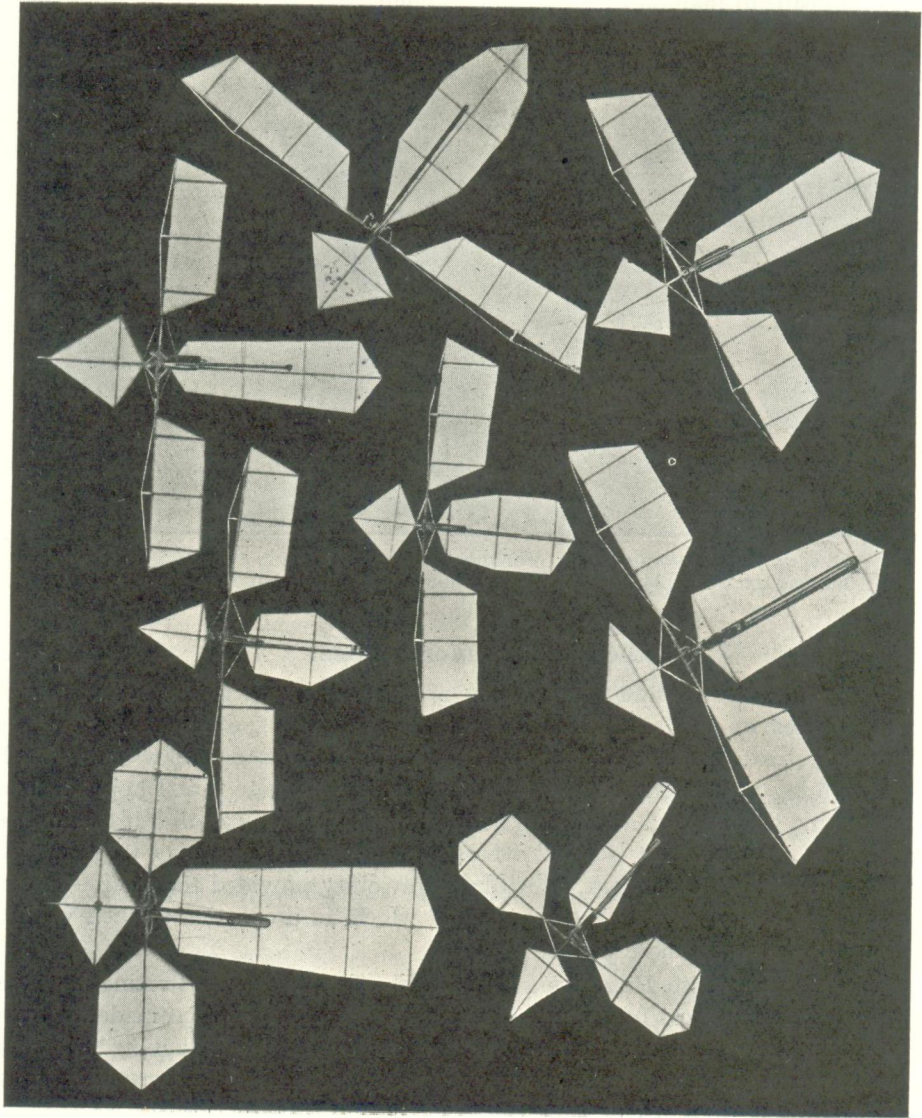


Fig. 3. Collection of Hargrave's earliest models, 1885.

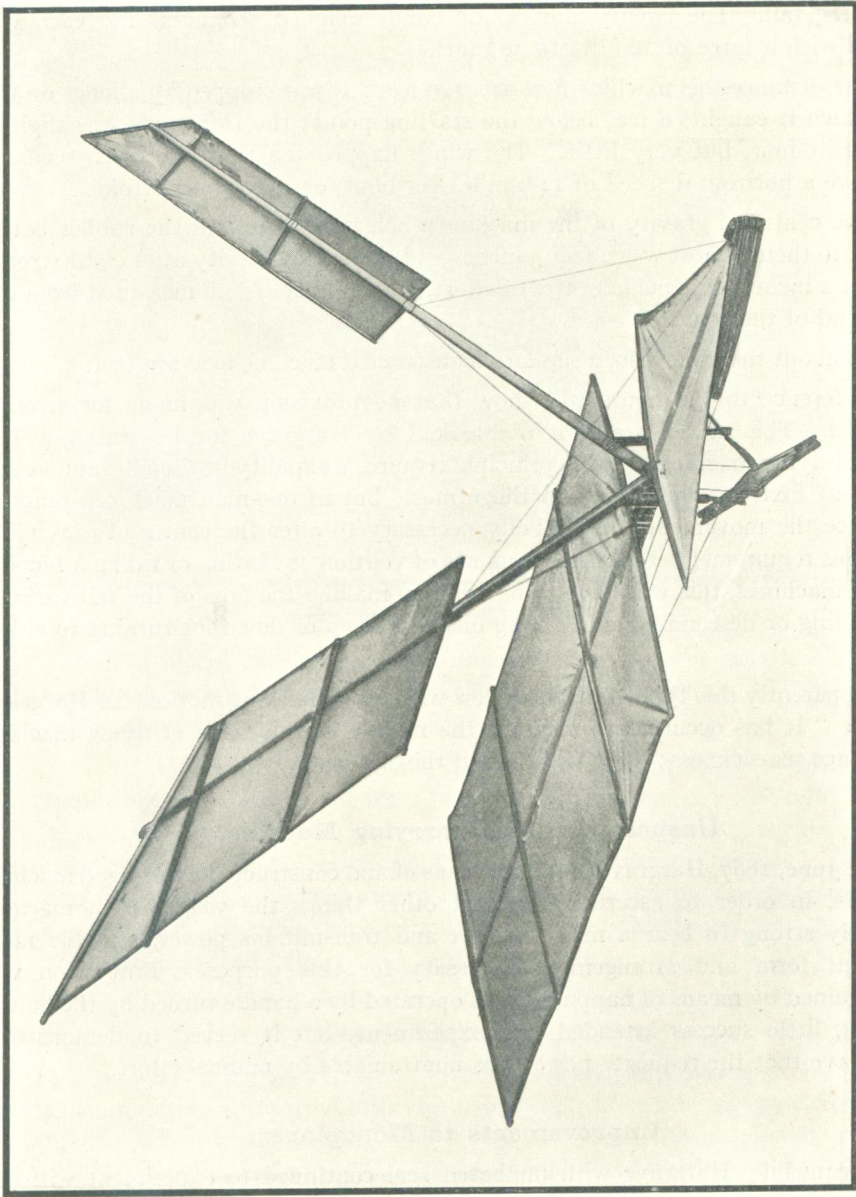


Fig. 4. Flapping-wing model using rubber bands as motive power. 1885.

was 1.47 lb., and it had an area of 840 square inches per lb. weight. The strut formed the backbone of the model; it was about $1\frac{1}{4}$ inches square, made of clear pine, and was hollowed out to about the thickness of cardboard. It tapered slightly towards the tail. The twenty-four elastic bands weighed 5 ounces, and each was stretched with a force of 12.6 lb. to 30.5 inches.

The distance this machine flew was 120 feet; it was stopped by a fence on the top of which it caught, 8 feet below the starting point; the trajectory was slightly ascending at first, but very little. The wings flapped ten times in seven seconds, which gave a horizontal speed of 14.6 miles per hour, or 15 feet per stroke.

The centre of gravity of the machine when wound up and the rubber bands stretched to their utmost was 2 feet 5 inches; the centre of gravity after eight strokes was 2 feet 2 inches; the mean centre of effort, 2 feet 9 inches; all measured from the forward end of the strut.

At about this time also, a similarly constructed machine flew 170 feet.

Reference to the figure will show that no provision was made for steering this model. This aspect was not overlooked by Hargrave for he stated, "The steering of flying machines on this principle requires a rapidity of thought and action that will at first tax the nerves to the utmost, but in one-man machines practice will reduce the movements of the body necessary to alter the centre of gravity to the various requirements to as simple an act of volition as skating or riding a bicycle. In larger machines, this will have to be done by making the area of the tail variable for ascending or descending, and tilting one corner up or down for turning to either side."

Apparently this type of machine flew with an undulating motion, for Hargrave remarks: "It has occurred to me that the motion of this form of flying machine will produce sea-sickness; time will show if this is correct."

Unsuccessful Man-carrying Machine.

In June, 1887, Hargrave produced plans of and constructed a full-sized machine on wheels, in order to ascertain amongst other things the weight of a machine sufficiently strong to bear a man's weight and transmit his power, and the most convenient form and arrangement necessary for this purpose. Propulsion was to be obtained by means of flapping wings operated by a handle turned by the hands. Naturally, little success attended this experiment, but it served to demonstrate to Hargrave that the requisite power was unattainable by manual effort.

Improvements to Monoplanes.

Meanwhile, Hargrave with unabated zeal continued to experiment with his models, which he gradually improved in order to obtain longer flights while still using rubber bands as the motive power. Improvements were effected in five main particulars:—(1) the triangular plane placed at the head of all the earlier models on the main strut anterior to the flapping wings was discarded; (2) the centres of gravity and effort were both brought further forward, resulting in a much easier and more graceful motion; (3) the mid-rib of the wings, which in earlier models

had been placed in various positions, ranging from the middle of the wing to a distance approximately one-third from the leading edge, was now placed at the forward edge of the wing, bringing the torsional stress of the rib into play and effecting a very marked improvement; (4) the wings were made longer and narrower, and with the outside edge square—this was found to offer more resistance, produced more thrust and flapped more slowly; (5) the rubber bands were increased to forty-eight.

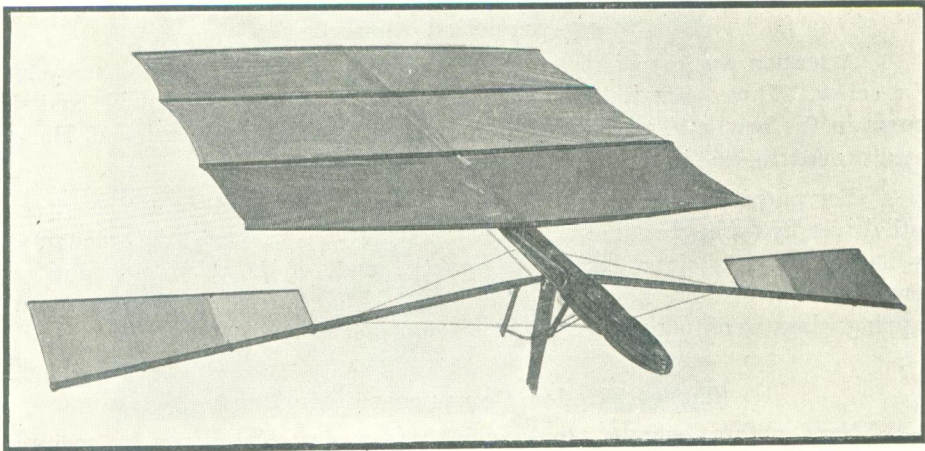


Fig. 5. Rubber-band flapping wing model flown in 1887.

