combustion of illuminants. The Commission, so far, has added a considerable amount of useful information and evidence confirmatory of the views held by physiologists in this country.

The Commission points out how in the case of a school building the chosen architect strives to outdo the others in the size and ornamentation of the building, and to satisfy the excessive requirements of the school committee. Then begins the process of trimming, and the heating and ventilating plant being the biggest single item of equipment, comes in for the most attention, with the worst results. And this, too, despite the fact that the ventilating plant is really the lungs of the building, and counts most for the comfort and efficiency of the occupants. "But, of course, there must be so many rooms, just so many gargoyles, and just so much marble. For these things are seen and read of all men."

THE UTILISATION OF SOLAR ENERGY.[1]

IN the first part of the paper referred to below are given particulars of the various apparatus which have been used to obtain power from solar radiation. In doing so the author was able to describe in fair detail the construction of such apparatus, but he stated that he had been unable to get any but the most meagre information as to the results obtained with the various plants, and much of that appeared to be untrustworthy. The case was very different in regard to Shuman's work since and including the year 1910, for the author himself had conducted the experiments with Shuman's plants.

Shuman set out with the idea that the principle of former workers in this field of using high-pressure steam was wrong. He argued that high-pressure steam meant a high temperature, and therefore a large loss due to radiation. We shall see later that though this is true, a better overall efficiency is attained when the steam pressure is higher and the boiler area is reduced, so as to save loss due to radiation. It is also a thermal advantage to have a high concentration of the solar radiation; but Shuman started first of all without any concentration (which has its advantages by reason of simplification); then he used a concentration of two to one, and finally 4·6 to one.

As steam was to be generated at a low (say atmospheric) pressure, an efficient engine for the use of such steam had to be designed, and in this Shuman was uniquely successful, for when the author tested a Shuman low-pressure engine at Erith he found that its steam consumption was only 22 lb of steam at 16·2 lb. sq. in. abs. per b.h.p. hour, the b.h.p. being 94·5. This beats all the old atmospheric engines, and indeed everything to date for steam at that pressure.

Shuman's 1910 sun heat absorber had an area of only 15 sq. ft., and the tests made with it showed that at its best 300 sq. ft. of it would be required to produce enough steam for one b.h.p., allowing the aforementioned 22 lb. per b.h.p. hour.

In 1911 Shuman made another absorber like that of 1910, except that it had two plane silvered glass mirrors, one attached to the upper edge of the "hot-box" and one to the lower, and so arranged that 2 sq. ft. of solar radiation were concentrated on to 1 sq. ft. of boiler surface. The hot-box (originated by H. B. de Saussure, the Swiss geologist, physicist, and naturalist, who died in 1799) was 3 ft. wide, 6 in. deep, and 66 ft. long. There were twenty-six such sections. The back was formed of $\frac{3}{8}$-in. millboard, on top of which was 2 in. of cork-dust, covered with $\frac{1}{4}$-in. millboard. The laminar boiler (about $\frac{1}{4}$ in. thick) was fixed in front of this, leaving an air space of an inch between it and the millboard. In front of the boiler was another air space of an inch, then a sheet of window-glass, another air space of 1 in., and finally the top sheet of window-glass. 10,296 sq. ft. of solar radiation were thus collected, and the best hour's run gave 816 lb. of steam at a pressure of 14·2 lb. sq. in. abs., equivalent to 26·8 b.h.p. and a thermal efficiency (of the absorber alone) of 29·5 per cent.

