AERIAL NAVIGATION.

BY

O. CHANUTE, C.E.,

OF CHICAGO.

A LECTURE DELIVERED TO THE STUDENTS OF SIBLEY COLLEGE, CORNELL UNIVERSITY.

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Until quite recent years, the possible solution of the last transportation problem remaining for man to evolve—that of sailing safely through the air—has been considered so nearly impracticable that the mere study of the subject was considered as an indication of lunacy.

And yet such measurable success has recently been achieved as to warrant good hopes for the future, and it is believed that speeds of 25 to 30 miles per hour, or enough to stem a wind less than a brisk gale, are even now in sight.

This is not unusual in the history of inventions. They are first proposed by the men of imagination, the poets and the dreamers, and next they are experimented upon by the more imaginative inventors, until at last some glimmer of success or some powerful incentive induces scientific men to investigate the principles, and ingenious inventors to endeavor to solve the problem.

Thus, if we are to believe ancient fable and history, desultory attempts to fly through the air followed close upon the invention of the land chariot and of the marine sail, but the mechanical difficulties in the way are so great that it is only since light primary motors have been evolved that any success at all has been achieved ; and even now the students of the problem are divided into two camps or schools, each of which expects flight to be compassed by somewhat different apparatus. These are :

1. Aeronauts, who believe that success is to come through some form of balloon, and that the apparatus must be lighter than the air which it displaces.

2. Aviators,* who point to the birds, believe that the apparatus must be heavier than the air, and hope for success by purely mechanical means.

Curiously enough, there seems to be very little concert of study between these two schools. Each believes the other so far wrong as to have no chance of ultimate success.

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* From *avis*, a bird. This comparatively recent French term seems so appropriate as to warrant its adoption into English.

Their work will be described separately ; and first that of the *Aeronauts*, in which it will be necessary to describe chiefly French achievements, that nation having taken the lead hitherto in studies aerial, probably in consequence of the invention of the balloon by Mongolfier in 1793.

AERONAUTS.

This great step (as it is believed to be) toward a possible solution of the problem at first excited the wildest hopes. Many believed the navigation of the air to be an accomplished fact. These hopes faded : it was soon found that an ordinary spherical balloon was at the sport of the wind ; and all sorts of impracticable devices were tried to control its motions, save till quite recent years (1852) that of furnishing it with a screw and an energetic motor.

While it is possible to impart low velocities, in calm air, to any kind of a balloon, yet the motive power which it could lift has been so small, and the consequent speed so inferior to that of ordinary winds, that until 1884 no balloon had ever come back to its starting-point.

We can perhaps best realize this deficiency of motive power by calculating approximately the speed which can be imparted to a spherical balloon by the motor it is capable of lifting ; and instead of selecting one of those generally employed in ascensions, of 30 or 40 ft. diameter, we will take as an illustration the great captive balloon built and operated by Giffard during the French Exposition of 1878, which was one of the largest and best ever built.

This was 118 ft. in diameter. Its volume was 882,925 cubic feet and its gross ascending power was 55,120 lbs. As the weight of the balloon proper, its car, appurtenances and fixtures was 30,536 lbs., there remained a net ascending power of 24,584 lbs., which might be utilized for a motor, its supplies, and a cargo.

Let us first calculate the resistance of the air to its motion.

Being a sphere 118 ft. in diameter, the area of its midsection was 10,936 sq. ft. This would not, however, offer the same resistance as a flat surface, the experiments of Hutton and of Borda having shown that the resistance of a sphere is 41 per cent. of that of a flat surface of area equal to its mid-section.

But to this is to be added the surface of the car and rigging, as well as that of the motor, its framing and machinery conveying power to the propeller. This is generally found to be equal to about $\frac{1}{10}$ the area of the balloon, and as the surfaces are mostly flat, the resistance is usually estimated at 50 per cent. that of a flat plane. Reducing these two factors to their equivalent flat feet, we have :

For the balloon : $\frac{10,936 \times 41}{100} = 4,484$ sq. ft.

For the car, etc.: $\frac{10,936 \times 50}{10 \times 100} = 546$ " "

Total equivalent flat surface .... 5,030 sq. ft.

We know by Smeaton's tables of air pressures that at a speed of 1 mile per hour the pressure upon a flat surface is 0 005 lb. per square foot, so that at this speed we may estimate the resistance of the balloon to be $5,030 \times 0.005 = 25.15$ lbs.—that is to say, that a force of but 25.15 lbs. continuously exerted would be sufficient to impart a speed of 1 mile per hour to this great mass in still air ; and as this velocity is 88 ft. per minute, we have for the power required :

$$25.15 \times 88 = 2213.2 \text{ feet-lbs., or } 0.067 \text{ H. P.}$$

This seems small indeed, but as the power required increases as the cube of the speed, let us see how fast the balloon can be driven by any available motor.

The net ascending power is 24,584 lbs., but not more than half of this (as shown by the subsequent practice of Renard and Krebs) is available for the motor. The remainder is required for the framing, the propeller, the transmitting machinery, the stores of fuel or supplies and the aeronauts. We will assume therefore 12,584 lbs. for the weight of the motor proper, and that this weighs but 110 lbs. per H. P., as was the case with the steam-engine used by Giffard in his navigable balloon of 1852. The possible H. P. is therefore :

$$\frac{12,584}{110} = 114.4 \text{ H. P.}$$

If we suppose this to be exerted through an aerial screw, inasmuch as the best that has yet been publicly tried gives out but 70 per cent. of the power applied (the remainder being lost in slip), we shall have for the real available power $\frac{114.4 \times 70}{100} = 80$ H. P. But as the resistance in still air requires an effective H. P. of 0.067 H. P. at 1 mile per hour, and the power required increases as the cube of the speed, we have

$$0.067\ V^3 = 80;\ V = \sqrt[3]{\frac{80}{0.067}} = 10.6 \text{ miles per hour,}$$

as the utmost probable speed which could have been obtained with the most energetic motor which this great balloon could have taken up into the air.

How far this would fall short of stemming the prevailing winds will appear from the inspection of the following table, quoted by M. Gatendorf as the average velocities of wind observed during a period of ten years in Germany, there being during that time per annum :

82	days of	wind	not	exceeding	11.18	miles	per	hour.
244½	"	"	"	"	"	22.37	"	"	"
38	"	"	"	"	"	42.50	"	"	"
½	day "	"	"	"		89.48	"	"	"

So that the occasions would indeed have been few upon which this air ship could have made any headway ; yet had its possible speed been 25 miles per hour, it might have gone out about three-quarters of the days in the year ; but in order to attain this speed it would have required a motor of nearly 1,500 H. P., which evidently it was quite impossible for it to lift.

Moreover, the recorded wind velocities are generally observed near the surface of the ground ; but at comparatively moderate altitudes, say 1,000 to 1,500 ft. above the earth, they are much greater. Records kept at the top of the Eiffel Tower for 101 days (June to October, 1889) show an average velocity of 15.75 miles per hour, while a similar instrument 925 ft. lower down registered during the same time an average speed of but 4.90 miles per hour, or less than one-third of that at the top, 994 ft. in the air.

It is probably for lack of a realizing knowledge of this peculiarity that so many past experiments with navigable balloons have proved such disappointments. The aeronauts measured the speed of the wind at the surface, and only went up into the air to be swept away by a swifter current.

In view of the fact that wind velocities are much greater at sailing heights than at the surface of the ground, the opinion may be expressed that aerial navigation cannot be accounted even a partial success until a velocity of 30 miles per hour is obtained ; but in order to remain well within the bounds of possibilities, the comparisons hereafter to be made will be based upon a speed of 25 miles per hour.

This brings us naturally to inquire as to what has thus far been done. It is clear that nothing was to be expected from any attempt to drive spherical balloons; that the resistance must be diminished in some way; and yet it took 79 years for aeronauts to realize the fact; for although General Meusnier had proposed them, and Robert Brothers had experimented with elongated balloons as early as 1784, it was not until 1852 that Henri Giffard, the future inventor of the injector, laid down the foundation for eventual success by ascending with a spindle-shaped air ship driven by a steam-engine.