Such a model embodying these improvements may be seen in Fig. 5. This was exhibited on 7th December, 1887, and the following details of its construction and performance may be found interesting :—

Total weight of the model, $33\frac{1}{2}$ ounces; weight of forty-eight vulcanised india-rubber bands, 10 ounces; area of body plane, 13·3 square feet; area of wings, 1·5 square feet; extreme length of model, 5 feet 7 inches; spread of wings, 6 feet 1 inch. Each wing flapped in an arc of $107^{\circ} 20'$. There were 470 foot-pounds of energy stored in the model when the bands were stretched to the tail by winding the cord on the winder. This model flew 270 feet horizontally in a dead calm.

Experiments with Motors.

The years 1888 and 1889 saw more marked improvements in Hargrave's models than during any period hitherto. Particular attention was paid to the motive power. In this connection Hargrave states: "Great efforts have been made to get a reliable motor; a single-cylinder vertical engine absorbed much time and labour, but want of skill in construction involved such an amount of unnecessary weight that if it is ever completed it will nearly all have to be re-made."

The centring difficulty gave birth to several curious mechanisms for pulling the crank off the centre. This was ingeniously and successfully overcome.

Petroleum spirit was next tried as a motive power, and Hargrave in the following words describes with evident good humour his efforts to construct a suitable

engine : " The next engine constructed had a variety of tackle or using petroleum spirit vapour as a motive power, the only result as yet being that manual skill in silver-soldering and light engine work was acquired."

At this time Hargrave discovered a simple mechanical movement by which a wing can be made to describe rigidly the figure-of-eight observable in the motions of the wings of living organisms.

Screw-propelled Monoplanes.

Attention was then directed to the propulsion of aeroplane models by means of a screw. Three varieties of models were made, namely, with double and single screws in the bow, and a single screw in the stern. The last-mentioned, Hargrave says, proved to be the most practicable and serviceable form.

For purposes of comparison two models were made of similar construction, both driven by rubber bands, one fitted with a revolving screw and the other actuated by flapping wings. Careful calculations were made of the relative weights, area, power, and the distance flown, with the result that as propellers, the screw and the flapping wings were found to be about equally efficient.*

Three-cylinder Compressed Air Engine.

Next, a three-cylinder trunk engine was made to be driven by compressed air. This was found to work very smoothly, and carried 120 lb. of air pressure. It combined lightness with accessibility, and simplicity of construction and adjustment in an eminent degree. The weight was but 19½ oz. This engine was made in about 120 hours at a cost for material of 12s.

Invention of Rotary Aeroplane Engine.

Having successfully constructed this engine, Hargrave at once set about improving on it, with the result that he conceived the idea of arranging the cylinders on the blades of the propeller. Such an engine with rotating cylinders has since come to be referred to generally as a rotary aeroplane engine. This was one of the greatest inventions of Hargrave's career, and in itself was sufficient to have stamped him as an engineer of exceptional resource and ingenuity. To quote Hargrave's own words, " The idea was conceived that a three-cylinder screw engine could be made by turning the boss of the propeller into an engine, thus allowing the cylinders to revolve on the crank-shaft, the shaft and crank-pin being stationary, and the thrust coming direct on the valve face. Of course, the idea was put into execution with all speed." The resulting engine weighed ¾ lb., and was found to work so satisfactorily that further experiments were conducted with it. These resulted in the production of an engine weighing only 7½ oz., with revolutions at the rate of 456 per minute, the receiver pressure falling from 150 lb. to about 120 lb. The

* This comparison between a screw and flapping wings cannot be taken to apply generally to their respective merits, for the design of screw as used by Hargrave was hopelessly inefficient. The extremities of his screws were always made the largest part, in order that the greatest disturbance of air might be effected, for here the speed is greatest. In modern efficient screws each part is made to do as much work as possible for it is desirable that the stream of air which is thrown backwards should be moving with a uniform speed in order to avoid turbulence. To meet these conditions, the screw is made of truly helical formation, that is to say, the angle of the blade with the plane of rotation is made least at the tip and gradually increases to a maximum at the centre or boss. Such a screw "grips" the air, and its progression is to some extent similar to that of a nut on a bolt.

cylinders were .88 inches diameter, the stroke was 1.3 inches, and the valve cut off at .75 of the stroke. The screw blades were set at an angle of 20° , the diameter of the screw was $36\frac{1}{4}$ inches, and the area of each blade was 32.7 square inches.

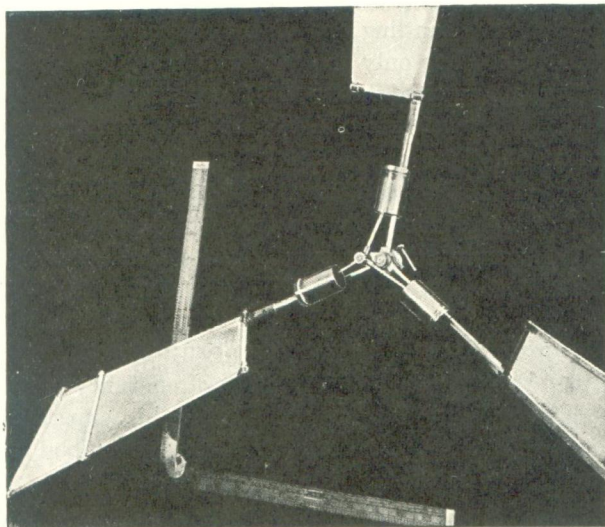


Fig. 6. Rotary aeroplane engine invented by Hargrave in 1889.

This engine is illustrated in Fig. 6, which is reproduced from the photograph taken of Hargrave's original model in 1889. It is worthy of note that several of the most successful early aeroplane engines were constructed on this principle, probably the best known being the celebrated French "Gnome." Yet how many people are aware that this was invented in Sydney by Lawrence Hargrave?

Planes placed at a Dihedral Angle.

With the adoption of the screw in place of the flapping wings, Hargrave set the two halves of the body plane at a dihedral angle. Greater stability was thereby attained, by lowering the centre of gravity and providing for greater lateral resistance to the atmosphere.

Centre of Gravity.

Much experimenting was done to ascertain the best position of the centre of gravity to ensure greatest stability. In the three most successful machines made up to this time (1889), the percentages of the area in advance of the centres of gravity were 19.3 per cent., 20 per cent., and 23.3 per cent. respectively. Hargrave remarks that "these positions were arrived at by experience gained by repeated wrecks when groping in comparative darkness."

Between August, 1889, and June, 1890, Hargrave's time was devoted principally to the simplification of the design of the engine and calculating its efficiency. He was convinced that no elaborate contrivances were required to make an aeroplane fly, and rather humorously remarks about the efforts of previous experimenters: "It is thought that much useful work has been lost to us by

experimenters loading their apparatus with devices to save them from damage, and artistic conceits to show where the passengers are to be seated in ornamental cars with flags, etc. It should be remembered that flying machines are only to battle with the air, and not for knocking down fences or ploughing up the ground. It is not usual to proportion the scantling and plating of ships so that they will stand beating on rocks and sand, but only to safely resist the strains produced by the winds and waves. Perhaps much of the writer's success has been due to the avoidance of this fault, although it is somewhat of a trial to see a month's work knocked out of all shape in a moment."

The one additional part allowed was a stick projecting about 16 inches before the engine, so that when the machine came to earth the stick was broken and the engine and the cylinder containing the compressed air were less injured than they otherwise would have been.

Flapping Wings driven by Compressed Air.

Having decided that about an equal degree of efficiency was obtained by the screw and the flapping wings, Hargrave continued his experiments with both. The improvements which have just been described are embodied in the model illustrated in Fig. 7. The features to be noted in this model are : (1) the dihedral

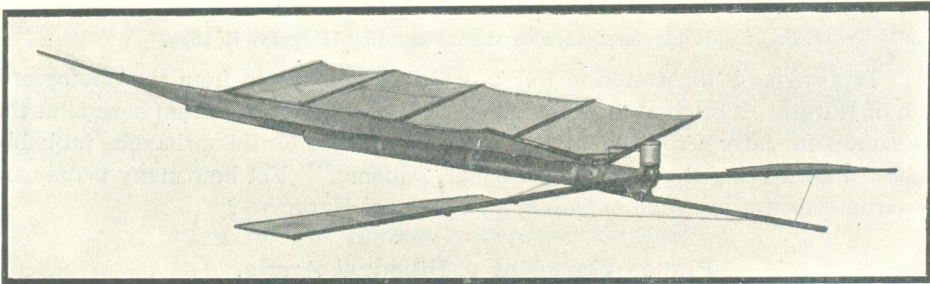


Fig. 7. Flapping-wing model driven by compressed air.
This machine flew 368 feet on 8th April, 1890.

angle of the two halves of the plane; (2) the long cylinder containing compressed air for driving the single-cylinder engine; (3) the flapping wings; (4) the length of the body; and (5) the projecting stick to break the fall. This model weighed 2.53 lb., and covered a total area (including wings) of 16.28 sq. ft. It flew 368 feet on 8th April, 1890.

Shorter Bodies Tested.

Hargrave now experimented with the object of discovering whether the long bodies, which had characterised his models up to this time, were really necessary, and whether equal and if not greater efficiency could not be obtained by shortening them considerably. The model illustrated in Fig. 7 was the actual one to be first experimented with. Hargrave states that this machine appeared to be perfectly balanced on its seventh trial, and yet, when the two intermediate segments on each side were removed the model was still in equilibrium although 41.8 per cent. of the area was in advance of the centre of gravity. The explanation given by Hargrave was : " It seems as if the centre part of the body is best removed, as it only serves

to conduct the air, the inertia of which has been overcome by the weight of the forward part of the machine, to the tail. Whereas if the middle of the body plane has been cut out the used air escapes upwards and the tail has a better chance of getting comparatively solid air to float on."

Heavier Monoplane Model.

In spite of these results, Hargrave continued to build his models with long bodies for some time afterwards, and on 3rd December, 1890, communicated to the Royal Society the results he obtained with a larger and heavier model built on the same lines as the one just described. There were, however, one or two slight modifications. This machine is illustrated in Fig. 8, and the similarity to the previous model is at once apparent. The greatest difference was in the weight. Whilst this latest machine weighed 4.63 lb., the previous one weighed only 2.53 lb. The wings were exactly the same area and length as those of the lighter model, but they were made of oak with five ash crossbars instead of four. Also in the heavier machine there was attached to the side of the air cylinder, a sixty-tooth clock-wheel with two ratchets, one of which was pulled up and down by a string fastened to the wing arm. This wheel registered the number of flaps the wings made in the course of the flight. It is clearly shown in the photograph of the front of this machine, reproduced in Fig. 9.

The sides of the body-plane sloped upwards at an angle of 18° , and the paper area was slightly less per pound weight than in the 2.53 lb. machine. Fearing that some objection might be raised to the increased area of the planes, Hargrave, with a levity which he occasionally allowed to brighten the technicalities of his papers, remarked, "The large area might be considered a defect, but when we consider that it consists only of a few sticks and tissue paper, and that the atmosphere is not by any means crowded with flying machines, the objection ceases to have much weight."