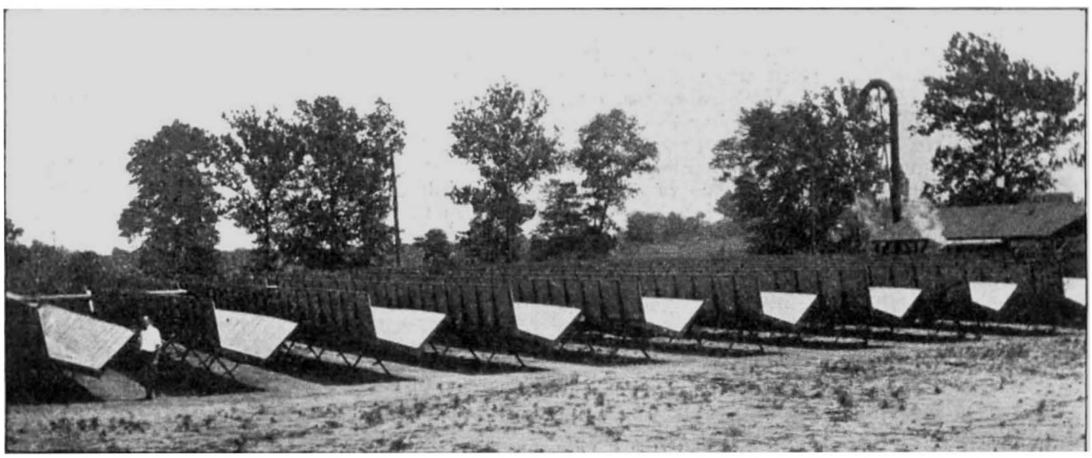

FIG. 1.—General view from the west of the Shuman absorber, Tacony, 1911.

The orientation of these reflectors was east and west, and they did not "follow the sun," consequently the output of steam fell off considerably in the morning and evening. The solar radiation was received on only *one* side of the 1911 boiler, while the other side lost some of it, but, due to Prof. C. V. Boys, F.R.S., the boiler which the author tested in Egypt in 1913 received heat on both of its sides, and its top edge as well, and the concentration was 4·6 to 1. The orientation of the reflectors was north and south, and they were made automatically to "follow the sun." Each reflector was trough-shaped, parabolic in cross section, 13 ft. 5 in. across the top and 205 ft. long, and there were five such sections. Hence 13,752 sq. ft. of solar radiation were collected. The

[1] Abstract of a paper read before the Royal Society of Arts on April 28 by A. S. E. Ackermann.

cast-iron boilers had a perimeter of 2 ft. 11 in., and were 205 ft. long. They were tested both naked and covered, the covering being formed of one layer of window-glass, butt jointed, and the best results were obtained when they were so covered. The best run of an hour gave 1,442 lb. of steam at a pressure of 15·8 lb. sq. in. abs., equivalent to 55·5 b.h.p. = 63 b.h.p. per acre of land occupied by the plant; while the

FIG. 2.—Shuman-Boys absorber, Meadi, 1913. One section of the absorber from the north.

average power for the five hours' run on that day (August 22, 1913) was 59·4 b.h.p. per acre, and the minimum on the same day was 52·4 b.h.p. per acre, a decrease of only 16·8 per cent. The maximum thermal efficiency of the absorber alone was 40·1 per cent., or 36 per cent. better than the thermal efficiency of the 1911 absorber, while its steam production was $33\frac{1}{3}$ per cent. better.

The author's experiments in Egypt show that a *de*crease of 20 per cent. in the humidity of the atmosphere caused an *in*crease of 30 per cent. in the steam production.

Nearly all the technical part of the paper is contained in three appendixes, while a fourth consists of the bibliography of the subject.

In appendix i. it is shown that when the 1913 absorber was tested with naked boilers, the solar heat not used, and expressed in B.T.U. per hour per sq. ft. of boiler surface per 1° F. difference in temperature between the boiler and the air, is nearly constant and equal to 8·68.

In appendix ii. is derived the equation to thermal efficiency of a solar heat absorber and the efficiencies calculated by means of it are compared with the actual thermal efficiencies.

In appendix iii. the equation to the thermal efficiency of the absorber is combined with the equation to the thermal efficiency of a Carnot engine, thus giving the overall thermal efficiency. From this it is shown that the theoretical maximum overall efficiency of the 1913 Egyptian plant was 5·9 per cent., while the actual efficiency was 4·32 per cent. Thus 73·2 per cent. of the maximum possible efficiency was attained.

