pressure, and for that reason, the pressure slope has been represented somewhat steeper than the gradient uld indicate.

CONCLUSION.

This short study is an example of the application of the theory of the gradient wind. In spite of the many observational errors that may creep into pilot-balloon data, especially when obtained by the single theodolite method, there is a striking congruity in the figures obtained. It is true that at present the making of such maps by this method is impracticable, not only because of the considerable computation involved, but also because of the number of aerological stations is too small to furnish as much data as would be required. Nevertheless, the difficulties of the proposition lie more largely with external circumstances than with the scientific reasoning. We must improve our methods of forecasting for aviation, and to do it we must have first-hand knowledge of what is going on aloft—not in a desultory and fitful manner, but in a solid, consistent network of aerological stations. Those the Weather Bureau is operating at present are doing excellent work, and the assistance of the Signal Corps is extremely useful, but still this is only a beginning and expansion in the aerological work is one of the greatest needs of the Weather Bureau. Such a method of drawing charts of the upper air may prove to be useful in preparing wind charts for aviators.

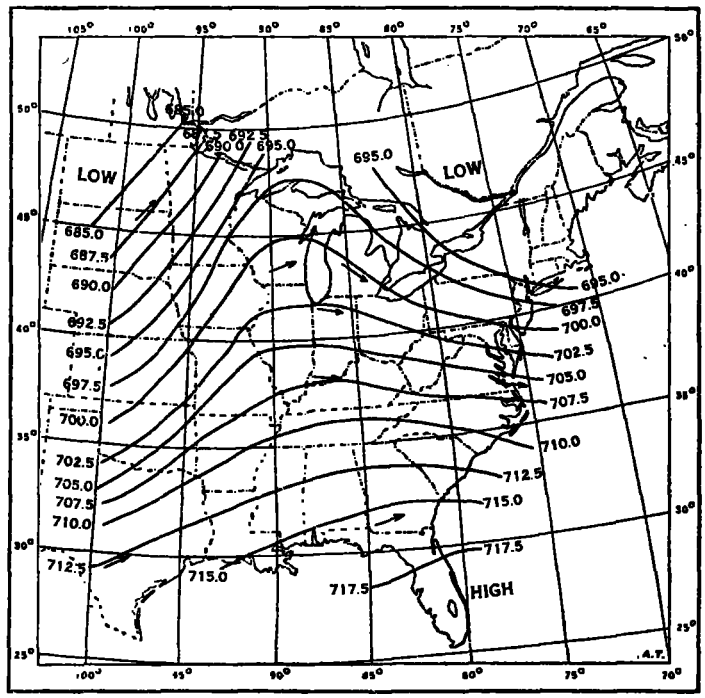

FIG. 7.—Pressure at the 3-kilometer level, in millibars, Mar. 27, 1920, 8 a. m., 75th meridian time.

THE WEATHER FACTOR IN AERONAUTICS.[1]

By C. LEROY MEISINGER.

[Weather Bureau, Washington, D. C., Jan. 20, 1921.]

"Scott and Cooke spend much time at the chart table, measuring angles of drift and calculating the course. Aerial navigation is more complicated than navigation on the surface of the sea, but there is no reason why, when we know more about the air and its peculiarities, it should not be made just as accurate."—Brig. Gen. Maitland, in the log of the R. 34.

SYNOPSIS.

Despite the significant advances of commercial aeronautics since the war, there remains a singular indifference of the public to the enterprise. It is believed that a recognition of the importance of the weather factor will assist in overcoming this indifference through the increase of safety and efficiency. Since lighter-than-air and heavier-than-air craft each have an important place in the scheme of aerial transport, their respective functions must be understood; the former is the probable carrier for long, non-stop flights, and the latter for the short fast flights.

The effect of winds on aircraft may be summed up in an equation, which expresses the speed along the course:

$$V = V_a \cos \theta_1 - V_w \cos \theta$$

wherein V_a is the still-air speed of the craft, V_w the wind speed, θ_1 the angle the craft must turn relative to its course to overcome the effect of drift and θ the angle between the wind direction and the course.

The experience of great European commercial aerial transport enterprises has indicated that the development of this form of transportation will naturally evolve a field for the aeronautical meteorologist, whose work will consist essentially in reducing for the benefit of his organization the detailed information for the individual pilots, a function too complex for any governmental agency to handle.

A specific example of the effect of winds on flight is given which indicates the lines along which meteorological information may be organized.

In this connection, one research problem of profound importance is that of the reduction of barometric pressure to levels in the free air. The success of this problem is largely dependent upon the amount of upper-air observations collected.

INTRODUCTION.

Civil aviation in the United States.—The trend of opinion among those who are most conversant with the results of the first years' efforts in commercial aeronautics seems to be that, to the present, these efforts must be regarded as demonstrations rather than as successful business enterprises. Some in America, make it appear that we must look to the other side of the Atlantic for our object lessons in commercial aeronautics, thereby neglecting the excellent large-scale activities of our own mail service and numerous successful smaller enterprises. We are likely to forget that the route between Miami and Habana, while perhaps not so difficult to fly, is about the same length as the much heralded London-Paris route; and that every day the mail planes are successfully flying over laps of such lengths that the famed European routes seem to diminish in importance as examples. We find that our activities are looked upon by European nations with a considerable degree of interest and our Aerial Mail regarded by Maj. Gen. Sir F. H. Sykes, comptroller general of civil aviation, as a "particularly interesting experiment."[2] There are those who point out that a lack of adequate laws is holding in leash numerous enterprises which stand ready to put into operation a large program of aerial transportation. The legal problem involved is of considerable magnitude and profound importance.[3]

Yet with all the interest and encouraging prospects of the efforts, there appears to be a singular indifference on the part of the public to commercial aeronautics. And this may be attributed in a large measure to the lack of publicity given the venture.[4] In any event, the fact must be recognized that the confidence of the public, one of the

[1] Presented, in part, before the American Meteorological Society, at Chicago, Ill., Dec. 28, 1920; and the Philosophical Society of Washington, Feb. 12, 1921.