GIFFARD'S BALLOON OF 1852.

On September 24, 1852, Giffard, then a young engineer 27 years of age, ascended from Paris in an elongated balloon filled with ordinary coal gas, driven by an aerial screw propeller actuated by a steam-engine of his own designing. He was at that time quite poor; but having been possessed since the age of 18 with the conviction that success was possible, he had communicated his enthusiasm to two of his college friends, who possessed limited means, and the three had contrived, amid many discouraging difficulties, to build and to equip this first navigable balloon.

It was in shape a symmetrical spindle, 144 ft. long and 39 ft. in diameter. The screw was three bladed and 11 ft. in diameter. The steam-engine was of 3 H. P., and weighed with the *empty* boiler 330 lbs., or 110 lbs. per H. P. In proportion to its power, this engine was much lighter than any previously built; but it was the utmost weight of motor which the balloon could lift, after making due allowance for the weight of the apparatus, its appurtenances, the aeronaut, the fuel, and the water. For the two latter 678 lbs. were allowed, of which 132 lbs. were in the boiler. Coke was employed as fuel, and the danger of setting on fire or exploding the gas escaping from the balloon was guarded against by surrounding the grate with a tight ash-pan, which again was surrounded with a vertical flue sheet. Thus no flame came into contact with the outer air, and the products of combustion, cooled in the return flue, were projected downward through an inverted smoke pipe, into which the steam from the cylinder was exhausted.

The cubic contents of the air ship were about 88,300 cub. ft., and being inflated with coal gas, its lifting power was 3,978 lbs. Had pure hydrogen been used instead, the lifting power would have been about 6,160 lbs., and a heavier motor could have been used; but this would have made little practical difference in the results as to speed. Fig. 1. is a side view of the entire apparatus. The surplus lifting power being only sufficient to carry up one man, Giffard went up alone, at about 5.15 in the evening. The wind on the day previously selected for the ascension blew with considerable force, and Giffard knew from his calculated resistances that he could not hope to stem it; but having attained an altitude of about 5,000 ft., he set the engine in motion. With 110 revolutions of the screw per minute, he was enabled to get a proper speed of the apparatus, which he estimated at 4.27 to 6.70 miles per hour, so as to deflect and turn the balloon from the line of the wind; and thus, while satisfied that this first air ship was quite unable to cope with the wind that day or with those generally prevailing, he yet was enabled to announce his deliberate conclusion that ultimate success was certain with a larger balloon and a more energetic motor.

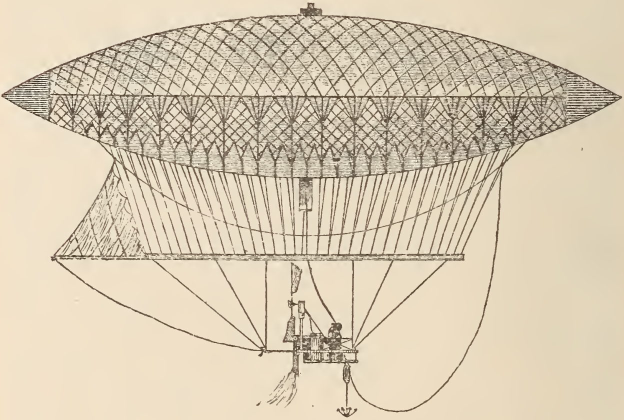

Fig. 1.

He further expressed his belief, as a result of this experiment, "that the danger resulting from the juxtaposition of fire and an inflammable gas might prove to be quite illusory;" but yet no other aeronaut since his time has dared to repeat the experiment.

He came down in safety just after dark, though not without some danger. It was clear that in order further to reduce the resistances a still more elongated balloon would be required, and he resumed his studies and designs for further experiments with unimpaired enthusiasm ; but the means of himself and friends were so far exhausted that it was only in 1855 that he was enabled to make a second trial with what he considered an improved apparatus.

This new balloon was 230 ft. long and 33 ft. in diameter, being thus 7 to 1 instead of $3\frac{2}{3}$ to 1, as in the former experiment. This change, which was made to reduce the resistance, resulted in such longitudinal instability as nearly to cost Giffard his life. He was on this occasion enabled to take up a companion (M. Gabriel Yon) to assist in the manœuvres, but notwithstanding this, the balloon would not keep a level keel. The wind blew, and although he attained greater speed than on the former occasion, he was unable to stem the current for more than a few minutes at a time, with all the power of his engine. One end of the balloon tipped up, and the flow of the gas toward that end aggravated the evil. The valve was at once opened, and the aeronauts came down as rapidly as they could ; but just as the ground was struck with considerable violence, the gas bag, tipping up more and more, slipped out of the netting and went to pieces.

This accident did not alter Giffard's conviction of ultimate success, but he determined first to make a fortune. He shortly thereafter invented the injector and eventually became a millionaire, while at no time did he abandon his aeronautical studies.

In order to work out practically all the details as to gas-tight envelopes, stability, appliances, manufacture of hydrogen, etc., he built in 1867 the great captive balloon for the Paris Exposition of that year. In 1868 he built one in London, and again in 1878 he carried out further improvements in a new captive balloon at the Paris Exposition, this being the one which has already been alluded to.

At length, in 1881, he determined upon the construction of a gigantic air ship, to contain 1,766,000 cub. ft. of hydrogen and to cost $200,000, out of which he expected a speed of nearly 45 miles per hour ; but he was near the end of his career. First his health failed, and then his eyesight ; he became a recluse ; and finally, discouraged and maddened by physical pain, he died by inhaling chloroform in April, 1882.

Giffard was thus the first to drive a balloon with a motor, and this he did with a steam-engine. It is probable that men before now have gone into a powder magazine with a lighted torch and have come out in safety ; still the practice is not to be commended. So Giffard went up with a lighted steam furnace under a gas bag open to the air through its lower valve and he came down safely not once only, but twice ; and yet other aeronauts believe the practice so dangerous that not one thus far has repeated the experiment.

THE DUPUY DE LÔME BALLOON, 1872.

During the siege of Paris, in 1870, some 65 ordinary balloons left the beleaguered city, but notwithstanding many efforts, not one of them succeeded in getting back. The

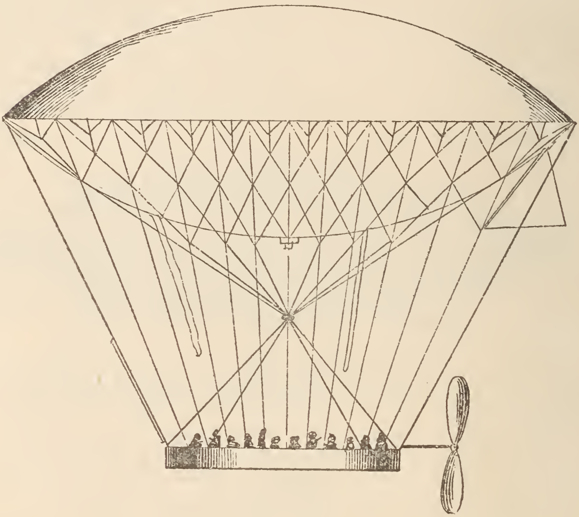

Fig. 2.

Government decided in October upon building a navigable balloon, to restore communications, and entrusted its construction to M. Dupuy de Lôme, Chief Naval Constructor, to whose skill was largely due the success of the earlier armored ships of France. He went most carefully into the questions of balloon resistances, stability and working details, and pushed the construction as fast as the disorganized industry of the city would permit ; but nevertheless the apparatus was completed only a few days before the capitulation.

Then came the insurrection of the "Commune," so that it was only on February 2, 1872, that the merits of the air ship could be tested.

The balloon was also a symmetrical spindle, 118½ ft. long and 48⅔ ft. in diameter (2.43 to 1). It contained 120,088 cub. ft. of pure hydrogen, and its lifting power was 8,358 lbs. Its principal features of novelty were a system of triangular suspension, by which all weights were concentrated at a single point a short distance above the car, and the introduction inside of the gas bag of an air pocket or bag, say one-tenth in cubic displacement of that of the balloon, so as to keep it distended and rigid at all times, by blowing in or letting out air. This valuable device was found to remove, for low velocities at least, the danger of deformation from end thrusts or resistance of the air. We shall find it used again in the Renard and Krebs experiments of 1884–85. Fig. 2 is a side view of this air ship.

