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BOMB SIGHTING

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Roger Welles,
Captain, U. S. Navy,
Director of Naval Intelligence.

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LECTURES ON BOMB-SIGHTING.

I.—General principles.
II.—The construction of bomb-sights.
III.—Bomb-dropping errors and their avoidance.
IV.—Bomb-dropping instruction and practice.

APPENDIX.

Generalized theory of sighting
Tables of sighting angles.
Sheet of curves.

USEFUL CONSTANTS.

1 mile per hour = 1.47 f. s. = $1\frac{1}{2}$ approx.
= 0.87 knot = $\frac{7}{8}$ "
1 knot = 1.69 f. s. = $1\frac{7}{10}$ "
= 1.15 m. p. h. = $1\frac{3}{20}$ "
1 foot per sec. = 0.68 m. p. h. = $\frac{7}{10}$ "
= 0.59 knot = $\frac{3}{5}$ "
1 kilometer = 0.62 mile = $\frac{5}{8}$ "
1 mile = 1.61 kilometers = $1\frac{3}{5}$ "
1 meter = 3.28 feet = $3\frac{3}{10}$ "
1 foot = 0.305 meter = $\frac{3}{10}$ "
Tan 1° = 0.0175 = $\frac{1}{60}$ nearly.
Tan 2° = 0.0349 = $\frac{1}{30}$ "
Tan 3° = 0.0524 = $\frac{1}{20}$ "
Tan 4° = 0.0699 = $\frac{1}{14}$ "

CHAPTER I.

GENERAL PRINCIPLES.

Trajectory of a Bomb.—The problem which bomb-sighting presents is that of discovering and allowing correctly for the motion of a bomb in its passage from an aircraft to the target. Bombs themselves differ, the height and speed of the aircraft, and the speed and direction of the wind may vary, so that the actual conditions under which bombs are dropped are rarely identical. The path of the bomb through the air, known as its *trajectory,* and the way in which conditions modify it, must therefore be the first consideration.

Whilst in an aircraft, the bomb shares the speed of the aircraft, and when released, it continues to move forward as before (neglecting air resistance in the first place for simplicity). It therefore appears vertically below the machine *throughout its fall to the ground.* This may be readily seen if the bomb is watched through a hole in the floor, and it will be noticed that slowly at first, but with increasing velocity, it moves downwards in obedience to the force of *gravity.* This force is practically constant, and has the effect of increasing the vertical speed of the bomb by 32.2 feet per second for every second it acts. There are three simple formulæ which express the facts about falling bombs, and they are of great use in making rough calculations. Thus:

Time in seconds of fall from height H feet $= \frac{1}{4}\sqrt{H}$.

Vertical velocity in feet per second after falling through height H feet $= 8\sqrt{H}$.

Height in feet fallen by bomb in given time T seconds $= 16\ T^2$.

Note that these formulæ are only approximate, and take no account of air resistance.

They enable us to draw out the trajectory shown in Fig. 1, remembering that the bomb in flight retains the speed of the aeroplane, here taken as 100 feet per second.

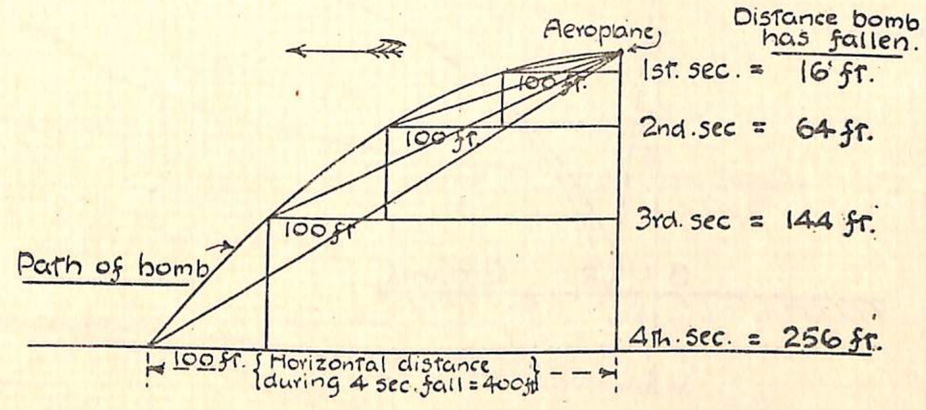


FIG. 1.

It is thus seen that, knowing the height by altimeter, the time of fall can be worked out, and therefore the horizontal travel of the bomb. The horizontal travel and the height obviously determine an angle such that if the bomb be released when the target bears at this angle to the vertical, the bomb will strike the target. The angle is termed the "*dropping angle,*" and the formal definition is:

Dropping Angle.—Dropping angle is the angle between the vertical and the line joining the aeroplane to the target at the correct moment for release.

Other definitions which may conveniently be given here are:

Air-Speed.—Air speed is the velocity of the aircraft relative to the air in which it moves, whether that air itself is in motion or not. Its symbol is V.

Ground-Speed.—Ground-speed is the velocity of the aircraft relative to the ground. Its symbol is G.

Wind.—Wind is the velocity of the air relative to the ground. Its symbol is W.

It is important to realize that since air-speed is relative to the air, and wind is measured relative to the ground, both these factors enter into the determination of ground speed.

Thus, if a machine is moving at 60 m. p. h. through air which is moving over the ground in the same direction at 20 m. p. h., its air-speed is 60 m. p. h., and its ground speed is 80 m. p. h., while if the wind reverses, the air-speed is still 60 m. p. h., but the ground speed is now only 40 m. p. h.

The trajectory of a bomb is therefore determined chiefly by three factors:

(*a*) Gravity.
(*b*) The speed of the aircraft from which it is released.
(*c*) The resistance of the air.

Factor (*a*) concerns chiefly the velocity and time of the bomb's fall; factor (*b*) concerns chiefly the horizontal motion of the bomb, including as it does, wind effects; factor (*c*) depends for its effect upon the form of the bomb, and modifies the effects of both (*a*) and (*b*).

Air-resistance Effects.—The effect of air-resistance is to retard the motion of the bomb through the air in a degree depending upon its shape and the relation between its shape and its weight.

The resisting force may be separated into two parts:

1.—Horizontal component of resistance.
2.—Vertical component of resistance.

Suppose *A* (Fig. 2) is an aeroplane which had dropped a bomb *R* when at the point *C*. In a vacuum the bomb would have moved horizontally forward, at exactly the same speed as the aeroplane, and have reached the point *V*. But a real bomb being retarded by air-resistance, would have fallen behind by a horizontal distance *BR*, and a vertical distance *VB*. The horizontal distance *BR* is dependent upon the bomb itself, upon the air-speed of the aeroplane, and upon the time it has been falling, *i. e.*, upon the height. The vertical distance *VB* is dependent upon the bomb itself and the height fallen, but is practically independent of the air-speed.

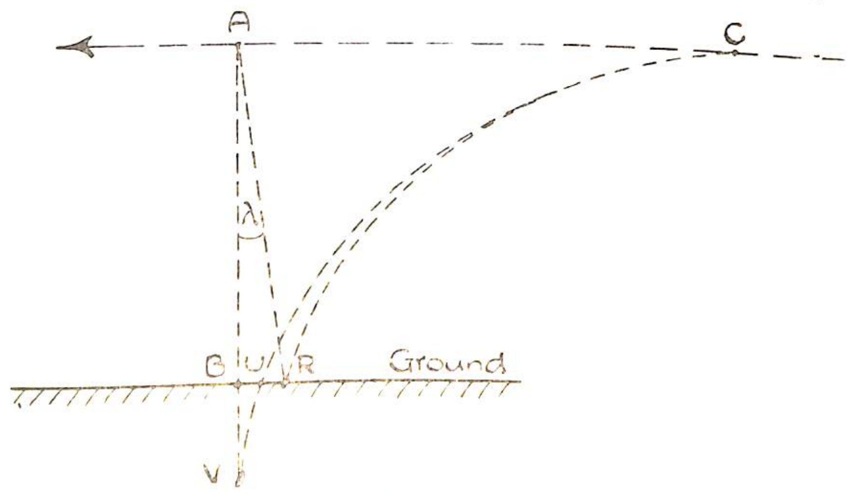


FIG. 2.

The distance *BR* is termed the *trail* of the bomb, and it is thus defined:

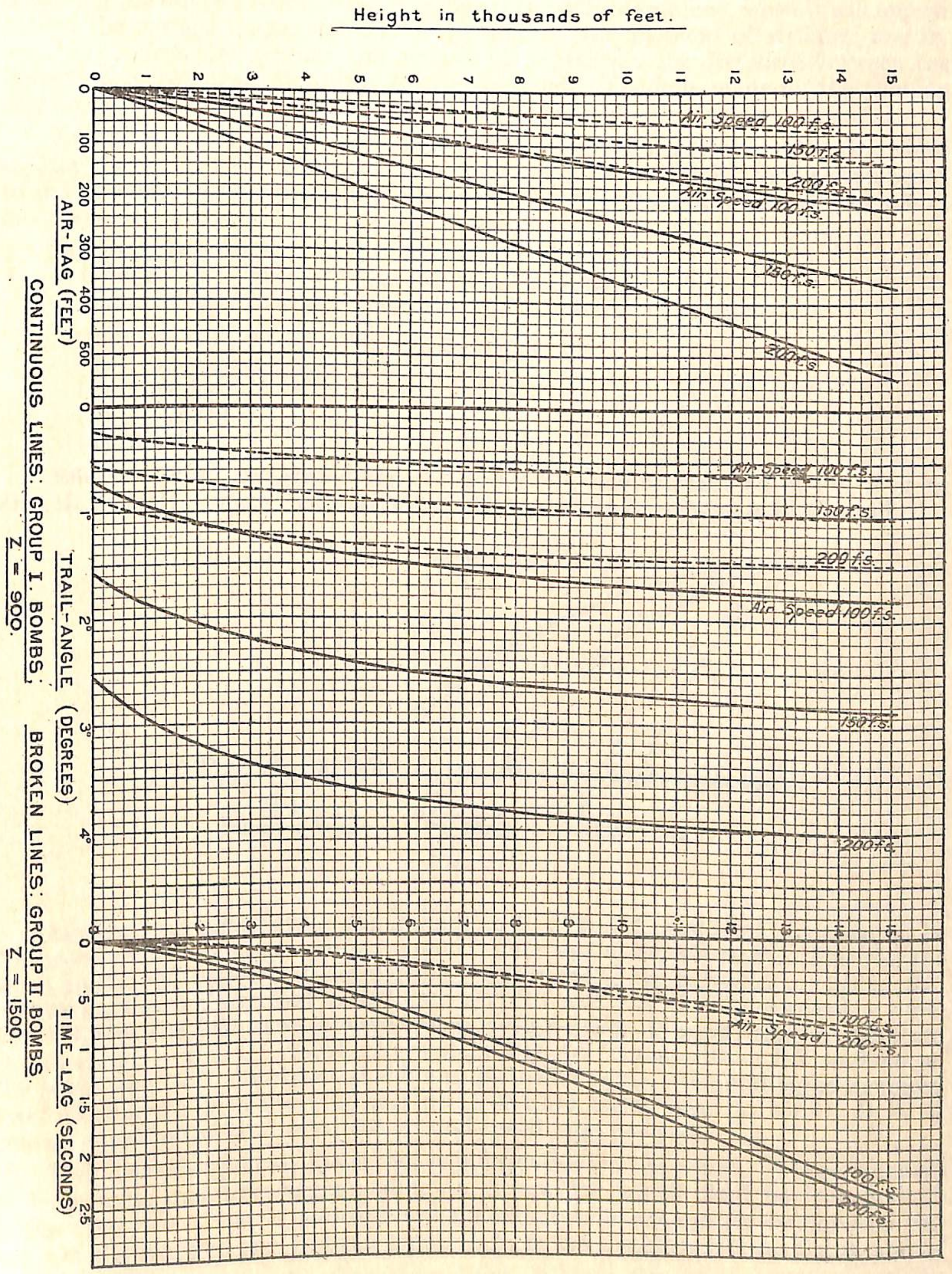
Trail.—Trail is the horizontal distance which a bomb trails behind the vertical dropped from the aircraft.

The trail distance clearly subtends an angle *BAR* at the aeroplane and it is found that the angle increases but slowly with respect to height, and is roughly proportional to air-speed.

Trail-angle. Trail angle is the small angle *BAR* by which the bomb as viewed from the aircraft appears to trail behind the vertical dropped from the aircraft.

Time-lag. Time-lag is the difference between the actual time of fall and the calculated time which a fall from the same height would take in a vacuum. Just as the height fallen by a bomb is a function of the time of fall, so is the vertical distance *BV*, and the time taken by the unresisted bomb to fall through the vertical distance *BV* is called the *time-lag*. Its symbol is *t*.

In Fig. 2 the real bomb is shown *R* at the moment of striking the earth. The vacuum bomb must at that moment be at *V*, having passed through previously and made a hole at *V*. The distance *VR* between the two bombs is termed *ground lag*.



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Ground-lag.—Ground-lag is defined as the distance measured on the ground between the spot where a bomb falls and the spot where it would have fallen had the air offered no resistance to its motion. Its symbol is L.

Difference between Trail and Ground-lag.—In order to appreciate the difference between trail and ground-lag, it needs to be realized that there are two ways of observing the fall of a bomb,—by watching it from the aeroplane, when it will appear behind the vertical by the amount of the trail at the moment of striking; and by watching it from the ground and afterwards measuring the distances between the holes in the ground made by the bombs dropped. The hole made by the vacuum bomb exists of course only in imagination, but its position is easily calculated.

In Fig. 2, UR is the ground-lag and BR is the trail, and it is seen that since striking the earth at U, the vacuum bomb has continued its motion for a period equal, to the time-lag, and moving forward with the same ground-speed as the aeroplane has traveled a distance $BU =$ ground-speed × time-lag.

We have therefore:

Ground-lag = trail − (time-lag × ground-speed),
i. e., Trail is always greater than ground-lag.

Ground-lag is therefore governed by four factors:

(1) Trail (which varies with air speed).
(2) Time-lag (which varies with height).
(3) Air-speed.
(4) Wind.

Effect of Wind on Ground-lag.—Consider the case represented in Fig. 3 of an aircraft flying (1) with a following wind, (2) in still air, (3) against a head wind.

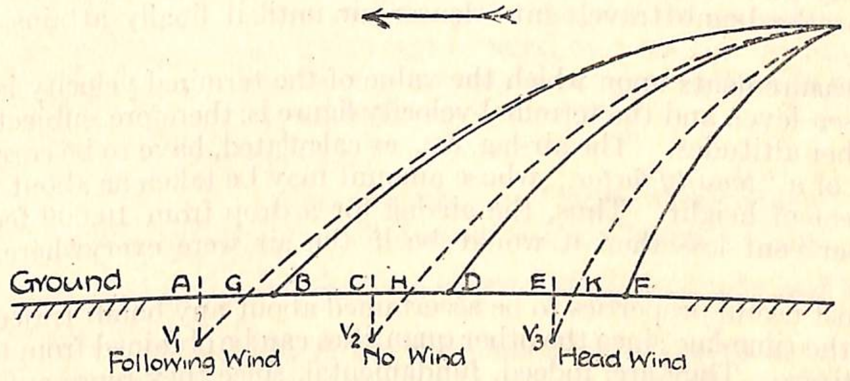


FIG. 3.

Let the real bombs strike the ground at B, D and F, and let V_1, V_2 and V_3 be the positions of the corresponding vacuum bombs at the same instant. Since for the same height and bomb, trail depends only on air-speed, we have $AB = CD = EF$, and we have seen above that in each case AG, CH and $EK =$ ground-speed × time-lag. But in the first case, ground-speed = (air-speed + wind) and in the third = (air-speed − wind). It is therefore plain that AG is greater than EK, and hence, GB is less than KF, the distances AB and EF being equal. Ground-lag is therefore least when flying with the wind and greatest when flying head to wind. It is, of course, equal to the trail when the ground-speed becomes zero.

Trail depends upon air-speed, but is independent of the wind. It is convenient to have some quantity corresponding to ground-lag which shall be independent of the wind also. Such a quantity is the horizontal distance *in the air* between the *paths* of the real and the vacuum bombs. It is the distance HD in Fig. 3, and is thus defined:

Air-lag.—Air-lag is the horizontal distance at any height between the vacuum flight-path and the real flight-path of the bomb. *In the absence of wind*, ground-lag and air-lag are the same. The symbol for air-lag is l.

Numerical Values and Formulæ.—It will be useful to have a statement of some of the simpler formulæ from which values of the above-defined quantities may be worked out for any given conditions. In these formulæ one bomb is distinguished from another by what is known as its *terminal velocity*. In a vacuum the speed of a falling body would go on increasing uniformly as long as it was allowed to fall; but in air a resistance is offered to the fall of the bomb which increases approximately as the square of the speed. A speed is ultimately reached at which the force of gravity is equalled by the air-resistance and no further acceleration takes place, so that the bomb continues to fall with this uniform speed, which is known as the terminal velocity. The greater the resistance of a bomb, the lower the speed at which the force of gravity is balanced, *i. e.*, the lower the terminal velocity. It has been found that the bombs now in use may be divided into two groups, the terminal velocities of the bombs in each group being nearly equal, thus:

Terminal Velocities of Bombs:

Group I., terminal velocity, *900 feet per second:*
16 lb., 50 lb., 65 lb., 100 lb., 112 lb., 520 lb.
Group II., terminal velocity, *1,500 feet per second*:
180 lb., 250 lb., 550 lb.

(NOTE.—The very greatly increased resistance which is offered to motion in the air at velocities at or over 1,100 feet per second which is the velocity of sound, would prevent a Group II bomb from actually achieving a velocity of 1,500 feet per second, however great the height of fall might be; the characteristics of the initial stages of its trajectory would, however, be those of a bomb which would, if the "square law" held good at all speeds, acquire a terminal velocity of 1,500 feet per second, so that the 1,500 may be looked upon as a sort of resistance coefficient, the use of which makes possible calculations of the lag.)

Tenuity Factor.—It must be remembered that since the density of the air decreases with altitude, the air resistance to the bomb will decrease, too. This is most noticeable when a bomb is released from a considerable height. The first stages of its fall take place in comparatively rarefied air, and as the effective terminal velocity is inversely proportional to the square root of the density of the air, its value is appreciably greater at a considerable height than it is at sea-level, and decreases gradually as the bomb travels into denser air until it finally attains its sea-level value.

The measurements upon which the value of the terminal velocity is based were made near sea-level, and the terminal velocity figure is, therefore, subject to a correction for higher altitudes. The air-lag, &c., as calculated, have to be corrected by the application of a "*tenuity factor*," whose amount may be taken as about 1.8 per cent. per 1,000 feet of height. Thus, the air lag for a drop from 10,000 feet would be about 18 per cent less than it would be if the air were everywhere at sea-level density.

The most useful properties to be ascertained about any bomb trajectory are the air-lag and the time-lag, since the other quantities can be obtained from these by very simple relations. They are, indeed, fundamental, since they represent the absolute loss of horizontal and vertical motion due to air resistance.

Average Values:

For bombs in Group I., air-lag $=\frac{H}{40}$; time-lag $=\frac{H}{7000}$; trail-angle $= 2\frac{1}{2}°$;

For bombs in Group II., air-lag $=\frac{H}{110}$; time-lag $=\frac{H}{20000}$; trail angle $= 1°$;

the air speed being 100 m.p.h. in each case, except in the case of the trail angle, which remains nearly constant, values at any higher air-speed being increased almost proportionately.

If, for example, the air-speed were 150 m.p.h. the air lag would be $\frac{H}{27}$ for Group I. bombs and $\frac{H}{73}$ for Group II bombs; but the time-lag would remain the same as at 100 m.p.h.