The equation to the thermal efficiency of the absorber is :—

$$\eta = \frac{Dsa - pk(T^4 - \frac{2}{3}A^4) - (1-r)Dsa}{Dsa} \quad . \quad . \quad . \quad (1)$$

and to the overall efficiency it is :—

$$\eta_0 = \frac{\{Dsa - pk(T^4 - \frac{2}{3}A^4) - (1r)Dsa\}(T - 568)}{Dsa} \quad . \quad (2)$$

The coefficient $\frac{2}{3}$ appears with the A^4, because the mirrors encircled only $\frac{2}{3}$ of the perimeter of the boiler.

Inserting the values of the known quantities for the Egyptian plant gives :—

$$\eta_0 = 0·71 - 404T^{-1} + 9·45 \times 10^{-10}T^3 - 1·664 \times 10^{-12}T^4 \quad (3)$$

where D = the width in feet of the reflector; p = the perimeter in feet of the boiler; r = the efficiency of silvered glass as a reflector of heat; s = the solar constant in B.T.U. per square foot per min. = 7·12; a = the coefficient of atmospheric transmission; T = the absolute temperature in degrees F. of the boiler; A = the absolute temperature in degrees F. of the

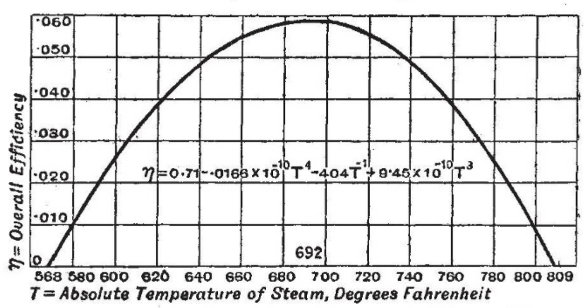

FIG. 3.—Curve showing the relation of the overall efficiency of the 1913 Shuman-Boys sun-heat absorber (with naked boiler), combined with a Carnot engine, to the absolute temperature of the boiler steam.

reflectors; 568 = the absolute temperature in degrees F. of the condenser; k = the coefficient of radiation, conduction, and convection = $10^{-10} \times 0·36$ B.T.U. per sq. ft. per min., this value having been determined by the author in 1899 under almost the same conditions as those to which it is now applied.

The graph of equation (3) is given in Fig. 3, from which it is seen that for a naked boiler, *i.e.* one without a glass cover, the maximum overall efficiency obtains when T=692° F. corresponding with a steam pressure of 21 lb. sq. in. abs. Or, of course, if equation (3) be differentiated with regard to T, and the result equated to 0, we also obtain T=692° F., from which is obtained the maximum value of η_0.

THE RIGID DYNAMICS OF CIRCLING FLIGHT.[1]

ONE of the main objects of the investigation described in this paper is to ascertain the conditions which render it easiest to steer an aeroplane in a horizontal circle of any radius that is not too small, and the idea of "inherent controllability" has been introduced to denote the property which a system may possess of freely describing a circular path without any pressure on the controlling rudders. In such cases the rudders will act as guides by preventing the aeroplane from leaving the chosen path, and as the system without them must, from the nature of the case, be wanting in directional (lateral) stability it is necessary for the working of such a system that the addition of the rudders should render it stable. The conditions for this must be worked out by the methods described in the lecturer's book, "Stability in Aviation."

It will be found that there are several different ways of obtaining inherent controllability and that in circling flight the system turns about a point which in some cases is in front and in some cases behind the centre of gravity. The axis of x or horizontal line through the centre of gravity in the direction of forward motion thus envelopes a circle of radius, a, the "turning point" being the point of contact of the axis tangent with its envelope, and the lateral or sideways velocity of the aeroplane being proportional to the distance of the centre of gravity from the turning point. This length and the inclination of the aeroplane to the vertical constitute two independent variables which can be so chosen as to satisfy two conditions of lateral equilibrium, but as there are three, a third variable is in general required, and if a rudder plane is used, this latter variable may be taken to be the pressure on that plane. The condition for inherent controllability is that the three equations of lateral equilibrium should satisfy some further identical relation by which the number of variables is reduced to two, and there are several ways in which this may be done.