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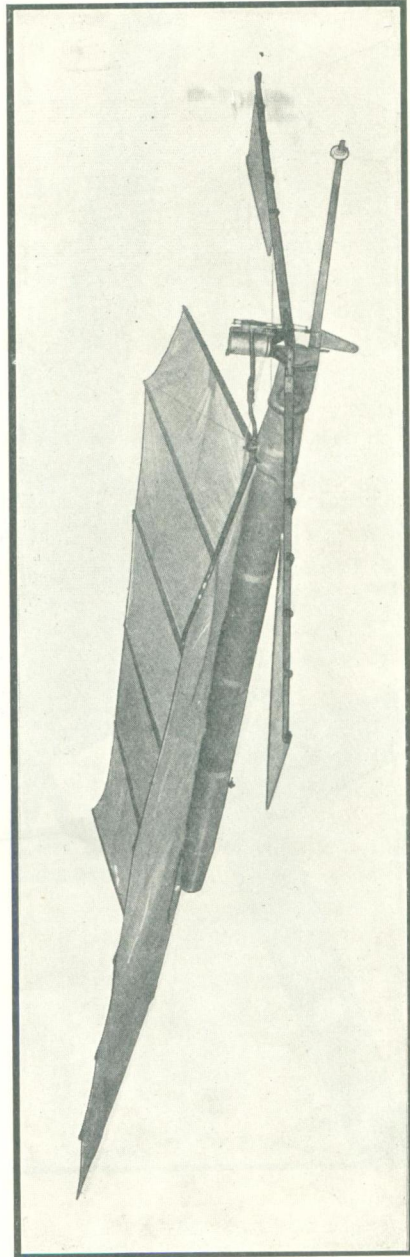


Fig. 8. Single-cylinder, compressed air, flapping-wing model. 1890.

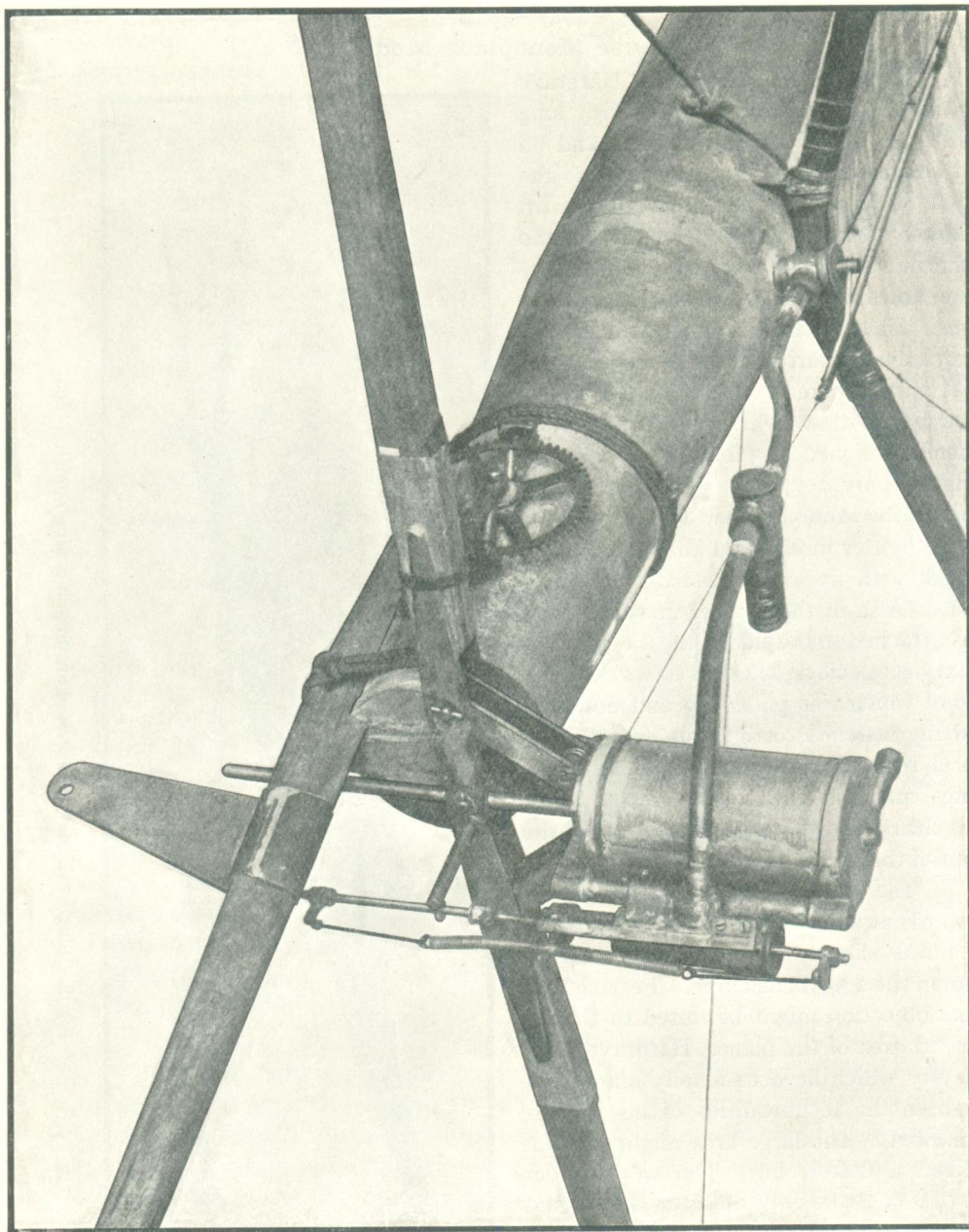


Fig. 9. Enlarged view of the front of the model illustrated in Fig. 7, showing details of the engine.

Flights of 305 and 343 Feet.

Altogether six flights were made with this model, and the apparent trajectories of the fifth and sixth, which measured 305 feet and 343 feet respectively, are shown in Fig. 10. These flights are described by Hargrave in the following words: "The machine in Trial 5 turned up and almost stopped, but resumed its course when the preponderance of the forward part brought it horizontal again. A lump of lead

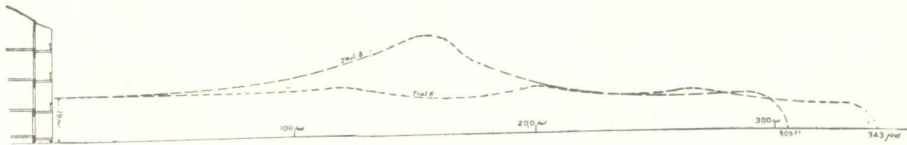


Fig. 10. Apparent course taken by the machine illustrated in Fig. 8, in its two most successful flights, which measured 305 and 343 feet respectively.

was put on the end of the breaking stick for Trial 6. (This is clearly shown in Fig. 8.) The lead shifted the centre of gravity 1 inch further forward, and produced the undulatory flight that is shown in the drawing. Each observation adds fresh weight to the assumption that the true position of the centre of gravity for a continuous rectangular surface is situated between $\cdot 25$ and $\cdot 2$ of the length from the forward end.

"After Trial 6 the machine was attached to the chronograph to see what the receiver pressure was at the thirty-eighth double vibration, the number registered by the counter; but after making three or four flaps at the rate of about 200 per minute, all the paper was dashed out of the wings, and the port link lugs were dragged out of the cylinder cover. But again knowledge is gained from failure; we learn that the chronographic test of the wing speed of the stationary machine is no guide to the speed of the flying machine, as the rapidly-flapping wing creates a vacuum behind it of sufficiently low pressure to allow the return stroke of the wing to pass so quickly through it that the shock of the wing against the air at the other side of the vacuum is strong enough to destroy the paper. The efficiency of the wings during the free flight is not impaired by this cause, as every stroke is taken in new and solid air, and the wing speed is obviously not in excess of 120 per minute."

COMPARISON OF FLYING MACHINES.

Observations made with—	Total area, sq. in.	Sq. in. area per lb. weight.	Weight, lb.	Power and foot lbs.	Distance flown, ft.
24 Band A	1,236	841	1.47	164	120
" B	1,381	1,132	1.22	197	170
" C	1,177	997	1.18	246	201
48 Band F	1,606	873	1.84	371	189
" G	1,551	843	1.84	341	171
24 Band H	1,986	1,555	1.28	193	192
" J	1,974	1,542	1.28	208	203
" K	1,974	1,542	1.28	218	209
48 Band L	2,130	1,019	2.09	470	270
48 Band—Screw	2,090	1,045	2.00	196	120
40.5 oz.—Compressed air	2,344	925	2.53	870	368
74 oz.—Compressed air	4,266	922	4.63	789	343

A table compiled at this time gave the dimensions and the flights of the principal machines of which complete observations had been recorded. It is reproduced above for purposes of comparison.

In July, 1891, Hargrave described two types of machines which he referred to as Numbers 13 and 14. These were driven by compressed air, and embodied those improvements which the experience gained from many flights had taught him to be the most effective.

Three-cylinder Screw Machine.

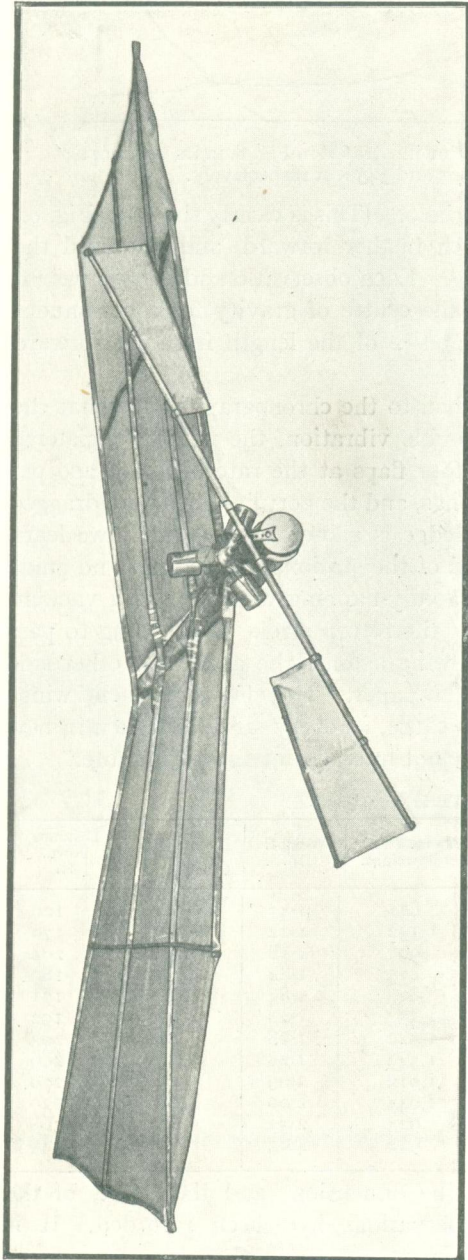


Fig. 11. Compressed air, bow screw machine driven by a three-cylinder stationary engine. 1891.

