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by Allen B. Henning, Reginald R. Lundstrom, and Jean C. Keating

Langley Research Center
Langley Station, Hampton, Va.

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SUMMARY

In order that the dispersion due to wind effects encountered in launching unguided rocket vehicles be compensated for, a method has been developed to calculate a launcher azimuth- and elevation-angle setting which would result in reaching the desired flight-path angle and heading angle at some point in space. This method employs predetermined charts, obtained from either a three-degree-of-freedom or a six-degree-of-freedom trajectory analysis capable of accounting for arbitrary wind velocities, to calculate the desired launcher settings. Actually, the wind-compensation method described herein needs only a single three-degree-of-freedom trajectory analysis for satisfactory results.

The effectiveness of this method is shown by the results obtained from the 12 Trailblazer-vehicle launchings discussed herein. Despite possible wind changes immediately before launch and dispersions caused by built-in discrepancies of the vehicles, this method has proved itself useful and accurate in obtaining the nominal trajectory requirements. Of the results from the 12 vehicles presented herein, 17 percent of the total were on the required nominal trajectory. Eighty-three percent of the total were within 4° azimuth and 1° elevation of the nominal trajectory angles. The remaining 17 percent were within 8° of the nominal azimuth and 2° of the nominal elevation. The results from a postflight simulation proved to be better than the actual flight results.

INTRODUCTION

As the range of unguided rocket vehicles is increased, deviations from the nominal trajectory can become a serious problem. It is necessary from a safety standpoint that the impact points of the various stages be accurately known. Also, in many cases the mission requirements dictate that the payload reentry be as close as possible to a predetermined position in order to obtain the desired data.

Quantities which cause dispersion from the nominal trajectory are wind, misalinement of the thrust vector or of booster fins, errors in setting the elevation and azimuth of the launcher, and variations in the weight, drag, thrust, and rocket impulse from the values used to compute the nominal trajectories. An investigation of the effects of these various parameters for a tandem-boosted vehicle showed that the greatest dispersion would come from wind, thrust misalinement, and fin misalinement. It also showed that a large static margin can reduce the effects of the misalinements but increase the effect of the wind. In some cases a combination of spin rockets and canted fins to induce roll may be used to reduce further the effect of misalinements. Since very little can be done about the misalinements, except to keep them small or induce roll, considerable benefit from a dispersion standpoint can be derived from a combination of a large static margin in the vehicle and a good wind-compensation method.

One of the early attempts at wind compensation for vehicles which are not launched vertically is mentioned in reference 1. A later method used for many vehicles is presented in reference 2, along with an extensive background on wind-compensation methods. The method of wind compensation presented in this report utilizes a simple three-degree-of-freedom trajectory analysis and shows that this simple analysis produces satisfactory results. The equations for this analysis are presented in appendix A. The method presented herein was originally produced for a reentry-physics program where much of the data obtained was from fixed cameras photographing the reentry. For this method, the altitude range is divided into a series of steps and the wind is assumed to have a constant velocity and direction for each step. The calculation for the launcher setting necessary to follow a certain nominal trajectory is made by the use of a series of predetermined charts, but the method is also adaptable to digital computers, as described in appendix B. This report also presents the results obtained by applying this wind-compensation method to 10 Trailblazer I vehicles and 2 Trailblazer II vehicles which were launched from NASA Wallops Station.

SYMBOLS

If conversion to the metric system is desired, it is assumed that:

1 U.S. foot = 0.3048006 meter
1 international statute mile = 1.6093440 kilometers
1 pound = 0.4536 kilogram

A,B,C,D computing-program constants determined from wind-compensation sensitivity factors for each step

C_A axial-force coefficient, $\frac{\text{Axial force}}{qS}$

C_l rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSd}$

C_{l_p} damping-in-roll derivative, $\frac{\partial C_l}{\partial\left(\frac{pd}{2V}\right)}$, per radian

C_{l_δ} roll derivative, $\frac{\partial C_l}{\partial \delta}$, per radian

C_m pitching-moment coefficient, $\dfrac{\text{Pitching moment}}{qSd}$

C_{m_q} damping-in-pitch derivative, $\dfrac{\partial C_m}{\partial\left(\dfrac{q'd}{2V}\right)}$, per radian

$C_{m_{\dot{\alpha}}}$ damping due to downwash lag on tail, $\dfrac{\partial C_m}{\partial\left(\dfrac{\dot{\alpha}d}{2V}\right)}$, per radian

C_N normal-force coefficient, $\dfrac{\text{Normal force}}{qS}$

C_{N_α} slope of normal-force curve, $\dfrac{\partial C_N}{\partial \alpha}$, per radian

d reference diameter, ft

g acceleration due to gravity, ft/sec^2

I_X moment of inertia in roll, slug-ft^2

I_Y moment of inertia in pitch, slug-ft^2

M Mach number

p rolling velocity, radians/sec

q dynamic pressure, lb/sq ft

q' pitching velocity, radians/sec

S reference area, sq ft

t time, sec

V velocity, ft/sec

W weight of vehicle, lb

X,Y,Z coordinate axis system of earth

x distance component in easterly direction, ft

y distance component in southerly direction, ft

α angle of attack, radians

γ	elevation angle or flight-path angle, deg
$\Delta\gamma$	change in elevation angle, deg
δ	fin deflection, radians
θ_l	launch angle which gives, with no wind, the same flight-path angle at maximum wind-compensation altitude as actual wind-influenced trajectory
$\Delta\theta_l$	difference between θ_l and desired nominal launch angle
$\Delta\psi$	change in ground azimuth angle, deg

Subscripts:

act	actual
corr	corrected
g	corrected for gravity
ref	referenced to flight-path angle at end of step
uncorr	uncorrected
y	yaw attitude

A dot above a symbol indicates the first derivative with respect to time.

WIND-COMPENSATION METHOD

The problem in wind compensation is not to predict the trajectory of a vehicle for a given launcher setting and wind-velocity profile, but rather to predict what launcher setting will give the desired trajectory. The wind-compensation method described hereinafter assumes that the effects of winds on the vehicle above the maximum wind-compensation altitude are negligible. The maximum wind-compensation altitude is the highest altitude to which the winds are taken into consideration. Thus, launcher settings which result in reaching the nominal flight-path angle (in both elevation and azimuth) at this maximum wind-compensation altitude should produce the desired impact point. It is further assumed that any difference between the actual and nominal values of altitude and horizontal distance up to this point will have a trivial effect. The following sections analyze the method of calculating the launcher settings from the measured wind profile that will give the desired trajectory.

Altitude Steps

The first consideration in this procedure, as in any wind-compensating procedure, is to decide upon the total altitude range the method must cover. This range is then divided into a number of steps within which the wind is assumed to have a constant speed and direction. The smaller the altitude range covered by each step, the larger the number of steps required; therefore, the constant-wind-per-step assumption is made more valid. However, the larger the number of steps, the greater the time required to calculate the launcher setting. In determining the number and ranges of the altitude steps needed for a particular vehicle, consideration of the altitudes of the thrusting and coasting periods should be made. Inasmuch as the wind-compensation results of thrust and coast are different, one step should not include parts of both, but rather the step should end or start at burnout or end or start at ignition. The maximum wind-compensation altitude in this report was determined by the end of a thrust period. This cutoff point should consider the high-velocity, high-altitude jet-stream winds, whether during coasting or thrusting, as in some cases the jet stream can be rather influential. The early part of the trajectory is much more sensitive to wind than the higher altitudes because of the lower velocity of the vehicle. Therefore, the low-altitude steps include a smaller altitude range, and the high-altitude steps include a larger altitude range. The selection of the number of steps, the altitude range for each step, and the maximum altitude for wind-compensation purposes depend on the characteristics of the vehicle and the trajectory for which the wind-compensation method is to be used.

Method of Analysis

The change in flight-path angle caused by a constant velocity head wind or tail wind was calculated for each altitude step. These flight-path calculations were made on an IBM 704 electronic data processing machine using the aerodynamic and mass characteristics of the vehicle in a three-degree-of-freedom program with the axial and vertical translations and pitch rotation as the three degrees of freedom. The equations used for the three-degree-of-freedom calculation are presented in appendix A.

After the method of wind compensation presented herein was developed, a six-degree-of-freedom computer program, described in reference 3, was devised for an IBM 704 electronic data processing machine. The program of reference 3 was used to calculate the effects of wind on the trajectory as a check on the results obtained when the simpler three-degree-of-freedom program was used, and it showed very good agreement. Therefore, a simple three-degree-of-freedom calculation can be used with good results for predetermining the sensitivity factors when a wind-compensation method similar to the method presented herein is used.

