velous immunity from fracture, only one single bar out of the many hundred in the bridge being ruptured. The conclusion at which practically every engineer who has examined the fallen bridge, and made a careful study of the strain sheets, etc., has arrived is, that there was something radically wrong with the design of the large compression members, and particularly the bottom chords. In this opinion we entirely concur, and for the reasons which are given below.

The general public has but a faint idea of the enormous stresses to which the members of a cantilever of the size of the Quebec Bridge are subjected. The chord member which failed was *supposed* to have a safe strength of 9,312 tons; that is to say, it could be subjected to an end pressure of this enormous amount without any signs whatever of deflection or buckling. In order to illustrate just what this means, our artist has prepared the accompanying drawing showing this member, 57 feet in length and measuring 5 feet 7 inches by 4 feet 6 inches in section, stood on end on a suitable pedestal, and carrying the United States armored cruiser "Brooklyn," whose weight is 9,215 tons. Now, according to the calculations of the engineers, this member should not only be capable of carrying the load of the "Brooklyn" without failure, but it should be possible to add as an additional load, say, the cruiser "Marblehead," of 2,100 tons weight, before the column would begin to show signs of distress, the total load of over 11,000 tons representing close to the elastic limit of the material, or the point at which the steel would begin to yield without recovery. Now, 11,320 tons represents the maximum possible load which it was estimated could come upon this member, due to the weight of the bridge itself, plus the weight of the live load, that is trains, vehicles, foot passengers, etc., plus the load due to a heavy wind storm. And, right here, we cannot but express our surprise that this member should have been made so light that, in the event of the maximum live load and the maximum wind pressure occurring at the same moment, the metal would be strained almost to the elastic limit. This is cutting matters down to a fine point with a vengeance. We understand that those who are responsible for the design claim that the probability of the conjunction of a maximum live load and a maximum wind storm was considered to be so remote as to be negligible in the computations. They considered, furthermore, that this contingency was preventable, since it would be possible in the event of a heavy windstorm to prevent more than a limited amount of traffic on the bridge. This was certainly a most astounding presumption; for it is always possible that a fully-loaded bridge may without warning be subjected to a gale of wind or even a tornado.

However, as a matter of fact, this compression member failed under a load of about 8,000 tons, or less, this being the calculated load which was upon the bottom chord at this point, when the bridge went down. How comes it then, that failure should have taken place when the chord was strained to only about two-thirds of its calculated strength? An examination of the drawing of this member, as here given, and of the direction in which it yielded, affords conclusive evidence that it gave way because the latticing which is supposed to hold its parts in true line was utterly inadequate to do so.

The member consisted of four deep parallel webs, or ribs, 4 feet 6½ inches in depth, each built up of four thicknesses of steel plate riveted together, and having a total thickness of about 3½ inches. Now the veriest tyro can understand that these four plates, 57 feet in length and 4 feet 6½ inches in width, if stood up on end, parallel with each other, would be capable of carrying but a very small load before they began to buckle out of shape. To render them capable of load carrying, they would have to be braced firmly together with a view to keeping them in true line. This fact can be illustrated in a homely way by taking an ordinary walking cane and leaning upon it. Before much pressure was applied it would begin to spring out of line. If it were held at its middle point, it would carry a much greater weight before deflecting, and if it were supported at three points, a greater load yet, and so on. Now the method adopted for preventing deflection of the ribs of the Quebec Bridge chords, transversely to their planes, was to tie them together at their edges with a latticing of diagonal angles, each measuring 4 inches by 3 inches and ⅜ inch in thickness, and transverse struts consisting of angles 3½ inches by 3 inches by ⅜ inch in thickness. This latticing, or trussing as it might be called, was riveted to the tops of the webs by ⅞ rivets, there being two rivets at each point of contact. *Theoretically*, these angles should have been sufficient to hold the webs in true line, that is, to hold them exactly parallel with the longitudinal axis of the chord member. *Theoretically*, if the ribs were absolutely true, and if the load of 9,000 or more tons was applied concentrically and in an absolute axial line with the member, there would be no stress on the latticing. As a matter of fact, not even the most careful manufacture can insure such mathematical exactness. The individual plates, and the columns as a whole, are certain to be somewhat out of line. Moreover, because of slight and unavoidable inaccuracies in manufacture, the load might be applied somewhat eccentrically; that is to say, it might bear more heavily on one edge of the column than the other. This might be further aggravated by the fact that the rivets of the latticing did not entirely fill the rivet holes, allowing a slight deflection of the whole column, until the angles of the latticing were under stress. Then there would be a tendency to tear the latticing apart, either by the rupture of the lattice angles, or, what is more likely, by the shearing off of the rivets. Undoubtedly this is what occurred in this member. In fact, two or three days before the disaster, the inspector had observed that the webs had actually sprung out of line from an inch and a half to two inches, and before the warning had been heeded and load taken off the bridge, the latticing tore asunder, and the thin and now unbraced web plates buckled like the walking cane above referred to, and twisted into the S form in which they now lie beneath the pile of wreckage.