[2] Civil aviation abroad. *U. S. Air Service*, December, 1920, pp. 24-26.

[3] Davis, Maj. W. Jefferson: Laws of the air. *U. S. Air Service*, December, 1920, pp. 17-20.

[4] Aerial mail as a promoter of commercial aeronautics. Editorial note. *Aerial Age Weekly*, Nov. 29, 1920, p. 315.

most important factors in the consideration, has not yet reached that stage that it is willing to give its enthusiastic support and approval to the institution of the aerial transport; and until it does reach such a state, there will be a struggle against a great obstacle in the efforts to "keep the eagle in the air."

Meteorology as an aid to civil aviation.—It behooves commercial aeronautics to look to those factors which will contribute toward the acquisition of the public confidence. Indeed, we may state the argument in the form of a syllogism of which the major premise is: Any agency that will serve to acquire the public confidence, through the elimination of accidents, the saving of property, the more efficient maintenance of schedules, and the yielding of profits to the promoters and stockholders in aerial transport enterprises, is one of decided importance to commercial aviation. The minor premise, which represents the phase of the question which it is the purpose of this paper to may be stated thus: The weather factor is such an agency. The conclusion is obvious,—that the intelligent use of weather data by any commercial aerial transport concern will contribute to the acquisition of this very desirable asset.

The application of meteorology to aeronautics is twofold: First, the study of climatological data will be of profit in the preliminary selection of air routes and landing fields; and, second, the consideration of the current weather conditions will be of immediate importance in the conduct of the craft in the air. The first of these applications has been discussed in an earlier paper.[5] The second will be considered here as far as it is possible to point out in a general way the use of current meteorological information.

THE FUNCTION OF DIFFERENT TYPES OF AIRCRAFT.

Speed, the chief characteristic.—To consider this question properly, it is necessary to have some appreciation of the functions of the different types of aircraft. The question has been asked, Which is the more practical in commercial aeronautics, the airplane or the dirigible? But it is generally conceded that this is hardly a legitimate question, since each type has a place to fill, which, instead of encroaching upon the domain of the other, is really supplementary to the other. Mr. G. Holt Thomas,[6] and other of the important men in the field of commercial aeronautics have pointed out that the commodity which the transport corporation has to offer is speed. If it can not supply speed—greater speed than it is possible to obtain with any other known means of surface transportation—it can not succeed.

The airplane vs. the dirigible airship.—As is well known, the airplane *does* supply speed, and much greater speed than can even be approximated by any means of surface transport. But the deficiency of the airplane is, despite the ambitious designs of the Fokkers, Capronis, or Lawsons of the commercial world, its limited carrying capacity, owing to the large weight of fuel which must be carried for long journeys. The dirigible balloon, on the other hand, has the ability to remain aloft for days at a time, and has a relatively large carrying capacity. Its limitation is speed, for, while the dirigible can travel fast, it can not greatly exceed the speed of fast trains, if it has an appreciable wind to contend with. But the fact that it can remain in the air for long periods and carry so much weight makes it appear as an efficient long distance carrier, such as might be used for transoceanic or transcontinental traffic.[7] The two types of craft do not, therefore, encroach upon each other.

The airplane is efficient for the short, high-speed transportation; the dirigible is suitable for the slower, but longer, journeys. The airplane, someone has said, will be the feeder to the dirigible. The transoceanic dirigible will be loaded from airplanes flying in from all directions to its terminals. The transcontinental dirigible will make few stops, but at each it can take aboard the gleanings of the airplane network in the vicinity of the airport. The relay method now employed in the Post Office Department is an example of the efficient use of the airplane in relatively short, fast, flights.

With this short and very general discussion of the two types of commercial craft, we may examine into the use and dissemination of data regarding current conditions and probable future conditions by a commercial aeronautic corporation. The important phenomena are, as has often been mentioned, winds and clouds. It is a self-evident fact that the aviator wants to fly at that level where he will receive the greatest assistance from the wind. But his question is, where are these favorable levels?

THE EFFECT OF WINDS ON FLIGHT.

The effect of wind components.—Before the above question is discussed, it will be well to call attention to the relations between winds and the motion of aircraft which are, for the most part, well known but perhaps not fully appreciated. Let us consider figure 1. Suppose that the direction AB represents the direction of desired flight, and its length the distance the flight of the craft in quiet air in unit time. Let a wind blowing at an angle θ to the course be represented by the vector CA. If the craft were wholly subject to the wind, as is a free-balloon, in unit time the craft would be carried to C′. If, however, the craft were trying to remain on the course AB, it would be necessary for the pilot to turn it through a certain angle which would be determined by swinging an arc of radius equal to AB with C′ as a center. Where this arc intersects the course AB at H is located the final position of the craft after unit time has elapsed. The vector AH, therefore, is the resultant of the two forces or the diagonal of the parallelogram of forces AC′HF.

It is instructive, however, to break the wind up into two components, the first, CE, parallel to the course AB, and the second, CD, perpendicular to it. Since, as was shown above, the perpendicular component CD is the cause of the turning of the craft through a certain angle θ_1, it is possible to show how much speed would be lost by the craft if the perpendicular component alone were operative. This is shown by projecting the point F on AB. In other words, the point G is the location of the craft after unit time with the wind component CD acting alone. If the craft is moved backward along its course by an amount equal to the parallel component CE, the point H is reached, as was shown above.

The effect of the perpendicular component.—The amount of the loss of speed attributable to the wind component perpendicular to the path is obviously given by the equation.

$$V_1 = V_a\ (1 - \cos\theta_1)$$

[5] Meisinger, C. LeRoy: Climatological factors governing the selection of air routes and flying fields. MONTHLY WEATHER REVIEW, September, 1920, pp. 525-527; reprinted in *Aerial Age Weekly*, Dec. 13, 1920, pp. 368-369 and 373; *Aviation and Aeronautical Engineering*, Dec. 13, 1920, pp. 423-425; and *Scientific American Monthly*, January, 1921, pp. 68-70.