The No. 13 machine is illustrated in Fig. 11. The air was compressed into a cylinder (called by Hargrave the receiver), 2 inches in diameter and 4 ft. 7 in. in length. The planes were broader than long, 5 ft. 7½ in. wide and 3 ft. 9½ in. long, and were set at a dihedral angle. Of the total area, 22·3 per cent. was in advance of the centre of gravity. A three-cylinder stationary engine (Fig. 12) was placed astride the forward end of the receiver, driving a two-bladed screw at the bow of the machine. The whole apparatus weighed 46·86 oz., when it was charged with air at a pressure of 230 lb. per square inch.

For the purpose of counting the number of revolutions made by the propeller in flight, a reel of cotton was placed on an axis parallel to the screw shaft, and an empty reel was secured on the crank shaft. The turns of cotton that were wound on to the latter reel were counted after the flight; these corresponded with the total revolutions. The screw or propeller was right-handed, and was 31·6 inches in length from tip to tip. Each blade was 5 inches wide at the outer edge, and 3 inches at the inner edge, and was 9 inches long.

This machine flew 128 feet with a fall of 3 feet 10 inches, while the duration of the flight was 8 seconds. The speed was therefore 10·34 miles per hour. The engine made forty-nine revolutions with a reduced pressure of 45 lb. per square inch.

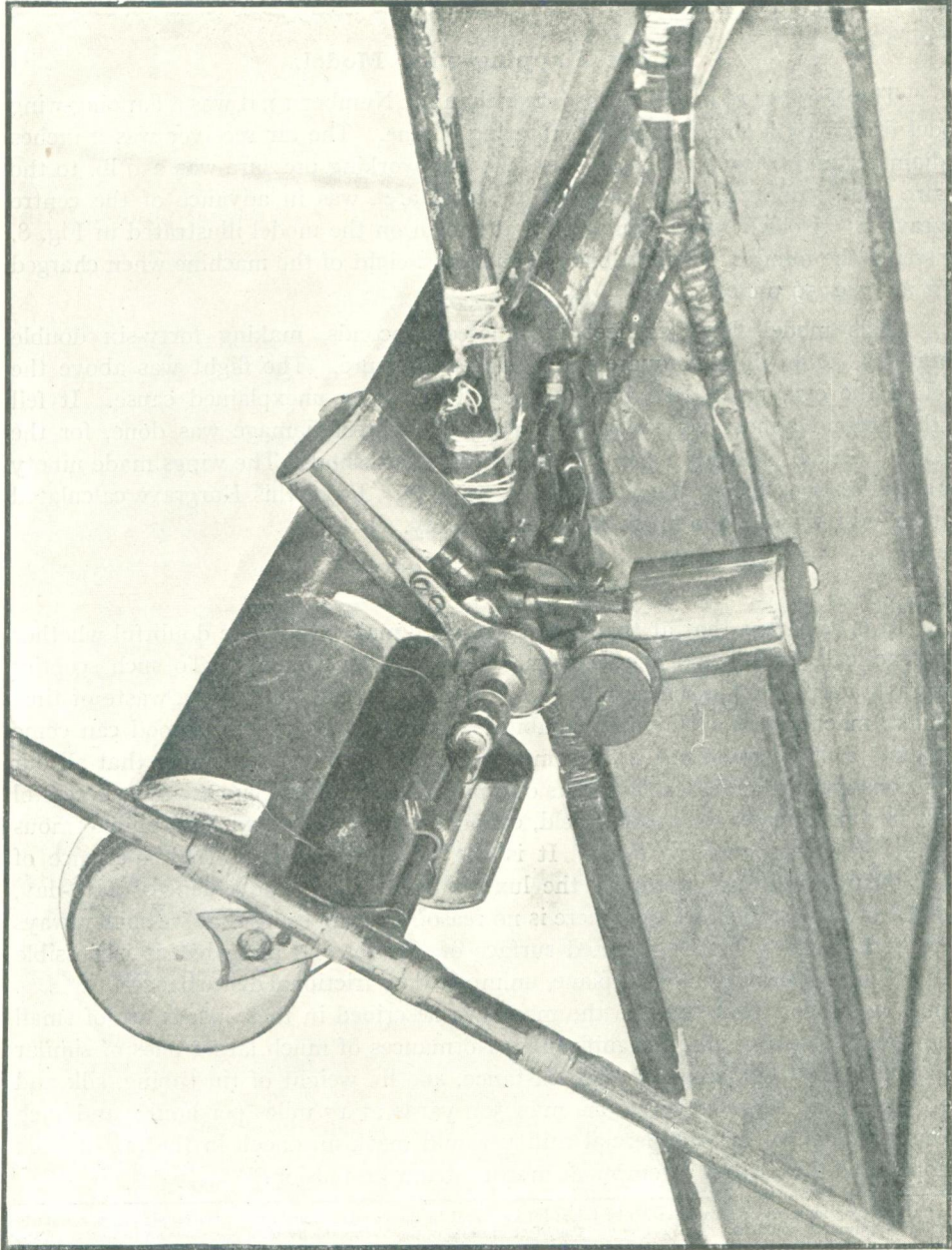


Fig. 12. Enlarged view of the front of the model illustrated in Fig. 10, showing details of the three-cylinder engine.

When the propeller revolved it was found that a listing moment or torque* was produced, which an ounce of lead, placed at the edge of the right-hand plane, 32·25 inches to the right of the centre of gravity, was found insufficient to counteract. This list, although slight, nevertheless turned the machine to port and consequently it flew in a curved course.

Larger Flapping-wing Model.

The Number 14 machine was larger than the Number 13, it was a flapping-wing model driven by a single cylinder vibrating engine. The air receiver was 2 inches in diameter and 6 feet 11 inches in length; the working pressure was 250 lb. to the square inch, while 22·27 per cent. of the total area was in advance of the centre of gravity. A clock wheel similar to that shown on the model illustrated in Fig. 8, registered the number of vibrations. The total weight of the machine when charged with air was 59 ounces.

This model flew 312 feet in nineteen seconds, making forty-six double vibrations, at 57 lb. per square inch reduced pressure. The flight was above the level of the eye, until the engine stopped from some unexplained cause. It fell to the ground almost vertically, and not the slightest damage was done, for the machine worked perfectly when removed to the workshop. The wings made ninety double vibrations before the pressure fell to 50 lb. From this Hargrave calculated that 600 feet was not too much to expect it to fly.

Reply to Sceptics.

It is apparent that at this time there were many who were doubtful whether any practical result could accrue from Hargrave's experiments. To such sceptics Hargrave addressed himself as follows: "It may be said that it is a waste of time to make machines of such small capabilities, and that no practical good can come of them. But we must not try too much at first; we must remember that all our inventions are but mere developments of crude ideas; that a commercially successful result in a practically unexplored field, cannot possibly be got without an enormous amount of unremunerative work. It is the piled-up and recorded experience of many busy brains that produces the luxurious travelling conveniences of to-day, that in no way astonish us, and there is no reason for supposing that we shall always be content to keep on the agitated surface of the sea and air, when it is possible to travel in a superior or inferior plane, unimpeded by frictional disturbances. . . . It does not follow that because the machines described in these pages are of small weight and large area, the insignificant performances of much larger ones of similar proportions are to be scouted. For instance, 400 lb. weight of tin tubing, silk and steel wire would serve to carry one man 500 yards at 17 miles per hour; and such a result, though of no commercial utility would mark an epoch in the art at least as hopeful as the earliest attempts at marine steam propulsion."

*This listing moment or torque has to be taken into account in the construction of modern aeroplanes, particularly in small high-powered machines. The torque has the effect of making the aeroplane fly with one wing down unless means are taken to prevent it happening. The tendency can be counteracted by a very slight aileron movement; but in most aeroplanes the angle of incidence of one wing is increased, and of the other decreased just at the tips in order to give an unequal lift on the two tips. The same result may be obtained by erecting the aeroplane so that when the aileron control appears central to the pilot, there is in reality a slight effect just sufficient to balance the torque. The Wright Brothers' machine was fitted with two screws revolving in opposite directions; the effect of the torque was, in consequence, completely absent.

The Sixteenth Monoplane.

During 1892, another compressed air-driven machine, No. 16, was constructed. In this model the planes were slightly longer than broad, while the engine was a single cylinder vibrating type, which drove flapping wings. Twelve trials were made with this machine, and one only proved successful. On this occasion it flew 343 feet in 23 seconds, with $54\frac{1}{2}$ double vibrations of the engine. It had 25.1 per cent. of the area in advance of the centre of gravity, and in flight ascended slightly, possibly 10 degrees.

Tandem planes were fitted to the No. 16 model during one of the experiments; the dimensions of the forward plane were 52 inches by 18 inches and of the after one, 64 inches by 18 inches, leaving a distance of 5 feet between. Hargrave stated that this form proved to be very stable, but no records of its flight are given.

First Steam Motor.

During the same year Hargrave set out to make a steam motor lighter than the compressed air apparatus, with a uniform boiler pressure, and capable of flapping the wings of standard size as fast as the compressed air engine did and for a longer time. This he succeeded in doing, using methylated spirit as fuel. The engine was fitted to a model similar to the Number 12 machine, and the whole structure only weighed 64.5 oz., which included $12\frac{3}{4}$ oz. for the strut and body plane, and 5 oz. for spirit and water. The motor therefore weighed $3\frac{1}{4}$ lb. It was found that .169 horse-power was developed when 2.35 double vibrations were made per second.

There is no record that this machine actually flew, but Hargrave calculated that if it were loaded with 10 oz. more spirit and water to bring it to the same weight as the Number 12 machine, which flew 343 feet with 38 double vibrations, the steam-propelled model was capable of attaining 546 double vibrations, which would give a possible range of 1,640 yards.

Having successfully constructed this engine, another having three cylinders was designed to rotate two wings through 360 degrees of arc, in exactly the same time without the inter-position of bevel gearing. The cylinders were attached to one wing and the crank shaft to the other, the cylinders being free to rotate in the opposite direction to the crank pin. This engine was estimated to develop at least 1 horse-power and to weigh $2\frac{1}{2}$ lb., but although complete plans were prepared, it was never actually built.

Second Steam Motor.

During 1893, Hargrave constructed his second steam motor for use on flying machine models. Its total weight without spirit, water, or body plane was 5 lb. 11 oz. This weight, however, included 6 feet 9 inches of $1\frac{1}{2}$ by $\frac{1}{4}$ inch redwood which formed the strut for the body plane. During portion of the time this motor was running it was working at a speed of 171 double vibrations per minute. On the assumption that this speed could be relied on for a few minutes, Hargrave calculated that, although the weight of the motor was twice that of the previous one driven by steam, the power was increased four-fold.

Last of Motor Experiments.

At this time also, three two-bladed screw motors were made, but these were only partially successful, and further experiments on motors were abandoned, in order that more attention might be devoted to the better disposition of the supporting surfaces of aeroplanes.

Hargrave now began his investigations into the behaviour of curved surfaces in the wind, the outcome of which was the development of various types of kites which will be described in the following section.

Part II.

Experiments with Box-kites and Curved Surfaces.

