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KITE EXPERIMENTS AT THE WEATHER BUREAU.

By C. F. MARVIN, Professor of Meteorology, U. S. Weather Bureau (dated July, 1896).

In November, 1895, the present writer was directed by Prof. Willis L. Moore, the Chief of the Weather Bureau, to consider the subject of devising kites and auxiliary apparatus for the meteorological exploration of the upper air. The definite object was to attain a height of at least 1 mile and, if possible, 10,000 feet or more, and to bring down continuous records of temperature, moisture, pressure, and wind. A considerable acquaintance with the present state of the art of making and flying kites showed that both the form of the body of the kite and the analysis of the action of the forces that affected it demanded fuller consideration than had hitherto been given. In view of the rapidly increasing interest in this subject it seems proper to lay before the cooperating observers of the the Weather Bureau the results that have been attained during the past few months, in order that those interested in the subject may in conducting their own experiments, profit by our experience.

With the advance of the science of meteorology, and especially with the progress in the development of the fundamental laws governing atmospheric phenomena, a growing

need arises for accurate knowledge of the conditions of the atmosphere with respect to its motion, temperature, pressure, moisture, etc., not only near the surface of the earth but particularly in the higher strata, where the forces in action have full scope and their effects are unmodified by such disturbing influences as exist near the surface.

Meteorological stations have been maintained on lofty mountain summits, in order to procure the desired information, and many perilous balloon voyages have been made with the express object of making accurate measurements of the atmospheric conditions at all elevations. Some use has been made of captive balloons, and within a few years remarkable results have been obtained in Europe by the use of free balloons of small size equipped with automatic instruments. Having no load of ballast to carry, these balloons when set free shoot upward with great velocity and attain very lofty elevations, whereupon, losing all effective lifting force by reason of the expansion and overflow of gas incident to the great diminution of pressure in the rarified strata of air, the partially inflated bag falls to the earth after a comparatively short journey. A notice attached to the balloon gives instructions respecting its disposition, and the finder receives a small reward for its safe return.

It appears, however, that even before balloons were invented, Dr. Alexander Wilson of Glasgow employed tandems of kites "to explore the temperature of the atmosphere in the higher regions." I am indebted to Professor Abbe for the following extract[1] giving an account of Dr. Wilson's experiments, which, owing to their early date and complete and interesting character, deserve special mention:

* * * * * * *

Among the more advanced students, who, in the years 1748 and 1749 attended the lectures on Divinity in the University, was Mr. Thomas Melvill, so well known by his mathematical talents, and by those fine specimens of genius which are to be found in his posthumous papers, published in the second volume of the Edinburg Essays, Physical and Literary. With this young person Mr. Wilson then lived in the closest intimacy Of several philosophical schemes which occurred to them in their social hours, Mr. Wilson proposed one, which was to explore the temperature of the atmosphere in the higher regions, by raising a number of paper kites, one above another, upon the same line, with thermometers appended to those that were to be most elevated. Though they expected, in general, that kites thus connected might be raised to an unusual height, still they were somewhat uncertain how far the thing might succeed upon trial. But the thought being quite new to them, and the purpose to be gained of some importance, they began to prepare for the experiment in the spring of 1749.[2]

Mr. Wilson's house at Camlachie was the scene of all the little bustle which now became necessary, and both Mr. Melvill and he, alike dexterous in the use of their hands, found much amusement in going through the preliminary work, till at last they finished half a dozen large paper kites, from 4 to 7 feet in height, upon the strongest, and at the same time upon the slightest construction the materials would admit of. They had also been careful in giving orders early for a very considerable quantity of line, to be spun of such different sizes and strength, as they judged would best answer their purpose; so that one fine day, about the middle of July, when favored by a gentle, steady breeze, they brought out their whole apparatus into an adjoining field, amidst a numerous company, consisting of their friends and others, whom the rumor of this new and ingenious project had drawn from the town.

They began with raising the smallest kite, which being exactly balanced, soon mounted steadily to its utmost limit, carrying up a line, very slender, but of strength sufficient to command it. In the meantime the second kite was made ready. Two assistants supported it

[1] Extract from Biographical account of Alexander Wilson, M. D., late Professor of Practical Astronomy in Glasgow, by the late Patrick Wilson, A. M., Professor of Practical Astronomy in the University of Glasgow. Transactions of the Royal Society of Edinburgh, Vol. X, Part II, pp. 279–297. 1825.

This memoir of Dr. Wilson, after being read at the Royal Society, February 2, 1789, was withdrawn by its author for the purpose of making some alterations upon it, and was never returned for publication. It was found, however, among the papers of Mr. Patrick Wilson, and is now printed with the consent of his family.

[2] As no public notice has hitherto been taken of this matter, though Mr. Wilson had always some thoughts of doing so, it is hoped that the following detail will not prove unacceptable or tedious to the reader.

between them in a sloping direction with its breast to the wind and with its tail laid out evenly upon the ground behind, whilst a third person, holding part of its line tight in his hand, stood at a good distance directly in front. Things being so ordered, the extremity of the line belonging to the kite already in the air was hooked to a loop at the back of the second, which being now let go, mounted very superbly, and in a little time also took up as much line as could be supported with advantage, thereby allowing its companion to soar to an elevation proportionally higher.

Upon launching these kites according to the method which had been projected, and affording them abundance of proper line, the uppermost one ascended to an amazing height, disappearing at times among the white summer clouds, whilst all the rest, in a series, formed with it in the air below such a lofty scale, and that, too, affected by such regular and conspiring motions as at once changed a boyish pastime into a spectacle which greatly interested every beholder. The pressure of the breeze upon so many surfaces communicating with one another was found too powerful for a single person to withstand when contending with the undermost strong line, and it became, therefore, necessary to keep the mastery over the kites by other means.

This species of ærial machinery answering so well, Mr. Wilson and Mr. Melvill employed it several times during that and the following summer in pursuing those atmospherical experiments for which the kites had been originally intended. To obtain the information they wanted, they contrived that thermometers, properly secured, and having bushy tassels of paper tied to them, should be let fall at stated periods from some of the higher kites, which was accomplished by the gradual singeing of a match-line.

When engaged in these experiments, though now and then they communicated immediately with the clouds, yet, as this happened always in fine weather, no symptoms whatever of an electrical nature came under their observation. The sublime analysis of the thunderbolt, and of the electricity of the atmosphere, lay yet entirely undiscovered, and was reserved two years longer for the sagacity of the celebrated Dr. Franklin. In a letter from Mr. Melvill to Mr. Wilson, dated at Geneva, 21st of April, 1753, we find, among other particulars, his curiosity highly excited by the fame of the Philadelphian experiment, and a great ardour expressed for prosecuting such researches by the advantage of their combined kites. But, in the December following, this beloved companion of Mr. Wilson was removed by death, to the vast loss of science, and to the unspeakable regret of all who knew him.

The limits of the present article preclude giving anything like a full historical notice of the use of kites for scientific purposes or for securing observations of the meteorological conditions of the upper air. A few references only will be given if with no other object than simply to show that the application of kites to practical, useful purposes is by no means a novel idea of the last few years, as some appear to think. Mr. W. R. Birt[1] on the 14th of September, 1847, flew a specially constructed kite at the Kew Observatory, in order to test and demonstrate its usefulness in obtaining measures of temperature, humidity, wind velocity, etc. The kite was caused to assume a more fixed position in the air by restraining it by means of three strings secured to the ground at the three corners of a comparatively large equilateral triangle.

Admiral Bach,[2] when in command of the *Terror*, used a kite to obtain the temperature of the upper air in Hudson Strait.

Espy, in his Philosophy of Storms, p. 167, states that "The Franklin Kite Club, at Philadelphia, have lately discovered[3] that in those days, when columnar clouds form rapidly and numerously, their kite was frequently carried upward nearly perpendicularly by columns of ascending air." The existence, for brief periods, of strongly ascending currents of air has also been repeatedly noticed in the Weather Bureau experiments.

E. Douglas Archibald[4] in England advocated the use of "A kite, or a series of kites flown tandem, that is, one above the other" for showing the direction of air currents, and for attaching thermometers, anemometers, etc., so that the condition of the air in the upper currents could be determined.

Experiments of this character were first regularly begun by Archibald[5] in November, 1883; the particular object in view being to ascertain the increase of wind velocity with elevation, Biram's anemometers being attached to the kite string for this purpose. The kites were diamond shape, with tails, and were flown tandem. Flax string was first employed, but acting upon the suggestion of Sir William Thomson, steel pianoforte wire was substituted, on which Archibald remarks:

This I have found a great improvement on the string. It is double the strength, one-fourth the weight, one-tenth the section, and one-half the cost.

A summary of the results obtained by Archibald will be found in Nature, Vol. XXXIII, 1885–86, p. 593.

Archibald also devised and made some use of a captive kite balloon which he described in Nature, Vol XXXVI, 1887, p. 278. This combination was designed to obviate the detrimental action of the wind on the balloon surfaces. As the balloon kite has often been proposed as of great utility it will be worth while to notice the results of Archibald's tests. The balloon had a capacity of 113 cubic feet; the octagonal kite measured 7 by 9 feet. Twelve hundred feet of steel pianoforte wire was paid out. Wind at Greenwich 12 miles per hour. The angles of elevation were as follows: Balloon alone, 38°; wire near ground, 18°. Balloon with kite, 41.5°; wire near ground, 35°.

