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ATTAINMENT OF A STRAIGHT-LINE TRAJECTORY FOR A PRESET GUIDED MISSILE WITH SPECIAL REFERENCE TO EFFECT OF WIND OR TARGET MOTION

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MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

ATTAINMENT OF A STRAIGHT-LINE TRAJECTORY FOR A PRESET GUIDED MISSILE WITH SPECIAL REFERENCE TO EFFECT OF WIND OR TARGET MOTION

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SUMMARY

A study is made of the requirements for the attainment of a straight-line trajectory for a preset guided missile in the presence of wind or target motion. The analysis indicates that: (1) the straight-line trajectory that will hit a target is a path that is straight relative to axes fixed in the target, but not necessarily straight relative to axes fixed in the air; (2) the launching airplane should itself be on a straight-line collision course in order to establish the right direction of launching and the right intelligence for the preset guided missile; (3) the straight-line collision course is characterized by a constant direction in space for the line of sight to the target (termed infinite navigation); and (4) the automatic pilot in the missile should be arranged to oppose any acceleration normal to a direction established by the line of sight at launching, but any desired acceleration may be permitted parallel to the line of sight.

A simple bombsight mounting is proposed whereby the pilot of the launching airplane can attain the desired straight-line collision course by flying the airplane so as to keep the target on the crosshairs. Recommendation is made that this bombsight mechanism be constructed and tested in flight.

INTRODUCTION

It has been thought that bombing technique would be simplified in the extreme by arranging the missile to maintain a straight-line course along the direction of launching. The lack of curvature in the trajectory would appear to eliminate range as a variable. Presumably, the pilot would then have merely to dive along the line of sight toward the target and release his bombs at any time.

A proper picture, however, is not as simple as this. For example, a wind velocity is equivalent to a target velocity in the opposite direction. An airplane diving so as to keep a moving target in its sight (if the sight is not properly offset) flies the curved pursuit path of figure 1. A bomb released from any point on this path and arranged to maintain a straight-line course along the tangent will strike short of the target. Again, even if there is no wind, the bombsight must be inclined downward from the airplane fore-and-aft axis by the angle of attack of the airplane in order that the line of sight be along the line of flight. This would appear to impose the troublesome requirement of ascertaining the angle of attack accurately.

These are but two of a number of complicating factors. Nevertheless it is possible to utilize the principle of the straight-line trajectory in a bombing technique that comes close to the simplicity visualized in the opening paragraph. It is the purpose of this report to present an analytical study that forms the basis for such a bombing technique.

ANALYSIS

If wind is present, the term straight-line trajectory is ambiguous, for it is necessary to distinguish whether the frame of reference is attached to the ground or fixed in the moving air. A straight-line path relative to the air happens to be a straight path relative to the ground if the missile maintains constant speed. If the missile accelerates, and the path relative to the air is straight, the path relative to the ground will be curved, in general, and vice versa. It will be shown that the proper objective for the so-called straight-line missile of this report is a straight-line path relative to the ground (axes fixed in the target).

If the target is moving to the right it is as though the whole air mass were moving to the left relative to the target. Therefore, wind and target motion have equivalent effects. The remarks of the last paragraph may be generalized to apply when wind and target motion are both present by replacing the word "ground" wherever it occurs with the word "target". Only constant wind or target speeds will be considered.

The Launching Airplane

The bombing airplane must be on a suitable course in order to aim the straight-line missile into the target. At the top of figure 2 is shown the vector velocity diagram for an airplane in the proper diving course for the case of a headwind. In the middle of the figure are shown the paths of the airplane and the target relative to a frame of reference fixed in and moving with the air. At the bottom of the figure is shown the path of the airplane relative to a frame of reference fixed in the target. If the missile maintains the forward speed of the airplane and is permitted no normal acceleration, the figures will apply to the missile as well as to the airplane.

It is evident that the ground speed vector of figure 2 lies along the line of sight in all three diagrams and lies along the path in the bottom diagram. Furthermore, the line of sight maintains a constant direction in space. These properties are characteristic of what may be called a straight-line collision course.