Dupuy de Lôme's ultimate purpose was that his balloon should be driven with an engine of some sort; but from a wholesome dread of fire, he tried his experiment with hand power. The total crew consisted of 14 men, of whom 8 laborers turned a winch, imparting 27½ revolutions per minute to a two-armed aerial screw 29½ ft. in diameter. This drove the apparatus at a speed estimated at 6.26 miles per hour, with an expenditure of say 0.8 H. P. It is believed that the speed was overestimated, but in any event it proved insufficient to stem the wind on the day of the trial. Dupuy de Lôme estimated that by substituting a steam-engine of 8 H. P., representing the weight of 7 men, or say 1,200 lbs., he could obtain a speed of 13½ miles per hour; but the experiment was not made, and the next in date was

THE TISSANDIER ELECTRICAL BALLOON, 1883.

Impressed with the belief that recent improvements in electrical engines afforded a safe and convenient motor for balloons, M. Gaston Tissandier, the distinguished author and aeronaut, constructed in 1883, with the co-operation of his brother, a navigable balloon 92 ft. long and 30 ft. in diameter (3.04 to 1), inflated with 37,439 cub. ft. of hydrogen, and with a lifting power of 2,728 lbs.

The netting in this case was formed of flat ribbons sewed to longitudinal gores, which arrangement was found materially to diminish the air resistance due to the ordinary twine netting. The apparatus was driven by a Siemens dynamo weighing 99 lbs., actuated by a primary battery (bichromate of potash) weighing 517 lbs. more and capable of developing $1\frac{1}{2}$ H. P. for $2\frac{1}{2}$ hours. The

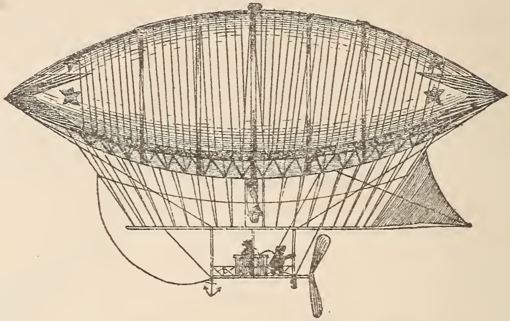

Fig. 3.

screw was 9.18 ft. in diameter, with two arms, and was rotated at 180 revolutions per minute. Fig. 3 shows this apparatus.

Two ascensions were made. The first was on October 8, 1883. On this occasion there was almost no wind at the surface, but at a height of 1,600 ft. it was blowing at the rate of about 6.7 miles per hour. It was found that the apparatus was just able to stem it, exerting the full power of the motor. After performing various evolutions the aeronauts came down, intending to go up again the next day ; but the weather being cool, the bichromate solution froze during the night, and although the balloon had apparently lost no gas, it was decided to empty it and to try it again after making some modifications in the rudder, which had not been found to work well.

The second ascension took place September 26, 1884, and on this occasion the balloon was found to obey its helm perfectly, to perform various evolutions and to attain a speed which, although inferior to that of the wind that day, was estimated by M. Tissandier at 9 miles per hour. This probably was also an overestimate. The longitudinal stability was satisfactory, and the necessary endwise rigidity was secured by maintaining an internal compression in the gas bag by means of a safety valve.

In neither trial could the air ship return to its starting-point because of the wind, and the results were so far inferior to those obtained at about the same time by the

French War Department, that these costly experiments, which had been carried out at private expense, chiefly in the interest of science, by two gentlemen of limited means, were not prosecuted further. They had pointed out the way, and established that by the substitution for steam of electric power, the following advantages were gained :

1. All danger from firing the gas was avoided.
2. The apparatus did not vary in weight.
3. The motor was more easily managed.

Others stepped in with abundant backing to carry on the evolution of the problem.

FRENCH WAR BALLOON, 1884–1885.

The aeronautical establishment of the French War Department, at Calais, was reorganized in 1879. There had been a similar establishment under the first French Republic, which had rendered some service by observing the enemy from captive balloons, but it had been disbanded. The new organization, which was chiefly intended to manufacture and man captive balloons, was in charge of able men, who had sufficient means to experiment, and the advantage of knowing all that had been accomplished by their predecessors. Giffard had pointed out the path, Dupuy de Lôme had gone into the mathematics of the question in an elaborate memoir, and Tissandier had exhibited the advantages of electric motors. The French officers in charge, Messrs. Renard and Krebs, improved very greatly upon all previous practice, and built, in 1884, an elongated balloon 165 ft. long by 27½ ft. in diameter, in which the largest section was no longer placed midway of the spindle, as in all previous attempts, but toward its front end, as obtains in the case of birds and fishes. Moreover, they placed the screw in front instead of behind, as previously practised ; but the great improvement consisted in largely increasing the energy of the motor in proportion to its weight. Besides this, they obtained stability and stiffness by the use of an internal air bag and a better mode of suspension, and they enclosed the whole apparatus in a shed, so that it might be kept permanently inflated and await calm days for experiment.

This air-ship, which was named *La France*, held 65,836 cub. ft. of hydrogen, and its lifting power was 4,402 lbs. The car was very long (105 ft.), in order to equalize the weight over the balloon and yet admit of both being placed close together, in order to bring the propelling arrangements as near the center line of gravity as possible. The screw was placed on the car ; it was with two arms, and 23 ft. in diameter. The power of the motor was ascertained by experiment in the shop to amount to 9 H. P., and speeds of 17 to 20 miles per hour were expected with 46 revolutions of the screw. Fig. 4 represents this airship.

The first trial was made on August 9, 1884, and on a calm afternoon the balloon ascended, proceeded some 2½

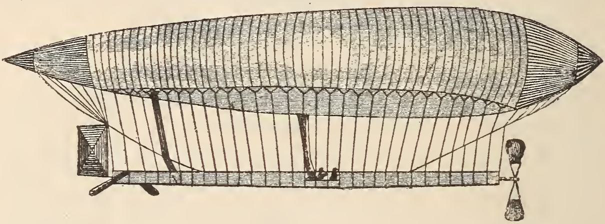

Fig. 4.

miles from the shed, and returned to its original starting-point, having proved perfectly manageable, and attained a speed of 10¼ miles per hour. This was the first time that a navigable balloon had returned to its landing, and the experiment attracted great attention, an account of it being, a few days thereafter, presented to the French Academy of Sciences. The aeronauts believed they could make still greater speed, but for obvious reasons they jealously guarded such details of construction as were not apparent from casual inspection in the air, and more particularly the construction of their motor and battery, concerning which more will be said hereafter.

A second ascension was made on September 12, 1884 (14 days before the last ascension of Tissandier), but although a speed of over 12 miles per hour was attained, an accident to the machine (heating of journals) compelled landing at Velizy, instead of returning to the starting-point. The latter was, however, successfully accomplished again, November 8 following, when two ascensions were made on the same day, and a speed obtained of 13.42 miles per hour.

Various minor improvements were made in the apparatus, and in the ensuing year three more trial trips were taken, making seven in all, on five of which the balloon returned to its starting-point, as follows :

SCHEDULE OF TRIAL TRIPS OF "LA FRANCE."

No. of Trial.	Date.	Rev. of Screw.	Speed, Miles per Hour.	Remarks.
1	August 9, 1884.	42	10.24	Returned to Chalais.
2	Sept 12, 1884.	50	12.19	Accident—descent at Velizy.
3	Nov. 8, 1884.	55	13.42	Returned to Chalais.
4	Nov. 8, 1884.	35	8.54	" " "
5	August 25, 1885.	55	13.42	High wind ; descent at Villacoubray.
6	Sept. 22, 1885.	55	13.42	Returned to Chalais.
7	Sept. 23, 1885.	57	14.00	" " "

From these experiments, which, it must be remembered, were tried merely to test the efficiency out of doors of a new war engine, Captain Renard, while stating that the resistance was greater and the speed less than he had at first expected, deduced the following formulæ :

(1) $$R = 0.01685\, D^2\, V^2$$
(2) $$W = 0.01685\, D^2\, V^3$$
(3) $$T = 0.0326\, D^2\, V^3,$$

in which

R is the air resistance to motion in kilogrammes.
V " " speed in meters per second.
D " " diameter of the balloon.
W " " work done in kilogrammeters.
T " " " " on the shaft of the screw.