IN the previous section we saw that between the years 1884 and 1893, Hargrave's time was devoted principally to the building and flying of aeroplane models with a single, *flat* supporting surface, and driven by clockwork, rubber bands, compressed air, and lastly, steam. In 1892, Hargrave had performed a few isolated experiments with curved surfaces, the behaviour of which opened up to his imagination far-reaching possibilities. He decided, therefore, to discontinue the line of research, which, till then, had monopolised his time and thought, and to concentrate his energies on the discovery of the dynamical principles underlying the movements of concavo-convex surfaces in a wind, in order to discover how they might be adapted to enable man to rise from the ground in a machine heavier than the surrounding atmosphere.

One of these experiments is worth recording. A piece of drawing-paper was curved by suitable cross-bars and battens (Fig. 13), and attached to one of the cross-bow models to see if any additional support could be obtained, but, as Hargrave states, "its erratic flight showed that complications would ensue from its adoption at the present stage of the experiments." What actually happened was this: with the leading edge tangential to the direction of impulse, two back somersaults were made before the apparatus fell to the ground, showing at once that the curved surface possessed unexpected lifting power. Hargrave's model had looped the loop! This fired his imagination; he contemplated the construction of a full-sized machine, but realised that the behaviour of curved surfaces was still a very uncertain factor, and that planes moving through still air were not under the same conditions as bodies flying in disturbed air. It was therefore decided that research in the behaviour of the kite would probably lead to the solution of stability and lift. Hargrave then, in 1893, began his kite experiments, which were destined to have an important influence on the solution of dynamic flight.

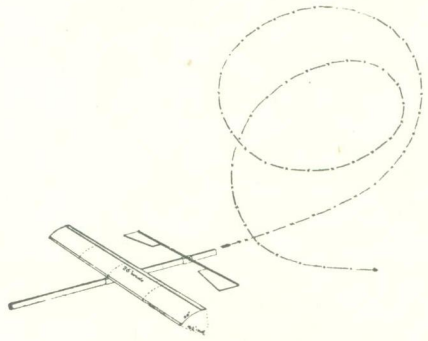


Fig. 13. Apparent track of a model with curved body-plane. 1892.

The Advent of the Kite.

Hargrave's earliest kites are illustrated in Fig. 14. The novelty, as he pointed out, consisted of the combination of two well-known facts. First, that the necessary surface for supporting heavy weights may be composed of parallel strips superposed with an interval between them.*

* This was described by Wenham in 1866, and adopted by Stringfellow in 1868. Hargrave had made an experiment in 1889 with superposed planes, but failed to show that any increased support was obtained. Professor Langley, however, had shown by inference that there is additional support.

Second, that two planes separated by an interval in the direction of motion are more stable than when conjoined.*

The kites shown in Fig. 14, adhere more or less to these two principles in their construction, details of which are given in the following table :—

PARTICULARS OF KITES.

Name.	No. of cells in each section.	Length of each cell parallel to the connecting stick.	Breadth of each cell horizontally at right angles to the stick.	Height of each cell vertically at right angles to the stick.	Radius of curved horizontal surface.	Length of the stick between the sections.	Material of which the surfaces were made.	Distance of point of attachment of string from forward section.	Weight of kite.
		inches.	inches.	inches.	inches.	inches.		inches.	ounces.
A	7	2	†3.75	†3.75		24	Paper	4	2.5
B	1	4.5	†13	†13		30	Aluminium	11	14.75
C	16	3	3	3		22	Cardboard	6.5	10.5
D	3	4	13.13	4	4.5	31.63	Wood and paper	12	11
E	1	4	10.7	6.25	4.5	21.25	Wood and paper ...	7.25	3.25
F	1	4	10.7	6.25		21.25	Wood and paper ...	7.25	3.25

† Distorted cylinder.

‡ Cylindrical.

Kites Possess Great Lift.

These kites differ from those so familiar to us in our youth, which floated at an angle of about 45 degrees, in which position the lift and drag are about equal. They have a fine angle of incidence, so that they correspond with the flying machines they are meant to represent. The fine angle of incidence causes the lift largely to exceed the drag and brings the kite so that the upper part of the string is nearly vertical. It was pointed out by Hargrave that if the kite is perfect in construction and the wind steady, the string could be attached infinitely near the centre of the stick, and the kite would fly very near the zenith. Moreover, any number of kites could be strung together on the same line, and heavy weights buoyed up in a breeze.

Superiority of Curved Surfaces.

Kites E and F are of equal weight and area. In E the horizontal surfaces are evenly curved, with the convex sides above; F has all the surfaces flat. Hargrave discovered that E pulled twice as hard on the string as F, and the important deduction was made that *a flying machine with curved surfaces would be better than one with a flat body plane.*

In theorising as to the cause of this lift by the curved surface, Hargrave made the very natural error of supposing that the wind drawing into and striking the concave side of the sail exerted a more powerful lift than the current impinging direct on the forward part of the convex side. It has since been demonstrated that this is not so; it is the upper surface which contributes most to the lift.

An experiment was tried with kite Z, which was made with flat, sloping wings as in Hargrave's monoplane models. It was found that it did not compare with the cellular form for steadiness. Hargrave realised then that the numerous accidents that had happened to the india-rubber and compressed air driven machines had been largely due to imperfections in the flat or V-shaped body planes.

* This principle was patented by Danjard in 1871, and a machine embodying it was exhibited by D. S. Brown in 1874.

Kite Experiments at Stanwell Park.

Hargrave continued his researches with kites during 1894 and 1895, and in June of 1895 communicated to the Royal Society an account of the progress he had made. The experiments were carried out at Stanwell Park, situated about 32 miles south of Sydney. Here, favourable winds generally prevailed, and the work was free from interruptions. Hargrave's idea at this time was to obtain by means of kites sufficient lift to raise an aeroplane well off the ground in order that it might begin its flight in the air. It must be remembered that the internal combustion engine was then in its infancy, and it was not possible to construct an engine of sufficient power to raise a man-carrying machine off the ground without making the engine itself far too heavy for the purpose.

The cellular kite was the one upon which Hargrave concentrated his study, and so impressed was he with its performance that he made bold to predict that "*in all probability it will prove to be the permanent type of the supporting surfaces of flying machines.*"

The distance between the fore and aft cells was greatly reduced; the exact distance they can be apart without impairing the efficiency of the after-cell was not determined, but as far as efficiency was concerned, a single cell was found to be in stable equilibrium.

Attempts to make Kites Soar.

The type of kite to engage most attention was the rectangular one with the upper and lower surfaces evenly curved, the convexity in both cases being above. Efforts were made to induce them to soar to windward of the peg to which the string was fastened. Fig. 15 shows the nearest approach to soaring that was attained, whilst above it is illustrated the kite which accomplished it. It will be noticed that the forward cell alone has the horizontal surfaces curved, and that the tail

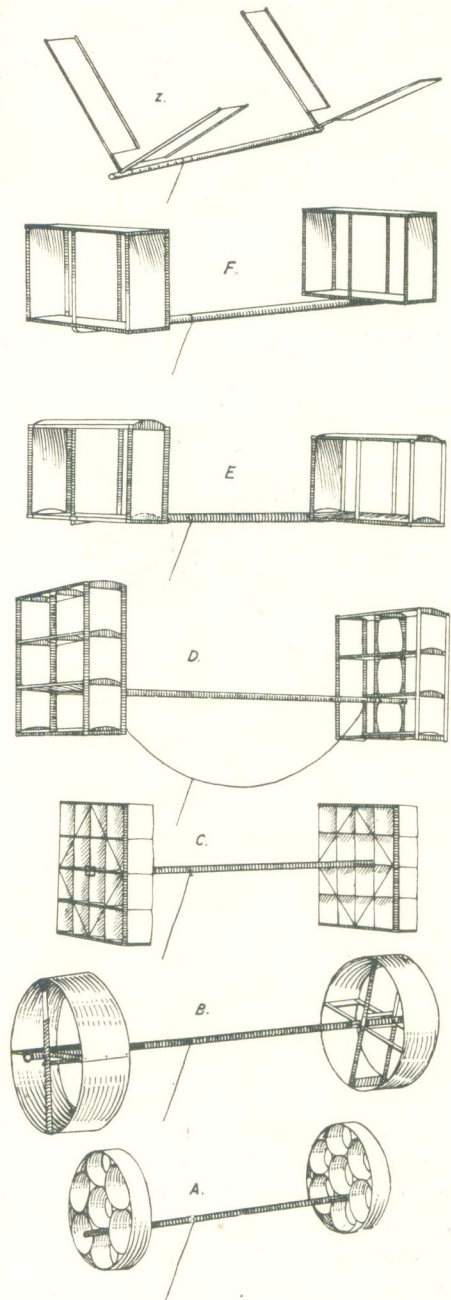


Fig. 14. Hargrave's earliest kites. 1893.

cell is smaller than the forward one. This kite was also provided with a wedge and screw, which secured the forward cell at an angle with the stick and tail cell, so that various degrees of tilt might be tried. In the experiment illustrated in Fig. 15, the stick and tail cell were tilted at an angle of 7 degrees.

Several other forms of kites are illustrated in Hargrave's paper, the most notable being that shown in Fig. 16. This kite has the horizontal surfaces of both cells curved.

Brief Trials with a Glider.

At this time Hargrave records that he made several attempts at soaring flight in a glider having four wings, each 8 feet by 4 ft. 9 in., equal to a total area of 152 square feet of arched surface. It weighed under 25 lb. This line of experiment, however, was not persevered with, "as it was seen that an accident might readily occur without making any real progress with the flying machine."

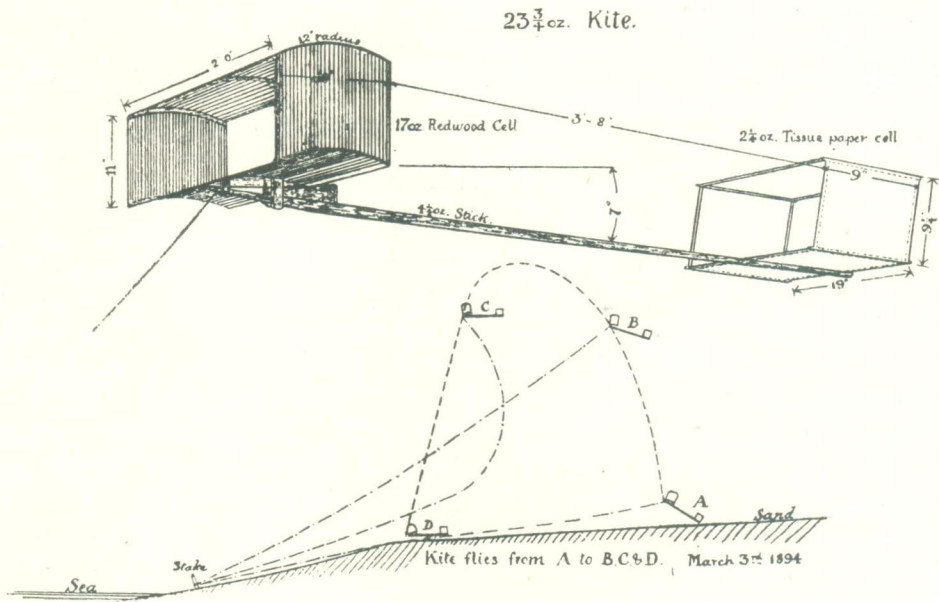


Fig. 15. Soaring kite and course taken in its flight. 1894.