[6] Aerial transport. (London), 1920, pp. 3-4, 7.

[7] Maitland, E. M.: The commercial future of airships. *U. S. Air Service*, January, 1921, pp. 22-26.

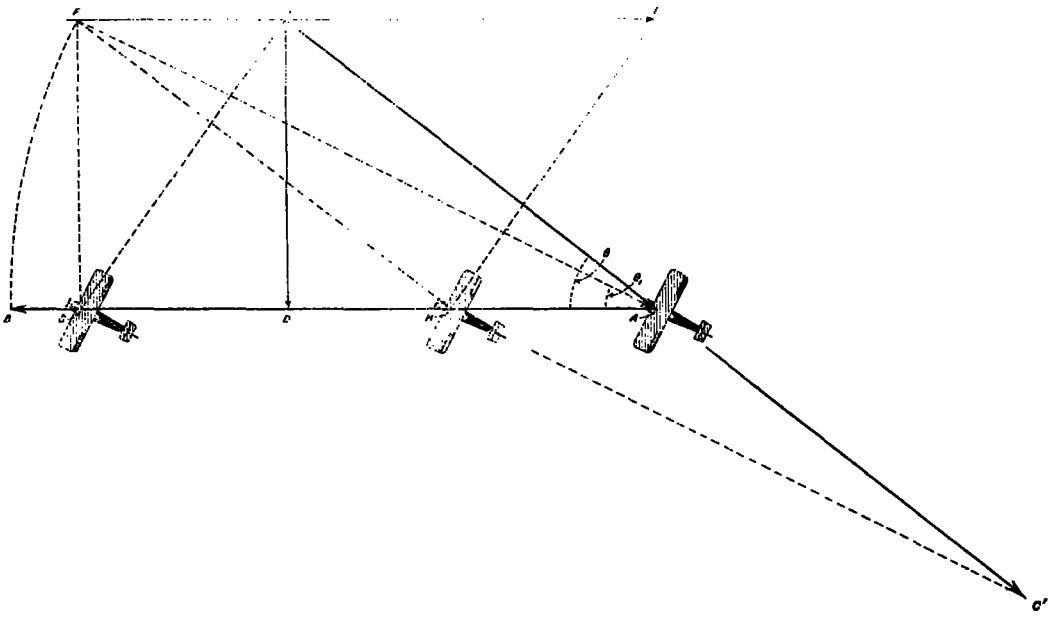

FIG. 1.—The effect of winds upon the movement of an airplane along a given course.

in which V_1 is the loss of speed, and V_a is the air speed of the craft. In order to show quantitatively what the loss of speed due to this perpendicular wind component may amount to, figure 2 has been drawn. The ordinates represent component magnitudes, the abscissae, craft speeds. The lines slightly rising to the right are drawn for each mile per hour loss. By knowing the airspeed of a given craft and the magnitude of the perpendicular component, it is possible to tell at once how much must be subtracted from the air speed to show the forward progress, neglecting the component parallel to the path. For slow craft and large wind components, this

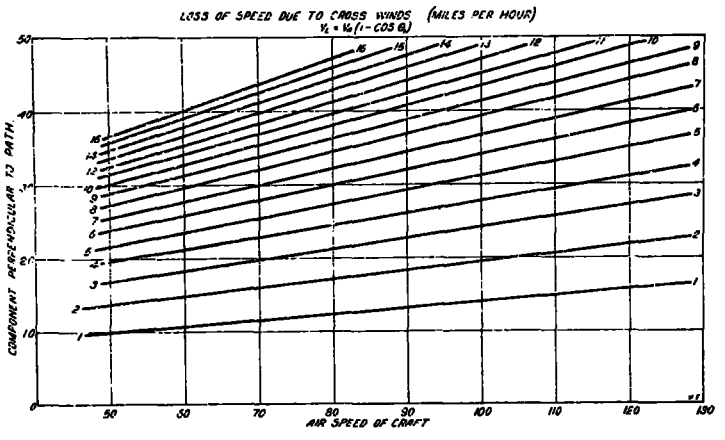

FIG. 2.—Loss of speed owing to the wind component perpendicular to the course.

may amount to 10 or more miles per hour, which would be worth considering in practice. For high speed craft, this quantity is considerably less.

The angle at which craft should be turned.—It will now be of interest to find the relation between the strength of the wind, and the angle from which it is blowing with respect to the route, under various conditions. It was shown in figure 1 and the discussion, that the angle at which the pilot must turn his craft with respect to the route is dependent upon the speed and direction of the wind and the speed of the craft. It is clear, therefore, that this angle may be given by the equation

$$\sin \theta_1 = \frac{V_w}{V_a} \sin \theta$$

or,

$$\theta_1 = \sin^{-1}\left(\frac{V_w}{V_a} \sin \theta\right)$$

where θ_1 is the angle between the craft and the course and θ is the angle between wind and course, and V_w and V_a the speeds of the winds and craft, respectively.

If this equation is solved for various values of the ratio $\frac{V_w}{V_a}$, there results a family of curves which, for the purpose in hand, may be most effectively plotted in polar coordinates. Such a diagram (fig. 3) will show the cor-

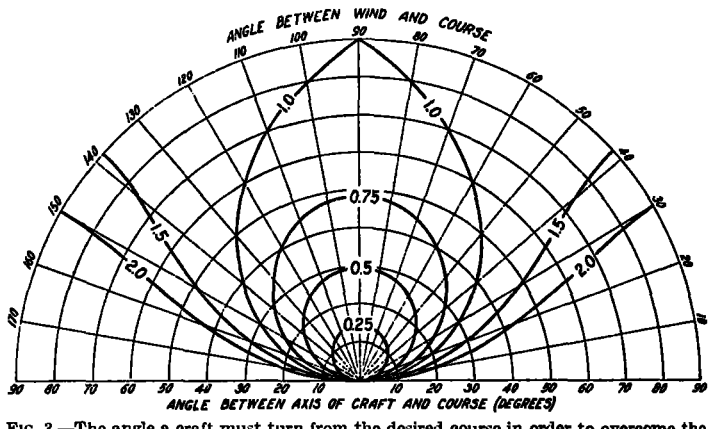

FIG. 3.—The angle a craft must turn from the desired course in order to overcome the effect of drift, for different ratios of wind speed to craft speed.