From this he calculates that a balloon 32.8 ft. in diameter would require 43½ H. P. to drive it at 22 miles per hour.

Since 1885 no outdoor experiments have been made so far as the public is aware, but it is understood that numerous experiments have been actively carried on within doors, which, being intended to improve a war engine, have been surrounded with profound mystery.

A year or so ago this policy of secrecy was apparently changed, and Commandant Renard began publishing a number of scientific papers upon various branches of the subject, such as the resistance of air, his experiments with aerial screws, the possibility of success with aeroplanes and the construction of his primary battery, which, after having been kept secret for a time, he now fully describes and figures, with the remark that "this publication now threatens no danger to the national security," from which it is not unreasonable to infer that he has found a more efficient motor. and that it is not electric; for he says further: "In the actual condition of industrial electricity, it is impossible that an electrical balloon shall constitute a true war engine."

At the Paris Exposition of 1889, the War Department erected a special building, and exhibited the air-ship *La France*, together with all its belongings, including the motor, battery, screw, etc., and full accounts of these exhibits have been published in various technical journals.

And yet the impression was produced on many minds while in Paris, more perhaps from what was not said than from what was shown and published, that the French War Department was, even now, in possession of important improvements and information which will afford increased speed, but which, as is right and proper, are kept secret, to prevent their use by possible enemies.

Should this conjecture be correct, it is not impossible that, in case France should be involved in a European war, we should soon see navigable war balloons flying at the rate of 25 to 30 miles per hour, going out over the enemy's lines on reasonably calm days to observe his positions and to drop an occasional explosive on his head. Indeed, in some of his writings, Commandant Renard, after laying down that "the conquest of the air will be practically accomplished when a speed of 28 miles per hour is obtained," expresses the opinion that we are on the eve of freely navigating the air, and that probably France will possess the first aerial fleet.

It is stated that the German, Russian and Portuguese Governments have recently organized aeronautical establishments, and are experimenting in secret. Should some notable success follow, it will not be the first time that a great invention has been advanced by the necessities of war.

Leaving speculation, however, the accompanying table gives the principal data as to the four air-ships which have been described, and the H. P. necessary to drive them at 25 miles per hour.

The last line shows how light a motor must be to produce 25 miles per hour without increasing the weight.

We will consider the all-important question of motive power after examining the probable requirements of apparatus heavier than the air.

SCHEDULE OF NAVIGABLE BALLOONS.

DATA.	Giffard, 1852.	Dupuy de Lôme, 1872.	Tissandier, 1883.	Renard & Krebs, 1884–85.
Length, out to out............ft.	144.3	118.47	91.84	165.21
Diameter, largest section.... "	39.3	48.67	30.17	27.55
Length to diameter...proportion	3.67 to 1	2.43	3.04	6
Cubic contents.................ft.	88,300	120,088	37,439	65,836
Ascending power.......... ..lbs.	3,978	8,358	2,728	4,402
Weight—Balloon and valves, "	704	1,255 5	374	812
" Netting and bands, "	330	396	154	279
" Spars and adjuncts, "	660	1,316.5	75	170
" Rudder and screw, "	....	165	....	193
" Anchor and guide rope............. "	176	308	110	....
" Car complete....... "	924	1,287	220	995
" Motor in working order........... "	462	2,000	616	1,174
" Aeronauts .... "	154	310	330	308
" Ballast and supplies "	567.6	1,320	849	471
" Total apparatus.... "	3,977.6	8,358	2,728	4,402
H. P. of motor............... ...	3	0.8	1.5	9
Weight of motor per H. P., lbs.	154	2,500	410	130
Speed obtained...miles per hour	6.71	6.26	6.71	14
H. P. required 25 miles per hour	155	52 (?)	77	51
Motor lbs. per H. P.............	3	38 (?)	8	23

POSSIBLE IMPROVEMENTS IN BALLOONS.

Before expressing an opinion upon the future speed of navigable balloons it may be interesting to review the various difficulties which have hitherto been met, and to inquire into what patent attorneys call "the state of the art."

The greatest speed thus far attained has been 14 miles per hour, which, as indicated at the beginning, is insufficient to cope with most of prevailing winds, particularly at sailing heights above the ground, and the following difficulties have been encountered and, to a certain extent, overcome.

1. Excessive loss of gas in early experiments.

This has been remedied by closer tissue of envelope and better varnishes, as well as by regulating valves, so that the loss of gas at the captive balloon in Paris last summer was said to average less than 2 per cent. per day.

2. Resistance of air to forward motion.

This has been largely diminished by pointed ends, but much remains to be done in ascertaining the best proportions.

3. Need of a propeller to act on the air.

This has been measurably solved by the aerial screw, which is said to exert from 50 to 70 per cent. of the power applied, but is yet less efficient than the marine screw, which works up to 84 per cent.

4. Need of steering gear.

This has been fairly worked out by various arrangements of rudders and keel cloths, which have given command of the apparatus when in motion.

5. Need of a light motor.

This is the great difficulty. Steam has been tried with a weight of 154 lbs. per H. P., including fuel and water, and electric engines with a weight of 130 lbs. per H. P. Neither are sufficiently light to give the necessary speed, except, as will be explained, for very large apparatus.

6. Need of endwise stiffness.

This has been remedied by compressing the gas inside the balloon, either through the use of a loaded safety valve or through the use of an internal air bag. As speed increases more will needs be done in this direction, and this will require stronger and heavier envelopes for the gas bag.

7. Need to prevent deviations in course.

This has been overcome by placing the screw in front, where it is more effective than behind.

8. Need of longitudinal stability.

This has only been partly solved by various methods of suspension. There is still a tendency to pitch when meeting gusts of air, and this will increase when greater speeds are attained. It will need to be worked out by experiment.

9. Need of altitudinal stability.

This is the tendency of the balloon to rise or fall with the heating or cooling of the gas. It has been met in only a crude way by alternately discharging either gas, to prevent the balloon from bursting, or ballast, to prevent it from coming down. This rapidly exhausts both gas and ballast, and limits the time of the trip.

It has been repeatedly proposed to substitute for this method a vertical screw, to raise and depress the balloon, which should then be at starting slightly heavier than the air which it displaces ; and one of the best proposals for this purpose is due to an American engineer, Mr. E. Falconnet, who patented it in 1885, together with many other features, to remedy the various difficulties which have been encountered ; but death cut short his labors, and his devices have never been experimented on.

The great desideratum is to gain increased speed, and there are at least four ways by which this may be accomplished.

1. By giving the balloon a better form of hull, so as to diminish the resistance. *La France* was rather blunt in front, and there is reason to believe that by simply moving the largest section further back, increased speed will result.

2. By designing a more efficient aerial screw. Commandant Renard has been experimenting in this direction. and says there is a shape much better than others, and that this form cannot be departed from without getting very bad screws ; falling, as he expresses it, into a veritable precipice on either side.

3. By devising a lighter motor, in proportion to its energy. This is the great field in which work remains to be done. It was announced in September, 1888, by a newspaper correspondent that Commandant Renard had built a motor weighing 1,100 lbs. and developing 50 H. P., but since then nothing has been heard of it.

4. By simply building larger air-ships, for, inasmuch as their contents, and consequent lifting power, will increase as the cube of their dimensions, while their weight will, approximately, only increase as the square, the surplus lifting power will evidently increase with the size, and greater motive power in proportion can be used.