For vacuum conditions, the time of fall in seconds from any height H is given by $T=\frac{\sqrt{H}}{4}$, or more exactly $\frac{\sqrt{H}}{4.01}$ and the real time of fall is obtained by adding to this the value of the time lag as given above, so that

$$\text{Real time of fall} = T + t$$

We have seen above that a change of wind direction from ahead to astern results in an increase of ground-speed and a decrease of ground-lag, and that air-lag and ground-lag become equal [illegible]. We must therefore connect air-lag and ground-lag by a formula thus:

$$L = l + W.t$$

where W is the speed of the wind and is to be taken as positive when it opposes the aeroplane.

Finally, since ground-lag=Trail − (time-lag × ground-speed),

i.e., $L=\text{Trail}-G.t$

we have, $\text{Trail}=L+G.t.=l+V.t$

and we have all the properties of the trajectory linked up with the fundamental quantities l and t.

The trail angles range from 1° to 1.8° for Group I. bombs at air-speed 100 f.s., and from 0.5° to 0.7° for Group II. bombs, between heights of 1,000 and 15,000 feet; being proportional to air-speed, with the addition of about twice as much again when bombs are dropped vertically tail-down.

Average values for horizontally-released bombs when the air-speed is 100 m. p. h. are:

Group I.	Group II.
2.5°	1.0°

and about half these values for an air-speed of 50 m. p. h. It is a useful approximate rule that trail is twice air-lag, and that air-lag is equal to time-lag multiplied by air-speed.

For the better appreciation of the foregoing, a brief account is appended of the experimental methods by which bomb-dropping data have been determined.

Upavon Experiments.—Among the earliest experiments were those made at the Central Flying School, by the aid of a camera-obscura and wireless telegraphy. A camera-obscura is a light-excluded hut, with a convex lens of long focus mounted in the roof, and directed vertically upwards. An aeroplane was caused to pass over the hut, flying in a straight line. An image of the sky was formed on a photographic plate at the focus of the lens. The plate was covered by a tray, which could be moved over the plate in such a way as to keep the image of the aeroplane continuously over a small hole in the centre, which was covered by a shutter opening electrically at regular time intervals. A series of photographs of the aeroplane in its path across the sky was thus taken, and from them were obtained:

1. The course of the aeroplane.
2. The height, since $\frac{\text{Span of wings}}{\text{Span in photograph}}=\frac{\text{Height of aeroplane}}{\text{Focal length of lens}}$.
3. The ground-speed, from the time interval of photographs and their distance apart.
4. The horizontal distance of the aeroplane from the camera at any moment (proportional to the distance of the image from the center of the plate).

The pilot dropped a bomb when he judged himself to be nearly over the camera, and the release-handle was arranged so that a wireless signal was sent out at the instant of release. The signal was automatically recorded by a syphon recorder, which was also used to record each opening of the shutter. It was therefore possible to determine the instant of release with regard to the photographs.

The vacuum point of impact was calculated from the ground speed, direction, and height of the aeroplane. The actual bomb was found and its horizontal distance from the vacuum point of impact was known. The distance between the points of impact of the real and the vacuum bomb was of course the ground-lag. By correcting for wind, the air-lag was determined.

The time of fall was measured by using live bombs, which exploding on impact, caused the needle of the syphon recorder to oscillate. A correction was applied for the time taken by the sound to reach the instrument, and the difference between the measured time and that calculated for vacuum conditions gave the time-lag.

Alternative Mode of Experiment.—The foregoing is an absolute method of measurement, and its objection is that it measures a small distance as the difference between two large ones. If we take a bomb which falls consistently with a high terminal velocity and therefore shows little lag, it is possible to calculate its lag with fair precision; so that if a group of other bombs is released simultaneously with this standard bomb and the distances apart of their points of impact with the ground are accurately measured, the relative ground-lag can be found, which when added to the calculated lag of the standard bomb, gives the absolute lag for each bomb.

Simultaneous Group Experiments at Grain.—This method has been employed at the Grain Experimental Station with good effect. Moreover, by photographing the group of bombs just as the first is about to strike the ground and afterwards photographing from the same position a staff of known length erected at the mean point of impact of the group, the vertical distances separating each bomb from the standar done were measured. The velocity with which the bombs were falling was known, and the relative time-lags could thus be found, which added to the calculated time-lag of the standard bomb, gave the real time-lag for each bomb.

It is evident that if the trajectories are photographed broadside on, or the inclination of the axis of the camera to the direction of flight of the aeroplane is known, the air-lags can be measured from the photograph and treated in the same way as the time-lags.

Mine Shaft Experiments.—Absolute determinations of time-lag, of great accuracy, were made by dropping dummy bombs down the shaft of a coal mine, about 2,700 feet deep, during the summer of 1916. The instants of release and impact were recorded electrically by an accurate chronograph on a moving strip of paper, and from the positions of the records with relation to other marks on the paper, made automatically by the chronograph at every half-second, the actual time of fall was arrived at.

The difference between it and the calculated time for vacuum conditions gave the time-lag.

CHAPTER II.

THE CONSTRUCTION OF BOMB-SIGHTS.

The purpose of a bomb-sight is to indicate to the operator the instant at which to release his bomb. This should of course be when his horizontal distance from the target is equal to the distance which the bomb will, after release, travel forward in its passage to the earth. We have seen that this is influenced by a number of factors, and in general, the instrument has to be arranged to take account of these. The manner in which this is done constitutes the difference between one bomb-sight and another.

The height of the aircraft can be read directly from the altimeter, and the air-speed from the air-speed indicator, on the instrument board. The remaining factor which can vary is the wind, and therefore the ground-speed. If it is considered that the velocity of the wind can be guessed sufficiently well, then all the data are to hand for fixing the dropping-angle, and this was the actual procedure with the first forms of bomb-sight.

Elementary Bomb-Sight. An elementary bomb-sight might be made with a wooden board and two nails. The figures show the arrangement and the way in which it is obtained from the trajectory.

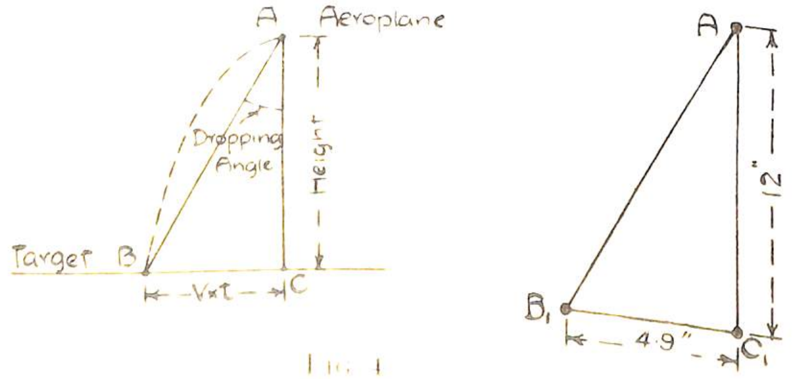


FIG. 1

AC is the height of the aeroplane. This is given by the altimeter.

BC is equal to ground-speed of aeroplane multiplied by (time of fall of bomb in vacuum) less the proper allowance for ground-lag.

To take a specific case, let—

$H = 3{,}600$ ft.; $V = 100$ m. p. h.; Wind $= 20$ m. p. h. against.

$$\text{Then, time of fall in vacuum} = \frac{\sqrt{3600}}{4} = 15/\text{secs.}$$

$$G = 100 - 20 = 80 \text{ m. p. h.} = 118 \text{ ft./sec.}$$

$$\therefore \text{distance } BC = 118 \times 15 = 1{,}770 \text{ ft. in vacuum.}$$

But there is air-resistance to be allowed for, and we have seen that air-lag at 100 m. p. h. air-speed is $\frac{H}{40}$, and time-lag in secs. $= \frac{1}{7000}$ height; also that

$$\text{Ground-lag} = \text{air-lag} + (\text{wind} \times \text{time-lag}),$$

$$i.\ e.,\ L = \frac{3600}{40} + \left(20 \times \frac{3600}{7000}\right)$$

$$= 90 + 10 = 100 \text{ ft.}$$

$$\text{Hence } BC = 1{,}770 - 100 = 1{,}670 \text{ ft.}$$

We now know AC and BC, and these fix the dropping-angle BAC. Having fixed a nail at A, measure AC_1 vertically downwards 1 foot, *i. e.*, $\frac{1}{3600}$ height, and from C_1 horizontally forward $\frac{1670}{3600}$ feet $= 4.9$ inches approximately, to the nail B_1. A spirit-level is added to read central when AC_1 is vertical, the aeroplane flying level; and the bomb is dropped when the nails A and B_1 come into line with the target.

It will be readily seen how impossible it would be to go through the above performance for every bomp dropped. Tables might be drawn up, giving the calculated dropping-angles for varying heights and speeds, and means provided for setting the wire B_1.

Lever Sight.—Such a method did take shape in the Lever Sight, in which sights A and B were mounted on a lever, pivoted at a point between them, and provided with an index and a quadrant scale of angles, so that the line of sight could be set at the angle read from the tables.

Low-height Sight, Mark I.—The objection to the use of printed tables while in the air was removed by the Low-height Sight, Mark I., which had two movable sights, a foresight moving vertically, set by a scale of heights, and a backsight moving horizontally and set to a scale of ground-speeds. There still remained, however, the necessity of guessing the wind and so inferring the ground-speed. To show how to avoid the necessity of guessing, we return to the consideration of the board with its nails.

Timing for Ground-speed.—If the time be taken by a stopwatch, for any object on the ground to change its bearing from AB_1 to AC_1, the aeroplane has moved over a distance BC on the ground which bears the same relation to the known height AC as B_1C_1 bears to $AC_1\left(i.\ e.,\ BC = AC \times \frac{B_1C_1}{AC_1}\right)$. If this distance BC be divided by the time taken, the resulting velocity is the ground-speed. For convenience, the wire B_1 may be arranged to slide along B_1C_1, and as the height of the aeroplane is increased it may be moved nearer to C_1, so that BC on the ground is kept a constant distance (say 1,000 feet), and the calculation of ground-speed is simplified. For this purpose a height-scale is placed along B_1C_1, with marks to which B_1 is set for timing at each height.