It is observed the effect of the kite was to increase the angular elevation of the balloon 3.5°, but the angle itself was only 41.5°. Now, any good kite is easily capable of sustaining 1,200 feet of steel wire so that both the kite and the wire will have an angular elevation of at least 60° and 58°, respectively. It appears, therefore, that under favorable conditions the kite is able to help the balloon, but the balloon, on account of the large surface exposed to the wind, will only serve to drag down the kite to a much lower position than it would attain alone. If little or no wind blows the balloon alone is sufficient, and is only trammelled by the presence of a kite.

In 1890 William A. Eddy, of Bayonne, N. J., "began experiments to determine the relations between the width and length of the ordinary kite." The object in view was "to evolve the best form of kite to be used in raising self-recording meteorological instruments to a great height, because many important problems in meteorology would be affected by investigations of the upper air currents." Beginning with star and hexagon kites with tails, Mr. Eddy was led to the reinvention of the so-called Malay tailless kite, a form which within recent years has, perhaps, been more extensively used for scientific purpose than any other.

The kite experiments made at Blue Hill under the direction of Mr. A. Lawrence Rotch, have aimed particularly to secure observations of the atmospheric conditions at as high elevations as possible. The work appears to have begun in the fall of 1894. Kites of the Malay or Eddy type were used at first and other forms later. A number of actual records of the temperature, pressure, and moisture contents of the air, also of wind velocity, have been obtained at various elevations up to something less than 4,000 feet, and the work reflects much credit opon the proprietor of the observatory and his assistants.

Probably the most remarkable modern inventor of kites is Mr. Lawrence Hargrave, of Sydney, N. S. W., Australia. Mr. Hargrave contributed an important paper to the meeting of the Aeronautical Congress, held in Chicago at the time of the World's Fair, 1893. In this paper were described models of flying machines and of the peculiar cellular kites which were afterwards greatly developed by the inventor and have since become widely known among kite experts. The description of the Hargrave cellular kites, which appeared in the American Engineer for April, 1895, p. 193, has brought these kites to the attention of some of the experimenters in the United States. In an article entitled "A Weather Bu-

[1] Phil. Mag., Vol. XXXI, 1847, p. 191.
[2] Quart. Journal, Met'l Soc., Vol. IX, 1883, p. 63.
[3] Probably about 1837.
[4] Quart. Journal, Met'l Soc., Vol. IX, 1883, p. 63.
[5] Nature, Vol. XXXI, 1884–1885, p. 66.

reau Kite," in the WEATHER REVIEW, for November, 1895, the writer credited Mr. S. A. Potter with being "the first in the United States to successfully construct and fly kites of this kind." The Aeronautical Annual for 1896, which did not reach the hands of the writer until after the article referred to had been written, contained accounts of successful experiments with the cellular kites by both Charles H. Lamson and J. B. Millet. The date of Mr. Lamson's experiments is not given. The work of Mr. Millet was done during August and September, 1895. Experiments were also made at Blue Hill with cellular kites in August, 1895, which were described in the Boston Herald, August 19, 1895, and Springfield Republican, August 21, 1895. It does not seem that this type of kite was then regarded with much favor or that further experiments with this form were actively pushed. Mr. Eddy also tried the cellular kites, at first on September 1, 1893, and again in December, 1895, but with unsuccessful results. He was finally successful in flying the kite independently for the first time on December 9, 1895. Mr. Potter's work can therefore scarcely claim to be first in mere point of time, the results, however, were highly successful and promising and this type of kite at once superceded all other forms in the Weather Bureau work.

The kite experiments at the Weather Bureau were first taken up by Mr. Alexander McAdie and Mr. S. A. Potter, only semiofficially, however. The work began early in November, 1894, and was carried on wholly outside of office hours and in addition to other regular duties. Nevertheless, owing to the industry and skill of Mr. Potter a large number of kites, mostly of the Malay type, were flown successfully from time to time at Mr. Potter's country residence. No methodical record of the progress of the work appears to have been kept, nor were instrumental or other accurate observations made of the results attained. A small thermograph, constructed mostly of aluminum, was purchased during the following spring from Richard Bros., and records of air temperatures at elevations of a few hundred feet were obtained on several occasions during the ensuing summer. The thermograph proved to be imperfect and ill adapted to the work. On one occasion a tandem of eleven Malay kites was successfully flown. A suitable reel for controlling the string with which the kites were flown was found indispensable, and a very convenient and efficient affair was devised by Mr. Potter.

The work finally assumed the character of an official investigation only in the fall of 1895. Prof. Willis L. Moore, as the new Chief of the Weather Bureau, at once recognized the great importance of extending the observations of the Weather Bureau into the upper atmosphere in order to advance the knowledge of storm generation and improve the daily forecasts. Mr. McAdie being detailed for duty at the office in San Francisco, Prof. H. A. Hazen, with Mr. Potter's assistance, was directed, on October 14th, 1895, to make experiments for the purpose of devising and perfecting an appliance that might be used in observing the meteorological conditions of the upper air. Subsequently, namely, November 18, 1895, the writer was also directed by Professor Moore, in addition to his other duties, to investigate the problem of constructing appliances for carrying meteorological instruments into the upper air. Professor Moore has himself proposed two different devices as being possibly of use in the solution of the problem in hand; namely, the combination of a kite and balloon, by which the desired observations can be obtained not only when the wind blows, but during calms or when the wind is too light to make the flying of kites alone successful, and a device constructed on the general plan of what we may call a soaring top. In fact, a toy of this character appears to have first suggested the idea to Professor Moore. The toy consists of a thin metal or card-board disk, cut up into a number of equally distributed radial gashes extending nearly to the center. The surfaces are then twisted or bent so as to take an oblique position, screw propeller fashion, in reference to the general plane of the disk. In fact, the disk resembles very much a small fan wheel, such as is commonly seen on electric fans. At the center the disk is fitted with a small axle at right angles. A suitable holder is provided, and when the disk is given a high speed of rotation by the unwinding of a string from the axle, as in spinning a top, the disk lifts out of the holder and soars to a considerable height in the air. Such a device, on the proper scale, either started at high velocity from the earth, or carrying its motor with it, may possibly be made to accomplish the desired results.

Professor Moore's aim has been to reach higher altitudes than those which have been heretofore attained by ordinary kites. Special funds were not available for costly experiments with balloons or combination affairs; moreover, kites themselves not only on account of their slight cost but also because of their general effectiveness, seemed the most promising subject for the first investigations. The effort has been therefore to develop the kite to the highest point of efficiency and ascertain to what extent it can be utilized in reaching elevations of from 1 to 2 miles or more.

The work at the present time is still in an experimental stage as it were, but it is believed enough has been accomplished to justify publishing preliminary results in the hope that the progress already made in the Weather Bureau investigations will stimulate to new efforts, and be helpful to the several private experimenters independently at work on the same problem, and if possible, therefore, hasten complete success.

On scientific methods in kite investigations.—While the literature on kites describes an almost endless variety of forms and shows some to have been employed in useful ways, that is, for drawing wagons, sleds in the Arctic regions, boats, etc., or for other purposes and for securing meteorological observations, of which latter use we have mentioned above a few cases only, yet no writer seems to have fully discussed the action of the kite from a scientific standpoint, or analyzed and explained the physical and mechanical principles involved therein. Sir Isaac Newton is said to have taught the boys how to fly their kites, but if one desires to learn much about the mechanics of a kite in action, a search in kite and aeronautical literature will prove fruitless, or nearly so; at least such has been the experience of the writer in the partial search that he has thus far been able to make. Some investigators in recent times, while spending years of work with the avowed purpose of developing the kite for useful purposes, have either assumed the deplorable attitude of discrediting the value of technical or so-called theoretical considerations as applied to kites, or have struggled on by cut-and-try processes in blissful ignorance of the real character of those laws of nature whose operation they seek to control.

It is unfortunate, to say the least, that any investigator of kites of the present day, having the benefits of modern advanced education, should entertain the scornful regard that seems to be current with some for the "theory" of kite flying, especially when the history of applied science affords such remarkable illustrations of the immense debt *practice* owes *to science*. *There could be no greater mistake* than to contemptuously confound science with theory. No more striking instance of the efficacy of scientific methods can be cited than to outline and contrast the growth of the steam engine and electric generators, motors, etc. Although Hero, 120 years B. C., described crude forms of heat engines, steam engines did not begin to be really useful until about the middle of the 17th century. For nearly 200 years thereafter the steam engine underwent a slow and tedious evolution, improving but little in the hands of men ignorant of the laws of thermodynamics. In fact, those laws were quite unknown. Towards the close of this period such men as Carnot, Joule, Clausius, Thomson, and others began to develop the principles of thermodynamics, and Rankine, less than forty years ago, with a master's hand, applied these principles to the practical problems in steam engineering. From this point on the development was very rapid. What 200 years, yes, 2,000 years, counting from Hero, failed to make of the steam engine was effected in a score of years when science pointed the way. The steam engine came into existence and underwent its slow and tedious development by blind experimentation before the rationale of its action was known or understood. The reverse is the case with electric generators, motors, etc. All the principal elements of their theory had been fully developed before the devices were invented. The result is that almost the highest possible state of perfection of these inventions was attained in a few years. Not only was the theory already available but it was developed and applied at every point in the construction and operation of these wonderful machines. The world now stands amazed at the marvelous rapidity of this growth. In the face of such facts as these, can anyone fail to perceive the importance and advantage of formulating the physical laws involved in the operation of any of nature's forces? Let us hope, therefore, that those who seek to develop and perfect the kite in order to apply it to useful purposes will help first to formulate the laws of all the actions involved.