rect angle at which the craft must be steered under the various conditions. It has been said that, in issuing information of a meteorological character to the Navy fliers when the NC planes started their trans-Atlantic journey, this angle was estimated and given to them, and for it they seemed especially grateful. It is the meteorologist alone who can tell the aviator the value of this

angle; and, knowing its value, the pilot can correct his compass bearing accordingly and steer to offset the wind without actually knowing what the wind is. This diagram is so plotted that the value of θ represents the direction, relative to the course, from which the wind is blowing, and r (the distance from the origin to any point) represents values of θ_1 in degrees. The speed ratios for which these curves were calculated are, successively, 2, 1.5, 1, 0.75, 0.50, and 0.25.

These curves are rather interesting in their direct application to the steering of aircraft. For instance, when the wind speed is greater than that of the craft (a condition which does not often obtain, although it is quite possible in the case of lighter-than-air craft) there will be some wind angle, less than 90°, where, in order to remain on the course, the craft must turn 90° to the path. If the wind is following (90° to 180°) progress

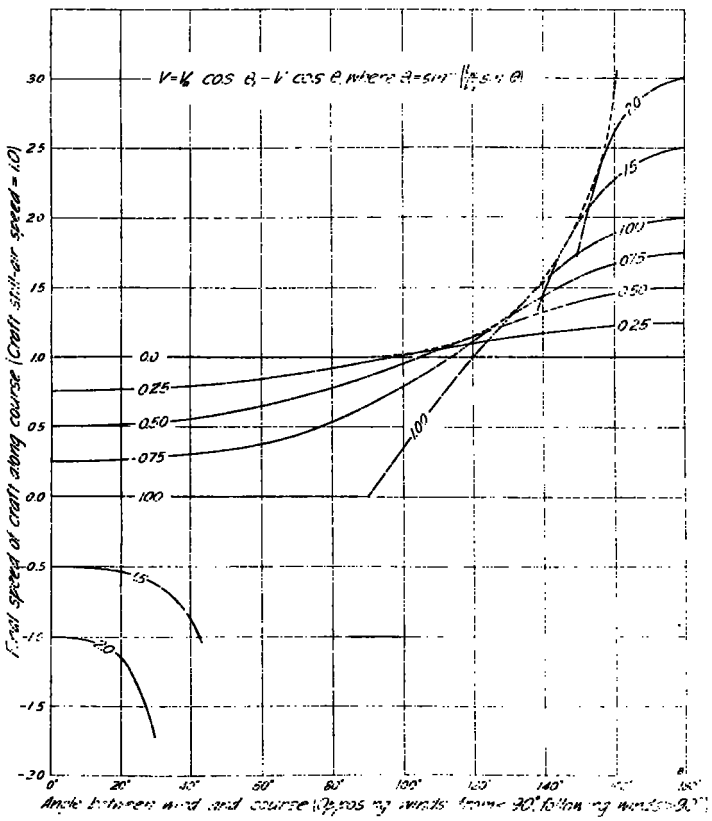

FIG. 4.—The possible speed along a given course with winds from any angle, for different ratios of wind speed to craft speed, regarding craft speed as unity.

will be made along the desired path; if it is opposing, (0° to 90°) the craft will be blown backward along the course. Specifically, it will be seen that where the speed ratio is 2, the craft cannot stay on its course if the wind comes from an angle greater than 30°; if the ratio is 1.5, the wind angle may be increased to about 42°; and for still smaller ratios the angle increases, up to the point where the ratio becomes 1, or where the wind speed and craft speed are just equal. At that point, with the wind coming from any direction less than 90°, the craft must head directly into it in order to hold its own. When the wind comes from more than 90°, it is clear that the craft will be materially aided on its course. When the craft is going faster than the wind, as is usually the case, the curves become closed and, regardless of wind direction, there is no condition where the craft must be turned as much as 90° in order to make headway on its course. As the ratio becomes smaller and smaller, the maximum ngle also decreases until the limiting case of a calm (ratio 0.0) is attained, when the craft will be directed toward its destination at all times.

Final speed along the course.—Knowing the value of the angle θ_1 under all conditions, we are enabled to draw figure 4, which gives the resultant speed along the course in terms of the craft speed (unity). The abscissae represent values of θ in degrees and the ordinates V, or the resultant speed along the course. These curves are drawn from the equation

$$V = V_a \cos \theta_1 - V_w \cos \theta$$

wherein the terms are the same as those in the equations above. The same interesting features of the curves which were noted in figure 3 are obvious here. For example, when the wind speed exceeds that of the craft, it is only within certain limited wind angles that the craft can stay on its course at all; and, if the wind is opposing, the values of V will be negative, as curves 2 and 1.5 in the first quadrant show. If the ratio is 1, there is no headway for winds up to 90°, but a rapid increase after that point. For all ratios less than 1 headway can be made along the course.