With this arrangement there is yet much room for improvement, for ground-speed has to be worked out and tables consulted to find the angle to which AB_1 must be set for bomb-dropping.

C. F. S. Scale.—The desired improvement was effected by the introduction of the C. F. S. timing scale. The horizontal height scale was retained, but a time scale was added graduated in seconds, and the wire B_1 was reset to the mark on the time scale corresponding to the number of seconds occupied in timing, and this was then the correct dropping-angle.

This was achieved in the following manner:—The object on the ground was timed back to the vertical over a distance in feet $= 100 \times ($time of fall of bomb from the particular height), *i. e.*, $100\times\frac{\sqrt{H}}{4}$ feet, and if d was the distance AC_1, the distance B_1C_1 on the height scale $=\frac{d}{H}\times\left(100\times\frac{\sqrt{H}}{4}\right)$, which reduces to $\frac{25.d}{\sqrt{H}}$. Thus B_1C_1 is inversely proportional to H, and the largest height-graduations come near the zero of the scale.

If N be the number of seconds occupied in timing,

$$G=\frac{1}{N}\left(100\times\frac{\sqrt{H}}{4}\right)$$

But horizontal travel of bomb $=G\times$(time of fall)

$$=\frac{1}{N}\cdot\left(100\times\frac{\sqrt{H}}{4}\right)\cdot\frac{\sqrt{H}}{4}=\frac{100.H}{16.N}$$

and distance on scale of seconds mark $=\frac{d}{H}\cdot\frac{100.H}{16.N}$

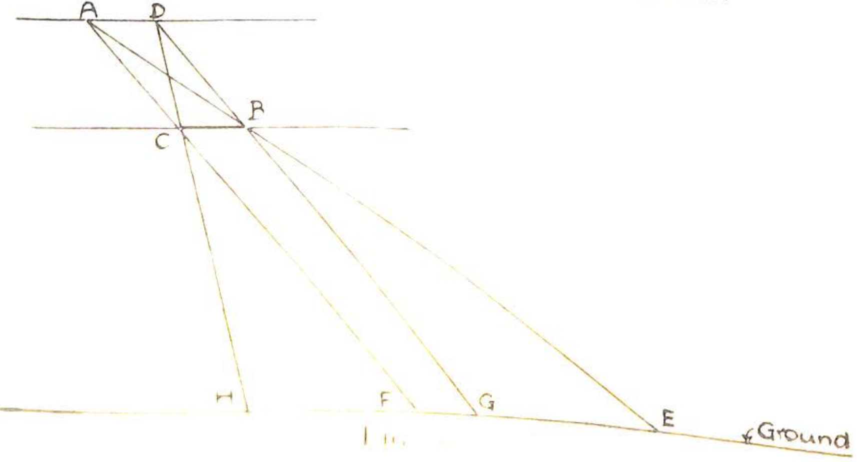
$$=\frac{1}{N}\cdot\frac{100.d}{16}.$$

Hence the graduations of the time scale are independent of the height, which is the essential condition that the time scale should apply to all heights. A suitable correction for lag was applied to the time scale, and a third scale showing actual angles was also provided for use if required.

"Tromboning."—A further feature in this type of bomb-sight remains to be considered. In timing back to the vertical, it is of course not possible to time on the target itself. This is not of importance when attacking a target ashore, as the timing can much better be done on some previous object that happens to be on the same course. In a seaplane it is not always possible to set the sight by timing on some preliminary object, as one may not show itself.

The "trombone" attachment which is fitted to the C. F. S. trombone-sight allows the timing to be done on the target itself. The foresight is set to the height at which the aeroplane is flying. The sliding backsight (or trombone) is also approximately set to the height by means of a scale. The target is then sighted through the sliding backsight and moving foresight, and a stopwatch started. The watch is stopped when target is sighted through the sliding backsight and fixed foresight. The moving foresight is then set to the number of seconds recorded, and the bomb is released when the target is sighted through the fixed backsight and moving foresight. The moving backsight need only be approximately set, for whatever its position along the slide the horizontal distance subtended on the ground is the same.

BC = Fixed distance on sight for timing over.



For since we know that the perpendicular heights and the bases of the triangles *ABC* and *DBC* are equal, we also know that the bases of the triangles *AEF*, *DGH* are equal, since *CB* is parallel to *HE*, this case being one of similar triangles.

Care should be taken, however, not to move the backsight too far forward, as otherwise there is danger of cutting into the dropping-angle. The scale provided should make this impossible.

From the C. F. S. sight, the word "tromboning" has been extended to any method of timing on the actual target, as distinct from some other object or "auxiliary target," and forms a concise expression.

Equal Distance Sight.—This is the name of a very important sight which appears in more than one form, but whose underlying principle is that an aircraft, if its ground-speed remains constant, passes over equal distances on the ground in the same time. Its use requires a special stopwatch (Reversing Stopwatch, Mark I.) whose hand can be reversed in motion at any instant, and whose dial is marked with a scale of heights, each height mark being placed at the number of seconds corresponding to the time of fall.

In the Equal Distance sight there are three sighting wires, *A*, *H* and *G*. The construction is such that *HK* is always parallel to the trail line, *AB*, and $HG = GK$. *HG* is arranged to be capable of being moved parallel to itself, the point *H* moving along a horizontal path. This construction has the merit that no matter where *HG* may be put, the distances *BC* and *CD* will always be equal. This is easily seen to be the case, for since $HG = GK$, therefore $AK = HL$. But $AK = MH$; therefore, $MH = HL$, and therefore, $BC = CD$.

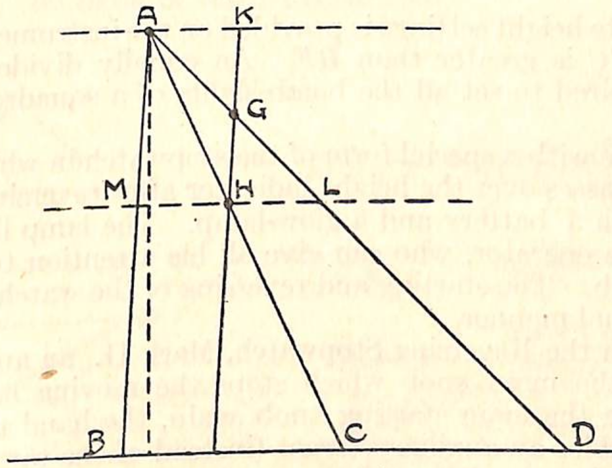


FIG. 6.

The Equal Distance bomb-sight is in its theory the simplest of all bomb-sights. Thus, in Fig. 7, *A* is the aeroplane, assumed to be at rest, whilst the target is moving towards it in the direction of the arrow. Draw *AE* perpendicular to the ground, and *AB* inclined to the vertical at the trail-angle; then a bomb dropped from the aeroplane would, if there were no air resistance, strike the ground at *E*, but owing to air resistance it falls behind and strikes at *B*. The object of the sight is to provide that the target shall reach the point *B* precisely at the same moment as the bomb itself reaches *B*. Let the ground-speed be such that the target moves from a point *F* to *B*, whilst the bomb falls from *A* to *B*. Then, if the bomb be released when the target is at *F*, the bomb will strike the target; the angle *EAF* is the bomb dropping angle.

Take any point *C* such that *BC* is greater than *BF;* and take a further point *D*, such that $CD = CB$. If now a stopwatch be started when the target appears along the line *AD*, and if the motion of the watch-hand be *reversed* in direction when the target appears at *C*, the watch-hand will have got back to the zero from which it started when the target arrives at *B*. It is also clear that at the moment when the target passed through the point *F*, the watch-hand would have still to run a number of seconds equal to the time taken by the bomb to fall from *A* to *B;* in other words, the watch-hand at that moment would point to the number of seconds equal to the time of fall. If, therefore, the watch-dial be graduated according to times of fall, the moment at which the target is at the bomb-dripping point *F* will be indicated by the hand reaching the time-of-fall point on the watch. (A movable pointer is provided to indicate this point). Thus there is no need for any calculation, nor is any movement of the sighting wires necessary. The only precaution to be taken is to see that the point *C* lies on the far side of the point *F*, and this is easily achieved by setting the time-of-fall pointer to the height given by the aneroid and timing any point on the earth's surface from *D* to *C* (or *C* to *B*—for these distances are the same) and seeing that it is greater than the time of fall; the sighting mechanism enables the position of the point *C* to be adjusted at will.

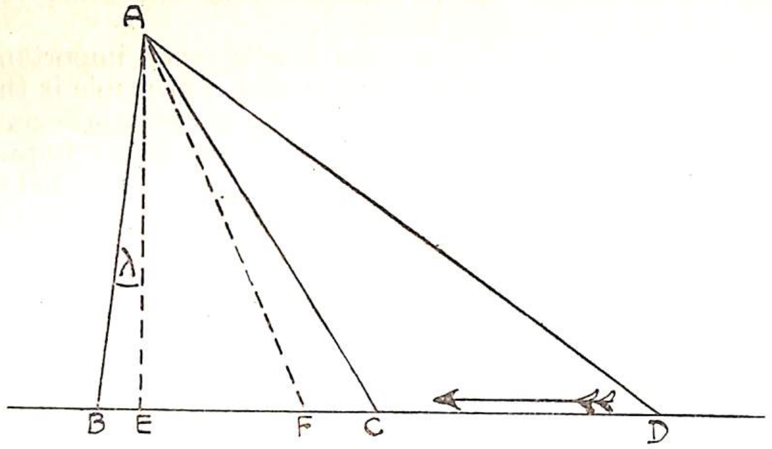


FIG. 7.

A scale of approximate height settings is provided on the instrument to serve as a guide in securing that *BC* is greater than *BF*. An equally divided scale is also provided should it be desired to set all the bomb-sights of a squadron to the same predetermined angle.