The construction and flying of kites on a large scale is purely and only an engineering problem. It is simply a question of stresses and strains, a question of the strength and resistance of materials, of the operation and equilibrium of certain well-defined forces. In fact, every element of the problem comes within the domain of ordinary mechanics and physics. Kites are amenable to development by the same engineering methods as those that have produced such wonderful results as the Forth Bridge, the Brooklyn Bridge, the Eiffel Tower, the Ferris Wheel, swift ocean steamers, those famous yachts Mayflower, Vigilant, Puritan, Defender, and others. Now that it is desired to put kites to certain useful applications, it is urged upon those who seek to effect this development that they discard the primitive cut-and-try method and adopt modern engineering methods. The cut-and-try method is good in a certain sense; it is like nature's method of "natural selection," but its operation is exceedingly slow. If time enough is expended in constructing and testing all conceivable kinds of kites, selecting the best, rejecting the inferior, it is possible that a kite may be evolved approaching the maximum possible efficiency, but the engineer has a short cut to this result. He analyzes the action of the kite in every detail; the efficiency of every element is studied separately. By these methods he is soon able to discover and lop off this or that useless member, to increase the efficiency of others and to introduce new members of peculiar and useful function.

When kites are used for carrying strings or ropes to inaccessible distant points, as from a stranded ship to the lee shore, or when used for transportation, as in pulling wagons, or towing boats, it is the object of the constructor to obtain the greatest possible tension or pull on the string, as held by the manipulator at the lowest end near the ground. But for meteorological use we need to have the greatest possible lifting power at the kite end. We must, therefore, develop the vertical and diminish the horizontal component of the pull on the string.

To be more specific, the kind of information needed, for example, is: (1) What is the relative lifting power in a given wind, square foot for square foot, of the single-plane kites, as compared with the cellular kites? (2) In cellular kites, (*a*), how near can the lifting surfaces be to each other without detrimental interference? (*b*) How short a distance may exist between the forward and after cell without the one impairing the effectiveness of the other? (*c*) What length, fore and aft, is the most effectual for the sustaining surfaces? (*d*) What is the most appropriate form and arrangement of the bridle, not only to secure the most satisfactory action of the kite under winds of variable force, but to likewise distribute the strain upon the framework so that lightness, but yet not corresponding weakness of construction, may obtain? (3) In general, for any kite, what is the best angle of incidence? (4) What is the loss due to the pervious structure of the cloth, as compared with paper or balloon fabric, etc.? These are but a few of the elements of the kite problem that need to be separately studied and in respect to which the maximum possible useful effects need to be developed and rendered available to the kite builder.

The writer has been led to make these remarks because so little or none of this kind of work appears to be contemplated by the several experimenters now independently at work trying to render the kite useful for meteorological and other purposes. Moreover, the above considerations should convince one that a line of analysis seeking to develop all the elements of kite behavior and formulate their relations is the shortest path to the complete solution of the problem.

THE WEATHER BUREAU WORK.

A few remarks describing the management of kites will enable the reader, unfamiliar with what we may call modern scientific kite flying, to form an idea of how the work is carried on. Details of the forms and construction of the kites will be given later. The kites range in size from 6 to 10 feet high, and are, therefore, easily carried about by one person.

The act of starting off or flying any of the larger kites is a very simple matter, especially when the wind is favorable and the kite a good flyer. With steady winds of about 15 miles per hour, the kite when faced to the wind will generally fly right up from the hand, sailing away and upward at an angle of from 30° to 50°. It is necessary only to keep the string under some tension as it is paid out. When the wind is rather feeble, especially if very light at the surface, it will generally be necessary for an assistant to carry the kite off some distance to leeward; seven or eight hundred feet is often not too far. When a favorable puff of wind is felt the assistant tosses the kite upward into the air. At the same moment the string, if managed by a reel, is wound in with sufficient rapidity to cause the kite to fly until fully sustained by the wind. A reel for managing the string is quite indispensable for extensive experiments, but in its absence it may be necessary in starting the kite in light winds to walk briskly to windward. It is almost impossible to describe the means and artifices employed by the skillful operator in managing kites that fly badly, or in working a kite up through strata that have feeble, fitful motion into stronger, steadier currents. Skill of this sort can be acquired only by experience.

If any apparatus is to be carried it is generally tied to the string below the kite or kites after the latter are in good flight and produce a steady and sufficient strain on the string.

The tension on the string varies greatly when only one kite is flying, owing to the tumultuous and ever changing character of the wind. These variations are very much less with two kites in tandem 200 or 300 feet apart. With a tandem of several kites the strain is naturally still more nearly constant.

The manner of flying kites in tandem is also very simple. The kite to be added is first flown on an independent string. A length of from 100 to 150 feet is generally sufficient. The end of this is tied to the main kite line at the desired point. The kite takes care of itself as string is paid out, although in some cases from time to time during its subsequent flight it may foul partly and temporarily with the main line. If there are no points or projections on the second kite that can be permanently caught on the main line, then the fouled kite will generally soon free itself. It ought to ride above the main line except during momentary lulls of the wind, and often owing to its own lack of perfect symmetry and exact correspondence with other kites or to variations of the wind, it will continuously tend to fly to the right or left. Thus several causes are seen to conspire which tend to make the kite stand free of the main line. There is always, however, in tandem flying, more or less wasted effort in the kites pulling at variance with each other. This will be discussed later.

The work done at the Weather Bureau by Mr. Potter in flying kites prior to the beginning of the investigations by the writer, consisted principally of tests of the Malay or Eddy kite. Although this form of kite is well known a brief description will remove any uncertainty respecting its construction. The frame consists of two sticks of the dimensions shown in Fig. 1. At the point of crossing the sticks are lashed firmly together with waxed string. The cross stick *A B* is bowed backward by means of a string, as shown in the end view, Fig. 2. The depth of the arch is best made about $\frac{1}{10}$ of the arc. A strong cord, *A C B D*, is passed around the frame and securely fastened to the ends of the sticks, so as to produce a perfectly symmetrical figure. The woven wire cord used for hanging pictures, which will not stretch, is much better than any kind of string for this purpose. Paper, calico, cambric, or silk may be used for the covering, which is allowed to bag slightly in order to improve the stability of the kite. The bridle is formed of a piece of stout cord whose ends are tied, respectively, to the point on *C D* at which the sticks cross and to a point near the end, *D*. The length of string should be such that when the bridle is drawn taut and laid over against the surface of the kite it will form the angle *O B D*, Fig. 1. The kite string is attached to the bridle by means of a weaver's knot near the point *B*. The exact position for the best effect can be found only by trial. Mr. Potter sought to improve upon this form of kite by substituting for the bowed cross stick two sticks set so as to form a slight dihedral angle, the effect being to impart a greater degree of stability. With the object of providing a degree of flexibility to the wings of the kite for the purpose of easing off the strains due to gusts of wind, Mr. Potter tried connecting the two cross sticks of a dihedral angle kite by means of a spring. He also inserted a spring of rubber bands in the bridle at *D*, expecting thereby that the after part of the kite would tip up so as to partly spill the wind and ease off the strain of heavy gusts. These attempts to compensate for the gusty character of ordinary winds met with but indifferent success, doubtless owing to the difficulty not only of securing the proper proportions between the strength of the springs and the surface of the kite, but of arranging that the spring should bend or elongate the right amount for a given variation of the total strain. To be effectual it is plain that springs for the above-mentioned purpose must be nicely gauged for both the total strain they must sustain and the flexture or elongation per unit strain.

Two sizes of cable-laid twine were used by Mr. Potter, namely, a heavy twine, $\frac{1}{10}$ of an inch in diameter, weighing about 3.75 pounds per 1,000 feet, and a lighter twine, 0.065 of an inch in diameter, weighing about 1.2 pounds per 1,000 feet. The cord was wound upon a large reel or flanged drum, about 18 inches in diameter. The box within which this drum revolved was firmly bolted to a low table with circular top, but in such a fashion that the box could at any time be revolved in azimuth upon the table top, so as to bring the reel in the proper azimuth according to the direction of the wind. The legs of the table were firmly anchored to the ground. (See further description, page 121.)

These appliances were installed at Mr. Potter's country residence near Washington. The exposure was exceptionally free from obstructions and in many respects very favorable for kite experiments.

