NOTES AND CORRESPONDENCE

Airlight Simulation Experiments

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As a result of some chance observations of certain reflection phenomena produced by the large plate glass windows of a meteorological observatory, the writer was led to carry out some experiments on artificial production of veiling luminance by interpolation of partially reflecting glass sheets. Analyses of these simple experiments quickly revealed sufficient reasons for rejecting the technique as a potential method for visibility research; but the same analyses convinced the writer that an extremely instructive laboratory experiment in physical meteorology might be built around the technique.

Suppose that one views a dark target on the horizon at distance x from the eye, and that the scattering coefficient of the atmosphere has some uniform value k over the entire path length x. If B_h is the apparent brightness (luminance) of the horizon sky adjacent to the target, whose *apparent* brightness B_x is contributed (by the hypothesis of its being a *dark* target) solely by light scattered into the eye by molecules or particulates lying along the optic path, then the eye perceives the apparent brightness contrast ratio

$$C_x = (B_h - B_x)/B_h = e^{-kx}, \qquad (1)$$

a well-known relation of visual range theory (Middleton, 1951, 1952; Neuberger, 1951; Johnson, 1954).

Let a thin glass sheet (an ordinary microscope cover glass, about 0.15-mm thick, proves best) be brought between target and eye and tilted to some arbitrary small angle α as in Fig. 1, momentarily assumed to be *not* so small as to make the target vanish. Let B_s be the apparent luminance of the sky just above the target at angular altitude 2α and let R be the reflection coefficient of the glass for rays of angle of incidence 90 deg$-\alpha$. Noting that an elevation view such as Fig. 1 actually represents the projection of *pairs* of rays of slightly differing azimuth joining eye (as vertex) to target and to horizon sky immediately to one side of the target (say, a dark tower), one sees that interposition of the sheet adds and subtracts brightnesses in such a manner as to yield a *modified* apparent contrast

$$C_x' = \{[B_h(1-R)+B_sR]-[B_x(1-R)+B_sR]\} \times \{B_h(1-R)+B_sR\}^{-1}. \qquad (2)$$

If α is not too large we shall have $B_s \approx B_h$, whence, approximately,

$$C_x' = [(B_h - B_x)/B_h](1-R) = (1-R)C_x \qquad (3)$$

in view of (1).

If the atmosphere's actual visual range is V for the observer's prevailing brightness contrast threshold ϵ (which will be no different for direct viewing than for indirect viewing through the sheet), then we may write, from the theory of the visual range,

$$k = V^{-1}\ln(\epsilon^{-1}) \equiv -V^{-1}\ln\epsilon. \qquad (4)$$

Now let the glass sheet be tilted to such a low α that the target seems to *just vanish*. From (3) and (4) we may then write that

$$C_x' = \epsilon = (1-R)\exp(xV^{-1}\ln\epsilon) \qquad (5)$$

and from this we obtain the principal working equation of the simulator regarded as a V-meter

$$V = [1 - \ln(1-R)/\ln\epsilon]x. \qquad (6)$$

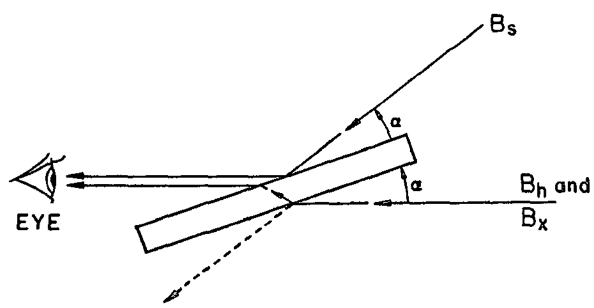

FIG. 1. Schematic ray diagram for airlight simulator. Multiple internal reflections within the glass sheet not shown.

If one seeks only the so-called "standard visual range" corresponding to the standard contrast threshold $\epsilon=0.02$, R is the only quantity in (6) to be evaluated. But, more generally, ϵ is known to be variable, becoming smaller (by as much as an order of magnitude) than 0.02 under conditions of high field luminance, or growing appreciably greater than the standard value for dim illumination at twilight or under a heavy overcast. Hence it is of interest that further experimental procedures can be devised whereby the simulator becomes an ϵ-meter.