The straight-line collision course has been treated in an unpublished report on some lateral paths of target-seeking aircraft relative to axes fixed in the air. The term constant navigation is applied to motion wherein the line of sight to the target makes a constant angle with the flight path. The term proportional navigation is applied to motion wherein the flight path turns through an angle that is n times the angle turned through by the line of sight. The parameter n is the navigation ratio. Evidently, for $n = \infty$ (infinite navigation, sometimes called 100 percent navigation) the line of sight must remain fixed in direction. Thus, the straight-line collision course is attained with infinite navigation. On the other hand, this same straight-line course is attained with constant navigation if the offset of the line of sight is just right; namely, that specified by the geometry of figures 1 and 2. To sum up, the straight-line collision course represents a general case of infinite navigation (if the target moves along a straight line with constant speed) and a special case of constant navigation.

Accelerating Missiles

Glide bombs may experience some longitudinal acceleration, depending on the speed and dive angle at launching, and bombs with rocket boost will, of course, experience a large acceleration. Figure 2 is still correct for the launching airplane and figure 3 applies to the accelerating missile. In figure 3 the acceleration of the missile is supposed to be constrained by an automatic pilot to lie along the proper direction to insure hitting the target. At the top of the figure is shown the vector velocity diagram for the missile at 0, 5, and 10 seconds after launching. In the middle are shown the paths of the missile and the target relative to the air with the extended path of the launching airplane dotted in for comparison. At the bottom are shown the paths of the missile and airplane relative to the target.

A significant feature is that the path of the missile relative to the air (fig. 3, middle) is curved by the acceleration, but the path relative to the target is a straight line (bottom). The only effect of the acceleration in this case is to cause the missile to reach the target sooner, and the trajectory relative to the target is along the same path as in figure 2 for the launching airplane and the constant-speed missile.

The initial ground-speed vector lies along the line of sight in figure 3 for the accelerating missile just as it does in figure 2 for the launching airplane and the constant-speed missile. The additional factor is that the acceleration of the missile (the velocity gained per unit time in fig. 3) is constrained to be along the line of sight. The line of sight is, in general, inclined to the fore-and-aft axis of the missile as in figure 3. Therefore, the acceleration must likewise be inclined to the fore-and-aft axis of the missile. This is a case of infinite navigation. It no longer fits the definition of constant navigation because the offset of the line of sight from the flight path varies continuously (fig. 3, middle).

Lateral Plane

The analysis has been illustrated by projections of the motion on the vertical plane. The same conclusions can be drawn from a consideration of projections of the motion on a horizontal plane. Figure 4 shows the horizontal projection of the straight-line collision course of which figure 2 shows the vertical projection. Here again it is seen that the ground-speed vector lies along the line of sight in all three diagrams, and lies along the path in the bottom diagram. Furthermore, the line of sight maintains a constant direction in space.

RESULTS AND DISCUSSION

It has been demonstrated that the straight-line trajectory that will hit a target is a path that is straight relative to axes fixed in the target. In the general case this path will be curved relative to axes fixed in the air.

Only straight-line paths that intersect the target are of interest, and these may be termed straight-line collision trajectories. The characteristic features of a straight-line collision trajectory (target axes) are: (1) the line of sight to the target maintains a constant direction in space; (2) the line of sight coincides with the trajectory relative to target axes; (3) the line of sight is, in general, offset from the tangent of the trajectory relative to air axes; and (4) the trajectory relative to air axes is straight only if there is no longitudinal acceleration of the missile, or no wind or target motion. Such a trajectory represents a case of so-called infinite navigation. If the speed doesn't vary it represents in addition a special case of constant navigation.

The bombing airplane should itself be on a straight-line collision course in order to establish the right direction of launching and the right intelligence for the preset guided missile. The automatic pilot in the missile should be arranged to oppose any acceleration normal to a direction established by the line of sight at launching. The insensitive axis of an integrating accelerometer control therefore should be alined parallel with the bombsight at launching, and the accelerometer should be gyro-stabilized to maintain this attitude during the flight of the missile. The response from integrated normal acceleration would be used for pitch control and the response from integrated lateral acceleration would be used for yaw control. These are navigational requirements and they leave out of account the additional requirements for stability. Means must be provided to compensate the force of gravity on the pitch element of the accelerometer.