When the writer began his investigations of the kite problem in December, 1895, he therefore found much of the necessary apparatus in readiness, and he takes this opportunity to testify to Mr. Potter's skill and experience, and his ability and ingenuity in designing and constructing kites. As will appear in the following pages, Mr. Potter proposed and constructed two or three modified forms of kites, each of which possessed more or less merit, and he had already been successful with the Hargrave kite.

The foregoing brief account sets forth the principal features of the status of the kite work of the Weather Bureau at the time the writer was directed by Professor Moore to investigate the problem of securing meteorological observations in the upper air. What follows aims to set forth the progress made up to July 1, 1896, in developing the kite.

As has already been said the construction and flying of kites on a large scale is purely and only an engineering problem. It is simply a question of stresses and strains, the strength and resistance of materials; a question of the operation and equilibrium of certain well-defined forces. These ideas have been constantly in mind in my efforts to improve and apply the kite to meteorological purposes. The results presented below aim to follow in some sort of logical sequence. Naturally the actual chronological succession of the experiments was often illogical and the results fragmentary in character.

The position a kite takes when poised in mid-air is the result of a condition of equilibrium of five different and wholly independent forces: these are: (1) The pressure of the wind on the kite surfaces. In this I mean to include every wind force whatever, whether exerted upon the extended sustaining surfaces or upon the relatively small ends, sides, edges of the sticks and framework of the kite, the edges of the cloth, wire ties, etc. The skin friction of the wind gliding over the surfaces, if considered, is to be included here also. The resolution of this composite force into its several components and the analysis of their separate effects is a question in itself. (2) The attraction of gravity for the kite. (3) The tension of the string at the kite, that is the restraining pull of the line. (4) The attraction of gravity for the string. (5) The pressure of the wind against the string.

Kite strings.—Inasmuch as the first requisites for kite flying on any extended scale are a convenient reel and plenty of string or line of adequate strength and quality to hold the kites, it will be appropriate to first dispose of some exceedingly important questions relating to the string.

The properties of most importance in determining the fitness of a given material for kite strings are (1) strength, (2) weight, and (3) diameter of the cord, that is, the amount of surface exposed to the pressure of the wind. Generally this last factor—the action of the wind on the string—has been quite ignored or, what is worse, if considered, has been regarded as too small to be of any importance. Such is far from being the case, especially in lofty flights, in which case we must deal with thousands of feet of line.

The size of string generally used in flying kites tandem measures at least one-tenth of an inch in diameter. The area of the longitudinal section of such a string equals a square foot of surface for each 120 feet of running length, that is to say, 44 square feet of surface to the mile. Even though the exterior surface of the string has a rounded form, yet the length we are obliged to deal with in a given case is so great, and a great portion of the string is set at so steep an angle across the direction of the wind, that we must not for a moment assume that the wind pressure on all this surface is too small to be worth considering or that the string can escape being depressed toward the earth by the wind to a very considerable extent. Every one perceives with the eye the very great effects that gravity is able to produce on a long piece of even very fine string, and we all know how great the tension must be to stretch a long piece of string until it is even approximately straight. The actual disturbing force of gravity in operation in such cases is a very feeble one; much feebler, indeed, than the pressure the wind may exert on the same string. If one is skeptical of this statement let him try the following simple but crucial experiment: Take several feet of gilling thread, or similar fine string, such as would be used for flying small kites. Suspend this in a slack loop with the ends on about the same level. If no wind is blowing, the loop will hang in a vertical plane. If, however, the string be suspended where freely exposed to the wind and so that the loop hangs directly across the direction in which the wind blows, the loop will no longer hang in a vertical plane, but will be blown strongly to one side and assume a steeply-inclined position. In fact, with string as light and fine as gilling thread the loop will be blown out quite horizontally with only a gentle breeze. In this experiment the wind and the force of gravity are the only external forces, aside from the reactions at the fixed supports, which affect the position of the string. The wind acts horizontally, gravity acts vertically, and the loop of string takes an inclined position intermediate between the horizontal and vertical. If the two forces are equal, the plane of the loop will be inclined 45° to the horizontal. The observed fact that the string, in many cases, is forced by even moderate winds to a much higher angle than 45° is very significant. It means that the pressure of the wind on each elementary portion of the string is much greater than the weight of an equal portion of the string. The fact that the string in the loop is under very feeble tension, whereas a kite string is under great tension, does not in the least alter the fact that the pressure of the wind on the string is equal to or greater than the attraction of gravity. Furthermore, the fact that the kite string hangs in the direction of the wind, instead of across it, can not annul the effect of the wind, which in such a case is superimposed upon the effect due to gravity, and quite escapes detection by simple methods. In fact, the effect we observe with the eye is commonly regarded as due to gravity alone, whereas it is really the effect of both gravity and the wind. The thoughtful investigator will derive a valuable lesson from a few experiments of the above-described sort with strings of different sizes.

Enough has been said to show that in selecting a kite string the *diameter* of the string may be of even greater importance than its weight.

The judicious selection of the kite string and the adoption of correct methods for uniting its different portions, or for attaching it to the kite, are impossible without a complete knowledge of the strength of the string itself, and of the knots, splices, and other junctions employed.

The testing apparatus described below was hastily improvised for service in the Weather Bureau work, but proves so simple and useful that others may wish to make and employ a similar one in their own work.

Two pieces of square steel, *A*, *B*, Fig. 3, driven through round holes in a flat bar of iron, convert the 4-foot bar into a powerful lever with the knife-edge at *A* for a fulcrum, and the edge at *B* for applying the force. The bent pieces of flat iron, *C*, *D*, form at once the stirrup for transmitting the strain from the knife-edge, *B*, and the jaws within which one end of the string or wire to be tested is grasped. The clamping of the jaws is effected by means of a small independent steel screw-clamp. These latter may be procured from dealers in hardware or tools generally. The support for the lever is most conveniently made of a stick of wood of the form shown and adapted to be attached when required to the side of a bench in such a manner that the long arm of the lever passes obliquely over the top of the bench. The knife-edge, *A*, is arranged to be supported on suitable metal surfaces at the top of the stick. At about 24 inches below the end, *B*, of the lever, a projection is formed in the board. Two iron blocks, *E*, *F*, provided with steady-pins and a clamp, constitute the jaws for grasping the remaining end of a string or wire to be tested. The edge of the projection at *G* has formed within it a narrow slot or rabbet through which the string may pass, while the plates, *E*, *F*, of the clamp abut against the lower face of the projection. This arrangement admits of testing specimens of considerable length. The necessary strain for breaking a specimen is easily produced by hanging any heavy weight upon the long arm of the lever. I have employed, for convenience, one of the Fairbank's 50-pound standard weights. In order to graduate the lever-arm so as to indicate the strain on the specimen in pounds, a rude wooden scale-pan was suspended from the clamp, *C D*, into which was placed objects of known weight up to about 150 pounds, due allowance being made for the pan. From the several positions of the sliding weight, when just balancing the known weights, the complete system of graduation for the lever is accurately determined. By this device strains of something like 350 pounds can be produced upon specimens to be tested. This is quite sufficient for kite work. Tests of the strength of strings, wires, knots, splices, etc., as given hereafter, were all determined by means of the device described above.

To grasp a specimen so that it shall not slip nor yet be impaired in strength, did not prove to be very difficult. The jaws of the clamps are comparatively smooth. To increase the holding of these they were occasionally rubbed with powdered resin. For testing hardened steel pianoforte wires it was necessary in addition to rub the ends of the wire itself with powdered resin, also to form a kink in the extreme ends of the wire and grasp the wire in such a manner that these kinks draw into the sharp angle formed by the slightly divergent jaws of the clamp at one end. With these expedients for grasping the wire excessive clamping was not necessary, and only occasionally would specimens break at the edge of or slightly within the jaws.

The following table contains information respecting the properties of materials that may be employed for kite strings:

Table I.—*Properties of materials for kite strings.*

Kind of string or wire.	Diameter.	Weight per 1,000 feet.	Breaking strength.	Relative surface exposed to wind; sq. in., per foot.
	Inch.	*Lbs.*	*Lbs.*	
No. 12 gilling thread	0.032	0.25	30	0.38
Cable-laid twine	0.065	1.20	62	0.78
Do	0.100	3.8	160	1.2
Do	0.150	7.1	300	1.8
Phosphor-bronze wire	0.028	2.5	80	0.34
Aluminum wire	0.0477	*2.15	*48	0.57
Steel piano wire	0.028	2.15	200	0.34

*Computed from general tables; not directly tested.

Tests of silk strings of suitable size for kites would form a valuable addition to this table, but specimens were not available.

From the table we see that aluminum, which many mistakenly regard as a peculiarly useful metal for almost every purpose, is, in fact, the worst material of all for a kite string. It is not only very much heavier, but thicker and more easily broken than fine cable-laid twine. On the other hand steel pianoforte wire is by far the strongest for the same weight and the most slender of any of the materials tested. The tendency of metallic wire of any kind to kink and give trouble on that account if employed for flying kites is by no means serious and the little extra pains required to prevent kinks and rusting, in the case of steel, is well repaid in the great superiority of steel in every particular. The writer at once substituted wire for string in December, 1895, and its admirable fitness for the purpose is abundantly confirmed by extended experience.