Computer runs were made with wind velocities of 0, 10, 20, and 40 feet per second for each step from both the front and rear of the vehicle. At altitudes above 5,000 feet, computer runs were also made for wind velocities of 80, 100, 160, and 200 feet per second. It was necessary to continue the computer runs for several seconds at zero wind velocity after the end of the step to allow the angle of attack to damp out to a value of zero. The change in flight-path angle for a given step was determined by plotting the flight-path angle against time for conditions both with and without wind and by calculating the difference in flight-path angle for that specific wind. This change in flight-path angle for a given step was plotted against wind velocity and found to be linear. The slope of this plot was used as the sensitivity factor for change in elevation angle for that step. Similarly, computer runs were made to determine the effects of yaw produced by various wind velocities. It was found for the trajectories of a particular vehicle that the angular change in yaw attitude between the trajectories with side wind and without wind was almost identical to the change in pitch angle between the trajectories with the same velocity head wind and without wind.

The change in azimuth angle may be found by projecting the change in yaw attitude angle onto the surface of the earth by the following equation:

$$\Delta\psi = \tan^{-1}\left(\frac{\tan \Delta\gamma_y}{\cos \gamma_{ref}}\right) \tag{1}$$

Since the change in pitch angle caused by a head wind is the same as the change in yaw angle caused by a side wind of the same velocity, the azimuth change may also be calculated by using the change in the flight-path angle; thus,

$$\Delta\psi = \tan^{-1}\left(\frac{\tan \Delta\gamma}{\cos \gamma_{ref}}\right) \tag{2}$$

A sensitivity factor (in degrees of change per foot per second of wind velocity) was determined for each of the steps in both azimuth and elevation from the plots previously made of change in flight-path angle against wind velocity. Since a wind from any direction may be divided into components along and normal to nominal flight azimuth (head and side winds), it is possible, with nothing more than these sensitivity factors, to compute correction angles on the assumption that the azimuth and elevation are independent of each other. Computation of correction angle in this manner would limit the corrections to small quantities for two reasons: (1) The azimuth sensitivity factor was determined with the assumption that the vehicle was flying at the nominal elevation angle. (2) If the azimuth correction were large, sizable errors would be introduced because the wind was split into components along and normal to the nominal azimuth, instead of the actual azimuth. This total azimuth correction or difference is often large.

The method presented herein has accounted for these two items, as follows. The first item was accounted for by making a cross plot to correct the azimuth change for change in elevation angle. The following approximate relationship is the actual equation used in the launcher-setting calculations for correcting the azimuth change:

$$\Delta\psi_{corr} = \Delta\psi_{uncorr}\left[\frac{\cos \gamma_{ref}}{\cos\left(\gamma_{ref} + \Sigma\Delta\gamma\right)}\right] \tag{3}$$

The need for this correction is shown by equation (1) and illustrated by the sketch of figure 1. The sketch shows that the azimuth change for the higher elevation angle is much greater than the azimuth change for the lower elevation angle. The change in yaw angle $\Delta\gamma_y$ from which these azimuth changes were calculated is the same for both cases. The second item is accounted for by starting with the highest altitude step and calculating the changes in azimuth and elevation angles at the same time for each step. The changes in elevation angle were accumulated as the calculation progressed from step to step; this procedure made it possible to use a plot to correct azimuth change for any difference between the actual elevation angle and the nominal elevation angle. Also, by summing the changes in azimuth angle to give the actual azimuth for each step as the calculation progressed, it was possible to use the angle between the wind and the actual azimuth instead of the nominal azimuth when dividing the wind into components.

A plot of the percent of change in total flight-path angle with altitude for a constant wind was made to illustrate the effectiveness of the winds on the vehicle throughout the altitude range of wind correction. One hundred percent of the change in total flight-path angle represents the total change that is realized from the ground to the maximum wind-compensation altitude for a constant wind velocity. Other points on the curve are determined by starting the constant wind velocity at different altitudes and calculating the change in flight-path angle from these altitudes to the maximum wind-compensation altitude. An example of this type of plot is presented in figure 2. The figure shows that the wind has a much lesser effect on the flight path during coasting flight than during powered flight. During flight the vehicle alines itself with the relative wind instead of the flight path. During the coasting flight, the vehicle merely drifts with the wind; however, during powered flight this relative wind alinement results in a thrust vector misalinement with the flight path. Since the thrust is large compared with the drag, the resulting deviation in the flight path for powered flight is in an opposite direction from the drift and is much larger. Figure 2 was used only as a guide in determining the ranges of the altitude layers.

After the launcher setting has been determined from the accumulated change in azimuth and elevation angles, a further adjustment can be made to account for the trajectory dropoff due to gravity from a change in launcher elevation angle. Gravity will decrease the flight-path angle a smaller amount at higher elevation angles than at lower elevation angles, and this effect is more pronounced at a lower velocity than at a higher velocity. Lower thrust accelerations cause much more of the altitude range to be traversed at a lower velocity than do the higher thrust accelerations; thus a greater trajectory dropoff due to gravity occurs. The gravity correction, which reduces the overall launcher correction, was applied to the final elevation setting of the launcher by the following empirical relationships:

$$\gamma_{launch} = \gamma_{nominal} + \left(\Sigma\Delta\gamma + \Delta\gamma_g\right) \tag{4}$$

where

$$\Delta\gamma_g = \left[\frac{\cos\left(\gamma_{ref} + \Sigma\Delta\gamma\right)}{\cos\gamma_{ref}} - 1\right]\Delta\gamma_{ref} \tag{5}$$

and

$$\Delta\gamma_{ref} = \text{Nominal launch angle} - \gamma_{ref}$$

Equation (5) for $\Delta\gamma_g$ may be transposed to give

$$\frac{\Delta\gamma_g + \Delta\gamma_{ref}}{\Delta\gamma_{ref}} = \frac{\cos\left(\gamma_{ref} + \Sigma\Delta\gamma\right)}{\cos\,\gamma_{ref}}$$

In words this equation says that

$$\frac{\Delta\gamma_{ref}\ \text{with gravity correction}}{\Delta\gamma_{ref}\ \text{without gravity correction}} = \frac{\text{Gravity component normal to flight path for}\ \gamma_{ref} + \text{wind corrections}}{\text{Gravity component normal to flight path for}\ \gamma_{ref}\ \text{without wind correction}}$$

It appeared that some such relationship as the one just mentioned should provide an adjustment in the right direction. By the use of many different wind profiles, comparisons were made between the trajectory as obtained from the six-degree-of-freedom program and from the wind-compensation method. Trials were made by correcting the steps individually and also by applying the gravity correction after all adjustments for wind had been made.

Equation (4) proved to give very close results when applied after summation of the wind corrections for the various steps had been made.

APPLICATION TO TRAILBLAZER VEHICLES

Vehicle Description

The wind-compensation system described herein has been used primarily on the Trailblazer reentry-physics research vehicles. The Trailblazer I vehicle is a six-stage, solid-fuel, rocket test vehicle which expends the first three stages to obtain altitude, and, after the apogee of the trajectory, the three remaining stages are fired in succession back into the atmosphere to obtain a high velocity for reentry of the sixth-stage payload. Similarly, Trailblazer II is a four-stage vehicle incorporating two stages to obtain altitude and, after apogee, utilizes the remaining two stages to obtain a high reentry velocity for the payload back into the atmosphere. Spin rockets and canted first-stage fins are used on Trailblazer I to reduce the effects of fin and thrust misalinement by spinning the vehicle to about 1 revolution per second directly after it has cleared the launcher. The third-stage fins are also canted to spin the vehicle to about 10 revolutions per second so that it will be spin stabilized as it leaves the atmosphere. Spin rockets were not used on the Trailblazer II vehicle. However, this vehicle does use cant in the second-stage fins to spin the vehicle to 10 revolutions per second for spin stabilization above the atmosphere. A photograph of these two vehicles on the launcher is presented in figure 3, and sketches, including the principal dimensions, are shown in figure 4. The aerodynamic and mass parameters for Trailblazer I are presented in tables I and II, respectively, and for Trailblazer II in tables III and IV, respectively. The aerodynamic parameters were calculated by use of the theory of reference 4 and checked against experimental data of references 5 and 6 for Trailblazer I and references 7 and 8 for Trailblazer II.

The nominal azimuth for Trailblazer I vehicles was to be 150° with respect to the launcher. Since most of the trajectory was out of the atmosphere, rotation of the earth was taken into consideration, and, in order to have a nominal azimuth of 150° at apogee, the vehicle would have to be launched at 148° azimuth. Trailblazer Ib to Trailblazer Ig were launched with 148° as the nominal azimuth. With the remaining vehicles the earth rotation was neglected since the 2° difference is small compared with errors in wind compensation, misalinements, and dispersion resulting from the ignition of the downward firing stages.