Ordinarily a bombing pilot would execute his dive in such a way as to keep the target continuously on the cross-hairs of a fixed bombsight pointed directly forward. His path in the presence of wind or target motion would be the curved pursuit path of figure 1. If at some point along this path the sight were frozen in attitude so that it could not turn with the airplane, the target would start to drift off the crosshairs. In the attempt to bring the crosshairs back on target the pilot would probably cause the airplane to execute a path somewhat as shown in figure 5. The maneuvering would approximate infinite navigation. The latter portion of the path would be the desired straight-line collision course for the bombing airplane. This can be seen to be true because the attitude stabilization of the bombsight has enforced the condition that the line of sight to the target maintain a constant direction in space. A straight-line collision course is unique in complying with this condition.

The mechanism envisaged for the procedure of the last paragraph and its operation are as follows: A relatively heavy gyro is attached to the bombsight and the whole mounted with complete freedom about all three axes and carefully balanced. The gyro is initially caged with the bombsight approximately parallel to the longitudinal axis of the airplane. As soon as the pilot has maneuvered to bring the crosshairs on the target, he uncages the gyro. This act stabilizes the attitude of the bombsight and the sequence of events described in the last paragraph takes place. It is assumed that the bombing run will be sufficiently short so that gyro drift will cause little error.

As a matter of interest, it may be noted that figure 3, bottom, suggests the possibility of line-of-sight control. That is, once the parent aircraft has attained a straight-line collision course and released the missile the latter can be controlled by radio or radar to remain on the line of sight to the target. The missile will traverse the same straight trajectory contemplated with the accelerometer control. A practical limitation is the necessity for the parent aircraft to pull out well before the target is reached.

RECOMMENDATION FOR RESEARCH

It has been shown that the establishment of a straight-line collision course for the launching airplane is a logical prerequisite to the attainment of a straight-line trajectory for its missile. Wind or target motion require that the bombsight be offset in order to establish this collision course. The simple bombsight mechanism described in the last paragraph shows promise of enabling the pilot to attain the proper course by flying the airplane so as to keep the target on the crosshairs. It is recommended that such a bombsight mechanism be constructed and tested in flight.

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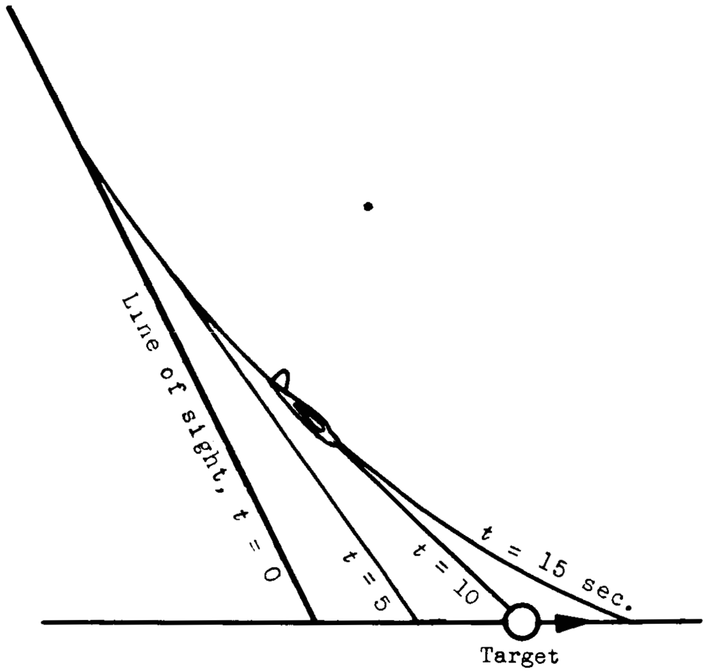

Figure 1.- Pursuit path due to wind or target motion.