It is our belief that not only was the lattice reinforcement absurdly light for the work it had to do; but that the outside dimensions of this member, which measured only 4½ feet by 5½ feet, were altogether too slight for the chords of a bridge of this enormous size. This criticism is borne out by a comparison with the sections, shown in our engraving, of the bottom chords of two other notable bridges, one the 1,000-foot, steel, arch bridge about to be built at Hell Gate across the East River, and the other the celebrated Forth Bridge, whose cantilevers have a span a little less than that of the Quebec Bridge. In the case of the Hell Gate Bridge the bottom chord measures 7 feet by 8 feet 6 inches; and, although the total combined dead, live, temperature, and wind loads have a total of only 8,420 tons, the total area of metal at any point of section is 811 square inches, as against 735 square inches in the Quebec Bridge, whose total load, as we have seen, is estimated at 11,320 tons. Moreover, the metal of the Hell Gate chords is distributed around the circumference, instead of across the whole member; and in place of light angle latticing it is stiffened throughout with solid cover plates, and has three one-half inch diaphragms, with stiffening angles, extending across it at three points of its length. The Forth Bridge bottom chord is an even stiffer construction than this. It consists of a tube 12 feet in diameter, built up of ten 12-inch longitudinal I-beams, riveted to an outer shell 1¼ inches in thickness, with circular stiffening webs worked in at 8-foot intervals throughout the whole length of the tube.

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THE GAMMETER ORTHOPTER—A BEATING-WING FLYING MACHINE.

BY H. C. GAMMETER.

The accompanying illustrations depict a beating-wing flying machine of my invention, the principal dimensions of which are the following: Width, 30 feet from tip to tip; length, including the rudder, 12 feet; area of the body, including the rudder, 48 square feet; area of the wings, 154 square feet; total area, 202 square feet; weight, 290 pounds, including fuel and gyroscope; weight with operator and fuel, 440 pounds; engine rated at 7 horse-power; weight of engine with clutch, 70 pounds; speed of engine, 1,200 revolutions per minute; speed of wings, 75 vibrations per minute.

As yet no outdoor tests have been made with this machine, for the reason that I was unable to continue my experiments at the time that I most desired to do so, and that it would have proven embarrassing to drop them, once begun. Moreover, they must, of necessity, become public in any attempt at free flight. Thus, I may mention that my indoor tests were very encouraging indeed, and prove that I have ample power to lift the machine entirely from the floor the instant the clutch is released. Owing to the confined area in the room in which I conducted the experiments, I was not always successful in causing the machine to rise. When suspended, the orthopter indicated a forward pull of approximately 24 pounds. These figures are, of course, indefinite, because the circulation of air within a confined space prevents any accurate measurement. Lack of experience in steaming and bending bamboos for the wings has left the material soft and weak. Hence, the necessity of piano wire stays.

The Editor of the SCIENTIFIC AMERICAN has expressed a doubt as to my ability to rise with a seven horse-power engine. This doubt is justifiable if the engine does not develop more than one-half its rated horse-power, which is frequently the case. But with seven actual horse-power, I fail to see why I should not succeed on a principle which is faithfully copied from nature. While I cannot hope to work as accurately as nature, yet with a seven horse-power motor I should have at least four times as much power as nature employs to do the same thing, after deducting fifty per cent for friction. Because I intended to experiment over water, I use inflated canvas-covered rubber floats, which appear in the illustration. But owing to the lateness of the season and the bad weather of autumn, I will substitute wheels and run on land.

