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The Effect of a Wind Gradient on the Rate of Climb of an Aircraft

By

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1. *Introduction and Summary.*—The behaviour of an aircraft climbing in the presence of a wind gradient is analysed by a method similar to that used in R. & M. 379[1], but with fewer simplifying assumptions. It is shown that the result obtained in the earlier paper is only correct if the angle of climb is small and if the true air speed is constant during the climb. With the climb techniques that are now usual, however, the true air speed is not constant during the climb ; with typical subsonic aircraft the effect of this is to change the correction due to a wind gradient by about 10 per cent. For aircraft climbing at supersonic speeds the effect of acceleration may be much greater than this.

Since the percentage change of rate of climb due to a given wind gradient is approximately proportional to the flight speed, the effect does *not* become less important as aircraft speeds increase. Moreover, wind gradients having a significant effect on the rate of climb are not confined to low altitudes. For a modern high-speed aircraft it is shown that the wind gradient may change the rate of climb by 20 per cent or more.

2. *Notation.*—

a	Velocity of sound
D	Drag
E_K	Kinetic energy of aircraft
E_P	Potential energy of aircraft
g	Acceleration due to gravity
h	Height
H	Energy height $= (E_P + E_K)/mg$
M	Mach number
m	Mass of aircraft
T	Thrust
t	Time
u, v	Horizontal and vertical components of velocity relative to ground
V	True air speed

V_1		True air speed at standard height
W		Horizontal wind velocity at height h
w	$=$	dW/dh
α_l, α_n		Components of acceleration parallel to and normal to line inclined at angle θ to horizontal
θ		Inclination to horizontal of velocity of aircraft relative to air
Suffix $_0$		Conditions in absence of wind gradient

3. *Equations of Motion.*—Consider an aircraft whose flight path lies in the same vertical plane as the wind velocity. (If the aircraft is flying against the wind, W is to be considered negative.)

The horizontal and vertical components of velocity relative to the ground are

$$\left.\begin{aligned} u &= W + V\cos\theta \\ \text{and} \quad v &= V\sin\theta \end{aligned}\right\} \qquad (1)$$

The velocity component v is the rate of climb, as usually defined.

The components of acceleration parallel to and normal to a line inclined at an angle θ to the horizontal are

$$\alpha_l = \dot{u}\cos\theta + \dot{v}\sin\theta \qquad (2)$$

and

$$\alpha_n = -\dot{u}\sin\theta + \dot{v}\cos\theta. \qquad (3)$$

Differentiation of equations (1) gives

$$\dot{u} = \dot{W} + \dot{V}\cos\theta - V\dot{\theta}\sin\theta \qquad (4)$$

and

$$\dot{v} = \dot{V}\sin\theta + V\dot{\theta}\cos\theta. \qquad (5)$$

Substitution in equation (2) now gives

$$\begin{aligned} \alpha_l &= \dot{W}\cos\theta + \dot{V} \\ &= wV\sin\theta\cos\theta + \dot{V}. \end{aligned}$$

Also,

$$\begin{aligned} mg\sin\theta &= (T - D) - m\alpha_l \\ &= (T - D) - mwV\sin\theta\cos\theta - m\dot{V}. \end{aligned} \qquad (6)$$

In the absence of a wind gradient the equation corresponding to (6) is

$$mg\sin\theta_0 = (T - D)_0 - m\dot{V}_0. \qquad (7)$$

It will now be assumed that, at a given height, V and C_L are unaffected by wind gradient* ; then $(T - D)$ is also independent of wind gradient and equations (6) and (7) give

$$\frac{\Delta v}{v} = \frac{\sin\theta - \sin\theta_0}{\sin\theta} = -\frac{Vw}{g}\cos\theta - \frac{\dot{V} - \dot{V}_0}{g\sin\theta}, \quad \ldots \quad (8)$$

where Δv is the amount by which the wind gradient increases the rate of climb.

Also, $$\frac{\dot{V}_0}{\dot{V}} = \frac{v_0}{v} = 1 - \frac{\Delta v}{v}.$$

Thus equation (8) becomes

$$\frac{\Delta v}{v} = -\frac{Vw}{g}\cos\theta - \frac{\dot{V}}{g\sin\theta}\frac{\Delta v}{v},$$

and hence $$\frac{\Delta v}{v} = -\frac{Vw\cos\theta}{g + \dot{V}\operatorname{cosec}\theta}. \quad \ldots \quad (9)$$

In the special case where the true air speed is constant during the climb ($\dot{V} = 0$) and where the angle of climb is small ($\cos\theta = 1$), equation (9) reduces to the simple form given in Ref. 1, *viz.*,

$$\frac{\Delta v}{v} = -\frac{Vw}{g}. \quad \ldots \quad (10)$$

It should be noted, however, that with the climb techniques that are now usual the true air speed is *not* constant during the climb. Thus equation (9) must be used in full unless it can be shown that $\dot{V}\operatorname{cosec}\theta$ is small compared with g. This point is considered later.