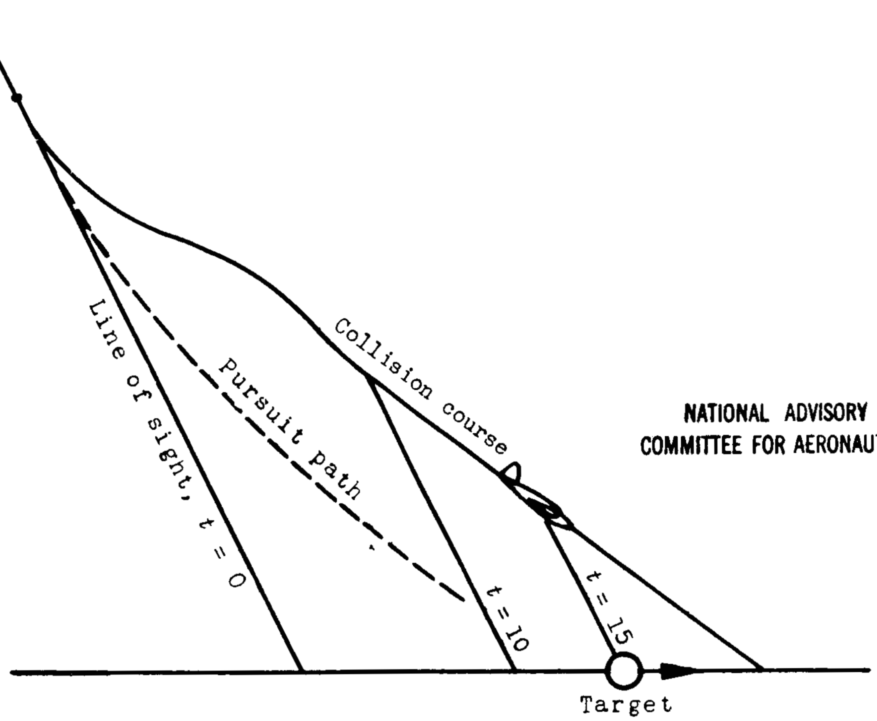

Figure 5.- Transition from pursuit path to collision course.