Let us suppose, for the sake of this argument, that no improvement whatever has been achieved in either of the first three ways which have been mentioned, and inquire simply what would be the effect of doubling the dimensions of *La France.* The comparison will be approximately as follows :

Principal Dimensions.	*La France.*	Double Size.
Length, out to out .... ft.	165	330
Diameter, largest section .... "	27.5	55
Contents of gas ....cub. ft.	65,836	526,688
Lifting power ....lbs.	4 402	35,216
Weight of apparatus .... "	2,451	9,804
" Cargo and aeronauts .... "	779	1,500
" Machinery .... "	1,174	23,912

As the motor (dynamo and battery) of *La France* weighed 130 lbs. per H. P., we have for that of double the size $\frac{23,912}{130} = 182$ H. P. motor, and calculating the speed by the formula of Commandant Renard, and inserting the new diameter, 16.8 meters, we have :

$$T = 0.0326 \times \overline{16.8^2} \times V^3 \text{ in kilogrammeters.}$$

But as we have 182 H. P., and there are 75 kilogrammeters in the H. P., we have further :

$$182 \times 75 = 0.0326 \times \overline{16.8^2} \times V^3,$$

$$\text{whence } V = \sqrt[3]{\frac{13650}{9.2}} = 11.2 \text{ meters.}$$

So that we see that the speed of the new air-ship will be 11.20 meters, or 36.7 ft. per second, say 25 miles per hour.

The same result is arrived at by considering that the new balloon will require four times the motive power of *La France* to go at the *same speed*, and that the power required increases as the cube of the speed. So that we see that a speed of 25 miles per hour is even now in sight, without any other improvement than doubling the size of the balloon.

It will not be safe to assume, however, that increased speed can be indefinitely obtained with mere increase of size, because with more speed a series of new difficulties are likely to arise, and some of the old ones to be aggravated.

The first of these will probably come from the lack of longitudinal stiffness. Although it has been found that a certain amount of internal gas pressure gives the elongated balloon sufficient rigidity to resist the pressures due to low speeds, so soon as these are increased there may be a tendency to buckle, twist and collapse, and this means more pressure, a stronger envelope and more weight ; or a rigid internal frame, as proposed by Mr. Falconnet ; and this also means much more weight.

Next, there will be in great balloons much greater difficulty in distributing equally the weight of the car and its contained motor over the gas-bag, because of the necessary greater concentration of weight in the car. It will besides be found more difficult to apply the propelling power near the line of equilibrium, so as to avoid oscillations.

There will also be increased difficulty from the flow of the gas back and forth inside of the elongated balloon, thus displacing its center of gravity, and threatening the danger which so nearly proved fatal to Giffard. Moreover, even slight changes of outer temperature, heating and cooling the gas in the balloon, and thus changing its ascending power, are likely to be far more troublesome when operating on large than on small masses of gas, so that it seems likely that large balloons will be found more unstable, both vertically and longitudinally, than the comparatively moderate sizes which have so far been experimented upon.

These difficulties can all be surmounted, no doubt, including the remaining one that large balloons will be costly, and that few can afford to experiment with them ; but the various appliances necessary for stability will involve more weight, and this again will require more size.

Be this as it may, it is evident that somewhere a limit will be reached beyond which unmanageable sizes will be met with. The weight, the size, the resistance will increase, as well as the speed, and somewhere there will be impracticability. We have seen that to go 25 miles per hour, and thus brave the wind about three-quarters of the time, we need an elongated balloon similar in shape to *La France*, 330 ft. long and 55 ft. in diameter. It is probable that, by improvement in the first three ways which have been mentioned, it may attain a speed of 30 or 35 miles per hour ; but when it is attempted to obtain 40 miles per hour out of it, it will grow to lengths of, say, 1,000 ft., or as long as four ordinary city blocks, and diameters of 150 ft., or the height of an ordinary church steeple.

These seem unmanageable and impracticable sizes for ordinary uses. They are greater than those of ocean steamers, because the speed required is greater, to overcome the aerial currents ; and the care and maintenance of these great air-ships will be a difficult matter.

It seems likely, therefore, that in the near future elongated balloons will be built which will be driven at 25 or 30 or a few more miles per hour, which will be able to sail about on all but stormy days ; but the cargoes carried in proportion to the size will be small, and to obtain speeds similar to those of express trains some other form of apparatus will have to be sought for.

PART II.—AVIATION.

Having sketched what has thus far been accomplished with, and what may be fairly expected from navigable balloons, we may next turn our attention to that other class of students who call themselves "Aviators," and who, discarding the use of a gas-bag, seek to solve the problem of flight by purely mechanical means. They point to the birds in confirmation of their views, and constitute by far the most numerous as well as the most ancient school; for, to say nothing of ancient traditions, earnest proposals have been brought forward during the last 400 years to compass flight by various mechanical contrivances.

With these students, the possibility of success has been more a matter of faith, of instinctive belief, than of sober calculation. They watched the birds, saw that they progressed through the air by mechanical action and skill, and were very much heavier, bulk for bulk, than the air which their bodies displaced (for we may dismiss with a smile the old-time assertion that birds gain levity by inflating their quills with heated air), and they hoped that man might accomplish similar results by somewhat similar means.

Impressed with these views, a number of these students have organized aeronautical societies in Great Britain, in France, and in Germany, and have for the past 20 odd years been reading papers, discussing the subject, and trying sundry experiments.

Very little practically has thus far come from these efforts, for curiously enough, and yet naturally, the first endeavors were to devise or to construct models, which have remained toys, before knowing accurately the resistances and conditions which they were to encounter in the air. In other words, the work began upon the constructive instead of the analytical features of the case, as usually happens at the outset of an invention, and while a good deal of valuable information has been gathered, no practical machine has yet resulted. Some theoretical investigations have been attempted, but unfortunately the scientists have been hopelessly at variance not only among themselves, but also, what is more important, with some of the ascertained facts.

Thus it has been so far unknown what power birds expend in overcoming the resistance of the air in their flight, or what amount of support they derive from it at various angles; and although the laws of fluid resistances laid down by Newton are known to be erroneous, they are still taught in the academies; and it was only the past summer that a new theory of flight, which may prove to be the correct one, was proposed simultaneously by two civil engineers at the Aeronautical Congress of the Paris Exposition.

Even the theory of the equilibrium of the common kite, supposed to have been invented by Archytas 400 years B.C., is still a subject of dispute, and every little while a fresh solution of its numerical reactions is proposed by a mathematician.

Possibly, in consequence of this state of uncertainty as to the laws of flight, the Aviators have been divided into three camps or sub-schools, which have looked for success from somewhat different contrivances, and who have advocated the following mechanical means :

1. The imitation of the flapping action of the wings of birds.

2. The sustaining of weight and obtaining progress simultaneously through the air by horizontal screws.

3. The sustaining of weight by fixed aeroplanes, and the obtaining progress by means of screws.

A great many experiments have been tried and a great deal of ingenuity has been expended in each of these three directions, but thus far not a machine has been able to leave the ground with its prime motor, and what measure of success has been attained can only be exhibited through toys, which give an idea of the principles involved.

The advocates of wing action hold that nature cannot err in her methods, and that success is only to be achieved by imitating her ; they have therefore endeavored to devise moving surfaces which shall repeat the complicated movements of the wings of birds, so as simultaneously to sustain and propel the apparatus. The only motive power which it has thus far been found practicable to use has been the torsion of india-rubber, and with this a number of clever mechanical birds have been contrived by Mr. Brearey in England, and by MM. Penaud, Tatin, de Villeneuve and Pichancourt in France.

The latter—that of Pichancourt—dates only from last summer, and is represented by fig. 5.

It measures about 12 in. from tip to tip of wings, and weighs 385 grains, one-third of which consists in the twisted rubber strings furnishing the motive power. The necessary flexion of the wings, to obtain a propelling as well as a sustaining reaction, is produced by a triple excentric, each actuating a lever fastened to a different point in the wings.