Determination of Altitude Steps and Compensation Factors

In order to compensate for the effects of winds on the Trailblazer vehicles described herein, trajectory computations for each vehicle were completed so that the proper altitude steps and the sensitivity factors could be determined. With the use of the aforementioned computer programs and the aerodynamic and mass characteristics of each vehicle, trajectories were calculated for a nominal elevation angle. During the first portion of each flight there is an instant when the aerodynamic parameters are nonlinear due to the relative wind moving across the vehicle at very high angles of attack. This nonlinearity is taken into account by adjusting the normal-force-curve slope for low Mach numbers as stated in table I when the three-degree-of-freedom program was used and by using the tabulated values of the aerodynamic coefficients for high angles of attack at low Mach numbers in table III when the six-degree-of-freedom program was used.

Eleven steps were used between the altitudes of 27 to 84,000 feet for Trailblazer I. The altitude range at each step was determined by using figure 2(a) and the periods of rocket burning and coasting as a basis. Six steps were used for the first-stage burning with small increments near the ground, two steps for a coasting period, one step for the second-stage burning, one step for another coasting period, and one step for the third-stage burning. The altitude ranges selected for the various steps are listed in table V. The sensitivity factors in both elevation and azimuth were then determined for each of the altitude steps as described in a previous section entitled "Method of Analysis." The sensitivity factors are plotted as changes in launch azimuth angle and launch elevation angle against the effective wind velocity on the left-hand side of figures 5(a) and 5(b), respectively. The effective wind velocity is the component of the wind velocity in the direction of flight for elevation corrections or is normal to the direction of flight for azimuth corrections. If the sensitivity factor is associated with a coasting period, the sign of the factor is negative; if the vehicle is in powered flight, the sign is positive. By the use of the right-hand side of figures 5(a) and 5(b), the effective wind velocities can be calculated by a plot of a family of straight lines that represent the wind velocity times the sine of the effective wind direction in figure 5(a), and the wind velocity times the cosine of the effective wind direction in figure 5(b). In a vast majority of cases, winds will not exceed 140 feet per second; therefore, figures 5(a) and 5(b) are limited to that wind velocity. In some cases the high-altitude jet-stream winds exceed this value but only affect one step in the calculation for a launcher setting. It is believed that instead of extending the plot to include these rare cases of winds exceeding 140 feet per second, these cases could be calculated by slide rule. The effective wind direction is the angle between the direction from which the wind is blowing and the direction of the vehicle heading. A left wind, with respect to the vehicle heading, and a head wind have a position sign, whereas a right wind and a tail wind have a negative sign. The sensitivity-factor signs and the wind-direction signs are used together algebraically to obtain the sign of the launcher angular change for each step. The positive sign of the launcher angular change increases the launcher elevation- and azimuth-angle settings, whereas a negative sign decreases the settings. The azimuth change was corrected for change in elevation angle by using equation (3). This equation is plotted in figures 5(c) and 5(d) so that the corrected azimuth can be read directly from the plot for the steps most influenced by this correction. Several steps were grouped into one plot to simplify correction; however, a separate plot could be made for each step for more accuracy. The sensitivity factors and azimuth-change corrections presented herein are all based on a nominal elevation-angle trajectory of 80°. A different set of curves would be used for any other nominal elevation-angle trajectory.

For Trailblazer II, 17 steps were used between the altitude of 26 to 83,000 feet or through the first-stage burning. Fifteen divisions were made; the high-altitude division was further divided into three equally weighted parts in order to prevent the highest altitude step from covering such a large altitude range. These 15 altitude divisions were determined by dividing the altitude range into layers such that for a constant wind velocity there would be the same correction in flight-path angle for each step. Though it was not at all necessary to the wind-compensation method to have equal sensitivity for each of the steps, the method did make hand calculation of the wind-compensation procedure somewhat easier and faster. The altitude ranges for each step are listed in table V. The sensitivity factors that were determined are presented in figures 6(a) and 6(b) as launch-angle change in azimuth and elevation against effective wind velocity. The right-hand sides of figures 6(a) and 6(b) have the same sign convention and purpose as figures 5(a) and 5(b). Since there are no coasting periods in the calculations for Trailblazer II, all the sensitivity factors have a positive sign. The plots of azimuth correction due to change in elevation angle are presented in figures 6(c), 6(d), and 6(e). An additional plot made from equation (4) for gravity correction is presented in figure 6(f) and is used as a final correction for elevation angle. The sensitivity factors, correction in azimuth change, and gravity correction presented herein are all based on a nominal elevation-angle trajectory of 80°.

Wind-Compensation Procedure

After the average wind velocity and azimuth have been determined from the measured wind profile for each altitude step, calculations of the launcher elevation angle and azimuth angle can be started. Wind corrections start with the highest altitude step considered and the flight-path angle is calculated for both elevation and azimuth that must exist at the beginning of the step (lowest altitude of step), for the particular wind value, in order that the nominal values of the flight-path angle will exist at the end of the step (highest altitude of step). This flight-path angle in azimuth and elevation at the beginning of the highest altitude step, then, must also be the value at the end of the next lower altitude step. The flight-path angles for the beginning of this second step are then calculated in like manner. This procedure continues for each step to the ground level. The usage of the wind-compensation charts of figures 5(a) and 5(b) is illustrated by selecting and introducing into the right-hand side of the figure an effective wind direction from the left side of the vehicle of 33° and a wind velocity of 88 feet per second. The progress of these numbers through the charts is shown by the dashed lines with arrows. Inasmuch as the sensitivity factor of the first step is used with this wind direction and velocity, the change in launch azimuth is shown to be 3.6°, while the change in launch elevation is 2.06°. The elevation change is not added to the nominal elevation angle at the end of each step but is accumulated to obtain total elevation change. The change in launch azimuth is added to the azimuth of the previous step after the azimuth change has been corrected for the change in total elevation from the charts of figures 5(c) and 5(d). When the azimuth change is large, an iteration process is made using the new azimuth as the vehicle heading, and the procedure is repeated again for that step. At the completion of all the steps, the last azimuth number is the launcher setting, whereas the last total elevation change has to be added to the nominal launch elevation angle to obtain the wind-corrected launch elevation angle. A form that was used for the Trailblazer I launcher-setting calculation is presented in table VI. Included in this form is a typical launcher-setting calculation illustrating the procedure described herein. The same procedure is followed for Trailblazer II by using the charts of figure 6. A correction for gravity is applied to the wind-corrected launch elevation angle by the use of figure 6(f), and this result is the launcher elevation-angle setting. Because of the higher acceleration of Trailblazer I which permitted less flight-path dropoff during the first few seconds of flight, it was believed that there was no need for the gravity correction on that vehicle.

RESULTS AND DISCUSSION

The wind-compensation method described in the foregoing section entitled "Wind-Compensation Method" has been used on 10 Trailblazer I and 2 Trailblazer II vehicles with satisfactory results. This section presents the preflight wind-profile data and the vehicle flight trajectories obtained by using the method presented herein. Also presented are the theoretical six-degree-of-freedom trajectory calculations for each case using the measured wind profile and actual launcher settings.

Wind Profiles

Three hours before the flight time of each vehicle, a high-altitude balloon, capable of being tracked by radar, was released in order to establish the wind velocities and directions above 18,000 feet. This balloon can reach an altitude of about 80,000 feet in approximately 90 minutes. At 90 minutes before launch, another balloon is released to remeasure the winds up to 18,300 feet. A final balloon is released 40 minutes before launch and tracked up to 5,000 feet. The selection of the types of balloons used, the methods of tracking and recording the balloon runs, and the actual reduction of wind velocity and azimuth data from the balloon runs were developed and performed by members of the NASA Wallops Station. Wind readings from the anemometer tower at 50-foot levels up to 250 feet are used and monitored constantly until launch time. The latest available wind data were used for calculating the launcher setting and these wind data are presented in figure 7 in the form of velocity and azimuth as a function of altitude. The wind data for Trailblazer Ib, Trailblazer Ic, and Trailblazer Id (figs. 7(a), (b), and (c)) go only to an altitude of 60,000 feet because, for these vehicles, winds during the third-stage burning were not accounted for. The later Trailblazer I vehicles were compensated for winds through third-stage burning, or to 84,000 feet. Trailblazer II was compensated for winds only through the first-stage burning to an altitude of 83,000 feet. The actual numbers that are used from the wind profile are the average velocity and direction over the altitude range for each step.

Flight-Test Results and Postflight Simulation

The results for 10 Trailblazer I and 2 Trailblazer II vehicles are presented in figures 8 and 9. Figure 8 shows plots of the trajectory and figure 9 shows time histories of flight-path angle and flight heading angle relative to the launcher. Also included in these figures is a theoretical trajectory from a six-degree-of-freedom calculation using the aerodynamic and mass parameters presented in tables I, II, III, and IV and the measured wind velocity and direction profiles.