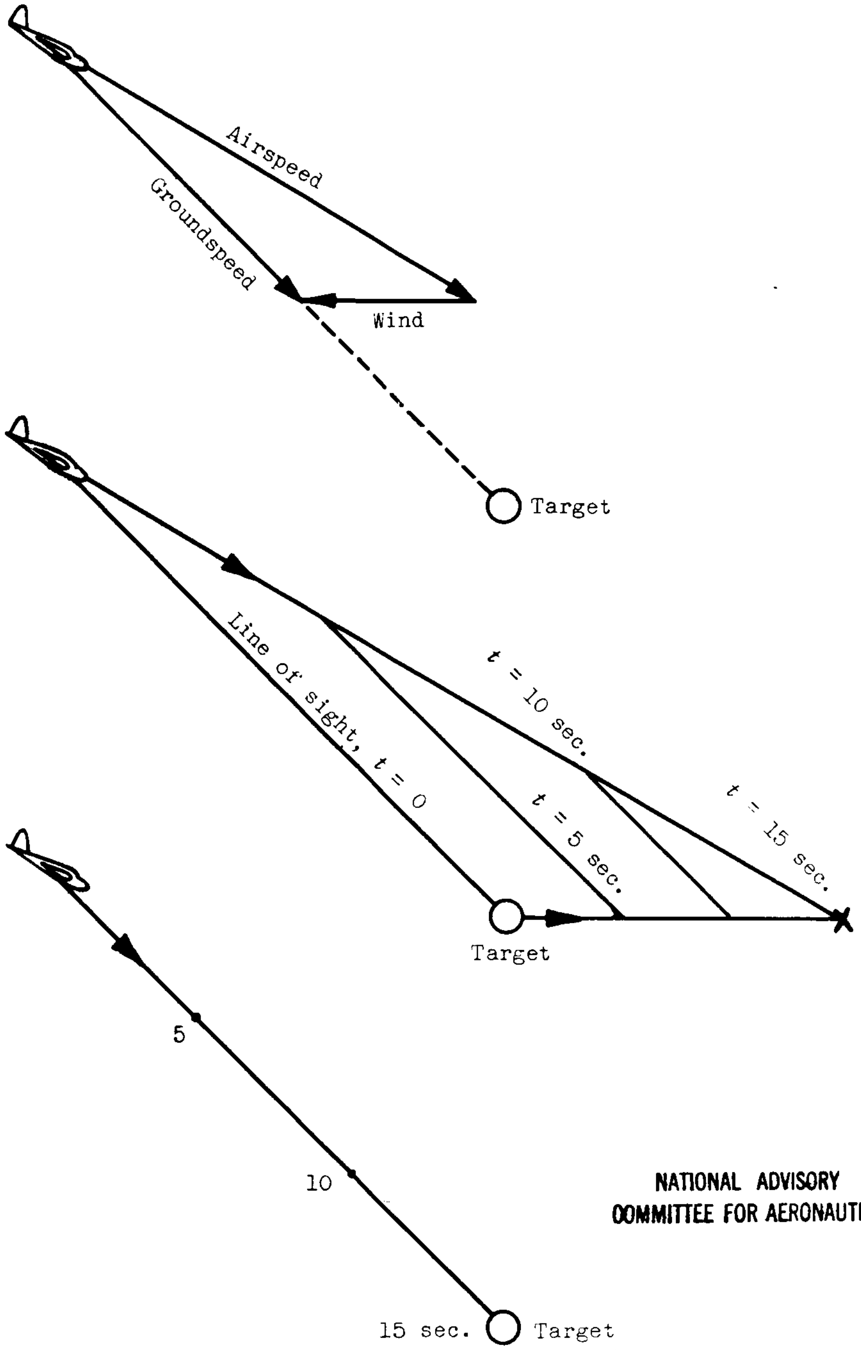

Figure 2.- Airplane on proper bomb-aiming course: projection in vertical plane. Top, composition of velocities. Middle, paths of airplane and target relative to the air. Bottom, path of airplane relative to the target.