The steel piano wire selected for the Weather Bureau work measured about 0.028 of an inch in diameter. This is the size generally employed for deep-sea sounding purposes. In the use of wire a question of first importance is, how shall it be spliced? In my early work the wire was spliced according to the recommendations of authorities on deep-sea sounding. Disastrous results ensued from the parting of the wire in the splices. Thereupon a thorough investigation of the strength of splices was made by means of which a form of splice was evolved that it has been impossible to break. The single wire either side of the splice will always break first. Fig. 4 shows a common form of soldered splice, recommended and used for splicing wire employed in deep-sea sounding. This is a bad form of splice and will, in almost every case, break in the middle and at a less strain than required to break the wire. The only part of the splice that is at all effectual in resisting strain is the short intertwisted portion in the middle. It is plain that throughout the whole portion, *a*, *b*, where one wire is coiled closely around the other which remains straight, practically the whole strain is carried, and necessarily must be almost wholly carried by the straight core wire. The solder of the splice can carry only a little of the strain. The coiled wire in the portion, *a*, *b*, is, therefore, so much wasted material. The mechanical principles involved in splicing a wire by twisting requires *that each part be twisted around a common axis.* It is wrong to twist one part wholly around the other which remains straight. According to this principle the splice shown in Fig. 4 is evolved into the splice shown in Fig. 5 by discarding the portion *a*, *b*, and elongating the middle portion. Although not necessary for strength it will generally be well to take one turn of the wire around the main part at each end of the splice and taper down the point somewhat by filing. This will lessen the danger of damaging the splice in case it drags across the edge of the reel or some rough hard object, and the splice will perhaps pass more easily through the hand or through oily cloths which must sometimes be employed to prevent rusting. In not a single case have soldered splices of this formation ranging from 2 to 2½ inches, extreme length, been broken. Fifteen specimen splices were tested. The wire outside of the splice was broken in every case at average strains of about 225 pounds. Minimum strength, 210 pounds; maximum strength, 235 pounds. The solder may be applied to the splice with an ordinary soldering iron, treating the splice first with soldering acid in the usual way. A better plan[1] is to submerge the splice in a small quantity of molten solder contained in a shallow groove in a block of wood. By this method there is little danger of overheating the wire and impairing its temper. Those familiar with soldering need not be told that the completed splice must be thoroughly washed with clean or alkaline water so that every trace of the soldering acid is removed, otherwise excessive rusting of the wire will quickly ensue. Keeping the wire thoroughly coated with a film of oil has thus far been sufficient to prevent rusting. The wire has, however, never been exposed much to rain and damp.

Inasmuch as the security and strength of the splice described above depends upon *the wires being evenly and uniformly twisted each about a common axis*, the twisting is best effected by using simple tools, such as shown in Figs. 6 and 7. The wires to be spliced are clamped in the small block of brass, *A*, having two shallow converging saw cuts as indicated by the dotted lines. The block is fitted with a brass plate covering the slots and kept in position by steady pins, *a*, *a*. The cover plate is made to clamp the wire in the shallow slots by means of a common machinist's hand vise, not shown. The brass block, *B*, also cut with slots converging the same as in *A*, serves for twisting the wires. The cover on the block, *B*, simply confines the wires to the slots without clamping them. Rotating the block, *B*, on its longitudinal axis twists the wires as evenly as can be desired. If the free ends of the wire are to be turned once closely around the main wire, this is effected by means of a tool shown in Fig. 7, which scarcely needs explanation. The splice is finished by nipping off the extreme free ends of the wires close down to the main wire and, if desired, the ends may be further touched up, before soldering, by careful filing to the form shown in Fig. 5.

While steel wire is the best material for the kite line, yet it is not convenient to form a continuous wire connection up to the kite, especially during the experimental stage of the work when alterations in the points and manner of attaching the wire to the kite are necessary. String is peculiarly adapted for such connecting purposes, on account of its flexibility and the facility with which it can be tied in knots. Twine of suitable strength has, therefore, been employed for the bridles of the kites. To the bridle is also attached a short length (from 4 to 6 feet) of twine which will hereafter be designated the "stray line." By this arrangement of bridle and stray line any desired adjustment and alteration of the bridle attachment may be made by means of knots hereafter to be described. The stray line provides means for readily attaching a kite to, or detaching it from, the wire, still preserving any desired bridle adjustment.

Correct engineering practice requires that we inform ourselves definitely concerning the strength of every important member of a structure. Therefore, when we employ string in the bridles and the stray lines of our kites we must definitely ascertain their strength, especially if tied and knotted together.

The question as to how well and conveniently knots answer their purpose, and to what degree they constitute a weak spot in the string containing them, is a very interesting one for investigation. Although string is used in the Weather Bureau work in only a subordinate capacity, yet a number of tests of strings united by different kinds of knots were made, and as the results may prove useful to those who employ string instead of wire for flying kites they are given in the table below. All the tests were made on new cord that had never been used. The cord was a hard twisted cable-laid twine, which measured between 0.105 and 0.115 of an inch in diameter and weighed in the slack cord 4.1 lbs. per 1,000 feet.

TABLE II.—*Strengths of cords united by various knots.*

No. of test.	Kind.									
	1	2	3	4	5	6	7	8	9	10
	Double overhand knot.	Sheet bend or weavers' knot.	Sheet bend, double turn.	Square knot.	Fisherman's knot.	Interlaced overhand knot.	Interlaced figure of 8 knot.	Carrick's bend.	Bowline bend.	Cord unknotted.
1	110	118	160	158	172	143	185	179	172	171
2	138	127	110	174	173	156	138	175	187	180
3	150	118	146	158	154	145	149	175	193	165
4	120	125	160	110	140	174	160	161	178	167
5	135	112	131	138	133	171	150	182	165	169
6	.....	.....	.....	168	.....	.....	140	.....	191	182
7	.....	.....	.....	163	.....	.....	162	.....	198	172
8	.....	.....	.....	143	.....	.....	170	.....	202	160
9	.....	.....	.....	.....	.....	.....	150	.....	190	194
10	.....	.....	.....	.....	.....	.....	135	.....	185	198

[1] Described in Deep-Sea Sounding and Dredging, Sigsbee. U. S. Coast and Geodetic Survey, 1880.

The exact structure of the knots will be understood from the illustrations, Figs. 8 to 16. The so-called "double overhand knot" was tested because it is so commonly used by a novice for uniting two strings, and because it has often been employed in flying kites tandem for the purpose of forming a loop in the main line, as shown at a, Fig. 8. It is a very bad knot for the purpose. The "weavers' knot" or "sheet bend" is very small and compact, but cuts upon itself badly and is weak. The "square knot" is much better, but is not always proof against slipping a little, which, if it occurs under considerable strain is almost certain to result in a break at the knot. The tendency to slip is almost wholly removed by drawing the parts taut in such form that the loose ends stand well out at an angle to the main parts. Do not tighten up the knot while the loose ends are held parallel with the main parts. Fig. 11 shows the knot correctly tied.

It seems there may be some difference in the strength depending upon whether a knot is tied *with* or *against* the "lay" of the cord. I have not, however, been able to definitely discover a difference of this sort.

The "fisherman's knot"[1] called also "surgeon's knot" by Eddy and Fergusson of Blue Hill, is compact and comparatively strong. The "interlaced overhand knot" is formed by tying a simple knot loosely on the end of one string and passing the end of the other string through and around the knot in the opposite sense, as shown in Fig. 13. The "interlaced figure of 8 knot" is formed in a precisely similar manner, based on the knot shown in Fig. 14. Each of the foregoing knots draws down exceedingly compact and hard, and it is almost impossible to untie them after being strained, especially the two latter. This is also true of the "Carrick's bend." The latter, however, is designed to unite heavy ropes, hawsers, etc., and in such cases the loose ends of the knot are "stopped" or lashed to the main parts, and in such condition the knot can not jam. Occasionally the knots enumerated from 1 to 8 in the table will sustain a strain that will break the cord, but such was found to be rather the exception and generally the string appeared to break at a weak point.

The king of all the knots, however, is the "bowline knot," not only because of its remarkable strength, which is such that the cord itself will break at a high strain while the knot holds in the majority of cases, but from the adaptability of the knot to a variety of purposes and from the fact that it never slips and can be untied with the least possible effort, even after sustaining excessive strains. Fig. 16 shows the manner of uniting cords by this knot, and although for this purpose it is less compact and neat than other knots, it is exceedingly trustworthy and can be depended upon to nearly or quite the full strength of the cord. It has no equal for uniting two cords differing in size. It will never break at the point, a, which I was at first inclined to regard as a weak spot. This knot is so excellent that its use is strongly recommended. The successive steps in a simple manner of tying it will be given, as the beginner may find some difficulty in forming the knot easily with no other guide than Fig. 16. The first step is to form a simple overhand knot, held as shown in Fig. 17; by a dexterous turn of the fingers the knot is brought to the form shown in Fig. 18, and finished by passing the end behind the main part and through the eye, as shown in Fig. 16. The act of tying the knot is one continuous motion. In drawing the knot taut it is not necessary or desirable to tighten up the crown (a, Fig. 16,) of the knot very much. To untie the knot the crown is first drawn over in a manner to free the knot, whereupon the whole is easily undone.