Another interesting feature of the curves is the indication of the point, or wind angle, at which the craft can proceed along the course at its own still air speed. This value is given by the value of the abscissa where the curves intersect the line $V=1$. It should be remarked that only those curves having a direct physical significance in relation to the flight of craft have been plotted here; in a mathematical discussion they are incomplete. Indeed, to the equation there are two solutions, only one of which has been plotted, and, in the case where the ratio is 1, one solution is used from $\theta=0°$ to 90°, and the other from $\theta = 90°$ to 180°. This remark applies also to the portion of the envelope which is drawn as a dotted line, and to which all the other curves are tangent. The physical significance of this curve is that it shows the maximum possible value of V corresponding to a given value of θ regardless of wind speed.[8]

[8] The equation of the envelope of this family of curves is obtained as follows:
If we transpose all terms of the resultant velocity equation to one side, we have

$$V - V_a \cos \theta_1 + V_w \cos \theta = 0$$

in which, in this discussion, we may consider V_a as unity, and θ_1 as $\sin^{-1}\left[\frac{V_w}{V_a} \sin \theta\right]$. V_w, when expressed in terms of V_a as unity, may be regarded as the variable parameter of the expression and it may be simplified so that it becomes

$$V - \sqrt{1 - V^2_w \sin^2 \theta} + V_w \cos \theta = 0 \qquad (1)$$

If this expression is differentiated with respect to the variable parameter, we obtain

$$\cos^2 \theta \, dV_w - [V^2_w \sin^4 \theta / (1 - V^2_w \sin^2 \theta)] \, dV_w = 0$$

or, by dividing through by dV^2_w,

$$\cos^2 \theta - [V^2_w \sin^4 \theta / (1 - V^2_w \sin^2 \theta)] = 0 \qquad (2)$$

Solving (2) for V_w, we obtain, as the solution pertinent to this problem,

$$V_w = \pm \frac{\cos \theta}{\sin \theta} \qquad (3)$$

The values of V_w for our practical purpose are always positive, so we may legitimately consider the plus sign to hold in the first quadrant, and the minus in the second; and, since the envelope will have no significance in the first quadrant, the plus value can be ruled out of this discussion, with the provision that must lie in the second quadrant. Bearing this in mind, we may thus eliminate V_w by substituting (3) in (1), thus obtaining

$$V - \sqrt{1 - \cos^2 \theta} - (\cos^2 \theta / \sin \theta) = 0$$

and, solving for V,

$$V = (\sin^2 \theta + \cos^2 \theta) / \sin \theta$$

$$= 1 / \sin \theta$$

$$= \csc \theta, \text{ the equation of the envelope.}$$

The author acknowledges the kind assistance of Mr. Edgar Woolard in th e discussion of these curves.

This discussion is an effort to combine in a manner which will be accessible to those interested, the chief factors involved in the effect of winds upon aircraft. In spite of the apparent simplicity of the question, there are many aviators and others who have not taken the trouble to think it through. It is hoped therefore that this discussion may serve a useful purpose. The author thanks the aeronautical department of the Goodyear Tire & Rubber Co. for permission to use charts and material on the navigation of airships set forth in one of that company's publications.[9]

Other graphical devices.—Another type of graphical illustration of the relations between wind direction and strength and the flight of aircraft has been made by Rev. Miguel Selga, of the Manila Observatory.[10] His method is to draw two circles of equal radii, but with the distance between the centers proportional to the ratio between wind speed and craft speed, e. g., if the craft speed is greater than wind sped, the centers of the two circles are less than their radius apart; if the speeds are equal, the center of one is on the circumference of the other; and, if the wind is greater than craft speed, the centers are a greater distance apart than the radius. With three such systems of circles, one is enabled to show vectorially the possible progress of the craft in any direction with a wind of constant direction, or, conversely, to show the progress along a given path with winds of various directions. These vectors are obtained by projecting horizontally the point on the wind circle corresponding to the direction from which the wind is coming, until it intersects the craft circle. A vector from the center of the wind circle drawn to the projected point on the craft circle represents the resultant motion. This method does not seem as satisfactory as that presented above, although it is of interest.

A mechanical device for correcting the route while in flight when the wind speed is unknown has been described by Lieut. Le Prieur.[11] Such devices would be useful in correcting data previously given to aircraft, and in following the changes of barometric pressure at upper levels

THE METEOROLOGIST AND COMMERCIAL AERONAUTICS.

The evolution of the meteorologist.—Just before digressing to take up the discussion of the effect of winds upon flight the question as to the aviator's ability to find the most satisfactory flying levels was raised. The pilot may feel that he can diagnose the air conditions sufficiently well to select his own flying levels; but at best this is only a method of trial and error, a method of approximation which not only is expensive in time and fuel but which, in the end, may be unsuccessful. It is no exaggeration to say that the meteorologist, properly equipped, can tell the aviator with more consistent accuracy where to fly than the pilot himself can determine. Most pilots are willing to admit this to-day, although it must be confessed that in the early days of the war many fliers were of the opinion that meteorologists were presuming a little to offer advice. Experience has shown both the value of such advices, and, indeed, the necessity for them. It is no longer a question of the presumptuous meteorologist and the pompous pilot, but of the pilot eager for more information and of the meteorologist exerting himself to the utmost to give it. In fact, so important has become the field of aeronautical meteorology that there exists to-day, and will exist to a much greater extent within a few years, a very interesting and extremely practical field for the new vocation of aeronautical meteorologist.

No more convincing proof of this point is to be found than that which comes from experience; and the experience of G. Holt Thomas on the London-Paris route, substantiates the argument. Regarding the maintenance of a meteorological department in his company, Mr. Thomas says:

> Years ago I was an ardent believer in the value of this science to the airman when he has to fly regularly; and the more I realize its potentialities, the more I know about it, the more I am convinced of the all-important part it must play in the development of commercial aeronautics.
>
> To this end, in our purely aerial transport enterprise we have, as I have already mentioned briefly, taken the step of forming our own meteorological department; and already, in the practical collaboration between this department and the pilots who are called on to fly from day to day, we have achieved results which are extremely interesting.
>
> * * * Having one's own meteorological department, ready always to answer questions is, as we have already proved, of the utmost value to an aerial transport enterprise operating machines daily along specified routes.

Again, H. B. Pratt, chief engineer of the airship department of the Vickers company, says:[12]

> Each aerodrome would contain a meteorological office working in association with Government meteorological stations, to issue weather reports for the guidance of airship navigators and to transmit navigating instructions by wireless telegraphy to them while in flight.