Four Kites Lift 208 lb.

On 12th November, 1894, a successful weight-lifting trial was accomplished by means of four kites attached to the one rope. Curved surfaces had previously been tried, but owing to their faulty construction and consequent lack of rigidity, one or more of the kites had been smashed. For this reason the kites with flat surfaces were substituted, with results which were entirely successful in spite of the consequent loss of lift. A diagram of this experiment is shown in Fig. 17. The kites varied considerably in size, but the fore and aft cells of each were of equal area. In the diagram the kites are lettered A, B, D, and E, A being the highest at the end

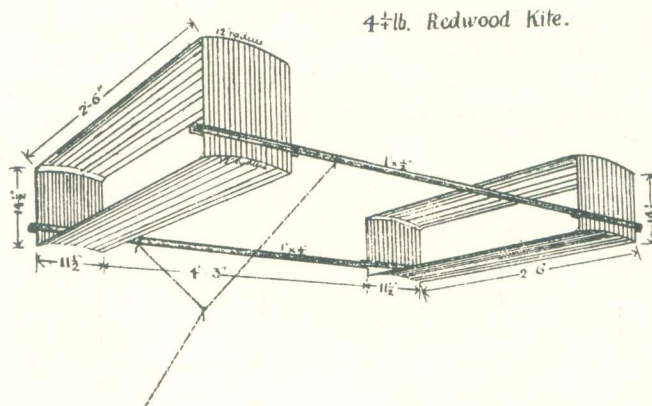


Fig. 16. Cellular kite. Both fore and aft cells are fitted with curved surfaces. 1894.

of the rope. The distance between A and B was 52 feet, between B and D 46 feet and between D and E also 46 feet. From kite E the rope was moored on the sand on the sea shore. The object of this experiment was to ascertain what velocity of wind was necessary to lift a man suspended from kite E. Hargrave seated himself in the sling, and 42 feet of Manilla rope was slacked between the anchorage and kite E. Soon the wind freshened to 18.6 miles per hour, and Hargrave was lifted clear of the ground, the actual pull being measured as 180 lb. maximum. The wind falling lighter, kites and experimenter came gently down, and another breeze was awaited. Soon a long and strong puff came and sent everything up like a shot to a height of 16 feet. The wind velocity was then 21 miles per hour,

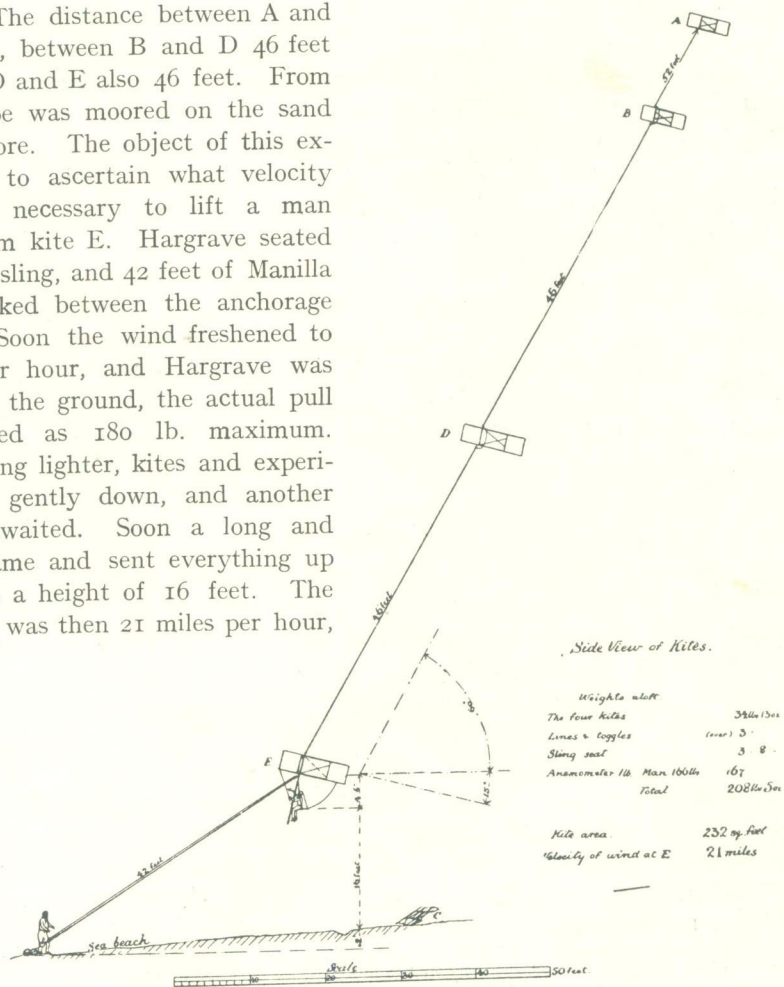


Fig. 17. Four kites lift a weight of 208 lb. a distance of 16 feet from the ground in a 21-mile per hour wind. 1894.

and the kites exerted a maximum lift of 240 lb. The total actual weight that was lifted was 208 lb. 5 oz. The angle at which A, B, and D were flying above was measured from E to be about 60 degrees, while the upper kites and E were sloped to the horizon at about the same angle, so that the forward ends of the cells were open to view from E.

In the following table are given the dimensions, weight, etc., of the four kites employed in this experiment :—

Kite.	Length of each cell.	Breadth of each cell.	Depth of each cell.	Distance between the cells.	Distance from the forward end of the forward cell to the point of attachment of the kite line.	Weight of the kite.	Area of the lifting surface.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	lb. oz.	sq. ft.
A	1 11	5 0	1 10 $\frac{1}{2}$	2 1	1 7	5 7	38.5
B	1 11	5 0	1 10 $\frac{1}{2}$	2 4	1 7	5 14	38.5
D	2 6	6 6	2 3 $\frac{1}{2}$	3 6	2 3	9 0	65
E	2 6	9 0	2 6	4 0	2 10	14 8	90

Hargrave's trend of thought, which prompted this experiment, may be gathered from his statement that—"The particular steps gained are the demonstration that an extremely simple apparatus can be made, carried about and flown by one man; and that a safe means of making an ascent with a flying machine, of trying the same without any risk of accident, and descending, are now at the service of any experimenter who wishes to use it."

Lift Varies with Aspect Ratio.

In August, 1896, Hargrave read another paper before the Royal Society on the cellular kite. In this paper he theorised on the lift and stability of a kite with concavo-convex horizontal surfaces and flat vertical ones. He also described an improved method of constructing such a kite of greater strength and rigidity than those used hitherto.

In comparing his cellular kites with the common kites in use previously, Hargrave attributed the greater lift of the former per square foot to the distribution of the lifting surface, the value of which depends within certain limits on the linear dimension that first meets the wind.* Thus a common kite of 25 square feet area cannot display more than about 7 feet of edge to the wind, whereas a cellular one of the same area can easily display 20 feet. This principle was first enunciated by Cayley in 1809, and was later confirmed by Wenham in 1866.

Vertical Surfaces Influence Stability.

Another principle stressed by Hargrave was that the great stability of the cellular kite was due to the vertical surfaces. There is no doubt that they played an important part in this connection, for in the kite they always remained parallel

* This is an important factor in the construction of modern aeroplane wings. In aeronautical language it is known as the "aspect ratio," and is defined thus: The distance between the inner and outer extremities of a plane is known as the span, that between the leading and trailing edges as the chord. The $\frac{\text{span}}{\text{chord}}$ is the aspect ratio, and this in modern machines, varies from five to eight or even more. It has been found that with cambered surfaces the efficiency increases with the aspect ratio. It is questionable, however, whether any material advantage is gained by making it greater than eight, for structural difficulties are then introduced.

with the direction of the wind. When, however, the first aeroplane built on the box-kite principle was tried out, it was found that the stability was perfect when headed against the wind, but became erratic in a side wind. This led to the entire removal of the vertical surfaces from the main planes.

Theory of Lift Possessed by Curved Surfaces.

In his communication to the Royal Society on 1st September, 1897, Hargrave endeavoured by numerous experiments to solve the problem of soaring in a horizontal wind. "There is no difficulty," he states, "in soaring if we assume an upward trend in the wind such as a cliff, building, or sloping hill will produce. But when we see birds soaring in light wind and storm, something beyond our knowledge is recognised as being at work."

Chanute had just previously published a series of articles in the American "Aeronautical Annual," dealing at considerable length with the question of sailing flight, and these articles inspired Hargrave to carry out some practical investigations into the subject. The basis of Chanute's work was the shape of the wings of soaring birds, which possessed a downward projecting lobe at the front edge and a sharp curve immediately behind the lobe on the under side. Hargrave conducted many experiments with the object of discovering how this shape affected the course, distribution, and pressure of the wind when soaring. A piece of aluminium, shaped as described above, was used in place of the wing of a bird (Fig. 18a). The direction of the wind was indicated by the flame of a candle. Briefly, the net result of these experiments showed that the wind on the under surface resolved itself into a vortex, the upper surface of which swept forward and caused a pronounced upward pressure on the lower side of the wing. The centre of the vortex was found to be approximately at the centre of the curve of the fore part of the aluminium sheet.

Having by candle flame demonstrated the direction of the wind on the lower concave surface, Hargrave verified his results by substituting for the aluminium sheet the wing of a gull (Fig. 18b). The ruffling of the feathers from behind forwards confirmed the conclusions already deduced. Here the arrows indicate the direction of the wind, and, although it is correctly shown to have a pronounced upward course in front of the leading edge, Hargrave failed to demonstrate the fact that this caused the upper surface to exert a far greater lift than the lower.

Lift of Curved and Plane Surfaces Compared.

In order to illustrate in the simplest possible manner the greater "lift" possessed by the curved than the plane surface, Hargrave constructed the apparatus shown in Fig. 19. This consisted of a horizontal rod, round which a curved and a plane surface were free to revolve, the one balancing the other. The rod was

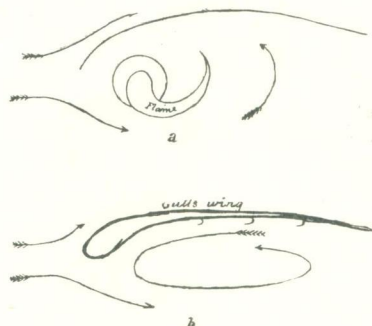


Fig. 18. Experiment with a curved aluminium sheet and the wing of a gull, to show the direction of the wind under a suitably curved surface. 1897.

pointed to the wind, and both surfaces received a blast of equal intensity. In the first case both the plane and the cord of the curve were set at a slight positive angle, 10 degrees, to the direction of the wind (Fig. 19A). Although in this position the plane surface possesses considerable lift, the curve easily rotated the arms against the lift of the plane.

The plane and the chord of the curve were next set parallel to the direction of the wind, *i.e.*, at no angle of incidence (Fig. 19B). In this case there was, of course, no lifting force whatever exerted by the plane, while the curve lifted readily and rotated the arms.