As already mentioned, when wire is used as the kite line, string need be employed only for bridles, stray lines, and other short connectors. The end of the wire is formed into a small eye which incloses an eyelet, as shown in Fig. 19. The string from the kite is attached to this eyelet by means of a bowline knot. A number of actual tests demonstrated the superiority of this knot for forming this junction.

While discussing knots it will be well to dispose of the matter and describe the manner of tying the bridle to the kite sticks and of adjustably attaching the stray lines to the bridle.

Fig. 20 illustrates both these connections. The clove-hitch reinforced by one or two half hitches of the loose end of the string around the main part of the bridle seems to answer every purpose for securing the bridle to the kite stick. I have been unable to discover a more excellent method of attaching the stray line to the bridle than by means of a bowline knot, the loop of which forms with the bridle a square knot, a, Fig. 20. The knot cannot slip in use and even if excessively strained it can be loosened with the slightest effort and in such a manner that the point of attachment can be easily shifted by any definite and precise amount. The simplest way of forming the square knot between the loop of the bowline and the bridle is to tie the bowline first, independent of the bridle, then pass the loop of the bowline around the bridle and draw the end of the stray line, which will generally be free, through the loop of the bowline, forming the knot shown in Fig. 21. This is easily converted into the square knot shown in Fig. 20. The complete arrangements of bridle and stray line was repeatedly tested with the result that the arrangement was fully as strong at every part as the cord itself.

It still remains to describe what methods have been developed for attaching kites in tandem. Where string is employed for the kite line a simple loop knot, a, Fig. 8, may be formed at any point desired. As already pointed out, and as shown in Table II, if this knot is tied in the manner figured, the strength of the line is thereby weakened in a very serious manner. As it is plainly very bad practice to impair the strength of hundreds of feet of strong cord simply by one or more weak knots, it is also plain that those who employ string for the kite line need a method much better than that just described for forming a loop or other device by which the following kites of a tandem may be attached to the main line. The importance of this little matter is still more apparent when we consider that if a single one of these knots or loops forms a point in the line which is 33 per cent weaker than the weakest place in the cord itself, a condition which the tests show is easily possible, then to safely sustain a given strain the entire length of line involved must be 33 per cent stronger, that is, approximately 33 per cent heavier than would be required if the strength of the cord was not thus impaired by loops. The weight and size of the string are of such vital importance in flying kites to extremely great elevations that bad practice of the kind just pointed out can not for a moment be tolerated.

The foregoing remarks apply equally in determining what arrangements will be admissible for attaching tandem kites to wire. Every device that impairs the normal strength of the wire must be ruled out. In speaking of the several kites forming a tandem it will be convenient to designate the top kite as the leader, or pilot, kite. The others may be called subordinate kites or followers, and the line of wire leading up from the reel will be called the main wire, or main line, while the relatively short branches leading up to the subordinate kites will be spoken of as secondary lines.

An angle in the continuity of the main line is formed at any point at which a secondary line is attached. This angle varies from moment to moment with the ever changing wind forces on the different kites. If wire is used and flexibility is not provided for at the point of attachment, or other means adopted to obviate ill effects from bending, then it is only a question of time before the strength of the wire will be

[1] Chamber's Encyclopedia. New edition, New York, 1892.

impaired. The writer has not been able to conceive of a clamp for this purpose that is entirely free from serious objections. After discarding loops of string firmly lashed with waxed twine to the wire he has, however, adopted the eyelet arrangement shown in Fig. 22. In addition to forming a perfectly flexible point of attachment, the strength of the junction, with double twisted wires either side of the eyelet, is stronger than the wire itself, as shown by actual tests.

Steel wire of the same size as the main kite wire is also employed for the secondary lines. The length ranges from 100 to 150 feet, with an eyelet in each end, as shown in Fig. 19.

The connection of the secondary line to the intermediate eyelet of the main line is made by a short piece of twine tied to the eyelets by means of the bowline knot.

The intermediate eyelets put into the main line are too small to present any difficulty in stowing away upon the reel. The only objection to them hitherto found is that the points at which attachment to the main line is possible are fixed and predetermined, and can not be chosen, as is sometimes desired.

The relative merits of several small kites flown tandem as contrasted with spreading the same amount of surface in one or two large kites, will be analytically discussed later. It may be stated here, however, that although the tension on the line becomes more and more steady the greater the number of kites in tandem, yet the gain in steadiness when more than two or three kites are employed is entirely unimportant, and, as will be shown hereafter, a large kite is more effective than an equal surface in small kites flown tandem. Based on these considerations the practice at the Weather Bureau has been to fly but a small number of kites tandem, and the use of eyelets at fixed points in the main wire has been generally satisfactory.

One further difficulty has presented itself in the use of wire, and for which thus far no satisfactory solution has been reached, namely; if the wire is in a state of internal strain, such that when stretched it tends to rotate on its longitudinal axis (and if no provision of a swivel or other device has been made for relieving this twisting strain), then under certain conditions of moderate strain, and at moments when the main and a secondary line take nearly coincident directions, the two may intertwist around each other for a length of many inches, but be again violently untwisted more or less completely when a condition of stronger winds and heavier strains prevail. It is needless to say that such action threatens to impair the strength of the line.

Swivels are believed to be of no avail to obviate this difficulty. In the first place they must be capable of resisting a strain at least as great as the ultimate strength of the wire. Made in the ordinary way the friction, owing to heavy strains that would occur in use, would wholly prevent their effectual action. A ball-bearing swivel would, we believe, not be much better. Moreover, even supposing an effective swivel available, as rotation of the kite wire can not take place across the angle formed at the point of attachment of a subordinate kite of a tandem, it would be necessary to provide a swivel at each point of attachment of a secondary line. The winding of bulky ball-bearing swivels on the reel presents a serious objection to their introduction.

From the foregoing statements and data respecting the materials and arrangements which form the kite line, it will be seen that the maximum of strength with the minimum of weight and surface exposed to wind action is approximately attained by the use of steel wire. With the arrangements recommended, there will be a uniform strength throughout, with no inherently weak points of construction nor portions of unnecessary strength, and, therefore, unnecessary weight. The main wire is expected to withstand the united pull of several kites, and must, therefore, be stronger than the bridles, stray lines, etc. These latter, when made of the cable-laid twine employed in making the tests given in Table II, are, as shown therein, stronger in proportion to the strains they must sustain than the wire itself. The excess of material and weight involved in this excess of strength is very small, however, and of no importance. For small-sized kites smaller twine may be safely employed.

The following table contains the results of tests upon splices, eyelets, and other members that go to form the line by which a kite or tandem of kites is anchored to the earth:

TABLE III.—*Ultimate breaking strength of members of kite line.*

Number of test.	Steel wire.	Marvin splice.	Eyelet, Fig. 19.	String tied in eyelet, Fig. 19.	Stray line and bridle.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1	229	225	206	207	184
2	220	210	216	185	194
3	219	225	....	170	188
4	250	228	....	181	198
5	223	223	....	183	184
6	213	225	....	181	194
7	220	229	....	....	161
8	....	229	....	....	191
9	....	210	....	....	201
10	....	226	....	....	202
11	....	225	....	....	205
12	....	233	....	....	200
13	....	233	....	....	194
14	....	231	....	....	207
15	....	231	....	....	194

The reel.—The reel required for the proper management of either the kite wire or string will need little or no description, except in respect to particular adaptations, and especially in regard to the means employed for measuring the total length of the wire or string and the length paid out to the kite at any time.

It will frequently be necessary, when flying kites in light winds, to keep the kite afloat by reeling in the wire more or less rapidly. For this purpose experience has shown that the circumference of the drum of wire or string should be scarcely less than 5 feet. A much larger drum than this, where it is to be operated by hand, will prove difficult or, at least, inconvenient to manage when the wire is under considerable strain. Moreover, it is desirable to avoid the use of multiplying gear, such as would be required with very large drums in order to secure adequate power for the purpose of winding in kites by hand when exerting strong pulls. A drum 18 inches in diameter operated by two hand cranks, each 15 inches long, represents something over a threefold reduction, which in the large majority of cases will prove ample.

A very interesting phenomenon connected with flying kites with wire is the electrification of the wire. To be able to observe effects of this sort, it is necessary that the reel of wire be insulated, which is accomplished satisfactorily if the drum is made of heavily shellacked wood. The core of the drum must be made very strong, to avoid the enormous crushing pressure incident to winding in turn after turn of the wire under heavy strain. For the same reason the flanges must be comparatively thick, to prevent flexure, and strongly riveted to the core, to prevent being forced asunder.

Fig. 23 shows the second reel employed in the Weather Bureau work. Our first reel was only 12 inches in diameter, and proved to be too small, and the flanges were too weak. About 10,000 feet of wire forms a layer on the large reel a little over 0.4 of an inch deep.

The inside end of the wire on the reel comes through the flange to the button, *a*, which can be electrically connected to the earth by the switch, *A*.