For several years past I have made a very careful study of the principles of aerial navigation, and have closely followed the experiments of Langley, Maxim, Manly, and others, besides devoting most of the past winter in Florida to observations of birds in flight. I have come to the conclusion that as nature teaches us how perfect flight may be obtained, it is advisable to copy her as freely as possible, at least for a beginning, and then to modify our designs to suit the conditions of artificiality. The enormous lifting power of movable wings always impressed me very forcibly.

In my first experiments I will depend entirely upon wings for lifting and propulsion. It is evident from the accompanying illustrations that the anterior edges of the wings of my machines are rigid, while the posterior edges are flexible, so that the wings may act as propellers, both on the up and down strokes. In form the wings are a close copy of a bird's, except that the outer three-fifths are valvular, so as greatly to reduce the resistance on the upstroke. Owing to the angle taken when the wings are open, they assist considerably in propulsion.

The feature in which my work has been exceedingly successful is the transmission of the power from the motor to the propelling mechanism. This transmission is not only exceedingly light and strong, but very simple and efficient. It consists of a light 20-inch gear of manganese bronze (preferably steel) containing a ball race cut into the face, leaving teeth upon both sides. This gear in turn revolves within a rigid ring held in the frame of the machine, and contains a corresponding groove for the balls. The ring at the bottom contains the bearing for the pinion (16 to 1) from the internal cone clutch, controlled by means of a lever adjacent to the steering wheel.

Rods leading to the wings connect with the gear from opposite sides, and clear the horizontal supports of the wings.

The wings are hinged at two points to the tubular frame, 30 inches apart. Two diagonals meet the braces on the bamboo, and converge at a point in line with the connecting rods. Thus, it will be seen that the thrust of one wing is virtually in line with the other, which permits both a light and strong construction.

It is in this respect that Blériot and others have failed in their attempts at constructing a beating-wing machine. Only one rudder will at present be used. This is balanced horizontally, and is controlled by means of a cable leading to the steering wheel. The wheel also contains a spark advance and throttle lever, as in an automobile.

The body of the machine is made of steel tubing 16 to 22 gage, while the wings are of common bamboo covered with Japanese silk.

Foremost in importance of all the features of a flying machine is the question of stability. This important problem, without the complete mastery of which aerial navigation can never succeed, has offered great difficulties in all attempts thus far made; and when success was finally achieved by Langley, it was only after many discouraging attempts.

In my machine stability is obtained by means of a low center of gravity, by requiring the operator to shift his weight and by keeping the area of the machine as small as possible, to eliminate danger from wind gusts.

More important than either of these, perhaps, is the placing of an inclosed horizontal flywheel in the center of the plane. It is almost incredible what resistance this wheel at 1,500 R. P. M. offers to any sudden change in direction. After a very careful study of the true gyroscope, I abandoned it as too complex. Provision is also made for a propeller, but merely to test the efficiency, as I do not believe I shall use it, unless it is deemed desirable to do so after being thoroughly launched in the air, in which event the wings may be held rigid and the propeller used. I hope to compete for the SCIENTIFIC AMERICAN trophy with this machine.

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Pennsylvania Railroad Prizes to Employees.

During this month the Pennsylvania Railroad will distribute $5,400 in prizes to the men whose tracks have been kept in the safest and most perfect condition in the last year. The main track will first be judged by engineers of the Maintenance of Way Department and the Division Superintendents, to be followed two weeks later by the General Manager's annual inspection. On this trip he will be accompanied by a party of about 200, traveling in the company's special track observation cars. General Superintendents, Division Superintendents, assistant engineers, supervisors, and their assistants will compose the party.

There are to be one $1,200 prize, four $800 prizes, and one prize of $1,000. The $1,200 premium for the best line maintained throughout the entire year; the $1,000 premium for the supervisor's division showing the greatest improvement in the year.