Two possible cases may arise: First the observer may occasionally be able to find a known visibility target which, with unaided eye, he perceives to be just at the visual range for his eye's prevailing contrast threshold. Or, secondly, the observer may not be so lucky as to spot such a target, but he may see *two* dark targets at *known* distances, both less than his current visual range.

For the first case, the less likely one, we require further that the observer have a *second* target at known $x<V$. He views that second target through the simulator, adjusts α to make it appear to vanish, calculates the value of R corresponding to this α, and substitutes this R, along with the target's known x and the true value of V which he here knows by hypothesis of the first target coincidentally lying at just distance V, and solves for his eye's prevailing threshold ϵ.

In the second (and much more probable) case, he uses the simulator in two successive operations to bring each target to his unknown threshold. Though he does not here independently know V, V is of course the same for both these applications of the working equation (6), so he eliminates V from his two conditional equations of form (6) and solves for his prevailing value of ϵ, obtaining

$$\ln\epsilon=[x_1\ln(1-R_1)-x_2\ln(1-R_2)](x_1-x_2)^{-1} \quad (7)$$

where subscript 1 refers to the more distant, 2 to the nearer target. Use of (7) to find ϵ under varying conditions of illumination (e.g., as a function of time of day) has instructional interest in its own right, independent of its use in establishing the correct value of ϵ for use in (6) to determine V.

For the present case of a nonabsorbing dielectric sheet the α-dependence of R is predictable from the Fresnel laws and from considerations of multiple reflections. The Fresnel laws give for the reflection coefficient of an unpolarized beam suffering only a single reflection at a dielectric discontinuity,

$$R'=(r_s+r_p)/2 \quad (8)$$

where r_s and r_p, the partial reflection coefficients for the two polarization components of the incident light, are formulated in standard references on optics or electromagnetic theory.

Having computed R' from the Fresnel equations employing the tacit assumption that we have *nonpolarized* beams to consider with the simulator (but see below), we get the corresponding value of R by taking account of the fact that, in both of the reflections indicated schematically in Fig. 1, and infinite series of multiple reflections actually occurs within the glass sheet. It is shown in works on physical optics that the required sum of the infinite geometric progression describing such a multiple reflection phenomenon is given by

$$R=R'[1+(1-R')^2/(1-R'^2)]. \quad (9)$$

Glass sheets illuminated at *low* angles of incidence exhibit such low R' that (9) yields $R=2R'$, but the simulator is found to yield threshold brightness contrasts only for rather small α, whence R is found to be larger than R' by an amount somewhat too great to be neglected (order of 10 per cent). Hence (9) enters nontrivially into the theory of the simulator.

Because α is small, the initial assumption that $B_s\approx B_h$ is fairly well justified. However, students should be asked to discuss this assumption quantitatively, using sky brightness data such as are presented by Humphreys (1940). Will accuracy depend on the relation between target azimuth and solar azimuth? Will there be *diurnal variations* in this degree of accuracy?

Since α can be as small as a few degrees, accuracy of V-determination will deteriorate if care is not taken in measuring the altitude angle, one of the intrinsic disadvantages of the technique as a practical method. An error analysis of the simulator can well form a central part of the student's work on the airlight experiment.

The Fresnel laws assume incident *unpolarized* light. The student should be asked to discuss the extent to which this working assumption may fail under certain conditions. It will be seen that this single difficulty would probably suffice to remove the simulator from serious consideration as a precise tool in visual range work. Analysis of this polarization problem will prove a profitable exercise for the student, since there are several interesting ramifications. It is recommended that auxiliary experimentation with a polarizer and the simulator be demanded of the student to extend his discussion of the effects of polarization of skylight, but details need not be here elaborated; informative effects will be quickly discovered.