Tests have been made with a special form of the stopwatch in which the moving hand is caused, when it passes over the height indicator after reversing, to complete an electric circuit through a battery and a glow-lamp. The lamp lights up for an instant and signals to the operator, who can give all his attention to watching the target, to release the bomb. The starting and reversing of the watch are performed by the operator in the usual manner.

Mark II. Watch.—In the Reversing Stopwatch, Mark II., an auxiliary knob is provided to the left of the main knob which stops the moving hand instead of reversing it. On pressing the main starting knob again, the hand takes up its reversed motion. This enables an auxiliary target (instead of the target itself) to be timed over the forward distance *DC*, and the hand stopped until the real target appears at *C*, when the hand is allowed to resume its motion as though the whole operation had been performed on the real target. The pilot can thus do his timing some while before reaching the scene of the attack, if he so desires, and have his sight instantly ready. Moreover, when thus set, the sight is ready for any target that may appear convenient. If the auxiliary knob be not employed, the watch behaves exactly as the Mark I. pattern.

Dropping Bombs in quick succession.—The ordinary method of using the sight is simple and accurate when dropping a few bombs singly or a number in a salvo. When, however, it is desired to drop a large number of bombs one at a time on a succession of targets fairly close to one another, it is a convenience to be able to set a sighting wire in a fixed position as in the C. F. S. sight, and drop bombs whenever any suitable target crosses the wire. To do this with the Equal Distance sight, all that is necessary is to shift the position of the forward slide until any object on the earth is found to travel from the first wire *G* to the second wire *H* in a time exactly equal to the time of fall of the bomb (*i. e.*, until the hand of the watch comes up to the height pointer). When this has been done, the second wire *H* will be at the correct bomb-dropping angle for that particular height, course and air-speed.

A number of special forms of the E. D. sight have been devised for particular machines, and with various accompaniments. In some, the principle has been applied optically by means of mirrors, lenses or telescopes; in others fixed horizontal sighting wires are mounted on a frame over a longitudinal slot in the floor of the aeroplane, two wires giving the line *GD* to the eye at *A*, and two other wires giving the line *HC* to the eye in the same position. In almost all these forms the one object is to secure equal distances *BC* and *CD* [illegible] point, and the method of use [illegible] the same general procedure.

Spotting Corrections.—It is simple to make a spotting correction with either the Mark I. or Mark II. watch. If the bomb falls "short," set the height index to a slightly lower reading; if it falls "over," set the height index to a somewhat higher reading. The correct amount of shift to give the height index is that fraction of a second which it would take the aeroplane to cover a distance equal to the amount short or over. Thus, at a ground-speed of 60 knots, a shift of the index by one second alters the point of impact of the bomb by about 100 feet.

Double Distance Method.—There are conditions (*e. g.*, when bombing at low heights, or in a fast machine at moderate heights) under which the angle *BAD* becomes so large that it may be difficult to secure the line of sight *AD* unobstructed in the machine. One way of meeting this difficulty is for the timing distance *DC* to be made *half* the distance *BC*. This would constitute a "Double Distance" method, and would need a special double-distance watch.

Drift Sights.—When operating over anti-aircraft fire it is not easy to use stop-watch methods of bomb-sighting, especially when the pilot is operating the sight. In such cases it is better to use the reading of the air-speed* indicator and to allow for the wind. By a comparatively simple addition to the Low-Height and similar sights, it is possible actually to measure the velocity and direction of the wind and thus set the sight for ground-speed without the use of any watch or other clockwork mechanism. This plan has been followed in the Low-Height sights (Marks II. and III.).

Consider the right-angled triangle *ofg*. If the length *of* and the angle *gof* are known, the triangle is completely determined and the length of *fg* can be found. This triangle is the basis of the Drift Method.

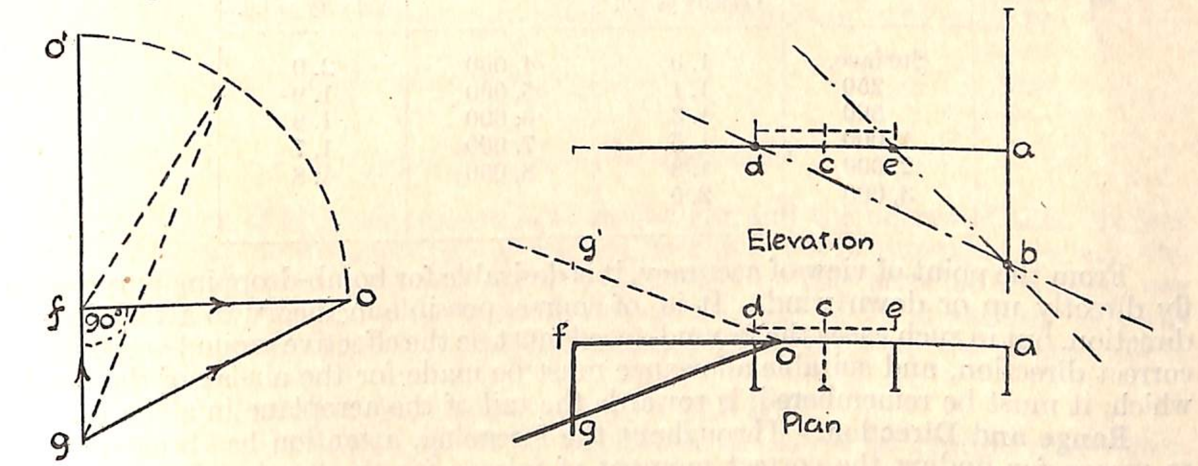


FIG. 8.

The pilot flies directly down-wind, say, as judged by the earth below appearing to pass away parallel to the axis of the machine. Noting the course he is on, he turns his machine through about 90°, by compass or otherwise, thereby flying directly across the wind. The surface of the earth, or sea, now appears to drift slantingly away to the right or left, and he turns the drift-bar attachment to the sight until it is parallel to the new direction of the earth-drift.

Now the drift-bar is the side *og* of the triangle and the length *fo* is proportional to the air-speed of the machine. The length *fg* is therefore proportional to the wind and its amount can be read off on a scale provided.

The actual sight is arranged for either up-wind or down-wind attack, and provides that the addition or subtraction of the wind is automatically performed by the operation of setting out the drift-bar *og*, the sighting wires being set accordingly.

The figure shows the arrangement, where *b*, *d* and *e* are sighting wires, of which *b* slides vertically and is set so that *ab* is proportional to the square root of the height, *i. e.*, to the mean speed of the falling bomb relative to the aeroplane; and *d* and *e* slide horizontally. *og* is a bar of any length which is pivoted at *o* so that $ac = of$ (*c* being the midpoint of *de*), both being proportional to the air-speed. Angle *ofg* is a right angle and gearing is provided so that *og* may be moved about its pivot *o*, and the sights *d* and *e* moved at the same time so that $cd = ce = fg$ in *all* positions of *og*. Thus if *ac* is proportional to the air-speed, $ac + cd =$(air speed + wind),

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* The fact that the air-speed indicator underestimates the air-speed at increasing altitudes is automatically allowed for in the construction of this Bomb Sight.

i. e., ground-speed when flying down-wind. Similarly, $ae=ac-ce$=ground-speed when flying up-wind. The sighting is performed along db in the former case and eb in the latter. On the sight, cf is kept constant, and o is fixed, so that if fo is shortened ca is shortened by the same amount.

When the bar og is only free to move out on one side of of, it is necessary to arrange that the drift shall be along og and not along og^1. It is for this reason that the pilot is instructed to bear to his *right* hand through 90° when approaching *down* wind, and to his *left* hand when approaching up-wind, the bar og being assumed free to move out to the right. It is apparent from the figure that the length fg is not appreciably affected by a quite considerable error in judging the amount of the right-angle turn.

Use of Drift-bar at High Altitudes.—The drift-bar is fitted as an attachment to the Low-Height sight, for which it is very useful, since it is almost impossible to employ timing methods at very low heights. It is obvious that the same method is available, in principle, at any heights, although at very great altitudes it is more difficult to determine the line of drift with accuracy. Fortunately, however, the velocity of the wind does not usually change much after a height of 2,000 ft. has been attained. So if the drift-bar is set at 2,000 ft. or over, it will in most cases be approximately correct at greater heights. The following results of experiments at Grain illustrate this:

AVERAGE OF 11 PILOT BALLOON ASCENTS AT GRAIN EXPERIMENTAL STATION, 1916–1917.

Height in Feet.	Velocity of Wind, taking Surface Velocity as 1.0.	Height in Feet.	Velocity of Wind, taking Surface Velocity as 1.0.
Surface.	1.0	4,000	2.0
250	1.1	5,000	1.9
500	1.3	6,000	1.8
1,000	1.5	7,000	1.7
2,000	1.8	8,000	1.8
3,000	2.0		

From the point of view of accuracy, it is desirable for bomb-dropping purposes to fly directly up or down wind. It is, of course, possible in theory to attack in any direction, but in such cases the ground-speed must be the effective ground-speed in the correct direction, and suitable allowance must be made for the air-lag of the bomb, which, it must be remembered, is towards the tail of the aeroplane in all cases.

Range and Direction.—Throughout the foregoing, attention has been confined to means for finding the correct moment of release for the bomb. It is a matter of at least equal importance that the vertical plane in which the bomb falls should be a plane passing through the target, and not one which misses it to the right or the left. The moment of release determines the range of the bomb, the direction of motion of the aeroplane at the moment of release decides the direction taken by the bomb. In every sight means must be provided to guide the pilot in steering a course which, if continued, would take him vertically over the target. A line or wire is therefore provided parallel to the longitudinal axis of the machine, and the steering is regulated so that the target appears to approach along it. As this might possibly be done with the machine flying with a list to one side, it is important to ensure that the eye is looking vertically downward on to the direction wire. It is not very easy to provide for this. A lateral spirit-level is generally provided, and a second direction wire or its equivalent may be added parallel to the first and vertically above it, the eye being placed so that the wires cover one another. The spirit-level, however, cannot be relied on when the machine is banked even for a slight turn. Gyroscopic or other more complex apparatus would be necessary to enable a sight to be completely undisturbed by banking. In its absence, careful steering and much practice must be the rule.