4. *Numerical Values of Wind Gradient.*—It is of interest to consider the order of magnitude of the wind gradients occurring in the atmosphere, and hence estimate the importance of the correction given by equation (9). For this purpose it is sufficiently accurate to use the approximate form given in equation (10).

At very low altitudes the wind gradient is often large, and for heights up to about 100 ft the relations given by Deacon[2] may be used. In this range of height, Deacon's results suggest that the *maximum* wind gradient is given very roughly by

$$w = \frac{10}{h}\ \text{sec}^{-1},$$

where h is the height in feet. Thus at heights up to about 100 ft the value of w may be $0 \cdot 1$ sec^{-1} or more. This conclusion is confirmed by some data quoted in R. & M. 1489[3], showing values of w of $0 \cdot 12\ \text{sec}^{-1}$ at 50 ft. and $0 \cdot 23\ \text{sec}^{-1}$ at 20 ft.

Between about 3,000 and 7,500 ft, results given by Petterssen and Swinbank[4] show that the maximum values of w are about $0 \cdot 01\ \text{sec}^{-1}$ or greater. At heights between about 20,000 and 50,000 ft, statistics given by Bannon[5] show that wind gradients of order $0 \cdot 005\ \text{sec}^{-1}$ are fairly common over Britain, and that gradients up to about $0 \cdot 02\ \text{sec}^{-1}$ occur occasionally. It should be noted that these gradients are not confined to very thin layers ; they are mean gradients over depths of several thousand feet. The larger wind gradients are usually associated with jet streams. The wind gradients above and below the core of a jet stream are of opposite sign and are usually approximately equal in magnitude.

* This assumption is considered further in sections 5 and 7.

Thus, for the purpose of estimating the importance of the effect of wind gradients on rate of climb, it may be assumed that the maximum values of w likely to be encountered are roughly as shown below :

h (ft)	w (sec^{-1})
Below 100	$0 \cdot 1$ or more
100 to 1,000	$0 \cdot 05$
1,000 to 50,000	$0 \cdot 01$

Substituting the *lowest* of these values ($w = 0 \cdot 01$ sec^{-1}) in equation (10) gives

$$\frac{\Delta v}{v} = - \frac{V}{3220} \quad \text{(with } V \text{ in ft/sec).}$$

For a typical modern aircraft V may be about 600 ft/sec during the climb. Thus even a wind gradient as small as $0 \cdot 01$ sec^{-1} can change the rate of climb by nearly 20 per cent. For aircraft climbing at higher speeds (including supersonic aircraft), the effect of a wind gradient will of course be greater. The larger wind gradients occurring at heights below about 1,000 ft will also have a greater effect ; this is considered below.

5. *Effect of Large Wind Gradients near the Ground.*—Immediately after take-off, the aircraft will normally be flying against the wind, so that w will be negative. If $(-\, w)$ is sufficiently large, it is clearly possible for the term $(-\, (Vw/g) \cos \theta)$ in equation (8) to be greater than 1. At first sight, this leads to an anomalous result, for if $\dot{V} = \dot{V}_0 = 0$, $\Delta v/v$ is then greater than 1, and if v is positive v_0 must be negative. The explanation is that if $(-\, (Vw/g) \cos \theta) > 1$, the assumption that $\dot{V} = 0$ necessarily implies $T < D$, if θ is positive (from equation (6)), so that if $\dot{V}_0$ is also zero, v_0 must be negative. Thus with $(-\, w)$ so large that $(-\, (Vw/g) \cos \theta) > 1$ (and with θ positive), equation (6) requires a positive value of $\dot{V}$ if $T > D$. Physically, this means that if the thrust is greater than the drag, the air speed must increase as the aircraft climbs into regions of higher wind velocity.