It appears therefore that the functions of a governmental meteorological agency must be twofold with respect to aeronautics. It must collect and disseminate meteorological data over the entire country, and it must conduct researches which will eventually have their reflection in increased accuracy of forecasting. The functions of the aeronautical meteorologist, by way of contrast, must be to interpret the collected data and to advise pilots in detail regarding the weather along their routes, and to care for numerous other requirements which will develop with his office.

AN EXAMPLE OF THE METEOROLOGIST'S WORK.

In approaching an intimate view of the work of the aeronautical meteorologist it is, of course, necessary to theorize; and, in theorizing, the author does not pretend to do more than suggest the activities which seem most likely to be essential, drawing upon the imagination for details which, with experience, might be found capable of great improvement. Such theorizing is necessary because there probably does not exist to-day on this side of the Atlantic a single enterprise which profits by the steady employment and the thoroughly organized activities of a meteorologist in connection with a flying route. If, then, practical objections may suggest themselves relative to the details of the following scheme, it should be remembered that the purpose is only to sketch broadly the activities of an office which does not yet exist.

Equipment.—The reader is, therefore, asked to imagine himself in the office of the meteorologist in the Blank Aerial Transport Corporation. The office is equipped, in addition to charts and diagrams which experience has demonstrated to be the most useful, with a relief model of the territory over which the aircraft of the Blank Corporation fly. The meteorologist is intimately familiar

[9] Goodyear Dirigible Balloon Operating Instructions, No. 202. Goodyear Tire & Rubber Co., Akron, Ohio.

[10] Selga, Miguel, S. J.: Velocidad del viento y de los dirigibles. *Revista de la Sociedad Astronómica de España y América*, September-October, 1920, pp. 83-85.

[11] Correcteur de route à dérivegraphe pour la navigation aérienne à l'estime. *L'Aerophile*, Nov. 1-15, 1920, pp. 326-332.

[12] Commercial Airships (London), 1920, p. 75.

with this territory and all the peculiarities which the irregularities of the terrain introduce into the meteorological phenomena in their vicinity; he is familiar with this not only through his knowledge of the physics of the atmosphere but also through first-hand experience in flying over the routes. Along the lines which join the principal cities and relay stations on the route are placed small vertical standards properly graduated so as to show altitude above sea-level. These standards are so arranged that at 500-meter levels (English units could be used, if necessary) small arrows could be placed so as to point in any direction. At each level there could be arrows of several different colors. In addition to these fixed standards, there are provided slots in the base, with small movable standards, each carrying a symbol representative of a given craft, and these standards can be moved at will to indicate the position of any machine at any time. There is wireless telephone apparatus in the office and all of the company's craft are equipped with similar apparatus, so that, at all times, the office can be in communication with its fliers. The meteorologist's office becomes, in a sense, a sort of dispatcher's office, and it not only keeps the pilots informed of weather conditions, but keeps close track of the position and progress of each craft.

Work.—With these brief and rather elemental notions of the meteorologist's equipment, let us endeavor to get some idea of his work. Through arrangement with the Weather Bureau, the meteorologist's office is in receipt of code messages giving the upper-air data as they are collected. As he begins his work in the morning the surface wind arrows on his relief model are set to correspond with the regular morning observations of the Weather Bureau; he has before him a copy of the morning weather map, drawn either in his office from the code message or furnished by the local Weather Bureau office. The upper-air wind arrows are set to show the conditions aloft corresponding to the last upper-air observations made at aerological stations during the night. And these are constantly being corrected upon the receipt of new observations. The flying weather forecast forms the basis of his bulletins, and these future conditions are set upon the relief model in arrows of another color, so as to distinguish them from the arrows representing observed conditions. Still other arrows may be set to represent conditions interpolated between the observed and the forecast, so that estimated conditions at any time can be seen readily. Upon the basis of this constant stream of observed and forecast data the meteorologist is enabled to issue extremely detailed reports or bulletins to his fliers at frequent intervals regarding winds, cloudiness, and visibility.

If conditions are normal, each pilot will communicate with the office every hour, giving his position and any information as to visibility, cloudiness, or unusual phenomena he may be encountering. This information keeps the meteorologist in immediate contact with the conditions and gives him a perspective which no other individual can have. There will be craft flying in each direction along all routes at all times and the office of the meteorologist thus will become an important clearing house for the latest information concerning the phenomena along the route.

Important phenomena.—There are many circumstances in which very definite and important phenomena are occurring; as, for example, the progress of the wind-shift line in a strong cyclone. The rate of progress of this line, the depth of the wind shift, and the occurrence of thunderstorms along it, are all conditions concerning which the pilot wants to know. Especially is this true of pilots of lighter-than-air craft. This system of hourly reporting, together with special reports when unusual conditions justify them, will more than pay for itself in the resultant efficiency. Once the craft is well under way, the meteorologist can tell the terminal station with considerable accuracy, barring mechanical accidents, when the craft will arrive there. This will be important for those concerned with the transportation of baggage to and from the airport; and it will mean untold convenience to the public which is to use the route.

WEATHER CONDITIONS ON AIR ROUTES.

Upper-air conditions on flying routes.—In figure 5, to show the nature of the use of upper-air information in this connection, the weather conditions have been drawn for several flying routes, giving especial regard to winds and their strength. Across the bottom of the figure is a map of several routes and above are sections along these routes showing direction and force of the wind. The New York-Omaha route has been given especial attention and the wind conditions drawn for 8 a. m., noon, and 3 p. m., 75th meridian time. The 8 a. m. and 3 p. m. data were observed and the noon section interpolated between the two. For the shorter routes, these conditions were shown for 8 a. m. only, since the time of a single flight would be so short as to fall under those representative conditions. In the wind speed and direction sections of the diagram the arrows show speed by barbs, each barb corresponding to 5 miles per hour, and the direction both by the orientation of the arrows and by small letters. The solid sections at the bottom of each section represent the general elevations of the country over which the route lies above sea level.

Above the wind direction and speed sections are shown curves indicating the speed of the parallel and perpendicular wind components in miles per hour for the three levels, 1, 2, and 3 kilometers above sea level. The ordinates of the curves show directly the magnitudes of the parallel component, while the perpendicular component is indicated by small numbers (miles per hour) at various points along the curve. It is easy to calculate from such data and other curves, such as those in the preceding figures, all the necessary information on flying conditions.