The optical requirements for a Trailblazer flight are very severe, and often, on a night when optical conditions are favorable, compromises for other conditions must be made. For example, if range safety personnel determined that the winds were too high for an elevation-angle launch of 80° but would allow a nominal launch angle of 78° or 79°, the decision might be made to take advantage of the good optical conditions and launch at a lower elevation angle. Likewise, when there were ships in the booster impact areas, the decision might be made to alter the launch azimuth rather than relinquish the good optical conditions. In some cases, when there was a long hold in the countdown, the wind data became several hours old. In such cases another balloon was usually released only if it did not delay the launching. Some degree of inaccuracy is involved due to wind changes which take place between the balloon ascent and the launch time, even when no holds in the countdown existed. Changes necessary to the nominal flight elevation and azimuth, balloon release times, vehicle launch time, and actual flight elevation and azimuth heading angles are presented in table VII for all 12 vehicles.

From observation of figures 8 and 9 and table VII, even though in some instances late wind changes and possibly insufficient thrust from the rocket motors occurred, it can be seen that this wind-compensation procedure is very effective. Eighty-three percent of the results shown herein are within an azimuth angle of 4° and an elevation angle of 1° from the nominal. Seventeen percent of the examples included in this 83 percent show perfect results; that is, the nominal in either azimuth or elevation angle is reached. The remaining 17 percent are within 8° azimuth and 2° elevation from the nominal angles. These results could be improved with the use of wind-profile data that are closer to launch time. Care was taken to get the most recent winds, but because of the time involved in obtaining wind data, determining the launcher setting, and setting the launcher, the accuracy of the wind data has decreased. The unscheduled holds which occur for various reasons that are too short for further wind calculation also increase the age of the winds used in this wind-compensation method to obtain the launcher setting.

The actual change in flight path of the vehicle was the result not only of wind but also of thrust and fin misalinements. As mentioned previously, differences between the winds actually encountered during the flight and the wind velocities used in the wind-compensation method also may have been present. In an effort to obtain an evaluation of the method on the basis of wind correction alone, a comparison has been made between the launch corrections as obtained from the wind-compensation method and the actual change in flight-path angle obtained from the postflight simulation calculations made with a six-degree-of-freedom program. This comparison is presented in figure 10 for both pitch and yaw as a plot of the correction applied to the launcher against the change due to wind as calculated by the postflight simulation for each Trailblazer I and II vehicle. Also shown are some Shotput data from reference 2 that have been calculated in the same way. These points are presented herein in order to give some comparison between the present method of wind compensation and the method of reference 2. Each vehicle presented in figure 10 is represented by a different data symbol, and information concerning the weighted wind velocity and direction is also included. Figure 10(a) shows the comparison of change in elevation angle applied to the launcher to compensate for winds and change in elevation angle as determined by the postflight simulation. Similarly, figure 10(b) shows the comparison of azimuth change applied to the launcher to compensate for winds and the azimuth change obtained from the postflight simulation. This comparison indicates better agreement in the elevation corrections when the method of reference 2 is used and about the same agreement in azimuth between the two methods. It should be mentioned that in the case of either method better agreement with postflight simulation can be obtained by increasing the number of altitude level steps. The Trailblazer results from figure 10, which are independent of the effects of fin and thrust misalinement, show better agreement between the launcher compensation used and the change obtained from the postflight simulation than the similar comparison from the actual flight results.

CONCLUDING REMARKS

The method of wind compensation developed and presented herein can use, with good results, simple three-degree-of-freedom trajectory analysis to obtain the sensitivity factors needed in order to determine the proper wind-adjusted launcher settings for unguided rocket vehicles.

This wind-compensation method, using winds that were measured up to about 80,000 feet prior to vehicle launch, has been applied to 12 Trailblazer vehicles. Of the results from the 12 vehicles presented herein, 17 percent of the total flight results were on the required nominal trajectory. Eighty-three percent of the total flight results were within an azimuth angle of 4° and an elevation angle of 1° of the nominal trajectory. The remaining 17 percent were within 8° of the nominal azimuth and 2° of the nominal elevation. The results from using the measured wind data and the corrected launcher settings in a six-degree-of-freedom computer program are independent of fin and thrust misalinements and these postflight simulation results proved to be better than the actual flight results.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., September 20, 1963.

APPENDIX A

THREE-DEGREE-OF-FREEDOM EQUATIONS

The following list of symbols are those not previously mentioned in the symbol section:

a_l	longitudinal acceleration, ft/sec^2
a_n	normal acceleration, ft/sec^2
c	reference length for damping term, ft
l	distance between center of gravity and center of pressure, ft
m	mass, slugs
T	thrust, lb
$\dot{\theta}$	pitch velocity, radians/sec
$\ddot{\theta}$	pitch acceleration, radians/sec^2
ϕ	angle between horizontal and relative wind, deg
V_f	velocity along flight path, ft/sec
V_w	wind velocity, ft/sec

The basic three-degree-of-freedom equations for pitch used herein are:

Axial translation -

$$ma_l + mg \sin \gamma = T \cos \alpha + C_{N_\alpha} qS \sin(\gamma - \phi) - C_A qS \cos(\gamma - \phi) \tag{A1}$$

Vertical translation -

$$ma_n + mg \cos \gamma = T \sin \alpha + C_{N_\alpha} \alpha qS \cos(\gamma - \phi) + C_A qS \sin(\gamma - \phi) \tag{A2}$$

Pitch rotation -

$$I_y \ddot{\theta} = C_{N_\alpha} qSl + C_{m_q} qSc \frac{\dot{\theta} c}{2V} \tag{A3}$$

The winds, either head wind or tail wind, were introduced into these equations by the following auxiliary equations:

$$\phi = \tan^{-1}\left(\frac{V_f \cos \gamma}{V_f \cos \gamma + V_w}\right) \tag{A4}$$

and

$$V = \sqrt{V_f^2 + V_w^2 + 2V_f V_w \cos \gamma} \tag{A5}$$

The head winds had a positive sign and the tail winds, a negative sign.

The vehicle was assumed to be aerodynamically and inertially symmetrical about its longitudinal axis; therefore, in considering winds from the side, the lateral and yaw parameters and angle were considered to be of the same value as the vertical and pitch parameters and angles.

In the case of yaw, the axis system was considered rotated 90° with the wind approaching the vehicle from the side (a wind from the right side had a positive sign and a left wind had a negative sign). Since the vehicle was assumed to be aerodynamically and inertially symmetrical about its longitudinal axis, the lateral and yaw parameters and angles were considered to be of the same value as the vertical and pitch parameters and angles. Therefore, the symbols in the following equations are the same as those used in the previous equations, even though the equations are used in a different sense. The equations used in the case of a side wind are:

Lateral translation, using axial-translation nomenclature -

$$ma_n = T \sin \alpha + C_{N_\alpha} \alpha q S \cos\left(\gamma_y - \phi_y\right) + C_A q S \sin\left(\gamma_y - \phi_y\right) \tag{A6}$$

Yaw rotation -

$$I_y \ddot{\theta} = C_{N_\alpha} \alpha q S l + C_{m_q} q S c \frac{\dot{\theta} c}{2V} \tag{A7}$$

with the winds introduced by

$$\phi_y = \tan^{-1}\left(\frac{V \sin \gamma_y - V_w}{V \cos \gamma_y}\right) \tag{A8}$$

and

$$V = \sqrt{V_f^2 + V_w^2 - 2V_f V_w \sin \gamma_y} \tag{A9}$$

Time histories of the velocity, altitude, and flight-path angle calculated from the pitch equations must be introduced into the calculations for the case of yaw.

APPENDIX B

COMPUTER PROGRAMING OF THE TRAILBLAZER WIND-COMPENSATION METHOD

In order to speed up the calculation of the launcher setting, the method as described in the text was incorporated into a computer program. It was deemed necessary for comparative purposes to program the computer so that the calculations done by the computer were the same as would be done by hand when the charts presented in the text were used. Therefore, the slopes of the curves for the various sensitivity factors were taken from the charts and used in the computer program.

The equations used for the calculation of the change in azimuth and elevation angles were as follows. For azimuth change,

$$\Delta\psi = AV_{w,az}^{3} + BV_{w,az} \tag{B1}$$

and for elevation change,

$$\Delta\gamma = CV_{w,el}^{3} + DV_{w,el} \tag{B2}$$

where $V_{w,az}$ is the effective wind velocity blowing from the left or right side of the vehicle for change in azimuth angle and where $V_{w,el}$ is the effective wind velocity blowing from the nose or tail for change in elevation angle.