Reference to Instructions.—For fuller details and diagrams of the sights here mentioned, reference should be had to the official printed instructions and, wherever possible, to the sights themselves.

Special Method with Airships.—When an airship is using a bomb-sight which has a special wind-speed scale [illegible] it is possible to make a measurement of the wind [illegible] up-wind until the ground appears stationary. The [illegible] will then be the velocity of the wind and [illegible]

CHAPTER III.

BOMB-DROPPING ERRORS AND THEIR AVOIDANCE.

Conditions for Accurate Bombing. Range Error and Line Error.—We have seen that to hit a given target—

(1) The bomb must be released at a particular instant determined by the height and ground-speed of the aircraft.

(2) The course of the aircraft at the moment of release, and the path of the bomb through the air, must be in a vertical plane passing through the target.

Errors in fulfilling these conditions are known respectively as *range errors* and *line errors*.

There will always be sufficient uncertainty in the actual conditions to make it unlikely that every bomb will succeed, but attention must always be directed to the avoidance of those sources of error which are under control, and it is desirable that these should be known, and their relative importance realised. The more important are here detailed, and likely values found.

RANGE ERRORS.

Examples of Range Errors.—(1) Sight not truly horizontal.
Suppose line of sight is tilted 2° forward.

H=6,000 feet: Correct dropping angle=14.5°;
Actual " " =16.5°.

Correct horizontal travel of bomb=6,000 × tan 14.5° - =1,551 feet.
Actual distance of aeroplane from target=6,000 × tan 16.5° =1,777 "

Aeroplane was too far from target by - - - - 226 "

i. e., bomb falls 226 feet short.

The error is directly proportional to the height and the degree of tilt. It is of less consequence in timing for ground-speed, but it is worth removing, in case the level is overlooked when setting the dropping angle. This error is relatively less serious in the Equal Distance sight, for which an error of 2° in the line of sight leads to an error of about 1° in the trail-angle, *i. e.*, an error on the ground about half of that above cited.

(2) Speed wrongly estimated by 5 m. p. h. (7.5 f. s.)
Height=6,000 feet. Time of fall=20 secs. Error on ground=7.5 × 20=150 feet.

This error is proportional to the error in speed and to the height.

(3) Error in height measurement.

Suppose bomb was dropped from 6,400 feet instead of 6,000. Time of fall is $20-19\frac{1}{3}=\frac{2}{3}$ sec. more. With a remaining horizontal speed of 100 f. s., this gives +66 feet on the ground. But the sighting angle was set to give 1,930 feet at 6,000, say, and this same angle gives $\frac{6400}{6000}\times 1{,}930=2{,}060$ feet at 6,400. Hence, the distance 66 feet has to be diminished by the extra 130 feet which the aeroplane was from the target, giving an error of 64 feet short.

An error of 400 feet in height estimation is of small account when over 4,000 feet up; below that, it becomes increasingly serious until at 1,500 feet it is fatal to accuracy. In Equal Distance sights an error in height estimation produces an error equal to the difference in time of fall multiplied by the ground-speed.

(4) Delay of 2 secs. in dropping bomb.

With a ground-speed of 100 f. s., this means 200 feet over. This error is jointly proportional to the ground-speed and the delay.

LINE ERRORS.

(1) **Examples of Line Errors.**—Course of aircraft at release inclined 10° to direction of target.

At 6,000 feet, horizontal travel of bomb=2,000 feet, say.

Target is missed by 2,000 × tan 10°=350 feet approx.

This error increases with height and ground-speed and the inclination.

The direction of the wind can be found by the following method.

The aeroplane, when at its bomb-dropping height, is pointed in the direction from which it is expected the wind will be blowing, and some object well ahead is noted on the fore and aft line. The pilot then concentrates himself on flying the machine on a steady course for some 15 or 20 seconds, and then looks to see in which direction the object has drifted. The machine is then turned between 5° and 15° in the direction to which the object has drifted, and the operation is repeated on some other object. After the third attempt the wind should be found, and its compass direction should be at once noted.

(3) It is essential that the pilot should be able to fly his machine level at a constant speed.

It is evident that if, when the bomb-sight is set for ground-speed by timing or otherwise, the machine is kept flying level by pushing the control stick forward, and during the bombing run it is prevented from climbing by throttling down, not only will the ground-speeds on the two occasions be different, but the sight, if it has been levelled for the timing run, will have to be re-adjusted for the bombing run.

It is very necessary that the pilot should learn to know at what engine revolutions his machine is trued up to fly level at any particular height, so that, at the commencement of any timing or bombing run, the only necessity is to close the throttle until the engine is doing the desired number of revolutions, when he will know that, with his hands off the control stick, he is neither climbing nor diving. If the bomb-sight is levelled on the fore and aft bubble for this engine speed, it never need be re-adjusted except when the height is widely different.

(4) As soon as the machine is throttled down or the tail plane adjusted for flying level, level the sight on the fore and aft bubble.

(5) The next operation is to set the sight for ground-speed. When this is done by timing, it is best to time on some preliminary object, and not on the target itself. During the bombing run interference may be expected from anti-aircraft fire, and in any case the pilot, if he is working the bomb-sight, is quite sufficiently employed in steering when attacking. Any timing can conveniently be done immediately after finding the direction of the wind. A prominent object should be selected which can be easily followed. If possible, two observations should be made and the mean taken.

(6) Care must be exercised in getting the machine into position for the attack, with the target bearing to the aeroplane in the compass direction of the wind. This can be done either by judgment and subsequent corrections made by right and left hand turns, or the machine can be steered 90° out of its course, and when the target bears just before the beam, a four-point turn made.

(7) During the run up to the target, use the latter for steering as little as possible. Select an object well beyond and in line with the target, and endeavour to keep the aeroplane pointed at it. If during the run, the object on which the pilot is steering is seen to be no longer in line with the target, it means the machine has been drifted by the wind, and a fresh object will have to be taken.

Do not attempt any correction at the last moment. The amount of correction required can not be judged, and matters will probably only be made worse.

If during the run it is necessary to put bank on, or use the rudder slightly to alter course, do not attempt to see if the line is correct until the machine is level again laterally.

The above are suggestions showing methods which have been found to assist in bomb dropping, but officers must realize that only when the requirements are fully understood, and with much care and considerable practice, can accuracy be attained.

CHAPTER IV.

Bomb-dropping Istruction and Practice.

Instructions in Bomb-Dropping.—The first essential to impress on pilots is that to drop bombs accurately they should have knowledge of what happens to a bomb on release. The trajectory of the bomb as described above should be properly understood.

There are three factors which influence the flight path of the bomb:

(*a*) Gravity.
(*b*) Forward horizontal velocity which it had in common with the machine.
(*c*) Air resistance.

A pilot should be made to understand that if a bomb be dropped from a machine which subsequently keeps on its course, and the fall of the bomb be carefully watched from the machine, it will be observed to remain almost vertically under the machine and start quite slowly on its downward path.

From this he will know that the bomb travels forward while dropping, at nearly the same speed as machine, so that if he knows the time of fall he can deduce the dropping angle.

The following two facts must be thoroughly understood:

(*a*) In order to hit the target, the course of the aeroplane must be such that if continued it would pass vertically above target.
(*b*) Bomb must be dropped smartly at a certain instant, depending on speed and height of machine.

As soon as the conditions necessary to hit the target have been grasped, frequent practice must be carried out.

The first runs should be for course-steering over the bomb-dropping mirror; and as soon as the pilot has become reasonably accurate in flying over the target, he should be sent up for practice, firing a Very's light or other signal to indicate the moment when he considers the bomb should be dropped. The first practice runs should be made up-wind; the timing period is longer, and more accuracy is possible in getting the line of flight.

In order that the practice should be of value, it is essential that—

(1) The operator should be able to see at once where his bomb has fallen in regard to the target; and
(2) He should always endeavor to discover the reason for missing, by analysing the causes of possible errors, as detailed in Chapter III.

It is well to remember that there must be a reason for the bomb falling, say, 400 feet over or short. The cause may be looked for under the following heads, viz:

(1) Sight not adjusted correctly for ground speed.
(2) Sight not adjusted correctly for real height of machine.
(3) Bomb dropped either before or after sight was "on."
(4) Sight not adjusted correctly in a horizontal position.

This will teach the pilot to correct his personal errors, and to pay the required attention to detail which is essential to accuracy.

As soon he has obtained a fair degree of accuracy at low heights, the altitude of the runs should be increased until heights of about 12,000 feet are reached. Practice at considerable heights is most essential. There are two methods by which practice can be obtained—by means of the bomb-dropping mirror or by the use of dummy bombs.

Bomb-dropping Mirror.—Briefly described, the instrument consists of a plane mirror which can be set truly horizontal, having at one end a metal batten, with a sighting hole 10 inches above the surface of the mirror. For the appreciation of the principles involved, assume that a sheet of plain glass replaces the mirror, and that the sighting hole is set *below* the glass in a corresponding position, so that the observer looks through the eye-piece and the glass at the aeroplane. Since the aeroplane is moving in a plane parallel to the plane of the glass, it will, in moving equal distances in the air, appear to move over equal spaces on the glass by the principle of similar triangles. By the use of the mirror we secure precisely the same result, with the convenience of looking down upon the picture from an eye position above it, remembering that we place the eye in exactly the same position above the mirror as we should place it below the glass. The length of the batten is simply a matter of convenience, and 10 inches was chosen for the simplicity of 10 as a divisor in making calculations, for if the reflected image of the aeroplane, as seen through the eye-piece, passes over a distance of 1 inch on the mirror, we know that it has actually travelled a horizontal distance in the air equal to $\frac{1}{10}$ of its height.