In Table 1 are given, for example, the length of time required for the flight between the various points, at various levels, both on the outward and return journeys, assuming an airplane whose speed in a calm would be 100 miles per hour.

TABLE 1.—*Time required for flight between various points at several levels, with a craft of still-air speed 100 miles per hour.*

Route between—	Distance.	Time.					
		Outward.			Return.		
		1 kilometer.	2 kilometers.	3 kilometers.	1 kilometer.	2 kilometers.	3 kilometers.
	Miles.	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*
New York to Washington	200	2 48	3 00	3 00	1 36	1 34	1 34
New York to Cleveland	410	4 36	5 30	5 27	3 36	3 12	3 14
Cleveland to Chicago	320	3 54	4 18	4 42	2 45	2 36	2 24
Chicago to Omaha	440	4 42	6 00	6 40	4 18	3 48	3 20
Chicago to Twin Cities	350	3 42	3 48	4 42	3 18	3 24	2 54
Chicago to St. Louis	280	3 20	3 48	3 42	2 24	2 18	2 20
Chicago to Indianapolis	180	1 46	1 48	1 30	1 50	1 54	2 24

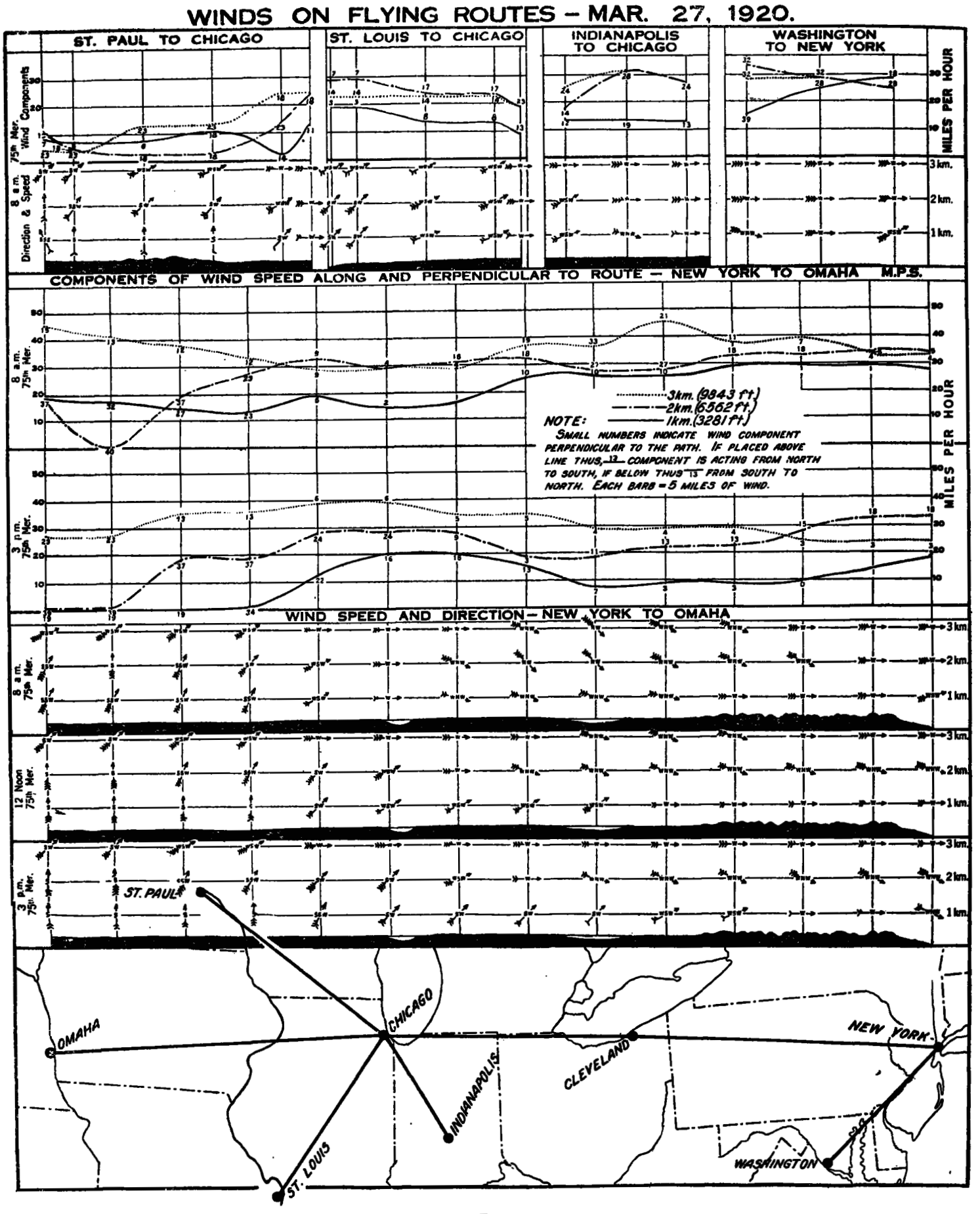
WINDS ON FLYING ROUTES – MAR. 27, 1920.
ST. PAUL TO CHICAGO
ST. LOUIS TO CHICAGO
INDIANAPOLIS TO CHICAGO
WASHINGTON TO NEW YORK
MILES PER HOUR
8 a.m. 75th Mer. Wind Components
Direction & Speed
3 km.
2 km.
1 km.
COMPONENTS OF WIND SPEED ALONG AND PERPENDICULAR TO ROUTE – NEW YORK TO OMAHA M.P.S.
8 a.m. 75th Mer.
3 p.m. 75th Mer.
3km. (9843 ft.)
2km. (6562 ft.)
1km. (3281 ft.)
NOTE: SMALL NUMBERS INDICATE WIND COMPONENT PERPENDICULAR TO THE PATH. IF PLACED ABOVE LINE THUS, 12 COMPONENT IS ACTING FROM NORTH TO SOUTH, IF BELOW THUS 13 FROM SOUTH TO NORTH. EACH BARB = 5 MILES OF WIND.
WIND SPEED AND DIRECTION – NEW YORK TO OMAHA
8 a.m. 75th Mer.
12 Noon 75th Mer.
3 p.m. 75th Mer.
ST. PAUL
OMAHA
CHICAGO
INDIANAPOLIS
CLEVELAND
NEW YORK
ST. LOUIS
WASHINGTON

FIG. 5.