A third-degree equation was used in order to account for any nonlinearity in the sensitivity factors associated with a particular vehicle. The constants A and C, in the case of the Trailblazer vehicle, were zero because, for the range of values used, the sensitivity factors had constant slopes. The constants B and D are tabulated for each step in table VIII for both vehicles, Trailblazer I and Trailblazer II.

A complete calculation is made for each step including correction of the azimuth change for a total change in elevation angle by the following relationship:

$$\Delta\psi_{corr} = \Delta\psi_{uncorr}\left(\frac{\cos\gamma_{ref}}{\cos\gamma_{act}}\right) \tag{B3}$$

where γ_{act} is the actual accumulated elevation angle corrected for wind for the particular step involved, and γ_{ref} is the flight-path angle at the end of each step that the vehicle should have attained when flying at the nominal elevation-angle trajectory. The constants γ_{ref} are also tabulated in table VIII for each step for both vehicles.

A further correction to the accumulated result of the elevation angle is made in the case of the Trailblazer II. This correction is for the change in gravity dropoff because of a change in elevation angle from the nominal. The following equation is adapted to the program:

$$\Delta\gamma_g = \left[\frac{\cos\left(\gamma_{ref} + \Sigma\Delta\gamma\right)}{\cos\,\gamma_{ref}} - 1\right]\Delta\gamma_{ref} \tag{B4}$$

The results from this equation are subtracted from the accumulated elevation angle and used as the elevation-angle launcher setting.

Because of the availability of an IBM type 650 electronic data processing machine at the launch site, a computer program (Bell Telephone Laboratories file number 2.0.008) was developed and used for both the Trailblazer vehicles. This program was written in the L_2 language which was applicable to the IBM type 650 electronic data processing machine. A block diagram of the program as used for the Trailblazer II is shown in figure 11. The computing time was found to be around 5 seconds per step, or 55 seconds for the Trailblazer I program and 85 seconds for the Trailblazer II program.

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TABLE I

AERODYNAMIC PARAMETERS FOR THE TRAILBLAZER I

M	$C_{N_\alpha}S$	$C_A S$	$C_{l_p} \frac{d^2}{2} S$	$C_{l_\delta} \delta S d$	$C_{m_q} \frac{d^2}{2} S$	$C_{m_{\dot{\alpha}}} \frac{d^2}{2} S$	Center of pressure
First stage, second stage, third stage, and velocity package							
0	*105.43	2.03	-264.97	-0.9494	-27,160	-2,716	42.545
.8	105.43	2.03	-282.64	-1.0106	-27,160	-2,716	42.545
1.0	114.60	3.68	-362.13	-1.2958	-31,057	-3,106	42.287
1.2	107.15	3.39	-362.13	-1.2958	-33,119	-3,312	42.195
1.4	97.64	3.14	-335.63	-1.2021	-35,182	-3,518	42.104
1.6	89.16	2.96	-309.13	-1.1043	-37,256	-3,726	42.017
1.8	82.34	2.77	-290.00	-1.1000	-35,813	-3,581	41.917
Second stage, third stage, and velocity package							
0	36.67	0.86	-18.25	0	-3,783	-756.6	28.33
.8	36.67	.86	-18.25	0	-3,783	-756.6	28.33
1.0	50.02	1.76	-24.55	0	-4,965	-993.1	28.67
1.2	48.53	1.60	-24.55	0	-4,897	-979.5	28.67
1.6	37.19	1.36	-18.25	0	-3,856	-771.2	28.42
2.0	30.77	1.19	-16.00	0	-3,214	-642.9	28.25
2.6	25.04	1.04	-13.00	0	-2,607	-521.3	28.00
3.5	17.76	.91	-9.75	0	-2,060	-411.9	27.64
4.5	14.90	.84	-7.25	0	-1,776	-355.2	27.42
Third stage and velocity package							
1.6	20.88	0.556	-29.2	-0.392	-1,269	0	23.033
2.0	16.20	.528	-25.6	-.344	-978	0	22.396
3.0	10.96	.460	-17.6	-.236	-650	0	21.060
4.0	8.72	.432	-12.0	-.164	-510	0	19.903
5.0	7.44	.420	-9.6	-.128	-432	0	18.892
6.0	6.60	.408	-7.6	-.108	-380	0	17.936
7.0	6.00	.404	-6.8	-.092	-344	0	16.804
8.0	5.60	.404	-6.0	-.080	-320	0	15.815
9.0	5.24	.404	-6.0	-.076	-296	0	15.399

*In order to account for the nonlinearity of the normal-force-curve slopes at launch where the angle of attack due to ground winds may be about 90°, the values of the normal-force-curve slope were reduced to a value such that the product of C_{N_α} times α would give a value of C_N corresponding to that angle of attack ($\alpha \approx 90°$). Then, for a given Mach number the values of $C_{N_\alpha}S$ are as follows: $M = 0$, $C_{N_\alpha}S = 4.80$; $M = 0.03$, $C_{N_\alpha}S = 18.96$; $M = 0.08$, $C_{N_\alpha}S = 82.31$; $M = 0.10$, $C_{N_\alpha}S = 104.04$; $M = 0.12$, $C_{N_\alpha}S = 105.43$. These values are an approximation and the center of pressure was constant.

TABLE II

MASS PARAMETERS FOR THE TRAILBLAZER I

Time, sec	W, lb	Center of gravity, ft	I_X	I_Y
First stage, second stage, third stage, and velocity package				
0	7,562.9	35.467	156.50	43,240
2.0	6,705.8	34.133	150.10	39,927
4.2	5,762.2	32.667	140.60	36,915
5.2	5,516.9	32.000	128.00	34,626
Second stage, third stage, and velocity package				
5.0	3,410.0	22.43	32.35	8,902
11.0	3,410.0	22.43	32.35	8,902
12.0	3,069.0	21.67	31.30	8,165
13.0	2,728.0	20.90	30.00	7,428
14.2	2,675.0	19.98	27.30	6,544
36.0	2,675.0	19.98	27.30	6,544
Third stage and velocity package				
34.40	2,110.3	16.91	18.80	2,193
36.10	1,776.2	16.56	16.30	2,034
38.20	1,363.6	15.94	13.20	1,838
39.13	1,180.9	15.58	11.80	1,751
39.80	1,069.1	14.98	10.90	1,702
40.80	872.6	14.45	8.70	1,542
45.00	872.6	14.45	8.70	1,542

TABLE III

AERODYNAMIC PARAMETERS FOR THE TRAILBLAZER II VEHICLE

M	$C_{l_p} \frac{d^2}{2} S$	$C_{l_\delta}\delta$	$C_{m_q} \frac{d^2}{2} S$	$C_{m_{\dot\alpha}} \frac{d^2}{2} S$
0	-1,028.65	0	-15,132.04	-8,107
.7	-1,245.21	0	-17,135.00	-9,610
1.1	-1,732.47	0	-36,706.00	-23,618
1.7	-1,096.33	0	-18,962.00	-7,511
3.0	-609.07	0	-15,213.00	-2,802
4.0	-460.19	0	-14,605.00	-1,922
5.0	-365.44	0	-16,269.00	-1,573

M	$C_N S$ for angles of attack of -						
	0°	4°	15°	20°	40°	70°	90°
0	0	9.17	39.30	37.73	77.55	86.98	109.52
.9	0	10.48	42.97	41.40	84.89	102.18	123.14
1.1	0	11.74	50.36				
2.0	0	7.70	33.01				
3.0	0	5.61	24.05				
4.0	0	4.77	20.44				
5.0	0	4.30	18.39				

M	$C_A S$ for angles of attack of -				
	0°	4°	25°	50°	90°
0	2.15	2.04	2.57	2.10	2.10
.5	2.25	2.15	2.67	2.20	2.20
.85	3.14	3.04	3.56	3.04	3.04
.90	4.24	4.14	4.66		
.95	5.34	5.34	5.71		
1.10	5.97	6.18	6.18		
2.00	5.03	5.24	5.24		
3.00	3.77	4.03			
4.00	3.20	3.51			
5.00	2.72	3.09			

M	Center of pressure for angles of attack of -				
	0°	4°	13.5°	20°	90°
0	40.01	40.32	40.01	37.17	35.00
.9	40.50	40.50	40.01	37.17	35.00
1.1	41.17	41.17	41.17		
2.0	39.00	38.82	38.82		
3.0	37.51	37.25			
4.0	36.65	36.08			
5.0	36.08	35.15			

TABLE IV

MASS PARAMETERS FOR TRAILBLAZER II

t, sec	Center of gravity, ft	I_X	I_Y	W, lb
0	35.65	528	64,100	13,351
1.7				12,488
1.9	35.10	455	60,300	12,377
10.0	34.13	423	56,800	
16.0	33.23	397	53,900	
20.0	32.37	374	51,500	
24.0	31.12	339	48,400	
27.0				6,387
28.0	29.35	296	44,400	
30.0				5,844
31.0	28.70	278	42,300	
36.0	28.25	263	40,900	5,495
40.0	28.25	263	40,900	5,495

TABLE V

ALTITUDE RANGE FOR A CORRESPONDING STEP NUMBER

Step	Altitude, ft	
	Trailblazer I	Trailblazer II
1	58,900 to 84,000	37,500 to 83,000
[a]2	18,100 to 58,900	25,000 to 37,500
3	11,840 to 18,100	18,300 to 25,000
[a]4	8,000 to 11,840	9,500 to 18,300
[a]5	4,700 to 8,000	5,700 to 9,500
6	2,000 to 4,700	3,700 to 5,700
7	800 to 2,000	2,500 to 3,700
8	500 to 800	1,730 to 2,500
9	250 to 500	1,200 to 1,730
10	130 to 250	860 to 1,200
11	27 to 130	600 to 860
12		420 to 600
13		295 to 420
14		203 to 295
15		134 to 203
16		78 to 134
17		26 to 78

[a]Coasting periods for Trailblazer I.