Upon being wound up and released, the apparatus flies slightly upward, and to a distance of 30 to 60 ft., in from 3 to 6 seconds. Similar but larger birds, of the same

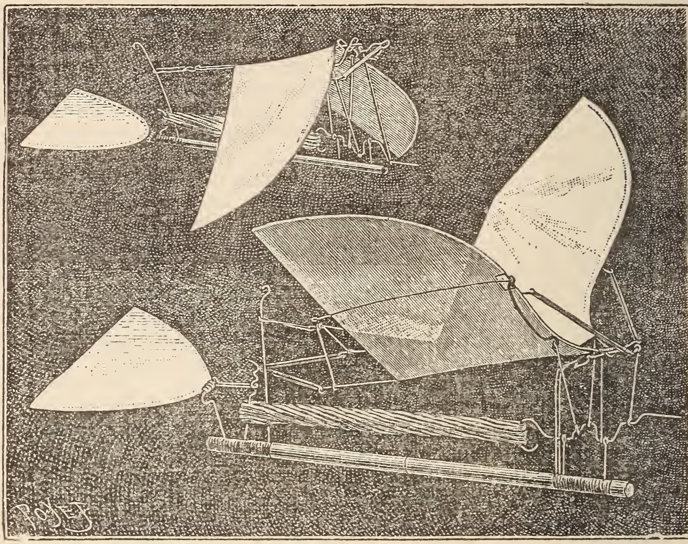

Fig. 5.

make, are said to have flown up to a height of 25 ft. and a distance of 70 ft. against a slightly adverse wind.

The relative power absorbed, however, is quite beyond the capacity of any known prime motor.

The next principle—that of an aerial screw to sustain and to propel simultaneously by its horizontal revolution—was actively promoted in France some 25 years ago, and great results were expected. It was proved, however, that it required about 1 H.P. to sustain 33 lbs. in the air, or much more than the energy of any engine, and the sole survivors of the many experiments made are the various flying screws which still amuse children ; the best of these being that of Penaud, shown in fig. 6, in which two screws rotate in opposite directions and cause the apparatus to rise or to fly in a circle, according to the proportions of its various parts.

And lastly, in recent years, experiments have been made with combinations of fixed surfaces, called aeroplanes, to sustain the weight, and of rotating vertical screws to propel. Machines or models on this principle have been built by Henson, Stringfellow and Moy in Great Britain, and by Penaud, Tatin, de Louvrié, and du Temple in France, but thus far not one has succeeded in lifting a

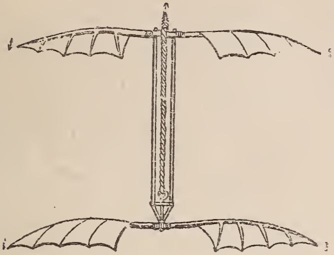

Fig. 6.

self-contained motor, and perhaps, after all, the best example of this class of contrivance is the artificial butterfly of M. Dandrieux, which is shown in fig. 7.

Fig. 7.

The flight of all these toys lasts but a few seconds, and none of them carries its own motive power, while it will be found by measuring accurately the foot-pounds expended, and the weights sustained in a given time, that not one of the prime movers known is as yet sufficiently light, in proportion to its energy, to furnish the power required to maintain them in the air.

This question of motive power, the vital one in Aerial Navigation, will be discussed more particularly hereafter, but it may here be mentioned that a few observers, who have been watching birds soar without flapping their wings in southern latitudes, believe that this species of flight involves no expenditure of power whatever, save for the getting under way. This opinion has been much ridiculed, but yet it is possible that if we take into account the force of the wind, the belief of these observers that certain birds can soar indefinitely at moderate speeds without other exertion than the passive one of keeping the wings rigidly extended may not be as absurd as at first sight appears ; but if man is ever to direct himself at will through the air, at satisfactory velocities, he will need power, and plenty of it ; more indeed in proportion to the weight of the motor and of its supplies than he has yet been able to devise.

Meanwhile a few observers and scientists have been patiently investigating the motions which birds perform in their flight. Among these may be mentioned the Duke of Argyle and his book, "The Reign of Law ;" M. Mouillard and his "Empire de l'Air ;" Dr. Petigrew and his book on "Animal Locomotion," and especially Professor Marey, who has just published a book, "Le Vol des Oiseaux," the result of 20 years' investigation, which is most interesting and valuable, but which, unfortunately, throws but little light upon the all-important questions as to the sustaining reactions to be derived from the air, and the power required for flight ; the latter having remained in controversy since the days when Navier made the erroneous calculation that a flying swallow exerted one-seventeenth of a H.P., or at the rate of no less than 3,586 H.P. per ton of weight.

Of course, the first thing to ascertain is to know what are the components of air pressure upon a plane in motion at a given velocity, if inclined to the current. In other words, what proportion of the usual right angle pressure remains if the plane be tilted, and how much of this new pressure acts as a sustaining force or *lift*, while how much opposes forward progress, and may be denominated *drift*. Some interesting experiments have been made in Great Britain on this subject, and more of them in France, but they have chiefly been made with some form of rotating apparatus, and it was found not only that the results obtained with direct currents did not agree with those of rotary machines, but that the latter showed greater pressures on planes inclined at angles of 50° to 70° than on those placed at right angles to the current (a most improbable condition), so that it is now believed that the centrifugal force of the rotating vanes in some way vitiates the results, and the French have been preparing to try a new set of experiments upon artificial currents to be produced by large ventilating fans.

Things were in this condition when an International Congress of Aeronauts and Aviators was held in Paris last August. During this a number of papers were presented, and among them were two which may lead hereafter to a new and more rational theory of flight. One was by a Russian engineer, M. Drzewieki, who, starting from the best empirical formulæ he could find, had calculated the weights sustained, the surfaces required, and the power needed for aeroplanes in artificial flight at various velocities, while the second paper was a theoretical investigation of the same subject by the present lecturer.

The remarkable result about these papers was that, starting from two different standpoints—the empirical and the theoretical—they closely agreed in their conclusions; and as the paper of M. Drzewieki was the most complete and thoroughly worked out, I shall prefer to give an account of it rather than of my own.

M. Drzewieki first showed that the hitherto received idea that a bird in flapping his wings generated thereby a sufficient pressure to sustain his weight is incorrect. It has long been known that the pressures experimentally obtained by striking the air with surfaces of equal area and velocity with those of the wings of a bird, or even with the wings of a dead bird dried and mounted in an apparatus, do not generate a sustaining reaction equal to the weight of the bird; but it was dimly believed that the living bird had the skill, in some mysterious way, of obtaining from his strokes sufficient intensity of pressure to sustain his weight. M. Drzewieki says that this view is quite erroneous, and that the bird is really sustained by the vertical component of the pressure due to his speed. In other words, that the flying animal is really an aeroplane, whose body and wings in all stages of their action make a very small angle with the impinging air, and that the propelling power is chiefly derived from the rear thrust exerted by the escaping air against the outer curved extremity of the quill feathers.

Moreover, if account be taken of the forward motion, the angle which the wings present to the line of flight must be less than 6°. It is imposssible to detect this angle of incidence by the eye. The wing seems to be flapped vertically downward ; or in soaring the bird seems to hold his wings and body absolutely horizontal ; but in point of fact we know that there must be an angle of incidence in order to obtain a sustaining reaction. This brings up the inquiry as to what that angle really is.

M. Drzewieki starts from Duchemin's empirical formula of the normal resistance which air opposes to an inclined plane moving against it, and deduces therefrom the sustaining reactions per square meter at various velocities for various angles from 20′ to 10°, and these are tabulated for ready reference. Next he calculates the horizontal components of the normal pressure for the same velocities and angles, this being the resistance to the advancement of the plane alone, and to this is added the head resistance due to the thickness necessary to secure the required strength of the plane, or, in other words, its hull resistance, and to this again is added the probable friction of the air against the sides. These three items together give the total resistance to forward motion, and are also tabulated for ready reference.

Then, by combining these two tables and plotting the resulting curves, in order to ascertain at what angle there is a minimum of resistance to forward motion, while yet retaining a sufficiency of sustaining power, it is found that this occurs for one and the same angle at all velocities, this being 1° 50′ 45,″ and this M. Drzewieki assumes as the angle of flight.