The face of the mirror is ruled with lines which constitute in effect a C. F. S. scale. A red center line is provided, which is pointed in the direction from which the aeroplane is attacking. Looking through the sighting hole, the image of the aeroplane is observed as it passes over a number of transverse lines, whose distances from a fixed line are proportional to the times of fall from the heights to which they correspond. Having timed it from the appropriate height-line, a small pellet is set to the resulting number of seconds on a scale of seconds marked on the center line, and on the eye side of the fixed "stop watch" line. The image of the aeroplane is further observed, and if at the moment when the pilot sends his release signal (by Very light or wireless) the aeroplane image is at the pellet, a hit is registered. If not, its distance in inches, over or short, left or right of the pellet is read as an error of so many tenths of the height of the aeroplane, and a signaller is dispatched to the indicated spot to wave a flag, and so show where the bomb would have fallen.

The sighting batten is pivoted and provided with an index moving over a scale of air-speeds, so that the sighting hole may be displaced from the vertical by an amount proportional to the trial angle and the lag of the bomb thus allowed for.

Dummy Smoke Bombs.—The other method of obtaining practice is by the use of the little dummy smoke bombs which have been designed so as to have the same trajectory as the standard bombs (Group I.). On striking the ground they give forth a volume of smoke which enables them to be easily located.

Recording Results with Dummy Bombs.—For the case of target practice with dummy or smoke bombs, a standard method has been devised of measuring up the distances of the points of impact from the target with a minimum of trouble.

Stations for two observers are chosen at a safe distance from the target, and some distance from each other, so that the angle subtended at the target by the two stations is roughly a right angle. The observer at each station has before him, supported on a tripod, a large rake or its equivalent, with the nails pointing vertically. The nails are numbered clearly and painted with different colors in such a way as to be easily distinguishable. An eye-piece or peep-hole is provided about 10 feet from the rake.

When a bomb is dropped, it gives up its column of smoke, and each observer looking through his peep-holes notes the numbers of the two nails between which he sees the smoke, roughly dividing the space by his eye. The line from the peep-hole to the bomb is thus determined, and the positions of the stations being known relative to the target, it is possible to lay the results down on a drawing-board and find graphically the position of the target and the bombs in correct relation. If the rakes are always placed at the same distance from the target the actual distances at the target may be marked under each nail.

Bogey Targets.—For effective comparison of the results of bomb-dropping practice, some standard method of judging performances is necessary. A system has been devised which consists in the fixing of a standard "score" to be attained by skilful operators under good weather conditions.

A whitened rectangle (about 12 feet by 8 feet) is placed on the ground as a target, and this forms the center of a series of imaginary circles, four in number, after the manner of a common rifle target and distinguished by the same names. The diameters of the circles have been chosen so that marks 4, 3, 2, and 1 (for "bull," "inner," "magpie," and "outer" respectively) correspond to the difficulty of making the hit. The diameters of the circles vary with the height of the attack. Thus for a height of 1,000 feet the diameters for the four circles are 100, 155, 225 and 400 feet.

The diameters of the circles have been so chosen that a first class shot would be expected to obtain 75 per cent of full marks and this score constitutes "bogey." All others should if possible be brought to this standard at any rate to [illegible] per cent performance.

From an examination of bomb-dropping results secured under varying conditions over a considerable range of heights it has been found that the factor [illegible] can be successfully [illegible] the [illegible] and the corresponding target [illegible]

bomb dropping ground the actual distances of hits are measured "over" or "short," " eft" or "right," of the edge of the target and the dropping-height is noted. These results are afterwards plotted on paper, and a set of circles is drawn about the target as centre, of the diameters given below. By this means the score is easily read off, as a good comparative figure is obtained whatever the height from which the attack is made, for comparison with "bogey."

The scheme of target diameters is as follows:—

Height.	Diameters in Feet.			
	Bull.	Inner.	Magpie.	Outer.
250	49	77	112	196
500	70	110	160	280
1, 000	100	155	225	400
1, 500	122	190	275	490
2, 000	140	220	315	570
3, 000	175	270	390	700
4, 000	200	310	450	800
5, 000	225	350	500	900
6, 000	245	380	550	980
7, 000	265	415	590	1, 060

(NOTE.—The diameters of the circles are proportional to $\sqrt{H}$.)

APPENDIX.

GENERALIZED THEORY OF SIGHTING.

The consideration of sighting questions, relating to either bombs or guns, is greatly simplified by the use of vectors. The procedure is to construct a vector diagram in such a way that the closing side of the diagram is the mean relative speed of the target to the bomb or projectile during its flight. If the bomb is released or the gun fired at the instant when this closing side is parallel to the line joining the target and the attacking machine, all corrections for deflection, own speed and drop are, *ipso facto*, automatically allowed for.

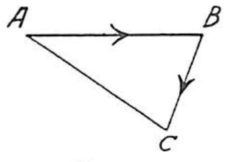

FIG. 9.

Thus, in Fig. 9, if AB is the vector representing the speed of the aeroplane relative to the target, BC the mean speed of the bomb relative to the aeroplane during its downward flight, then AC is the correct sighting line for releasing the bomb; note that the perpendicular to AB is inclined to BC at the trail angle, and to AC at the "bomb-sighting" angle. If the aeroplane were diving instead of flying horizontally, exactly the same principles would apply, but the triangle would then take the form shown in Fig. 10.

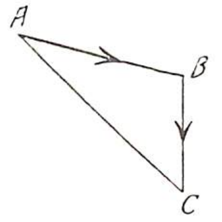

FIG. 10.

AB is parallel to the fore and aft line of the machine and its length proportional to the speed relative to the target; BC is parallel to the trail line and its length proportional to the mean speed of the bomb relative to the aeroplane; AC is the correct sighting line. It is obvious that the same construction would also apply to the case of a gun fired in the direction BC, the length of that line would, of course, then be proportional to the mean speed of the bullet or projectile relative to the aeroplane.

TABLE OF SIGHTING ANGLES.

Air-speed: 45 *m. p. h.*

Height (Feet).	Ground-speed: m. p. h.							
	10	20	30	40	50	60	70	80
	Ground-speed: Knots.							
	8.7	17.4	26.1	34.7	43.4	52.1	60.8	69.5
	°	°	°	°	°	°	°	°
500	8.8	17.7	25.7	32.9	39.1	44.4	48.8	52.6
1,000	6.0	12.5	18.7	24.5	29.8	34.6	38.9	42.7
2,000	4.0	8.7	13.3	17.7	21.9	25.9	29.6	33.0
3,000	3.1	7.0	10.8	14.5	18.1	21.6	24.9	28.0
4,000	2.5	5.9	9.2	12.5	15.7	18.8	21.8	24.7
5,000	2.1	5.2	8.2	11.1	14.1	16.9	19.7	22.3
6,000	1.8	4.6	7.4	10.1	12.9	15.5	18.1	20.5
7,000	1.6	4.2	6.8	9.3	11.9	14.3	16.8	19.2
8,000	1.4	3.8	6.3	8.6	11.1	13.4	15.7	18.0
9,000	1.2	3.5	5.9	8.1	10.4	12.6	14.8	17.0
10,000	1.1	3.3	5.5	7.7	9.9	12.0	14.1	16.2
11,000	1.0	3.1	5.2	7.3	9.4	11.4	13.5	15.5
12,000	0.9	2.9	4.9	7.0	9.0	10.9	12.9	14.9
13,000	0.8	2.7	4.7	6.7	8.6	10.5	12.4	14.3
14,000	0.7	2.6	4.5	6.4	8.3	10.1	11.9	13.8
15,000	0.6	2.5	4.3	6.2	8.0	9.8	11.5	13.3

Air-speed: 60 *m. p. h.*

Height (Feet).	Ground-speed: m. p. h.								
	20	30	40	50	60	70	80	90	100
	Ground-speed: Knots.								
	17.4	26.1	34.7	43.4	52.1	60.8	69.5	78.1	86.8
	°	°	°	°	°	°	°	°	°
500	17.5	25.5	32.8	39.0	44.2	48.7	52.5	55.7	58.5
1,000	12.2	18.5	24.3	29.6	34.4	38.7	42.6	46.0	49.0
2,000	8.5	13.0	17.5	21.7	25.7	29.4	32.9	36.1	39.1
3,000	6.7	10.5	14.2	17.8	21.3	24.6	27.8	30.7	33.5
4,000	5.6	9.0	12.2	15.4	18.5	21.5	24.4	27.2	29.8
5,000	4.8	7.9	10.8	13.7	16.6	19.4	22.0	24.6	27.1
6,000	4.2	7.1	9.8	12.5	15.2	17.8	20.3	22.7	25.0
7,000	3.8	6.4	9.0	11.5	14.0	16.4	18.8	21.1	23.4
8,000	3.5	5.9	8.3	10.7	13.1	15.4	17.6	19.8	22.0
9,000	3.2	5.5	7.8	10.1	12.3	14.5	16.7	18.7	20.8
10,000	2.9	5.1	7.3	9.5	11.6	13.7	15.8	17.8	19.8
11,000	2.7	4.8	6.9	9.0	11.1	13.1	15.1	17.0	19.0
12,000	2.5	4.5	6.6	8.6	10.6	12.5	14.5	16.3	18.2
13,000	2.3	4.3	6.3	8.2	10.1	12.0	13.9	15.7	17.5
14,000	2.2	4.1	6.0	7.9	9.7	11.6	13.4	15.2	16.9
15,000	2.1	3.9	5.8	7.6	9.4	11.2	12.9	14.7	16.4

NOTE.—Angles are measured from the vertical.

TABLE OF SIGHTING ANGLES.