[redacted]

TABLE VI

SAMPLE FORM USED FOR TRAILBLAZER I LAUNCHER-SETTING CALCULATIONS

Wind run 3 Release time 0116 e.s.t. Date 9/16/61

Step	Altitude, ft	Wind velocity, ft/sec	Wind azimuth, deg	Effective wind direction, deg	Change in azimuth, deg (a)	Azimuth, deg	Change in elevation, deg (b)	Total change in elevation, deg
						150.00		0
1	58,900 to 84,000	22.01	227.2	77.2 right	-1.63	148.37	0.14	0.14
2	18,100 to 58,900	90.64	230.4	82.0 right	1.54	149.51	-0.08	0.06
3	11,840 to 18,100	37.31	259.0	109.1 right	-3.06	146.85	-0.26	-0.20
				112.1 right	-3.00	146.91	0.31	0.25
4	8,000 to 11,840	27.17	275.0	128.1 right	0.22	147.13	0.04	-0.21
5	4,700 to 8,000	23.74	314.0	166.9 right	0.03	147.16	0.03	-0.18
6	2,000 to 4,700	44.19	360.0	147.2 left	1.34 (1.28)	148.44	-0.45	-0.63
7	800 to 2,000	50.50	357.0	151.4 left	3.15 (2.73)	151.16	-1.24	-1.83
				154.2 left	2.87 (2.46)	150.80	-1.27	-1.90
8	500 to 800	47.50	348.0	162.8 left	1.14 (0.92)	151.72	-0.79	-2.69
9	250 to 500	42.00	352.0	159.7 left	2.00 (1.50)	153.22	-1.16	-3.85
10	130 to 250	24.20	345.0	168.2 left	0.59 (0.41)	153.63	-0.60	-4.45
11	27 to 130	14.70	330.0	176.4 right	0.22 (0.12)	153.75	-0.73	-5.18

Launcher settings: Azimuth 153.75° Elevation 74.8°

[a]Single values (steps 1 to 5) and first values (steps 6 to 11) of change in azimuth were obtained from figure 5(a). Numbers in parentheses (steps 6 to 11) were obtained from figure 5(c) or 5(d).

[b]Values of change in elevation were obtained from figure 5(b).

TABLE VII

BALLOON LAUNCH TIMES AND VEHICLE-TRAJECTORY INFORMATION

Trailblazer vehicle	High-altitude balloon release		Final balloon release		Vehicle launch		Nominal trajectory		Launch setting		Trajectory results at 83,000 ft	
	Date	Time, e.s.t.	Date	Time, e.s.t.	Date	Time, e.s.t.	Elevation angle, deg	Azimuth angle, deg	Elevation angle, deg	Azimuth angle, deg	Launch elevation angle, deg	Azimuth heading angle, deg
Ib	6/25/60	1830	6/25/60	2353	6/26/60	0117	82.0	148.0	79.0	145.5	81.6	144.5
Ic	8/28/60	1858	8/28/60	2125	8/28/60	2238	82.0	148.0	84.0	139.0	82.3	148.0
Id	8/28/60	1858	8/29/60	0032	8/29/60	0113	82.0	148.0	83.5	141.0	82.0	149.0
Ie	10/21/60	1706	10/21/60	1859	10/21/60	2209	82.0	148.0	79.2	151.0	80.7	149.5
If	1/17/61	1704	1/17/61	2102	1/17/61	2300	82.0	148.0	79.0	117.0	82.6	138.5
Ig	4/20/61	2102	4/20/61	2316	4/21/61	0056	80.0	148.0	80.7	150.0	81.5	151.5
Ih	5/17/61	1801	5/17/61	2247	5/18/61	0110	80.0	145.0	78.7	157.0	79.7	143.5
Ii	9/16/61	2025	9/16/61	2210	9/16/61	2347	80.0	150.0	78.0	157.0	80.0	148.5
Ij	4/2/62	1733	4/2/62	2305	4/2/62	2357	80.0	150.0	77.0	148.5	78.2	145.0
Ik	7/27/62	1722	7/27/62	2029	7/27/62	2150	80.0	150.0	78.5	142.0	80.0	147.0
IIa	12/13/61	2047	12/14/61	0031	12/14/61	0209	80.0	155.0	75.3	143.0	79.0	151.5
IIb	5/5/62	1759	5/5/62	2344	5/6/62	0041	80.0	155.0	78.0	136.0	80.7	158.0

TABLE VIII

COMPUTER PROGRAM CONSTANTS

Step	B	D	γ_{ref}, deg
Trailblazer I			
1	0.0759	0.0279	68.37
2	-.01715	-.0060	69.52
3	.0869	.022	75.34
4	-.01055	-.0025	76.28
5	-.0063	-.0015	77.12
6	.0559	.012	77.62
7	.1304	.028	78.03
8	.08155	.0175	78.57
9	.1374	.0295	78.91
10	.1188	.0255	79.67
11	.23255	.0500	79.92
Trailblazer II			
1	0.01875	0.00633	69.135
2	.01875	.00633	70.940
3	.01875	.00633	71.905
4	.05625	.01900	72.667
5	.05625	.01900	74.197
6	.05625	.01900	75.265
7	.05625	.01900	76.078
8	.05625	.01900	76.746
9	.05625	.01900	77.255
10	.05625	.01900	77.758
11	.05625	.01900	78.238
12	.05625	.01900	78.594
13	.05625	.01900	78.786
14	.05625	.01900	78.850
15	.05625	.01900	78.880
16	.05625	.01900	78.900
17	.05625	.01900	78.924