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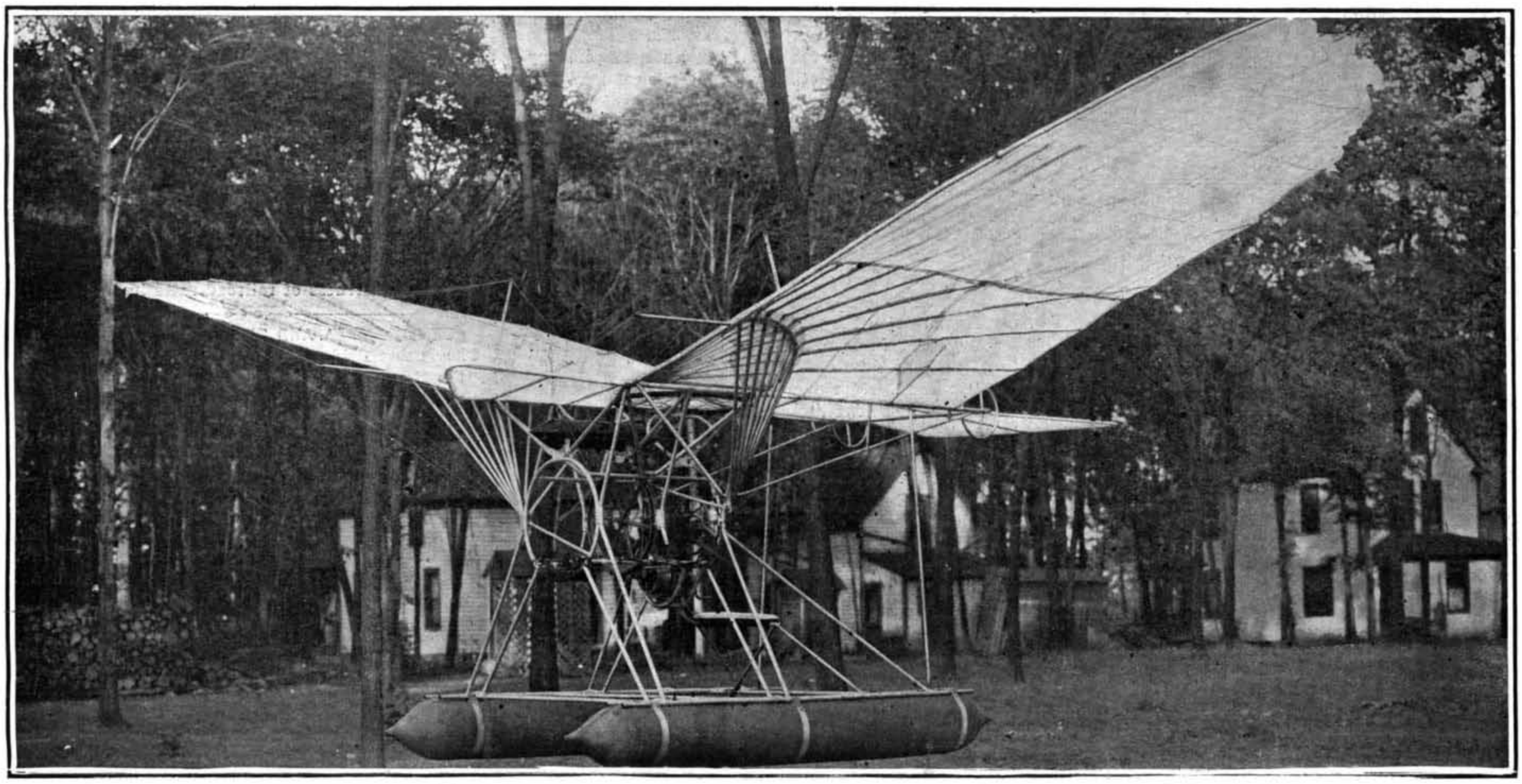
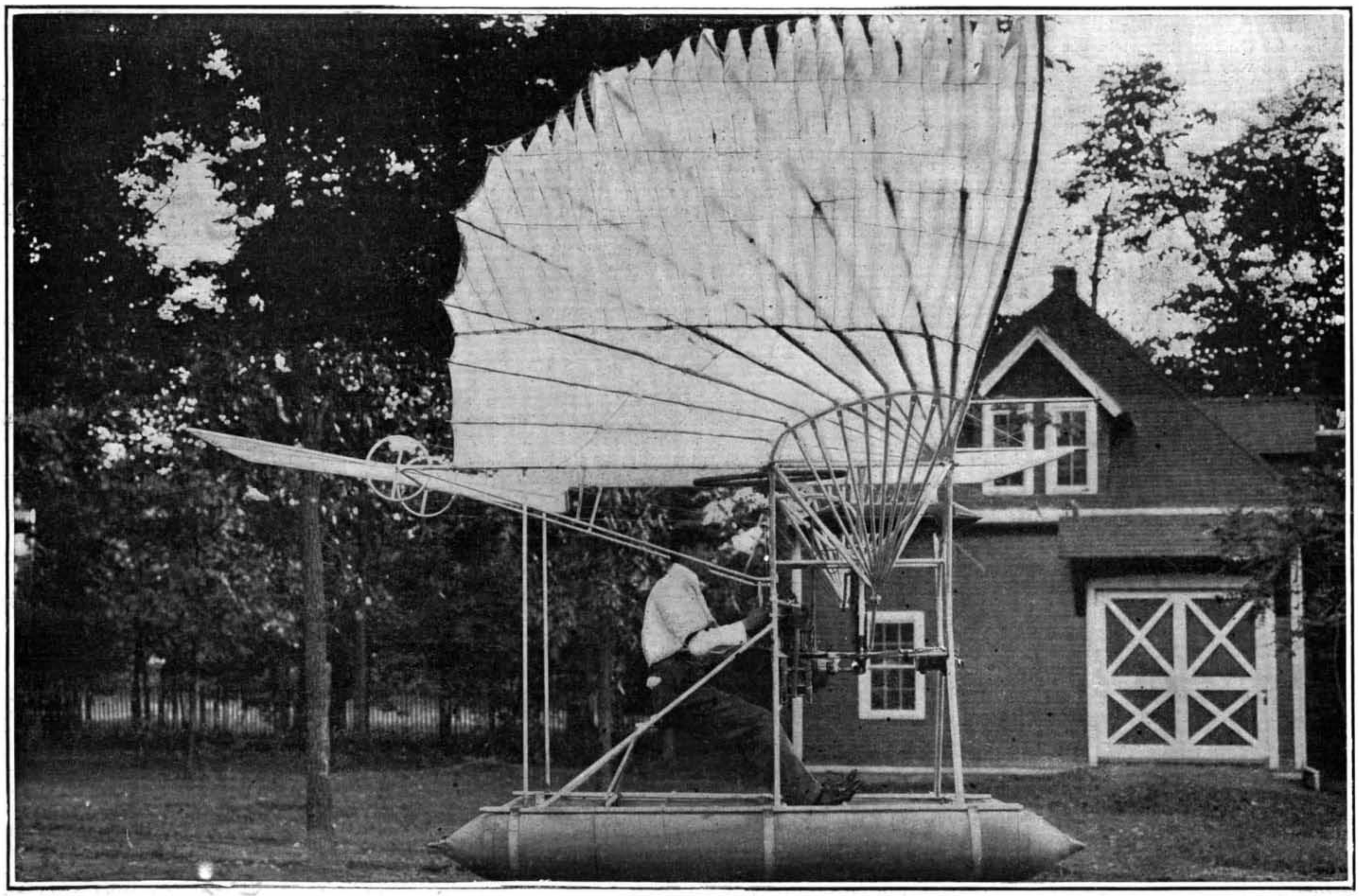


The Gammeter Orthopter. Width, 30 Feet from Tip to Tip; Length, Including Rudder, 12 Feet; Area of Body, Including Rudder, 48 Square Feet; Area of Wings, 154 Square Feet; Total Area, 202 Square Feet.



Side View of the Gammeter Orthopter. Weight, 490 Pounds With Operator and Fuel; Engine Rated at 7 Horse-Power; Speed of Engine, 1,200 Revolutions Per Minute; Speed of Wings, 75 Vibrations Per Minute.

A NEW BEATING-WING FLYING MACHINE, A COMPETITOR FOR THE SCIENTIFIC AMERICAN TROPHY.—[See page 258.]