Air-speed: 75 *m. p. h.*

Height (Feet).	Ground-speed: m. p. h.							
	40	50	60	70	80	90	100	110
	Ground-speed: Knots.							
	34.7	43.4	52.1	60.8	69.5	78.1	86.8	95.5
	°	°	°	°	°	°	°	°
500	32.6	38.9	44.1	48.6	52.4	55.7	58.5	60.9
1,000	24.1	29.4	34.3	38.6	42.4	45.9	48.9	51.7
2,000	17.2	21.5	25.5	29.2	32.7	35.9	38.9	41.7
3,000	14.0	17.6	21.1	24.4	27.6	30.5	33.3	36.0
4,000	11.9	15.2	18.3	21.3	24.2	27.0	29.6	32.1
5,000	10.5	13.5	16.3	19.1	21.8	24.4	26.9	29.2
6,000	9.5	12.2	14.8	17.4	19.9	22.4	24.8	27.0
7,000	8.7	11.2	13.6	16.1	18.5	20.8	23.1	25.2
8,000	8.0	10.4	12.7	15.1	17.3	19.5	21.7	23.7
9,000	7.4	9.7	12.0	14.2	16.3	18.4	20.5	22.4
10,000	6.9	9.1	11.3	13.4	15.5	17.5	19.5	21.4
11,000	6.5	8.6	10.7	12.7	14.7	16.7	18.6	20.5
12,000	6.2	8.2	10.2	12.1	14.1	16.0	17.9	19.7
13,000	5.9	7.8	9.7	11.6	13.5	15.4	17.2	19.0
14,000	5.6	7.5	9.3	11.2	13.0	14.8	16.6	18.3
15,000	5.4	7.2	9.0	10.8	12.5	14.3	16.0	17.7

Air-speed: 90 *m. p. h.*

Height (Feet).	Ground-speed: m. p. h.								
	50	60	70	80	90	100	110	120	130
	Ground-speed: Knots.								
	43.4	52.1	60.8	69.5	78.1	86.8	95.5	104.2	112.9
	°	°	°	°	°	°	°	°	°
500	38.5	43.8	48.4	52.3	55.5	58.3	60.7	62.8	64.7
1,000	29.1	33.9	38.3	42.2	45.6	48.7	51.5	53.9	56.1
2,000	21.1	25.1	28.9	32.4	35.6	38.6	41.4	44.0	46.4
3; 000	17.2	20.7	24.0	27.2	30.2	33.0	35.7	38.2	40.5
4,000	14.8	17.9	20.9	23.8	26.6	29.3	31.8	34.2	36.4
5,000	13.1	15.9	18.7	21.4	24.0	26.5	28.9	31.2	33.4
6,000	11.8	14.4	17.0	19.6	22.0	24.4	26.7	28.9	31.0
7,000	10.8	13.3	15.7	18.1	20.4	22.7	24.9	27.0	29.0
8,000	10.0	12.3	14.6	16.9	19.1	21.3	23.4	25.4	27.4
9,000	9.3	11.5	13.7	15.9	18.0	20.1	22.1	24.1	26.0
10,000	8.7	10.8	12.9	15.0	17.1	19.1	21.0	23.0	24.8
11,000	8.2	10.2	12.3	14.3	16.3	18.2	20.1	22.0	23.7
12,000	7.7	9.[illegible]	11.7	13.7	15.6	17.4	19.3	21.1	22.8
13,000	7.3	9.[illegible]	11.[illegible]	13.1	15.0	16.7	18.6	20.3	22.0
14,000	7.0	8.9	10.[illegible]	12.6	14.4	16.1	17.9	19.6	21.[illegible]
15,000	6.[illegible]	8.[illegible]	10.[illegible]	12.1	13.9	15.6	17.[illegible]	18.9	20.[illegible]

NOTE.—Angles are measured from the vertical.

TABLE OF SIGHTING ANGLES.

Air-speed: 105 *m.p.h.*

Height (Feet).	Ground-speed: m.p.h.							
	70	80	90	100	110	120	130	140
	Ground-speed: Knots.							
	60.8	69.5	78.1	86.8	95.5	104.2	112.9	121.6
	°	°		°	°	°	°	°
500	48.2	52.1	55.3	58.2	60.6	62.8	64.6	66.2
1,000	38.0	41.9	45.4	48.5	51.3	53.8	56.0	58.0
2,000	28.6	32.1	35.4	38.4	41.2	43.8	46.2	48.4
3,000	23.7	26.9	29.9	32.8	35.5	38.0	40.3	42.5
4,000	20.6	23.5	26.3	29.0	31.5	33.9	36.2	38.3
5,000	18.4	21.1	23.7	26.2	28.6	30.9	33.1	35.2
6,000	16.7	19.2	21.7	24.1	26.3	28.6	30.7	32.7
7,000	15.3	17.7	20.0	22.3	24.5	26.7	28.7	30.6
8,000	14.2	16.5	18.7	20.9	23.0	25.1	27.0	28.9
9,000	13.3	15.5	17.6	19.7	21.8	23.7	25.6	27.5
10,000	12.5	14.6	16.7	18.7	20.7	22.6	24.4	26.3
11,000	11.8	13.8	15.9	17.8	19.7	21.6	23.3	25.2
12,000	11.3	13.2	15.2	17.0	18.9	20.7	22.4	24.2
13,000	10.8	12.7	14.6	16.4	18.2	20.0	21.7	23.4
14,000	10.3	12.1	13.9	15.7	17.5	19.2	20.9	22.5
15,000	9.9	11.7	13.5	15.2	16.9	18.6	20.3	21.9

Air-speed: 120 *m.p.h.*

Height (Feet).	Ground-speed: m.p.h.								
	80	90	100	110	120	130	140	150	160
	Ground-speed: Knots.								
	69.5	78.1	86.8	95.5	104.2	112.9	121.6	130.3	139.0
	°	°	°	°	°	°	°	°	°
500	52.0	55.2	58.1	60.5	62.7	64.6	66.2	67.6	68.9
1,000	41.7	45.2	48.4	51.2	53.7	57.9	57.9	59.7	61.3
2,000	31.8	35.1	38.2	41.0	43.6	46.0	48.2	50.2	52.1
3,000	26.5	29.6	32.5	35.2	37.7	40.1	42.3	44.3	46.3
4,000	23.0	25.9	28.6	31.2	33.6	35.9	38.1	40.1	42.1
5,000	20.6	23.3	25.8	28.2	30.6	32.8	34.9	36.9	38.8
6,000	18.7	21.2	23.7	26.0	28.2	30.3	32.4	34.4	36.2
7,000	17.3	19.6	21.9	24.1	26.3	28.4	30.4	32.3	34.1
8,000	16.0	18.2	20.5	22.6	24.7	26.7	28.6	30.5	32.3
9,000	15.0	17.2	19.3	21.4	23.4	25.3	27.2	29.0	30.7
10,000	14.2	16.2	18.3	20.3	22.2	24.1	25.9	27.7	29.4
11,000	13.4	15.4	17.4	19.3	21.2	23.0	24.8	26.5	28.2
12,000	12.8	14.7	16.6	18.5	20.3	22.1	23.8	25.5	27.1
13,000	12.2	14.1	15.9	17.7	19.5	21.2	22.9	24.6	26.2
14,000	11.7	13.5	15.3	17.1	18.8	20.5	22.1	23.8	25.3
15,000	11.[illegible]	13.0	14.7	16.5	18.2	19.8	21.4	23.0	24.6

NOTE.—Angles are measured from the vertical.

Glossary of Terms.

Air-lag.—The horizontal distance at any height between the vacuum flight-path and the real flight-path of the bomb.

Air-speed.—The velocity of the aircraft relative to the air in which it moves.

Auxiliary Target.—Any object which is used for the purpose of setting the sight before the actual target enters the field of view.

Backsight.—A sighting rod or wire on a bomb-sight which has to appear in line with the foresight and the target at the correct instant for dropping the bomb.

Bomb-sight.—An instrument designed to indicate the correct instant at which a bomb should be released to strike the target.

C. F. S. Sight.—A sight embodying the C. F. S. scale, in which a variable distance on the ground is timed-over, according to a height-scale provided, and the resulting time applied to another scale by which the dropping-angle is directed set.

Drift-bar.—A wire or bar which can be set to indicate the direction of motion of the machine over the ground.

Drift-sight.—A bomb-sight in which the ground-speed is arrived at by noting the reading of the air-speed indicator and adding or subtracting the wind found by the drift-bar. The addition or subtraction is automatic.

Dropping-angle.—The angle between the vertical and the line joining the aeroplane to the target at the correct moment for release.

Equal-distance Sight.—A sight based on the principle that, under similar conditions, an aeroplane passes over equal distances in equal intervals of time.

Foresight.—The sighting rod or wire on a bomb-sight furthest from the observers eye.

Ground-lag.—The distance, measured on the ground, between the spot where a bomb falls and the spot where it would have fallen had the air offered no resistance to its motion.

Ground-speed.—The velocity of an aircraft in flight relative to the ground.

Lever Sight.—A bomb-sight in which the sights are mounted on a pivoted lever which can be set to the dropping-angle.

Line Error.—The perpendicular distance from the line of attack, of the point of impact of a bomb.

Low-height Sight.—A name given to the class of bomb-sights in which the altitude is too low to enable chronograph methods of sighting to be used. The sighting-wires are set to height and ground-speed, the latter being guessed or measured by the drift method.

Range Error.—The distance from the target, measured parallel to the line of attack, of the point of impact of a bomb.

Smoke Bomb.—A miniature bomb used for practice purposes or for making a spotting correction. It emits smoke on striking the ground.

Spotting Correction.—An adjustment of a bomb-sight based on an estimation of the error of a bomb previously dropped.

Tenuity Factor.—A correction employed in bomb-dropping calculations to allow for the decrease of atmospheric density with altitude.

Terminal Velocity.—The limiting speed of fall of a body, *i. e.*, the speed at which air resistance and weight exactly balance.

Time Lag.—The difference between the actual time of fall of a bomb and the time of fall from the same height in a vacuum.

Trail.—The horizontal distance which a bomb trails behind a vertical dropped from a uniformly moving aircraft.

Trail Angle.—The small angle by which the bomb as viewed from a uniformly moving aircraft appears to trail behind the vertical.

Trajectory.—The path of a falling bomb.

Tromboning.—A term given to the operation of measuring ground-speed by sighting on the actual target instead of on an auxiliary target.

Wind.—The velocity of the air relative to the ground.