In Fig. 19C the plane was left parallel to the blast, and the curve was sloped at a negative angle. This angle was increased to at least 10 degrees, and the lift of the curve still rotated the sleeve against the resistance of the plane.

In Fig. 19D the plane was set at a positive angle of 6 degrees, leaving 16 degrees between the plane and the curve. The plane in this position exerted greater lift than the curve and the arms rotated in the opposite direction.

Although these experiments demonstrated in a most convincing manner the greater lift exerted by a curved surface than by a flat one, it must not be thought that this principle was discovered by Hargrave. It was demonstrated in England by Phillips in 1884, and later confirmed by Lilienthal in Germany. Nevertheless considerable credit must be given to Hargrave for the ingenious and practical experiment he devised to illustrate the phenomenon.

Vortex Forms under Curved Surface.

In order to account for this lift Hargrave maintained that the vortex under the wing revolved in such a way that the actual air which impinged on the concave

surface had a forward and upward motion, thereby pushing it into the low pressure above the wing. He was clearly of the opinion that the lift exerted by the wind on the concave was greater than that on the convex surface. This was a natural conclusion, which the shape of the curve at once suggested, and the opinion was

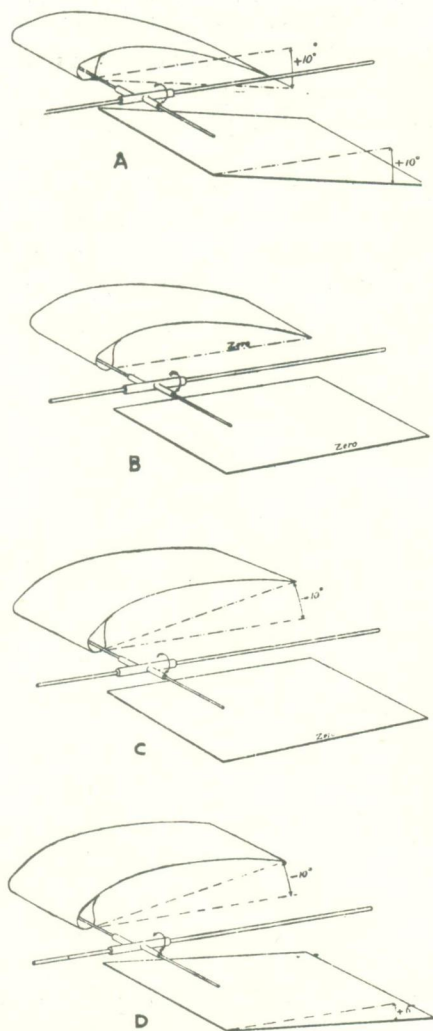


Fig. 19. Experiment to illustrate the greater lift possessed by a curved than a plane surface. 1897.

shared by all the early experimenters. It has since been shown that by far the greater lift is exerted on the convex surface, which may be four or even five times greater than that on the concave surface, according to the design of the wing. This is caused in large measure by the fact that the air as it approaches the wing has a pronounced upward trend, from which the wing derives considerable advantage in increased lift, due to the consequent negative pressure or suction immediately behind and above the leading edge on the upper surface.

Successful Soaring Experiments.

On the completion of this series of experiments with curved and flat surfaces Hargrave reverted to his experiments with box-kites. In order to prevent the breaking of his models and the consequent loss of time in repair work, he rigged up the apparatus shown in Fig. 20. This consisted of two poles 24 feet high and 48 feet apart; a cord connected the tops of the poles, and the string of the soaring kite was tied to the middle of the cord at a sufficient height to prevent it striking the ground. "I stand," says Hargrave, "to leeward of the poles and start the soaring kite at a positive angle, it then flies as an ordinary kite to near the zenith. The vortex then forms under the curved aluminium surfaces and draws the apparatus at the full stretch of the string and cord, through the 180 degrees of arc to windward of the poles. The flag shows the wind to be horizontal, and the string that is plainly visible in the photograph shows the soaring kite pulling about 20 degrees to windward of the zenith. The wind was blowing at 12 or 14 miles per hour, which was inadequate to effect the best pull the affair was capable of."

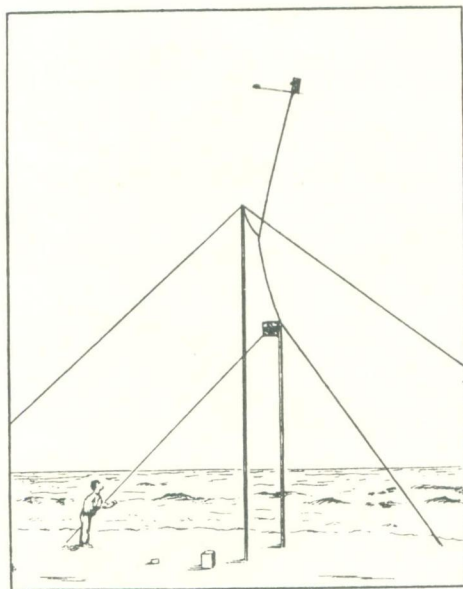


Fig. 20. Structure used for soaring kites. 1897.

The projected area of the two curved surfaces of this kite was 1 sq. ft. 45 sq. in., and the weight was 1 lb. 4½ oz. It was also provided with a cylindrical aluminium tail.

Kite with Cylindrical Extremities.

In his paper entitled "Aeronautics," read on 1st June, 1898, Hargrave gave the results of further experiments with kites flown on the apparatus shown in Fig. 20. In order to obtain stability in a fore and aft direction the kite was attached to the middle of a tubular rod, which was provided with a cylindrical cell at each extremity. The principle underlying this arrangement was similar to that of a tight-rope walker holding a long pole. A great degree of stability was procured by this means. The kite itself differed from those previously flown, which were principally of the box type,

inasmuch as it consisted of the one surface curved similarly to the small model shown in Fig. 18. The curved surface was constructed of vulcanite, for it was found that muslin stretched over a frame did not possess sufficient rigidity to allow the kite to soar. Rigidity of construction was found to be essential, for springy and vibratory surfaces were not conducive to steady soaring. In reality their practical effect was to increase the head resistance.

Kite with Vertical Fin.

Repeated experiments with this type of kite resulted in the attainment of greater efficiency by the refinement of details. These were described in November, 1898. The long tin rod was made much more rigid and the curved surfaces were

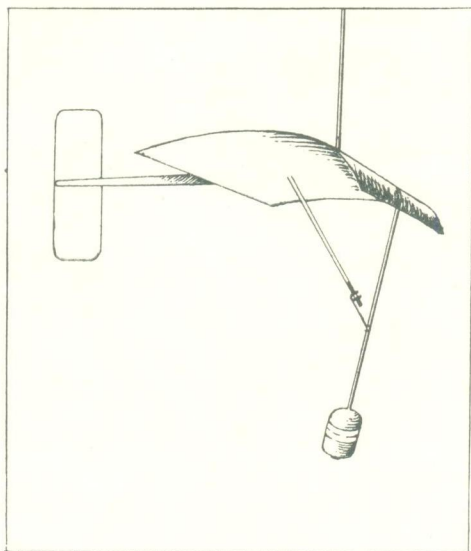


Fig. 21. Curved wing section fitted with vertical fin and weighted to obtain a low centre of gravity. 1898.

made of redwood. After repeated trials with this improved kite, it was found that the cylinders at the ends of the rod did not retain the curved surface at the proper soaring angle, but, sooner or later, the apparatus tipped up or down. For this reason the weight was transferred to a point below the curved surface. A kite embodying this idea was then made (Fig. 21). It will be seen that this model was provided with a vertical, but lacked a horizontal rudder. Owing to the disposition of the weight, the centre of gravity was low, and it was therefore considered that the kite would automatically balance itself, and a horizontal rudder would retard rather than assist the balance. In practice it was found that this kite was very steady, and soared in a 12-14 mile-per-hour wind.

Sailing Birds Dependent on Wave Power.

Kites embodying further modifications of this principle were experimented with, and varying success attended the trials, but the science of aero-dynamics was not materially advanced thereby.

In 1899, Hargrave returned to the study of the soaring of birds. After very close observation he discovered that many sea-birds are not entirely dependent on a head wind to enable them to soar, but may derive sufficient energy from the power of the waves in apparently still air. The basis of Hargrave's theory is contained in the following statement :—" As to the effect of the wave on the air, we will suppose the water to be quite flat and the air motionless, a heavy undulation comes on the scene, it has to pass, so it pushes the air up with its face, letting it fall again as its

back glides onwards. The air on the face is slightly compressed, that on the back lowered in pressure, both operations taking power out of the wave and eventually largely contributing to its extinction.

"The closer the bird is to the surface of the water, the firmer and more inelastic is the uplift of the raising air. The bird appears to feel the surface with the tip of its weather wing."

While this theory of the motion of the air over sea waves is a very feasible explanation of the force which enables a bird to soar there, it by no means clears the way for a soaring machine to imitate it. This was well recognised by Hargrave, for he stated that, "This is the solution of the problem of a sailing bird's progression totally denuded of complications. It becomes a giant's task to compute the result when the effect of cross seas, wind at all angles, and ever-varying force, arched surfaces, head resistance, ratio of weight to area, and the intelligence of the guiding power crop up. These questions all combined have been considered in the evolution of a sailing bird and must be reckoned with by the designer of a wave-driven flying machine."

Concluding Stages of Hargrave's Work.

At this time, 1899, events in the world of aviation were moving apace. Gliders were being built in Germany, England, and America, and records were being made in gliding flight almost daily. Men were now able to study the requirements of a stable aeroplane by the behaviour of their gliders in the air. Any unsteadiness, either for-and-aft or laterally, was noted, and the disposition of the parts altered to correct it. Ideas were copied, the one from the other, until stability was secured.

Hargrave, situated so far from the centre of operations, could not now keep pace with such rapid and ever-changing development. He had built a solid foundation, and was content to watch others complete the superstructure. His was the spirit of the true scientist—he was convinced that the ingenuity of man was capable of overcoming the difficulties of dynamic flight and endeavoured to accomplish it, but, though he did not completely succeed in his goal, he made the way much easier for others to follow. His papers and ideas were sent abroad freely and with no binding patent rights, in order to assist others in the attainment of the common objective, for Hargrave was more concerned with the advancement of aviation than with the notoriety of Lawrence Hargrave.

Kite with Reverse Curves.

After a lapse of ten years he contributed, on 1st December, 1909, his last paper on aero-dynamics to the Royal Society. This contained a description of the construction and properties of a rigid box-kite, which proved to be more stable than any of those used hitherto. A replica of this kite was presented by Hargrave to the Technological Museum in 1912, and a photograph of it is shown in Fig. 22. It will be seen that the horizontal surfaces, both upper and lower, consist of reverse curves. Looked at from above, the front half is slightly convex, while the rear half is correspondingly concave. The outside edge of the frame is perfectly straight. This kite was 2 ft. 8 in. long, 4 ft. 8½ in. wide, and 1 ft. 7¼ in. high; the total lifting surface was 25.09 square feet, and the weight was 2.28 lb.