For the purpose of indicating the number of rotations made by the reel the axis is provided with a suitable worm, arranged to actuate the dial mechanism of an ordinary anemometer. The length of wire corresponding to any particular dial reading is obtained by means of a numerical table, the computation of which will be explained later.

The carriage upon which this reel is mounted is shown in Fig. 24. It is the same carriage employed by Mr. Potter in his work with string. A central bolt confines the box, *A*, to the low table, *T*, but permits rotation thereon, aided further by castors near the four corners.

The rope brake, *b*, Fig. 24, which passes almost completely around the reel in a friction score, or groove, of the flange, serves perfectly to control the rapid paying out of wire, the necessary restraint being produced by tightening gently the slack end of the rope at *c*. The reel being of wood, and, therefore, but a poor conductor of heat, temperatures sufficient to scorch the rope and wood in the groove have sometimes resulted from the great friction, but no serious difficulty has been experienced on this account.

When wire is paying out under control of the brake the rapid rotation of the hand cranks is somewhat objectionable. To provide them with ratchet connections so that they may remain stationary when the reel is unwinding, as is done in some forms of reels for deep-sea sounding purpose, is not altogether desirable in kite work, as the strain on the wire is sometimes exceedingly variable. Moreover, a rigid handle is most trustworthy in cases where it is necessary to control the reel by the handle for both winding and unwinding.

A common and well known form of spring balance has been generally employed to ascertain the tension produced by the kites. One method has been to hook the dynamometer directly to one of the crank handles, fixing it in such a position that the restraint is exerted in a direction closely at right angles to the crank arm. This method, which is preferred from the fact that the reel can be quickly disengaged from any restraint should emergency demand, requires that a reduction factor be applied to the observed dynamometer reading, depending upon the ratio between the crank arm and drum radius at the point from which the wire draws. The ratio is always known for any given length of wire out, so that the reduction presents no difficulty.

A second method, which measures the tension directly, consists in arranging the dynamometer to draw over the surface of the drum itself by means of a cord wound partly over the outer layers of wire, as shown at Fig. 25.

When reeling in distant kites the wire is guided wholly by shifting the carriage of the reel slightly in azimuth, as may be required from time to time. We have found the direction of the wire to remain so nearly constant that this means of control is ample, and it further avoids any necessity of touching the wire with the hands, which is liable to induce rust. Near the close of the operation, when the kites are but 100 or 200 feet distant, it may be necessary to guide the wire by hand. As a precaution against rust, the wire in reeling in is sometimes oiled by causing it to draw through a piece of folded cloth held in the hand and saturated with oil.

The evaluation of the readings of the dial showing the number of revolutions of the reel is effected once for all by accurately measuring in sections a long length of wire as it is wound upon the reel. In the case of the reel under discussion the length of wire was measured by causing it to pass around a disk having a known circumference and which revolved with the greatest freedom. The disk, in fact, was mounted upon the spindle of an anemometer, the dial readings of which indicated the number of turns of the disk. The tension of the wire was regulated by causing it to pass between a friction plate of wood so arranged as to guide the wire in its passage to and from the measuring disk and at the same time prevent any slipping or shifting of the wire on the grooved periphery of the disk. The apparatus is shown diagrammatically in Fig. 26. The observations for the measurement of the wire are of the following nature: The end of the wire being passed around the disk and secured to the reel, note is made of the dial readings to the nearest tenth of a revolution of the disk and reel, respectively. Approximate chalk mark subdivisions answer for the fractions of revolutions. When fifty turns of wire are wound on the reel, readings of the dials are again noted, and so on. In addition to noting the readings for each fifty turns of the wire, readings are also recorded at the end of each full layer. In winding the wire on the reel, originally, it is not difficult to lay it on very evenly for a depth of seven or eight layers, but splices and other irregularities break up smooth winding, and after a time definite layers cannot be formed. It is impracticable, however, to guide the wire in even layers when reeling in kites. By a preliminary weighing of several of the sections of wire wound on, and by accurate determination of their respective weights per unit length obtained by measuring and weighing short samples, the above-described series of observation may be made to suffice first, for determining the exact periphery of the measuring disk and then the length of wire corresponding to any number of turns of the reel. In this case it will of course be necessary (*a*) to note the dial readings at the times the splices between sections pass on to the reel, and (*b*) to make slight corrections for the few inches of the wire used in forming the splices.

To show what variation may be expected in different portions of wire, nominally of the same size, and to present data from which an idea of the accuracy attained in measuring the length of the wire by the above-described means, the following observations are quoted:

Table IV.—*Weight per unit length of samples of steel music wire. Nominal diameter of wire, 0.028 inch.*

Sample.	Length.	Weight.	Weight per foot.	Whole coil.		Periphery of disk.
				Weight.	Length.	
	Feet.	*Grms.*	*Grms.*	*Grms.*	*Feet.*	*Feet.*
1	27.335	27.343	1.0003	1248.9	1251.0	3.1511
2	18.445	18.370	.9959	2240.0	2244.0	3.1558
3	23.057	21.966	.9527	2241.0	2335.2	3.1433
4	12.396	11.956	.9666			
5	29.989	28.996	.9666	2286.2	2368.6	3.1700
6	11.696	11.272	.9637			
7	30.703	29.618	.9647	2239.3	2316.7	3.1502
8	12.034	11.655	.9685			

Mean periphery, 3.1541.

Note.—Samples joined by brackets were cut from outer and inner ends of the same coil.

A layer of wire on the large reel contained, on the average, about 155 turns. All the observations in a single layer were combined as an average for that layer. The law of increase of the periphery of the reel, with successive layers of wire is practically a linear law. A ready and sufficiently exact solution of the observation equations is therefore obtained by aid of a diagram. The table, V, contains the results for the large reel.

There is doubtless a slight difference in the average length per revolution depending on whether the wire is wound in smooth layers or not, but I have been unable to definitely evaluate any difference of this sort, notwithstanding that what I may call the calibration measurements agree and harmonize among themselves with considerable precision. Moreover, in using the wire, several thousand feet may be unwound from smooth layers and wound on irregularly, and it will be found the dials come back to the starting point very satisfactorily. Differences of a fraction of one per cent may be due to differences of tension.

TABLE V.—*Observed and computed length of wire of large reel.*

Layer.	Turns of reel.	Total length by measuring disk.	Tabulated length.	Difference, obs. — table.	
		Feet.	*Feet.*	*Feet.*	
	31	151.5	151.4	+ 0.1	* Outside fractional layer.
....	331	1,614.7	1,614.0	+ 0.7	The extreme outside layers were not distinguishable in the observations.
13	481	2,342.3	2,342.0	+ 0.3	
12	631	3,067.7	3,067.8	— 0.1	
11	743	3,608.2	3,608.2	0.0	
10	931	4,512.6	4,513.0	— 0.4	
9	1,092	5,284.5	5,285.2	— 0.7	
8	1,244	6,011.0	6,011.8	— 0.8	From the eighth layer, to and including the first the winding is in smooth layers.
7	1,395	6,731.8	6,731.5	+ 0.3	
6	1,547	7,454.0	7,453.7	+ 0.3	
5	1,696	8,159.6	8,159.6	0.0	
4	1,831	8,797.8	8,797.2	+ 0.6	
3	2,011	9,647.0	9,644.8	+ 2.2	
2	2,170	10,394.7	10,390.9	+ 3.8	
1	2,331	11,146.6	11,144.1	+ 2.5	

[To be continued in May REVIEW.]

NOTES BY THE EDITOR.

MEXICAN CLIMATOLOGICAL DATA.

In order to extend the isobars and isotherms southward so that the students of weather, climate and storms in the United States may properly appreciate the influence of the conditions that prevail over Mexico the Editor has compiled the following table from the Boletina Mensual for March, 1896, as published by the Central Meteorological Observatory of Mexico. The data there given in metric measures have, of course, been converted into English measures. The barometeric means are as given by mercurial barometers under the influence of local gravity and therefore need reductions to standard gravity, depending upon both latitude and altitude; the influence of the latter is rather uncertain, but that of the former is well known. For the sake of conformity with the other data published in this REVIEW these corrections for local gravity have not been applied. The Editor regrets that the table for April, 1896, can not also appear in this number of the MONTHLY WEATHER REVIEW.

Mexican data for March, 1896.