I may here mention that these two reactions, or components of the normal pressure due to the angle of incidence and to the speed, formed the subject of the paper read by myself at the Paris Congress, and of a similar paper which I presented before the American Association for the Advancement of Science at its last meeting, and that I had reached the conclusion that the most favorable angle for soaring was between 1° and 2°.

Assuming 1° 50′ 45″ as the angle of flight, and allowing for the vertical and horizontal components of the normal pressure due to the speed at that angle, as well as for the hull resistance and friction, M. Drzewieki then gives four formulæ, supplemented by tables, which produce the following elements :

1. The weights per square meter, which can be sustained at this angle of 1° 50′ 45″ at various speeds.

2. The work done (kilogrammeters) to overcome the forward resistances under the same circumstances as above.

3. The proportion of the work done to the weight sustained.

4. The amount of surface required to sustain 1 kilogramme at various velocities.

The consequences which M. Drzewieki deduces from these formulæ and the plotting of their curves are the following :

1. An aeroplane progressing horizontally, with the angle of incidence (1° 50′ 45″) corresponding with the minimum of work, meets practically the same resistance at all speeds, so that the work done is approximately a function of the weight of the apparatus, multiplied by the velocity.

2. Aeroplanes designed for small speeds need relatively large surfaces and small weight ; these conditions he believes to be difficult of realization in practice.

3. The greater the speed, the less surface needed to support a given weight.

4. The less the surface, and therefore the greater need of speed, the greater must be the motive power.

These conclusions are believed to be approximately sound, and M. Drzewieki sustains them by showing that in flying birds the smaller is the sustaining surface in proportion to their weight, the greater is their customary speed, giving a table of the proportions of some 64 birds, which shows that the surfaces of the body and extended wings range from 7.56 sq. ft. to the pound for the bat, which flies at the rate of about 20 miles per hour, to 0.43 sq. ft. per pound for the male duck, who progresses at about 60 miles per hour. He estimates that for a speed of 90 miles per hour, the surface required will be but 0.22 sq. ft. to sustain a pound of weight.

It seems to follow as a conclusion that if aeroplanes are ever built to carry tons of weight, their proportion of surface to weight may be considerably less than those which obtain with birds, but that the speed will need to be greater than that of flying animals in order to obtain support from the air, while the motive power required will vary approximately only in the direct proportion of the weight carried. This important conclusion seems to hold out hopes that success may eventually be attained if the stability of the apparatus can be secured.

M. Drzewieki also discusses this question of stability. He shows that the transverse equilibrium can easily be maintained by a diedral upward slant of the wings of an aeroplane, arranging them like the sides of the letter V, but at a very obtuse angle, so that any tendency to tilt shall at once develop greater pressure in that direction, and thus restore equilibrium. This was pointed out as early as 1809 by Sir George Cayley, in a remarkable series of papers published in *Nicholson's Journal*, which are well worth reading.

M. Drzewieki states the law of longitudinal equilibrium to consist in placing the center of gravity of the whole apparatus vertically below the center of pressure due to the angle of flight, and he gives the rule, first formulated by Joëssel, for determining this center of pressure. He moreover states that these two centers, of gravity and of pressure, must be but a very short distance apart, in order to prevent oscillations. This solution is substantially, for flat angles of incidence, the same as that of Sir George Cayley, who states that the center of gravity must be at right angles to and below the center of pressure ; but it is to me doubtful whether this is the best solution for assuring the longitudinal stability of a flying apparatus, and this important, almost vital question is likely to prove a stumbling-block in the way of future experimenters.

Assuming it to be solved, M. Drzewieki estimates that an apparatus, built to the best possible proportions as to exposed surface and form, and sailing at an angle of 1° 50′ 45″, will require to drive it at 25 miles per hour but 5.87 H.P. per ton of its weight. This assumes the thickness of apparatus and consequent hull resistance to be but $\frac{1}{100}$ of its horizontal dimensions, while for birds it generally runs from 5 to 10 per cent. That is to say, that birds exposing a horizontal surface of say 100 sq. in. generally expose a maximum cross-section vertically of 5 to 10 sq. in., while M. Drzewieki believes this can be reduced to the proportion of 1 sq. in. per hundred for an aeroplane.

My own estimate of the power required by a common pigeon gliding at an angle of 1° with the horizon was 9.33 H.P. per ton of his weight, and 10.49 H.P. per ton at an angle of 2° for this same velocity of 25 miles per hour.

These are considerably less than the powers required to drive a balloon of moderate size at the same speed, for we have already seen that the air-ship *La France* would require 51 H.P. to attain 25 miles per hour ; or, as it weighs 2.2 tons, the motor would needs develop 23.2 H.P. per ton of the weight of the whole apparatus. For the balloon of double this size, the power required is at the rate of 10.34 H.P. per ton of apparatus. This power required would moreover increase in the case of the balloon, as the cube of the velocity, while M. Drzewieki shows that in the case of an aeroplane the power will increase only in the direct ratio of the speed, because as the velocity becomes greater the area of sustaining surfaces required becomes less, and he estimates that an aeroplane will require 10.43 H.P. per ton to go 44.72 miles per hour, and 20.62 H.P. per ton of its weight at 89.44 miles per hour.

This brings up the question of possible motors, and if we confine ourselves for the present to 25 miles per hour, and assume the power required at 10 H.P. per ton of apparatus, we see at once that only a fraction of that weight can be devoted to the motor. Let us assume, and I think this is not far wrong, that only one-quarter of the weight can be apportioned to the motor and its supplies; the remaining three-quarters being required for the weight of the framing, the aeroplane surfaces, the various appurtenances, and the aeronauts, we then have but $\frac{2000}{4 \times 10} =$ 50 lbs. per H.P. as the weight allowable for the motor and its supplies for such period of time as it is to consume in its trip. This does not greatly differ from the proportion in the pigeon, whose pectoral muscles weigh $\frac{10}{43}$ of his total weight, or 46 lbs. per H.P., including, it must be remembered, the stored-up energy which enables him to accomplish long flights without alighting.

Now, how does this compare with the weight of the engines manufactured by man? There are three classes of

1. Steam-engines.
2. Gas-engines.
3. Electric motors.

The machines in common use, being designed chiefly for strength and durability, are needlessly heavy, and it is only by inquiring into what has been done for special purposes that we ahsll get an idea of their possibilities.

Thus as to steam-engines: Ordinary stationary machines weigh with their boilers from 500 to 1,600 lbs. per H.P.; locomotives, from 200 to 300 lbs.; marine engines for Atlantic steamers, 480 lbs., and light launch engines—those of Herreshoff, for instance—some 60 lbs. per H.P. For aeronautical purposes, however, a steam-engine was built by Stringfellow, which weighed but 13 lbs. and exerted 1 H.P., and another was built by Moy and Schill of 3 H.P. and 80 lbs. weight, thus being about 27 lbs. per H.P.

But these weights, while including the boiler, do not include the water and fuel. These supplies may be estimated at 22 lbs. of water and 4 lbs. of coal per hour, so that if a large engine can be built as light per H.P. 13

lbs. as that of Stringfellow, it would still need, if for so, short a trip as two hours, 52 lbs. of supplies per H.P. making a total of 65 lbs., including the engine itself.

The principal weight is that of the water. It has been proposed to utilize part of this over and over again, by equipping navigable balloons with surface air condensers, but the difficulties in the way of this, chiefly from the added weight, are almost insuperable.

Next, therefore, gas and petroleum engines suggest themselves. As now made they are excessively heavy, weighing from 280 to 1,000 lbs. or even more per H.P., so that the advantages of dispensing with the boiler and its water supply are completely lost. They are comparatively of recent invention, however, and it is believed that corresponding reductions of their weight can be made,* such as have been effected for the steam-engine, and as will be seen hereafter for electric motors, and that this is a promising field for experiment; for even if aerial navigation be an Utopia never to be realized, improvements which will permit a reduction in the weight of gas-engines are likely to cheapen their cost materially, and to extend their use, as well as the profits of their builders.

And, lastly, we will consider the electric motors, with which whatever of success the navigable balloon has so far attained has been accomplished. They involve, like the steam-engine, two separate parts, the motor proper and the generator, which latter may be either a primary battery or an accumulator.