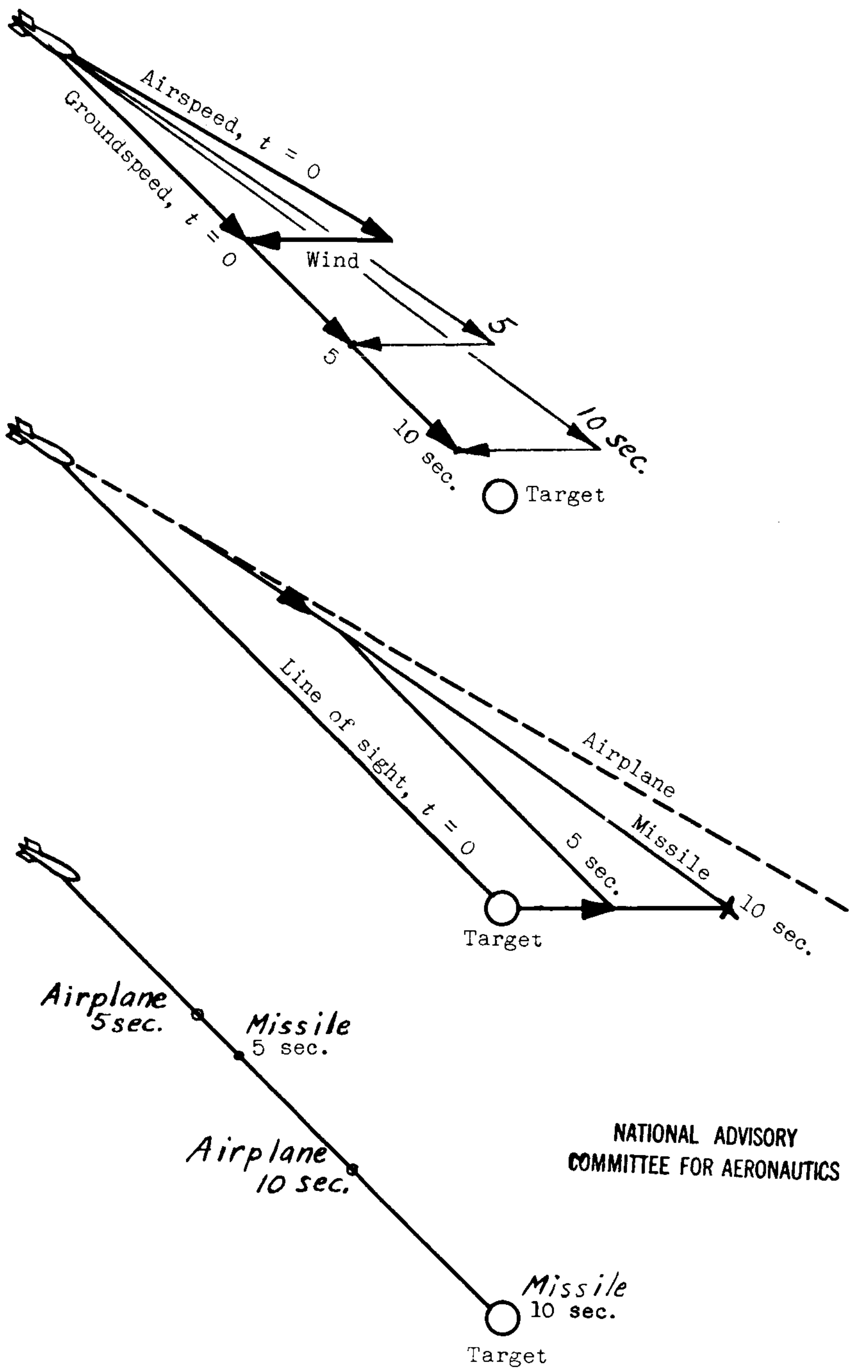

Figure 3.- Accelerating missile on straight-line trajectory: projection in vertical plane. Top composition of velocities. Middle, paths of launching airplane (extended), missile and target relative to the air. Bottom, paths of airplane and missile relative to the target.

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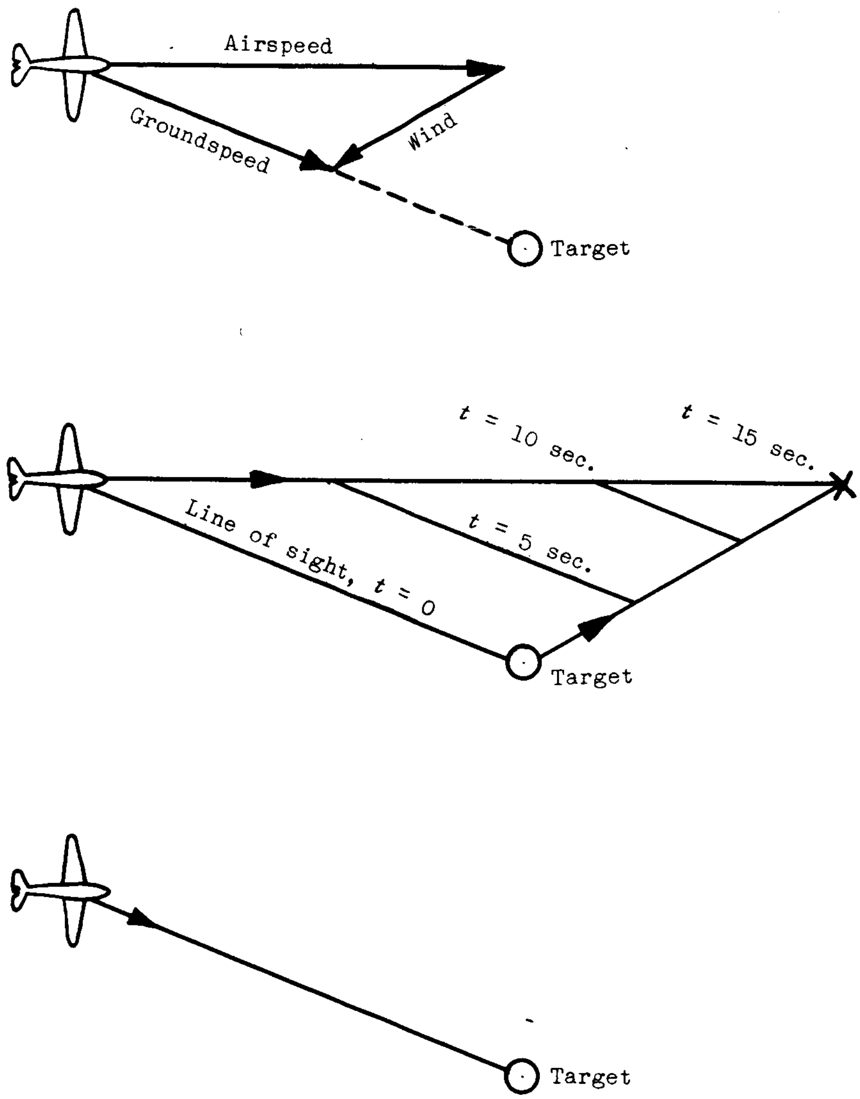

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Figure 4.- Airplane on proper bomb-aiming course; projection in horizontal plane. Top, composition of velocities. Middle, paths of airplane and target relative to the air. Bottom, path of airplane relative to the target.