Thus, in regions of large wind gradient near the ground, the second term on the right-hand side of equation (8) is likely to be very important. Unfortunately, the assumption made in deriving equations (8) and (9), that at a given height V is independent of wind gradient, will not be correct in such cases. A further investigation of climbing flight near the ground would require a more detailed analysis, taking values of $\dot{V}$ and $\dot{V}_0$ appropriate to a particular take-off technique.

The case where w has a large *positive* value corresponds to an aircraft climbing down-wind near the ground. This is of less practical importance than the case considered above, but again the acceleration term in equation (8) is likely to be important. When w is positive the wind gradient reduces the rate of climb, but it should be noted that if v_0 is positive v can never be reduced to zero.

6. *Energy Relations.*—Considering the usual low-altitude case, where the wind velocity increases with height, equation (9) shows that the wind gradient increases the rate of ascent of an aircraft flying against the wind, at a given speed. It is of interest to consider the source of the energy required for this increased rate of ascent, since the work done per unit time by the propulsion system of the aircraft is not affected by the wind gradient. For simplicity, it will be assumed here that V is constant ($\dot{V} = 0$).

It is more convenient to consider an aircraft flying down-wind. Then, since the rate of climb is *reduced* as given by equation (9), the rate of increase of potential energy is *less* than it would be in the absence of a wind gradient by an amount

$$\Delta\left(\frac{dE_P}{dt}\right) = mV^2w \sin\theta \ \cos\theta. \qquad \ldots \qquad (11)$$

The Kinetic Energy of the aircraft is

$$E_K = \tfrac{1}{2}m(u^2 + v^2)$$
$$= \tfrac{1}{2}m(W^2 + V^2 + 2WV\cos\theta).$$

Therefore $$\frac{dE_K}{dW} = m(W + V\cos\theta) = mu,$$

and $$\frac{dE_K}{dt} = \frac{dE_K}{dW}\frac{dW}{dh}\frac{dh}{dt} = muwV\sin\theta$$

$$= mVw\,(W + V\cos\theta)\sin\theta. \qquad \ldots \qquad (12)$$

Subtracting equations (11) and (12) now gives

$$\frac{dE_K}{dt} - \Delta\left(\frac{dE_P}{dt}\right) = mwWV\sin\theta = \frac{d}{dt}\left(\tfrac{1}{2}mW^2\right). \qquad \ldots \qquad (13)$$

In the usual case where the wind velocity W is small compared with $V\cos\theta$ (the horizontal component of the relative air velocity), equations (12) and (13) show that

$$\frac{d}{dt}\left(\tfrac{1}{2}mW^2\right) << \frac{dE_K}{dt},$$

and $$\frac{dE_K}{dt} \simeq \Delta\left(\frac{dE_P}{dt}\right).$$

The wind gradient then reduces the rate of increase of potential energy by an amount equal to the rate of increase of kinetic energy.

It is convenient to introduce an ' Energy Height ', similar to that suggested by Lush[6]. For the present purpose the energy height (H) will be defined by

$$mgH = E_P + E_K,$$

i.e., it is the height at which the potential energy of the aircraft would be equal to the sum of the potential and kinetic energies at the actual height h. This definition is the same as that used by Lush, but it is now necessary to allow for the effect of the wind in calculating the kinetic energy E_K.

Thus, if V is constant and W is small compared with $V\cos\theta$, the rate of increase of energy height (defined as above) is independent of wind gradient. If W is not small compared with $V\cos\theta$ this is no longer true ; there is then a transfer of energy from the wind to the aircraft (with the aircraft flying down-wind), represented by the term $d(\tfrac{1}{2}mW^2)/dt$ in equation (13).

In the extreme case where $\theta = 90$ deg, equation (9) shows that the wind gradient has no effect on the rate of climb. The motion of the aircraft is then similar to that of a balloon with a constant rate of climb.

$\Delta (dE_P/dt)$ is zero, but the kinetic energy increases at a rate given by

$$\frac{dE_K}{dt} = \frac{d}{dt}(\tfrac{1}{2}mW^2) = \frac{d}{dt}(\tfrac{1}{2}mu^2) \text{ (since) } u = W).$$

The whole of this increased kinetic energy is derived from the wind.

7. *Assumption of Constant Lift and Drag Coefficients.*—So far, it has been assumed that the lift and drag coefficients of the aircraft have the same values as in a climb at the same air speed in the absence of a wind gradient. In fact, the curvature of the flight path caused by the wind gradient alters the lift coefficient, and hence has some effect on the drag coefficient. (In most cases the flight path will be curved, even in the absence of a wind gradient, but in this discussion it is only the *additional* curvature caused by a wind gradient that is relevant.) For the purpose of estimating the order of magnitude of the *change* of C_L due to a wind gradient, it is sufficiently accurate to assume that θ is constant during the climb.