The results here summarised lead to some interesting conclusions which were quite unexpected when the paper was commenced. In particular, they show the differences in behaviour between wings that are bent up and down respectively, the advantages, in certain circumstances, of curved wings as contrasted with plane wings bent into a simple dihedral angle, and generally that the form and curvature of the wing areas may play a much more important part in circling flight than had been anticipated.

The applications to the flight of birds are obvious, and suggest much interesting material for discussion. At any rate, a good many peculiarities in the wing structure of the circling birds appear to admit of interpretation on dynamical principles.

With regard to the possible application of these results to actual areoplanes, it remains to be seen how far it is desirable or practicable to realise the conditions of inherent controllability in a real flying machine. But the lecturer suggested that a study of the present work, followed by a few experiments, will either lead to improvements in the steering of aeroplanes, or if the present arrangements are the best, it will now be easier to understand the reason why.

Summary and Conclusions.

(1) In steady motion in a horizontal circle, both the longitudinal and the lateral equations of equilibrium are affected.

(2) The turning point may be in front of or behind the centre of gravity, its distance when in front being denoted here by b.

The axis of the aeroplane then envelopes a circle of a certain radius a, the real radius of the circle described being $\sqrt{(a^2+b^2)}$.

The system usually cants over sideways through a certain agle ϕ.

(3) Given the velocity and radius of the circle it is not usually possible to satisfy the three equations of lateral equilibrium by assigning suitable values to b and ϕ, but when this is possible the system is said to be inherently controllable.

In an inherently controllable system the rudder planes merely act as guides, and it is necessary that they should be so placed as to render the motion laterally stable.

In other cases steady motion can only be maintained by pressure exerted by the rudders or a couple applied by means of *ailerons* or some such action representing the third unknown variable required for the solution of the three simultaneous equations of lateral equilibrium.

(4) In a system of straight planes $\sin\phi$ is proportional to the radius a of the envelope, but it also appears that the other conditions of lateral equilibrium are only possible when pressure is applied by means of a rudder, and when a and ϕ have certain definite values. The only way of varying the radius of the circle actually described is by varying the position of the turning point, which may be in front of or behind the centre of gravity.

The addition of boxed-in ends or vertical partitions improves the steering, but it still leaves $\sin\phi$ proportional to a. The inference one would naturally derive from the formulæ is that all such systems would be liable to sway from side to side of the straight path in curved arcs of finite radius. In no case can the radius of the circular envelope exceed the limit corresponding to $\phi=90°$.

(5) With bent-up wings, as in the "Antoinette type," it is possible to satisfy the conditions of equilibrium so that a is no longer limited and ϕ no longer large. Such a system can be steered in a circle of large radius without being inclined at a large angle.

In general, circular motion can only be maintained when pressure is applied by means of a rudder or a couple applied by means of *ailerons*, but if the two principal moments of inertia about axes perpendicular to the line of flight are equal, the rudder exerts no pressure, and the system is inherently controllable, the inclination satisfying the relation $U^2=ga\tan\phi$.

(6) Another kind of "inherent controllability" in which the system always remains level, the inclination ϕ being zero, is possible in certain systems. A necessary condition is that the wings should be bent downwards and not upwards at the tips, and it will be usually advantageous that they should be most bent down at their extremities. The condition representing this fact is that the space between the wings and a chord joining their tips should be as large as possible.

This arrangement of the wings somewhat reproduces the action of gulls' wings in circling flight, and it will be found that differences in the form and

[1] Abstract of the third Wilbur Wright Memorial Lecture delivered before the Aeronautical Society on May 20, by Prof. G. H. Bryan, F.R.S.