After noting the phenomena basic to the above type of airlight simulator, the writer examined Middleton's summary of visual range measurement techniques and noted some resemblance between the simulator and Waldram's "Disappearing Range Gauge." From Middleton's discussion of that superior device, the writer drew the idea of a simulator intermediate in principle between the two. By holding a mirror just in front of the objective lenses of a pair of binoculars, and at such height as to block out roughly the lower half of the field, judicious tilting of the mirror in the general manner indicated for the glass sheet in Fig. 1 led to an extremely vivid airlight-simulation effect *far more striking than that given by the partially reflecting sheet.* If binoculars and suitable rigs for holding mirrors at controllable tilts were provided students, this technique would afford a more impressive alternative experiment. The analysis, though not identical with that outlined here, would obviously be similar. Even if not used as an alternative instructional experiment, it is recommended that arrangements be made to permit the phenomenon to be examined at least casually by all students doing the above simulator experiments, for the veiling illusion with binoculars and mirror will surely leave a lasting impression of the basic phenomenon of contrast attenuation via interposition of a veiling luminance in the visual field.

REFERENCES

Humphreys, W. E., 1940: *Physics of the air*, 3d ed. New York, McGraw-Hill, 676 pp.

Johnson, J. C., 1954: *Physical meteorology.* New York, Wiley and Sons, 393 pp.

Middleton, W. E. K., 1951: Visibility in meteorology. *Compendium of meteor.*, Boston, Amer. Meteor. Soc., 91–100.

——, 1952: *Vision through the atmosphere.* Toronto, Univ. Toronto.

Neuberger, H., 1951: *Introduction to physical meteorology.* State College, Pa., Pennsylvania State Coll., 271 pp.

An Example of a Nocturnal Low-Level Jet Stream[1]

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The low-level jet stream was clearly identified for the first time as a boundary layer phenomenon during the 1953 Great Plains Project (Lettau and Davidson, 1957). Using serially released lighted balloons and helicopter-dropped smoke bombs (the Loeser techniques), this jet was described as a phenomenon where the wind speed reaches a sharp maximum at heights of the order of 1000–2000 ft above the surface. It is clearly related to the stability of the boundary layer, reaching its greatest intensity near sunrise and dissipating rapidly with solar heating of the ground and the reestablishment of adiabatic conditions (Barad, 1961).

With the operation late in December, 1960, of the meteorologically instrumented 1400-ft television tower near Dallas (Cedar Hill), Texas, the first detailed data pertinent to the formation and dissipation of the low-level jet stream are now becoming available. Ambient temperature at the lowest measuring level (30 ft), temperature difference between each of the next successive 11 levels and wind speed in north-south and east-west components are being obtained continuously and (normally) being read out as 10-min averages taken six times per hour. More explicit details pertinent to the meteorological sensors and data processing equipment can be found elsewhere (Stevens and Gerhardt, 1959; Mitcham and Gerhardt, 1960).

This paper will merely present the time and height variations encountered during a typical jet stream as observed from the Cedar Hill facility. More comprehensive analyses relating jet stream characteristics to the other meso- and synoptic-scale circulation parameters are underway and will be reported later. Fig. 1 shows the total wind vectors as observed at each of the 12 levels at hourly intervals from 0100 CST to 0900 CST, using in each case the 10-min average reading ending at 9 min 40 sec, past the hour. The jet stream slowly reaches its maximum intensity by 0709 when the largest wind direction change over the 1400-ft height interval also occurs. One hour later the jet has all but disappeared and there is little indication of any wind direction shear. There is evidence of a more or less consistent error in the wind at level 12 due to the wind interference from the large triangular tower superstructure and a smaller error at level 10.

The similarity of this structure to the lower level stability is shown in Fig. 2 where the temperature-height profiles are plotted for the corresponding hours. It should be noted that the jet stream is still growing in intensity during the initial lower-level reestablishment of adiabatic conditions but dissipates rapidly as soon as unstable lapse rates build up to that level. A consistent temperature offset at level 11 was caused by a partial blocking of the air ventilation current past the sensors at that level which has subsequently been corrected. The local weather observations made at Love Field, Dallas, show clear skies and unlimited visibility during the entire period with a relatively uniform east wind of 7–10 mph. The diurnal temperature range at the 30-ft tower level was from 54F to 81F. All of the north Texas region was experiencing light E to SE winds and clear skies due to the return flow around a

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