The qualities of kites after this design are thus summed up by Hargrave :
“ These rigid stable aeroplanes are superior to the very best cellular kites I can make ; they are lighter, pull harder per square foot, attain a greater angle of elevation, and have fewer parts.”

Concerning the stability of the reverse curve, it has been found by experiments carried out at the National Physical Laboratory of the United States of America that such a curve in the trailing edge of a wing may increase the stability to a surprising degree, but the lift and efficiency are correspondingly reduced with each

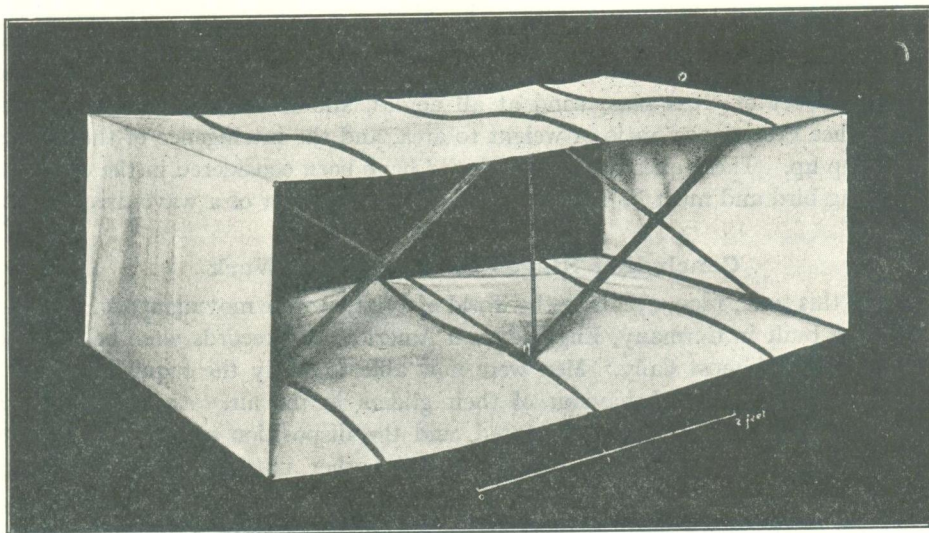


Fig. 22. Box-kite with reverse curves. 1909.

increase in the amount of reverse curvature. When this is very slight, however, it has been found possible to increase the stability while the lift and efficiency are maintained.

Review of Hargrave's Work.

Having traversed the ground covered by the aeronautical work of Lawrence Hargrave, a brief review of the most important features of that work will perhaps assist the reader correctly to appraise its value to the science of aerodynamics and the development of the aeroplane.

First, with regard to the early flat-surface monoplanes, it may be said that the experiments conducted with these, although extremely interesting and far more advanced than any previous attempts at dynamic flight, did not in themselves advance the science to any great extent. The models flew in a more or less straight course for greater distances than any other machines had flown previously, but they were unable to rise from the ground, and no provision was made for such movements as ascending and descending, for turning on a horizontal axis or to right and left. They were capable of being flown only on perfectly calm days, for a slight gust of wind was sufficient to upset them. Perhaps their greatest value lay in the stimulus they gave to the study of flight by bringing many other workers into the field.

It was but natural that Hargrave should have endeavoured to imitate the flight of birds by means of artificial flapping wings, for one would readily imagine that such a method of propulsion was the last word in efficiency, in view of the speed and control exercised by a bird in the air. But it must be borne in mind that the screw propeller is not naturally available in an animal's construction. This is clearly pointed out by Lougheed in his book, "Vehicles of the Air," wherein he states—"It is a common argument that birds, which may be considered the flying machines *par excellence*, fly on this plan. True enough, but it is equally true that most animals walk on legs and most fishes swim with tails and fins, despite which man finds that with wheels and screw propellers, he can secure results vastly superior to any that are to be found in attempts to copy nature's mechanisms more closely. It is a point deserving of regard in this connection that the real reason the continuous rotating mechanism is unknown in the animal economy may be the excellent one that it is not available. A wheel or any similar continuous rotating element in a machine involves a complete separation of parts, mere contact or juxtaposition being substituted for the complete structural continuity that is rendered imperative in the natural machine by nature's self-contained processes of manufacture, growth and repair—processes with which man's mechanisms are not handicapped, however imperfect they may be in other respects."

Hargrave made a comparison of the relative propelling powers of flapping wings and a screw under what appeared to him to be similar conditions, and found them to be about equally effective, but as previously pointed out, his design of screw is now known to have been very inefficient.

His engines were for their time very efficient, wonderfully simple, and extremely light. They remain as a tribute to his ingenuity. Probably his most resourceful engineering discovery was that of the rotary engine. Engines of this type have proved to be peculiarly adapted to aeroplane work for a fly-wheel effect is obtained which increases the smoothness of running. The well-known "Gnome" aeroplane engine embodied this principle, and many records were made with it. Other successful rotary engines were the "Clerget" and "Le Rhone."

How many Australians, familiar with the word "Gnome," familiar, too, with the wonderful performances the engine accomplished, know that it was through our own Australian inventor that its manufacture was rendered possible? The majority probably look upon it as a French invention; it certainly was a French patent, for Hargrave refused to patent anything. His own prediction, made in 1907, is thus borne out, for he stated—"Ideas of a more or less bizarre nature, apparently ridiculous when first presented, are sometimes examined by the most remote people and their merit recognised and acted upon. Then, maybe, after many years, the invention is brought to its place of origin as a valuable foreign production. This, being the unalterable way in which humanity is built, must be accepted without demur."

Resourceful as were Hargrave's experiments with monoplane models, ingenious as were his inventions of light engines, they did not penetrate the mist which enveloped dynamic flight. Rays of sunshine became visible with the advent of the box kite, and it is upon this that Hargrave's place in the history of aeronautical

development is chiefly founded. His kites possessed greater stability, more lift and less drag than any apparatus previously discovered. He was the first to demonstrate that a relatively small surface arranged as in his kites was sufficient to lift the weight of a man from the ground. Having accomplished this, the steps which led from there to a man-carrying aeroplane consisted of a light and efficient engine, and the fitting of an adjustable tail for steering. The principle of the latter had been enunciated by Hargrave and others, the former was evolved from the light internal combustion engine of the automobile and motor-cycle. No more convincing argument can be advanced for the epoch-making importance of the Hargrave kite than the fact that the first aeroplane ever to fly publicly, that of Santos Dumont, in France, was simply an arrangement of those kites.

The Sydney Technological Museum is fortunate indeed in possessing the original monoplane models, described by Hargrave in the "Proceedings of the Royal Society of New South Wales." All of these models flew various distances, and records of their flights are carefully preserved. They were more or less damaged when they came to earth at the end of their flight, but the broken parts were not replaced; they were carefully bound together so that the form of the original model as it actually flew is preserved for all time. Only one box-kite, a replica of that flown in 1909, is in the possession of this Museum; the whole of Hargrave's other kites and inventions went to Germany.

There has been much controversy relative to this action of Hargrave, and many false impressions have gained credence. A correct account of what actually took place, and the motive underlying Hargrave's decision are, I believe, contained in the following statement.

The models were offered to the New South Wales Government in 1909 on condition that they be open to inspection by the public and that they be placed in show-cases. Statements have from time to time been made in the press and elsewhere that this offer was refused by the Government of the day, of which the Hon. C. G. Wade was Premier. Such statements are absolutely contradicted by the official papers which deal with the offer. The following letter, a copy of which is filed in the Premier's Department, Sydney, was sent to Sir James Graham (who was acting on Hargrave's behalf) by Mr. J. L. Williams, then Under Secretary for Justice :

" 29th December, 1909.

" Sir,

" Referring to the question asked by you of the Premier in the Legislative Assembly on the 21st September last respecting Mr. Law. Hargrave's offer to present to the New South Wales public a large collection of models of flying machines, &c., I have the honour to inform you that Mr. Wade has approved of accommodation for the collection being found in the Technical Museum, Ultimo, in which institution the earlier ' Hargrave ' flying machine models are already housed and displayed.

" I have the honour to be, Sir,

" Your obedient servant,

" J. L. WILLIAMS,

" Under Secretary for Justice."

Whatever reports may have gained currency to the contrary, this documentary evidence must be accepted as a correct and final statement of actual fact.

About this time a proposal was made to Hargrave, on behalf of Germany, that if the models were presented to that country, a special building would be allotted to them. This offer Hargrave accepted, and much criticism has been directed against him for what has been termed his lack of patriotism. Now, I question whether a more patriotic Australian* ever lived than the same Lawrence Hargrave. Right throughout his writings his love of Australia is unmistakably revealed, and one of his greatest desires was that Australia should get the credit for the work he did. I believe that Hargrave's decision was reached as a result of the fact that he looked upon the development of aviation from the view-point of civilization, rather than from a national one. He desired his work to benefit mankind, and countries and border lines had no place in his vision. He was persuaded that in Germany his models would be readily available to students and engineers all over Europe, while in Australia their influence would scarcely be felt. Hargrave succumbed to the argument, and the models were lost to Australia for all time. He never suspected that very soon the aeroplane was to become an efficient fighting machine, that his models and ideas were to be used in the development and improvement of aeroplanes destined to fight against his beloved native land. He never suspected that his own son was to lose his life at the hands of those he had so unselfishly benefited. Hargrave was an idealist—war was anathema to him—and he never really recovered from the shock of his son's death. It has been stated, and, I believe, truly, that the bullet that killed his son killed Lawrence Hargrave.

* Actually, Hargrave was born in England in 1850 and came to Australia when 16 years of age. On account of the fact that the rest of his life was lived, and the whole of his technical training received, in Australia, he is usually regarded and may justly be claimed as an Australian.

**List of Papers on Aeronautics and Kites read by Hargrave before the
Royal Society of New South Wales.**

- The Trochoided Plane. 6th August, 1884.
Notes on Flying Machines. 3rd June, 1885.
On a Form of Flying Machine. 2nd December, 1885.
Notes on a Model shewing one form of Serpentine Progression. 2nd June, 1886.
Recent Work on Flying Machines. 1st June, 1887.
Autographic Instruments used in the Development of Flying Machines. 7th
December, 1887.
Flying Machine Memoranda. 7th August, 1889.
On a Compressed Air Flying Machine. 4th June, 1890.
On the 74 oz. Compressed Air Flying Machine. 3rd December, 1890.
Nos. 13 and 14 Compressed Air Flying Machines. 1st July, 1891.
Flying Machine Work and the $\frac{1}{8}$ I.H.P. Steam Motor weighing $3\frac{1}{4}$ lb. 3rd
August, 1892.
Flying Machine Motors and Cellular Kites. 7th June, 1893.
Aeronautical Work. 5th June, 1895.
On the Cellular Kite. 5th August, 1896.
The Possibility of Soaring in Horizontal Wind. 1st September, 1897.
Aeronautics. 1st June, 1898.
Soaring Machines. 2nd November, 1898.
Sailing Birds are Dependent on Wave Power. 6th September, 1899.
Rigid Stable Aeroplanes. 1st December, 1909.

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