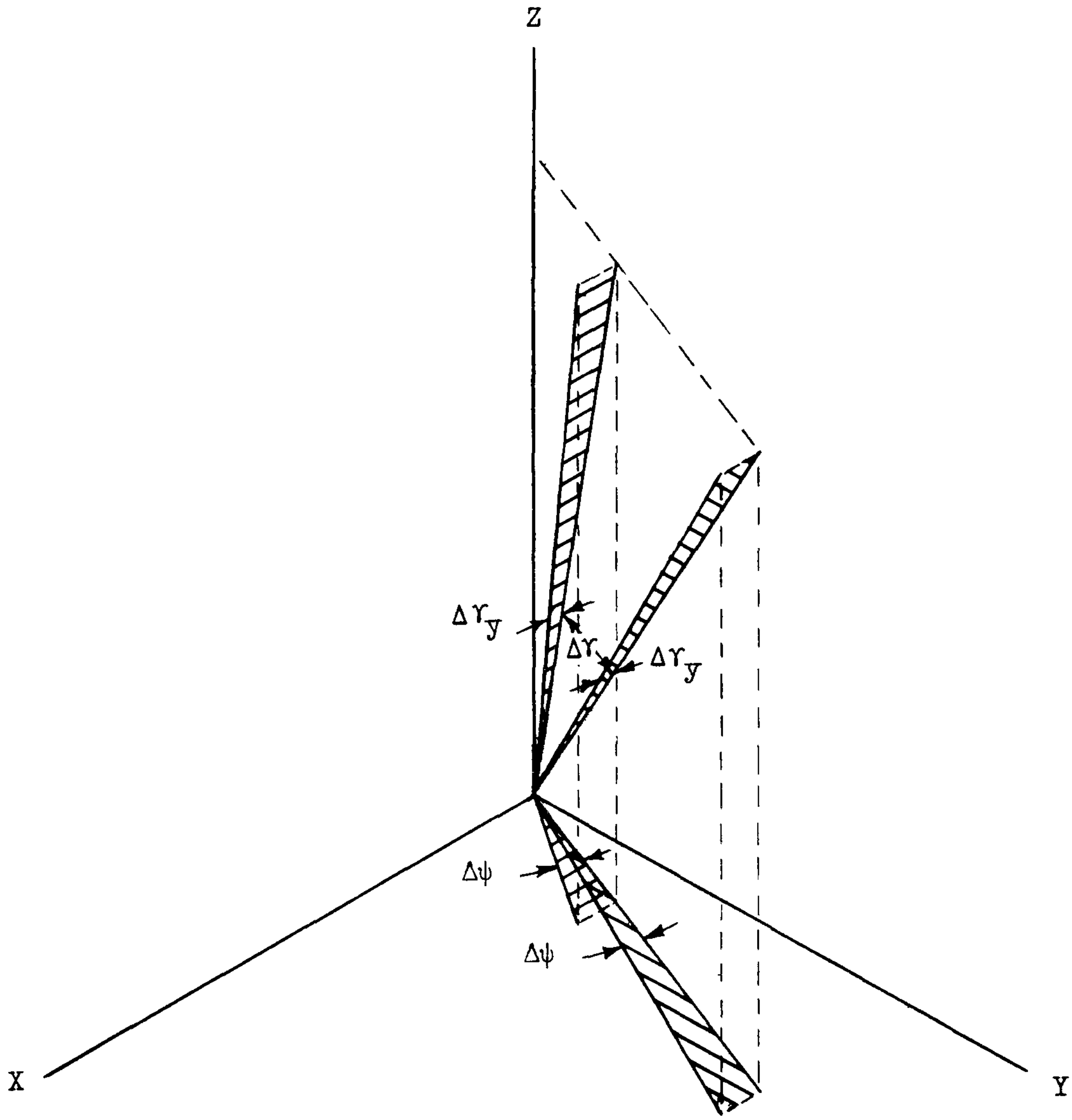
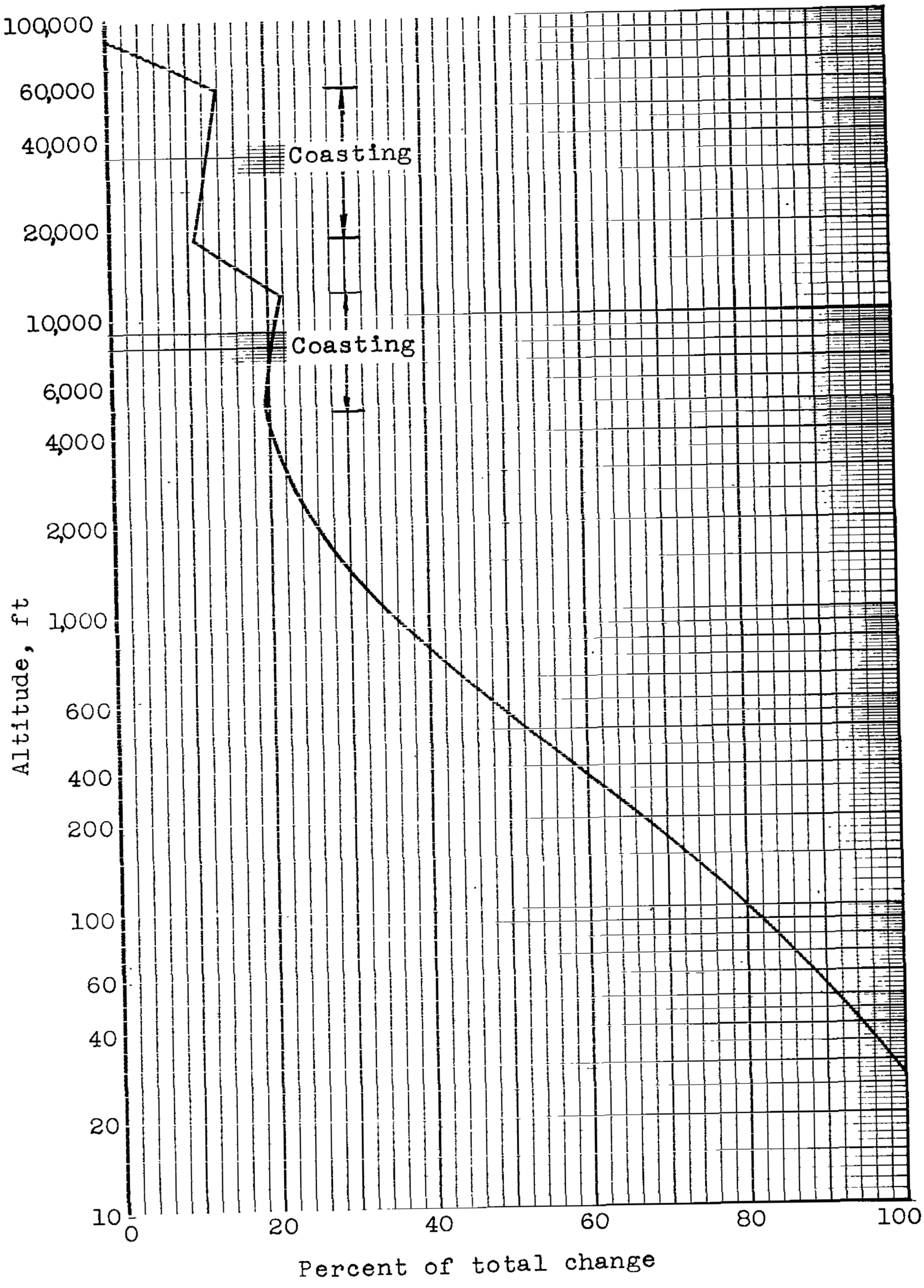
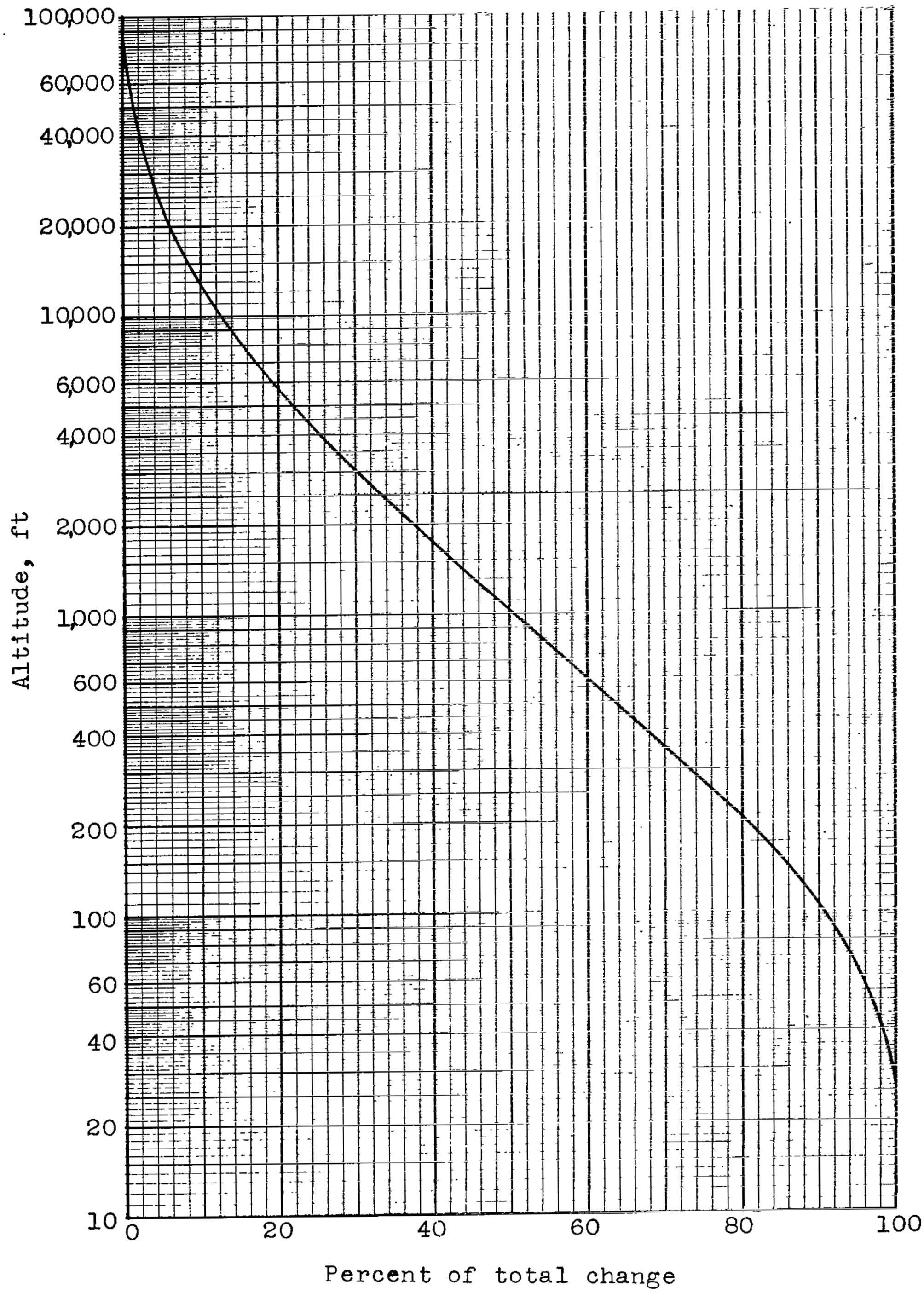


Figure 1.- Illustration of difference in change in ground azimuth because of change in elevation angle for a constant angle in yaw attitude.