Stations.	Altitude.	Mean barometer.	Mean temperature.	Relative humidity.	Precipitation.	Prevailing direction.	
						Wind.	Cloud.
	Feet.	*Inch.*	° *F.*	%	*Inch.*		
Aguascalientes	6,112.3	......	......	......	......	......	......
Campeche	40.4	......	......	......	......	......	......
Colima (Seminario)	......	28.28	73.9	62	0.00	ssw.	w.
Colima	1,291.7	......	76.3	......	......	......	......
Culiacan	112.2	......	......	......	......	......	......
Guadalajara (H. de B.)	5,141.2	......	......	......	......	......	......
Guadalajara (Obs. S. Est.)	5,188.0	......	......	......	......	......	......
Guanajuato	6,761.3	23.65	66.2	30	T.	sw.	sw.
Jalapa	4,757.3	25.53	64.8	60	2.69	nnw.	......
Lagos (Liceo Guerra)	6,274.5	24.12	65.5	33	0.02	sw.	sw.
Leon	5,901.0	24.26	66.0	28	T.	sw.	w.
Mazatlan	24.6	29.94	72.9	77	T.	nw.	sw.
Merida	50.2	29.94	77.2	60	0.00	ese.	n.
Mexico (Obs. Cent.)	7,488.7	23.05	61.5	42	0.04	n.	sw.
Mexico (E. N. de S.)	7,480.5	23.03	61.7	49	0.04	nw.	......
Morelia (Seminario)	6,401.0	23.94	62.2	44	T.	ssw.	w.
Oaxaca	5,164.4	25.05	70.7	52	1.45	w.	sw.
Pabellon	6,312.4	23.96	66.0	36	T.	sw.	sw.
Pachuca	7,956.3	22.61	58.1	60	0.13	nne.	......
Progreso	......	......	......	......	......	......	......
Puebla (Col. d'Est.)	7,118.2	......	......	......	......	......	......
Puebla (Col. Cat.)	7,112.0	23.32	63.7	45	0.20	......	......
Queretaro	6,069.7	24.16	64.2	39	0.03	e.	nw.
Real del Monte (E. de H.)	9,095.2	......	......	......	......	......	......
Saltillo (Col. S. Juan)	5,376.7	24.81	64.6	57	0.00	s.	sw.
San Luis Potosi	6,201.9	24.10	64.8	49	0.06	e.	w.
Silao	6,063.1	......	......	......	......	......	......
Tacambaro	......	......	......	......	......	......	......
Tacubaya (Obs. Nac.)	7,620.2	22.94	60.1	44	0.06	nw.	......
Tampico (Hos. Mil.)	......	......	......	......	......	......	......
Tehuacan	5,152.8	......	......	......	......	......	......
Toluca	8,612.4	21.80	60.8	41	0.14	w.	wsw.
Trejo (Hac. Silao, Gto.)	......	......	......	......	......	......	......
Trinidad (near Leon)	6,010.1	......	......	......	......	......	......
Veracruz	47.9	......	......	......	......	......	......
Zacatecas	8,015.2	22.52	60.4	34	0.00	sw.	s.
Zapotlan (Seminario)	5,124.8	25.04	68.5	......	0.00	se.	sw.

METEOROLOGICAL TABLES.

By A. J. HENRY, Chief of Division of Records and Meteorological Data.

For text descriptive of these tables and charts see p. 16.

Chart VIII. Kite Experiments at the Weather Bureau.

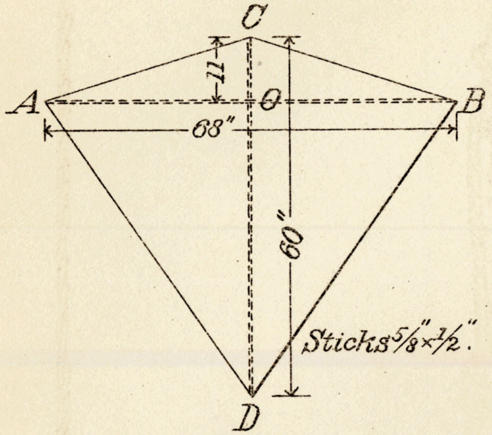

Fig. 1.

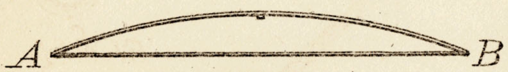

Fig. 2.

Fig. 4.

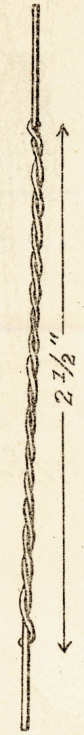

Fig. 5.

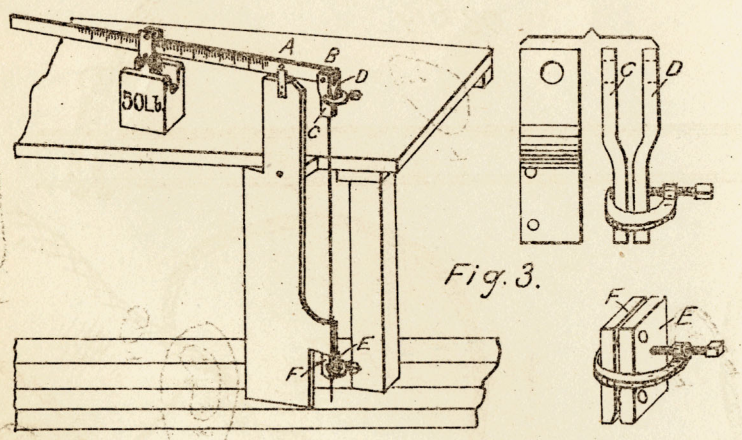

Fig. 3.

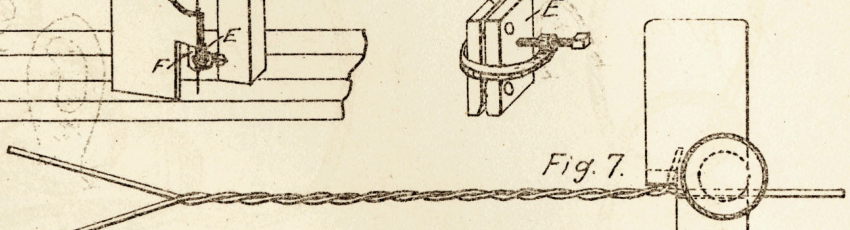
Fig. 7.

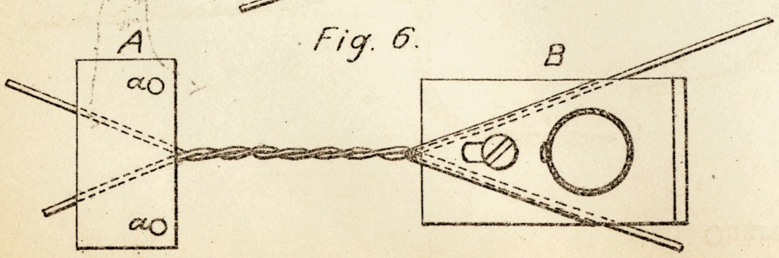

Fig. 6.

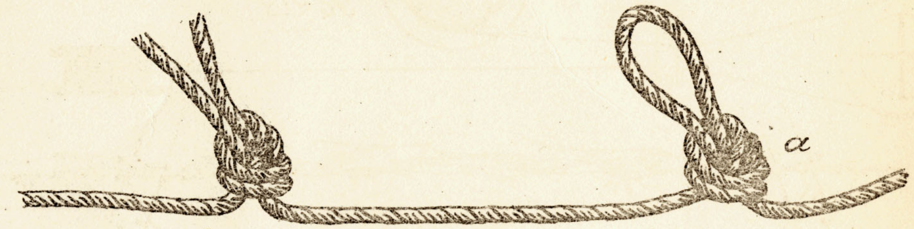

Fig. 8.

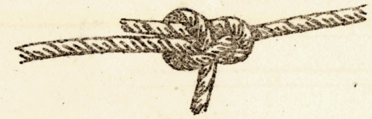
Fig. 9.

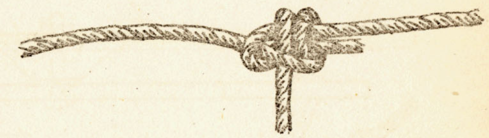
Fig. 10.

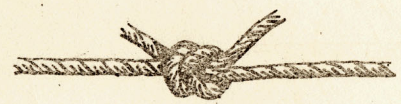
Fig. 11.

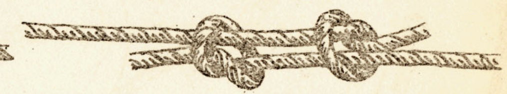
Fig. 12.

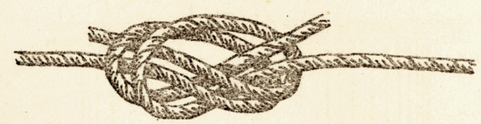
Fig. 13.


Fig. 14.

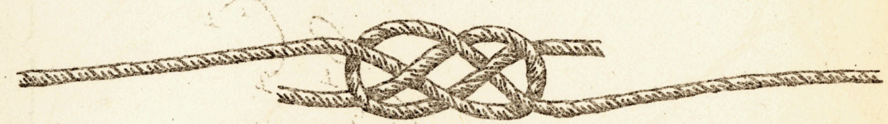
Fig. 15.

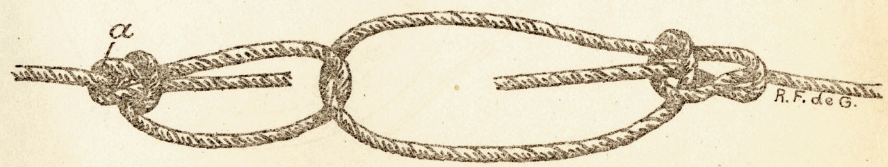

Fig. 16.

Chart IX. Kite Experiments of the Weather Bureau.