The weights of the motors or ordinary dynamos used in this country run from 92 to 260 lbs. per H.P. developed, while abroad they run from 68 to 350 lbs. per H.P.; but the special dynamo used by Commandant Renard weighed but 26.4 lbs. per H.P., and a very small one, built of aluminium by M. G. Trouvé, weighed at the extraordinary rate of but 7.7 lbs. per H.P.

M. Trouvé is now building for the Portuguese Government a 10-H.P. dynamo, which will weigh less than 220 lbs., and which is to be used to drive a navigable balloon. The total weight of the motor, batteries for several hours of work, screw and accessories, is estimated at 1,496 lbs., or at the rate of 149.6 lbs. per H.P. developed.

Contrary to expectation, accumulators are found, by comparison of numerous data from various makers, gath-

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* Since reading this lecture, the Author has seen an account of a three-cylinder petroleum engine built for marine purposes, in France, which develops 5 H.P., and weighs but 440 lbs., thus being in the ratio of 88 lbs. per H.P. It consumes, as near as may be, 1 lb. of petroleum per H.P. per hour.

ered by M. Tissandier, to be actually heavier than primary batteries. As they are charged to last various periods of time, it is necessary, in order to compare them, to reduce them to the common standard of one H.P. for one hour, and it is then found that accumulators of the best make weigh from 107 to 162 lbs. per H.P. per hour, a fair average being 135 lbs. ; while the primary battery of Commandant Renard is stated by himself to weigh but 66 lbs. per H.P. per hour, and to last a little over 1 hours, this being the present possible length of his trips. Thus the L MOTOR IS DECOMPOSED, into 26.4 lbs. of dynamo and 103.6 lbs. of primary battery, making in the aggregate the 130 lbs. per H.P., as has already been mentioned.

It will be observed that all these weights of motors are in excess of the 50 lbs. per H.P., which have already been assumed as the weight which can be afforded for aerial navigation, and yet not so greatly beyond it as to shut off all hope of improvement. Hitherto it has not been generally realized that the chief obstacle in the way of success is the want of a light motive power, one which shall develop great energy with little weight, and it is possible that when inventors turn their attention in this direction still lighter motors than at present known shall be the result.

It has been suggested repeatedly that a suitable motor for aerial navigation may be found by the invention of some kind of explosive engine, utilizing the force of gunpowder, nitro-glycerine or some other substance which can be flashed from the solid or liquid form to the gaseous condition ; but such a motor is yet to be invented, and, what is more difficult, regulated and perfected. Attempts in this direction, notably with gunpowder, actually antedate the steam engine, but the difficulties of controlling power so intense and so rapidly generated have hitherto been found too great to be overcome. It would be rash to say that they cannot be, although true explosive engines have thus far exhibited an unpleasant irregularity of working, frequently giving deficient strokes, but at times coming out with powerful explosions which may kill the inventor.

It is believed that gas or petroleum engines, which are also explosive engines, with the difference that the working substance is already in the gaseous form, and thus subject to fewer irregularities of expansion, present greater chances of success in obtaining a light motor for aerial purposes, and would-be inventors are advised to turn their attention in this rather than in other directions.

But even if the motor is worked out, there will remain some serious difficulties to be encountered before man can fly through the air at satisfactory speeds. The first of these is the requirement for absolute stability which has already been alluded to. The apparatus must balance itself in the air automatically, and must possess sufficient surface to come down as a parachute should the machinery break down while sailing. The second difficulty will consist in the necessity for obtaining high initial velocities, so that the sustaining pressures shall be great, and that the dimensions and weight of the apparatus may consequently be reduced to a minimum. This difficulty of getting under way is the principal one encountered by birds, and probably furnishes the reason why none of them have attained the size of land and marine animals.

It has been pointed out that there are no flying birds much over 30 lbs. in weight, and, reasoning from analogy, it has been argued that man cannot hope to improve upon nature in this direction ; but not only are birds much more complicated in structure than a flying machine needs to be, having many functions to perform such as wing-folding, feeding, reproduction, etc. besides that of mere flight, but they evidently expend much more energy in starting than in any other portion of their evolutions.

The smaller ones jump from the ground into the air with all their might, and then beat their wings with much greater rapidity and amplitude than in their normal flight. If rising vertically they soon exhibit signs of distress. The larger birds in starting from the ground are compelled to run considerable distances, always against the wind, in order to gather headway and supporting power, and even with the most energetic flapping they cannot rise at a steeper angle than 45°. All birds prefer to start from a perch, for by directing their first course downward they gather velocity from the action of gravity ; at times some of the larger ones obtain relative velocity by simply spreading their wings wide open to the breeze while yet on the perch, the object in every case being to avoid the great exertion required to obtain speed, for once fairly under way they are masters of their movements.

Resort to some equivalent devices will evidently be open to flying machines, but it is evident that until the question of stability has been thoroughly worked out, such experiments will be exceedingly dangerous ; no such apparatus has yet succeeded in raising itself from the ground with the whole of its motive power, and the most that can be said at present is that recent elucidations of the laws of flight seem to indicate that it is not impossible for man to succeed with an aeroplane.

There are probably scores of shapes which can be made available for such machines, just as there are hundreds of forms of birds who display various peculiarities in their flight; but in every case there will be the same requirements as to a light motor, absolute automatic stability and some device for gaining initial velocity, as well as for landing safely. This will require much experimenting, and a beginning has scarcely been made, so that even granting the accomplishment possible, the working out of the problem may prove to be slow.

Success might be much hastened, however, by a working association of searchers in this field of inquiry, for no one man is likely to be simultaneously an inventor, to imagine new shapes and new motors; a mechanical engineer, to design the arrangement of the apparatus; a mathematician, to calculate its strength and stresses; a practical mechanic, to construct the parts, and a syndicate of capitalists, to furnish the needed funds. It is probably because the working out of a complex invention requires so great a variety of talent, that progress in other fields has proved so slow, several generations sometimes passing before an important invention such as that of the steam-engine, the telegraph, or the reaping machine is finally perfected and brought into general use.

CONCLUSION.*

To sum up, therefore, the present "State of the Art"—if it has yet progressed sufficiently to be called an art—may be stated as follows:

A measurable success has been attained with navigable balloons. They have been driven 14 miles per hour, and it is probable that speeds of 25 to 30 miles an hour, or enough to go out when the wind blows less than a brisk gale, are even now in sight. Very much more speed than this is not likely to be obtained with balloons, for lack of sufficiently light motive power, and because of unmanageable sizes.

Much greater speeds can perhaps be attained eventually

* I have refrained in this paper from discussion of the various mathematical formulæ concerning air resistances, because not only are they a matter of controversy, which must hereafter be settled by experiment, but also because the figures of M. Drzeweiki, which are based on empirical formulæ, may be in need of revision; for the benefit of the curious in such matters, however, it may be stated that his paper can be obtained (in French) in *L'Aéronaute* for October, 1889.

with aeroplanes ; recent investigations indicate this ; but even a beginning is prevented by the lack of a light motor, and by questions as to the stability of the apparatus as well as to safe ways of gaining high initial velocities. Whether these difficulties will ever be overcome no one knows, but they indicate the direction for investigation and experiment, while the probable benefits to man of a solution of the problem are so great that they are well worth striving for.

Success with aeroplanes, if it comes at all, is likely to be promoted by the navigable balloon. It now seems not improbable that the course of development will consist, first, in improvements of the balloon, so as to enable it to stem the winds most usually prevailing, and then in using it to obtain the initial velocities required to float aeroplanes. Once the stability of the latter is well demonstrated, perhaps the gas-bag can be dispensed with altogether, and self-starting, self-landing machines substituted, which shall sail faster than any balloon ever can.

If we are to judge of the future by the past, such improvements are likely to be won by successive stages, each fresh inventor adding something to what has been accomplished before ; but still, when once a partial success is attained, it is likely to attract so much attention that it is not impossible that improvements will follow each other so rapidly that some of the present generation will yet see men safely traveling through and on the air at speeds of 50 or 60 miles per hour.