An inspection of this table will show at once that considerable advantage is to be gained by the careful selection of flying levels. It is strikingly illustrated by the Chicago to Omaha flight. By flying low toward Omaha much time could be gained, on this occasion almost two hours could be saved, by flying at the 1-kilometer level instead of the 3-kilometer level. On the journey from Omaha to Chicago about an hour could be saved by flying high. Differences in time as great as an hour are of considerable importance in the delivery of mail, especially in the case of the relay system, in which the mail is taken from the plane at Omaha and placed on the train. If a certain train is missed, there may be another two, three, or four hours lost before the mail would get out of Omaha for the West. Indeed, the minutes are important in the making of connections with railway trains.

Another interesting situation might occur occasionally, which would show how the meteorologist's skill and ingenuity could be brought into play. To illustrate the type of situation in mind, suppose there is a low-pressure area centered north of the Great Lakes, in such a manner that there are northwest winds blowing at Chicago and southwest at New York. A dirigible capable of 64 miles per hour in still air is to fly from Chicago to New York. Let us assume the radius of the curvature of the wind path through Chicago and New York is 500 miles, and that the gradient is such as to produce approximately a steady upper-air wind of 50 miles per hour. It is seen that the speed of the ship will be higher if it follows the curved wind path, rather than cuts across isobars, as it were, in a straight line to get to its destination. In this case, its forward speed along the wind path would be about 114 miles per hour, along the straight line about 102 miles per hour on the average. The path of the faster course is longer by about 50 miles than the path of slower travel. But by following the curved path the dirigible will arrive in New York about 20 minutes earlier than if it attempts to cut across.[13] This gain is in this example not particularly important although it is representative of what might occur and the type of judgment the aeronautical meteorologist might be called upon to possess.

The value of such an organized system of detailing the information lies, as was suggested in the beginning, in the increase of safety in flying and in the increased economy in the maintenance of schedules and in overhead expense. A consistent program of detailed meteorological information would undoubtedly effect tremendous financial savings, when the large fuel expenditure alone is taken into consideration.[14]

CONCLUSION.

It will suffice, in conclusion, to review briefly the essential points of the discussion. An effort was made to show that a consideration of the weather factor in aeronautics must lead to beneficial results in commercial aviation; and that the requirements of commercial aviation must eventually bring into being the vocation of aeronautical meteorologist. For the Weather Bureau, there will always be the domain of public service, even with respect to aeronautics, which no private enterprise could possibly usurp; and that domain is the collection and dissemination of current and climatological meteorological information, and the conduct of organized research. The accurate reduction of atmospheric pressure to levels in the free air must, if it is successfully accomplished, result in untold value to aviation. A governmental agency is the only one that can accomplish this. And this leads to the theme which, while it can not grow old to those interested in upper-air research, has often been seen in these columns, and that is the necessity for an enlarged program of aerological observation. The rôle of meteorology in aeronautics is not a minor one, important as are many others; and it is a safe prediction that the development of commercial aeronautics will evolve the methods for giving the necessary consideration to the weather factor.

[13] "Undoubtedly captains of the big aerial liners of the future will become wily and cunning masters of the art of selecting the right way and the right height and often, by making wide *détours*, will, by their air knowledge alone, save many hours on long sea and land passages."—Big. Gen. Maitland, in the log of the R. 34. *Commercial Airships*, Pratt. Appendix, p. 231.

[14] Report of Air Mail Service, October, 1920, *Aviation*, Jan. 10, 1921, p. 51. Cf. also DeHaviland on Civil Aviation, *Aerial Age Weekly*, Jan. 17, 1921, p. 486.

CERTAIN RELATIVE INSOLATION VALUES.

By W. J. HUMPHREYS.

The brief table of relative insolation values given on page 20 of Davis's *Elementary Meteorology*, and copied on page 80 of Humphreys's *Physics of the Air*, has recently been questioned by Prof. R. D. Calkins of the Central Michigan Normal School, Mount Pleasant, Mich.

This table indicates that, neglecting atmospheric absorption, or at the limit of the atmosphere, the amount of solar energy delivered per day per unit horizontal surface is greater at the Equator at vernal equinox than at autumnal equinox; this is correct, and is because the earth is nearer the sun on the former date than on the latter.

The table further indicates that at 20° north latitude less insolation is received during the day at vernal than at autumnal equinox; this is an error. Insolation is greater at vernal than at autumnal equinox at all parts of the world. Finally, the table indicates that no insolation is received during the day at winter solstice at 60° north latitude. This obviously is an error since latitude 60° N. is still considerably short of the arctic circle.

It therefore seemed worth while, perhaps, to recalculate the entire table. This was done, using the data of the Nautical Almanac for 1921, and the results are given, with Prof. Davis's kind approval, in the accompanying table. The *yearly totals* are reduced from values given in a different unit by Angot, *Annales du Bureau Central Météorologique*, for 1883.

Relative values of total diurnal insolation per unit horizontal surface at the limit of the atmosphere.

Latitude.	Equator.	20° N.	40° N.	60° N.	North Pole.	South Pole.
Vernal equinox	1.000	0.940	0.766	0.500	0.000	0.000
Summer solstice	0.882	1.044	1.107	1.093	1.201	0.000
Autumnal equinox	0.987	0.927	0.756	0.494	0.000	0.000
Winter solstice	0.941	0.676	0.357	0.056	0.000	1.283
Annual total	348	329	275	198	144	144