With this assumption, equations (3), (4) and (5) give

$$\alpha_n = - wV \sin^2 \theta .$$

Hence
$$\frac{\Delta C_L}{C_{L0}} = - \frac{wV \sin^2 \theta}{g \cos \theta} \qquad \ldots \qquad (14)$$

(neglecting the difference between $\cos \theta$ and $\cos \theta_0$). To investigate the order of magnitude of this term, the following values will be used :

$$w = 0 \cdot 01 \text{ sec}^{-1}$$
$$V = 700 \text{ ft/sec}$$
$$\theta = 20 \text{ deg.}$$

Equation (14) then gives

$$\frac{\Delta C_L}{C_{L0}} = - 0 \cdot 027.$$

Except at high values of C_L, $\Delta C_D/C_D$ will be less than $\Delta C_L/C_{L0}$, so that in a typical case the change of C_D due to the curvature of flight path associated with a wind gradient is not likely to be more than about 1 or 2 per cent. The effect of this on the rate of climb will usually be unimportant.

8. *Simplifying Assumptions in Equation* (10).—The simpler equation (10) can be used instead of (9) in cases where θ is small (so that $\cos \theta \simeq 1$) and $\dot{V} \operatorname{cosec} \theta$ is small compared with g.

For the purpose of estimating the order of magnitude of the angle θ, the fighter project considered by Kelly[7] will be taken as an example of a subsonic aircraft of fairly high performance. For this aircraft at full climbing power at sea level the maximum value of θ is about 22 deg, while the value for maximum rate of climb is only about 15 deg. Thus in this case the error in the correction for wind gradient, due to assuming $\cos \theta = 1$, will not exceed about 7 per cent even at the maximum value of θ. (The error in the actual calculated rate of climb will not normally exceed about 1 per cent.) For rocket-powered aircraft of the future the values of θ may be greater and it may then not be permissible to assume $\cos \theta = 1$.

The magnitude of the term $(\dot{V} \operatorname{cosec} \theta)/g$ will now be considered. For any given climb technique the true air speed is a function of height and may be expressed as

$$V = V_1 f(h),$$

where V_1 is the true air speed at some standard height. The acceleration is then given by

$$\dot{V} = vV_1 \frac{df(h)}{dh},$$

and $$\frac{\dot{V}\operatorname{cosec}\theta}{g} = \frac{\dot{V}V}{gv} = \frac{V_1 V}{g}\frac{df(h)}{dh} = \frac{V}{g}\frac{dV}{dh}$$

$$= \frac{V_1^2}{2g}\frac{d[f(h)]^2}{dh} = \frac{1}{2g}\frac{d(V^2)}{dh}\,. \quad \ldots \quad (15)$$

Thus $(\dot{V}\operatorname{cosec}\theta/g)$ is independent of the rate of climb and is proportional to the square of the reference speed V_1, if the function $f(h)$ is given. The magnitude of this term in comparison with unity will now be considered for various cases.

For subsonic aircraft of moderate performance, Lush[6] has pointed out that the usual climb technique gives an acceleration of roughly half that obtained in a climb at constant E.A.S. For the purpose of estimating the importance of the acceleration term it is therefore convenient to consider a climb at constant E.A.S. at low altitude, as an extreme case.

Taking the mean rate of change of air density in the standard atmosphere from sea level to 10,000 ft, it is found that the acceleration is given approximately by

$$\dot{V} \simeq 1\cdot3\, Vv \times 10^{-5} \text{ (in ft sec units)},$$

where V is the true air speed at 5,000 ft.

Thus $$\frac{\dot{V}\operatorname{cosec}\theta}{g} = \frac{\dot{V}V}{gv} = 1\cdot3\frac{V^2}{g} \times 10^{-5}\,.$$

Even at a climbing speed as high as 700 ft/sec, this term is only about $0\cdot2$. Since the acceleration will not usually be more than about half that obtained in a climb at constant E.A.S. (for the class of aircraft considered here), it may be concluded that the acceleration term will not usually change the value of $\Delta v/v$ by more than about 10 per cent.

For some supersonic aircraft and very high-performance subsonic aircraft the climb may be made at constant Mach number. In the standard atmosphere below 36,000 ft the rate of change of velocity of sound with height is given approximately by

$$\frac{da}{dh} = -\,0\cdot004 \text{ sec}^{-1}.$$

Thus for an aircraft climbing at constant Mach number,

$$\frac{\dot{V}\operatorname{cosec}\theta}{g} = \frac{V}{g}\frac{dV}{dh} = -\,0\cdot004\,\frac{VM}{g}\,. \quad \ldots \quad (16)$$

Putting $M = 0\cdot9$ and taking the value of V appropriate to 5,000 ft, this becomes

$$\frac{\dot{V}\operatorname{cosec}\theta}{g} = -\,0\cdot11.$$

Thus in this case the acceleration term *increases* the effect of a wind gradient by about 10 per cent. (In the case considered before, where the true air speed increased with height, the effect of a wind gradient was *reduced* by the acceleration term.)

For some supersonic aircraft the optimum climb procedure may consist of a climb at constant (subsonic) Mach number to some intermediate height, followed by level acceleration to a supersonic speed and a final supersonic climb at gradually increasing Mach number. In the final supersonic climb the acceleration may be of order $g/4$ and the angle θ may be as small as 7 deg. These figures give $(\dot{V}\operatorname{cosec}\theta)/g \simeq 2$, so that the correction for wind gradient given by equation (9) is only about one third of the value for zero acceleration.

9. *Conclusions and Discussion.*—It has been shown that a wind gradient may have an important effect on the rate of climb of an aircraft, and that the effect is *not* confined to low altitudes. Nevertheless, the wind gradient will usually only be large enough to have an appreciable effect over a limited range of altitude, so that the effect on the total time to climb to a given height will usually be fairly small.

The result obtained in Ref. 1 is only correct if the angle of climb is small and if the true air speed is constant during the climb. In fact, the true air speed is usually *not* constant during the climb, and for typical subsonic aircraft this may change the effect of a wind gradient by about 10 per cent. For an aircraft climbing at supersonic speed, accelerating during the climb, the acceleration may reduce considerably the effect of a wind gradient. In a typical case of this kind the effect of a wind gradient is only about one third of the value calculated by neglecting the acceleration.

It should be noted that a wind gradient can have no effect on the ceiling of an aircraft, because the *change* of rate of climb becomes zero when the rate of climb itself is zero.

The effect of a wind gradient on the initial rate of climb, immediately after take-off, may sometimes be large, but in this case the acceleration term on the right-hand side of equation (8) is likely to be important and the assumption made in deriving equations (8) and (9), that at a given height V is independent of wind gradient, will not be correct. Fortunately, however, the effect of a wind gradient in this case is favourable, so that no difficulty should arise if take-off tests for acceptance purposes are always made in conditions of very small wind gradient. If an aircraft turns down wind immediately after take-off, however, the rate of climb may be seriously reduced by a wind gradient.

The present practice at the Aircraft and Armament Experimental Establishment is to apply a correction based on Ref. 1 (equation (10) of this paper), where climbing tests are made in the presence of a known wind gradient. It is usual to make climbing tests on reciprocal courses, and whenever possible these are made with the plane of the flight path normal to the wind velocity. If this latter condition is satisfied the wind gradient should have no effect on the rate of climb.

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REFERENCES

No.	Author	Title, etc.
1	Presented by the Superintendent, Royal Aircraft Factory	The effect of a wind gradient on the rate of climb of an aeroplane. R. & M. 379. 1917.
2	E. L. Deacon	Vertical diffusion in the lowest layers of the atmosphere. *Q. J. Roy. Met. Soc.* Vol. 75, pp. 89 to 103. 1949.
3	F. B. Bradfield and J. Cohen	Wind tunnel test of lift and drag measured in a velocity gradient. R. & M. 1489. 1932.
4	S. Petterssen and W. C. Swinbank ..	On the application of the Richardson criterion to large-scale turbulence in the free atmosphere. *Q. J. Roy. Met. Soc.* Vol. 73, pp. 335 to 345. 1947.
5	J. K. Bannon	Shear frequencies in the upper troposphere and lower stratosphere over England. *Meteorological Magazine,* Vol. 79, pp. 161 to 165. 1950.
6	K. J. Lush	A review of the problem of choosing a climb technique, with proposals for a new climb technique for high performance aircraft. R. & M. 2557. 1948.
7	Wing Cdr. L. Kelly	Optimum climb technique for a jet propelled aircraft. College of Aeronautics Report No. 57. A.R.C. 15,057. 1952.

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