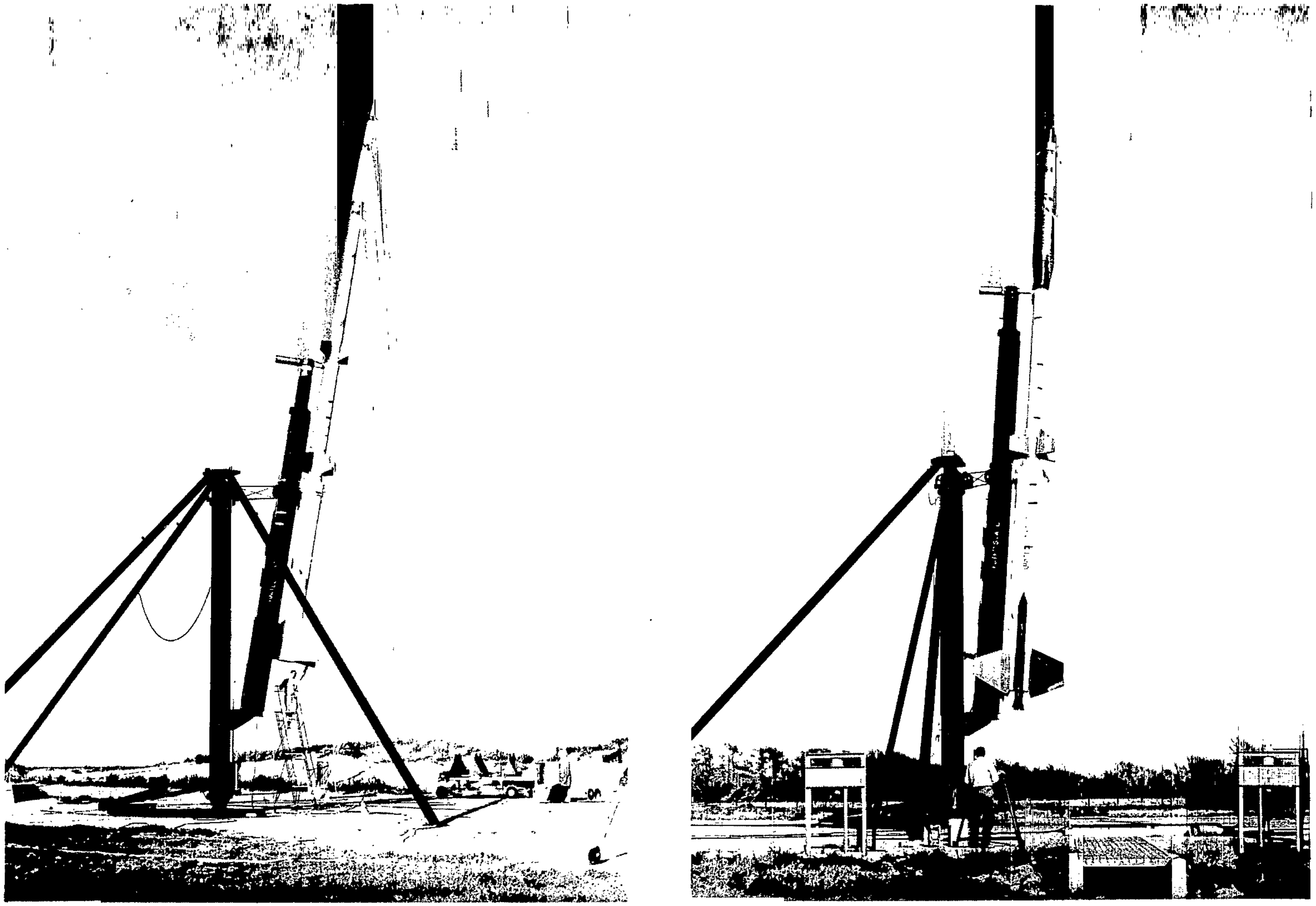
(a) Trailblazer I.

Figure 2.- Variation of altitude with percent total change in flight-path angle because of a constant wind.



(b) Trailblazer II.

Figure 2.- Concluded.



(a) Trailblazer I. L-60-5894

(b) Trailblazer II. L-61-8802

Figure 3.- Photographs of Trailblazer reentry research vehicles.

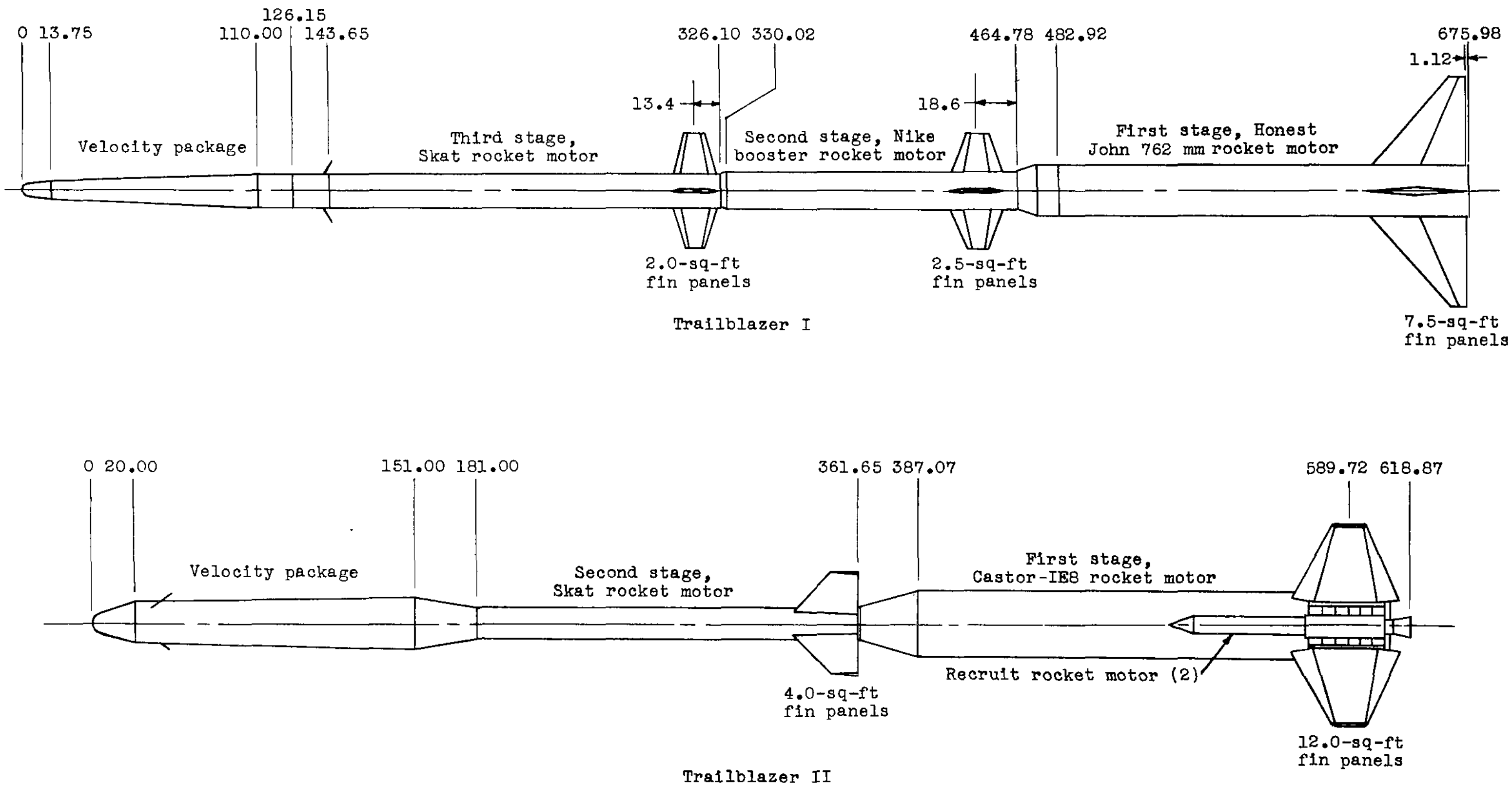
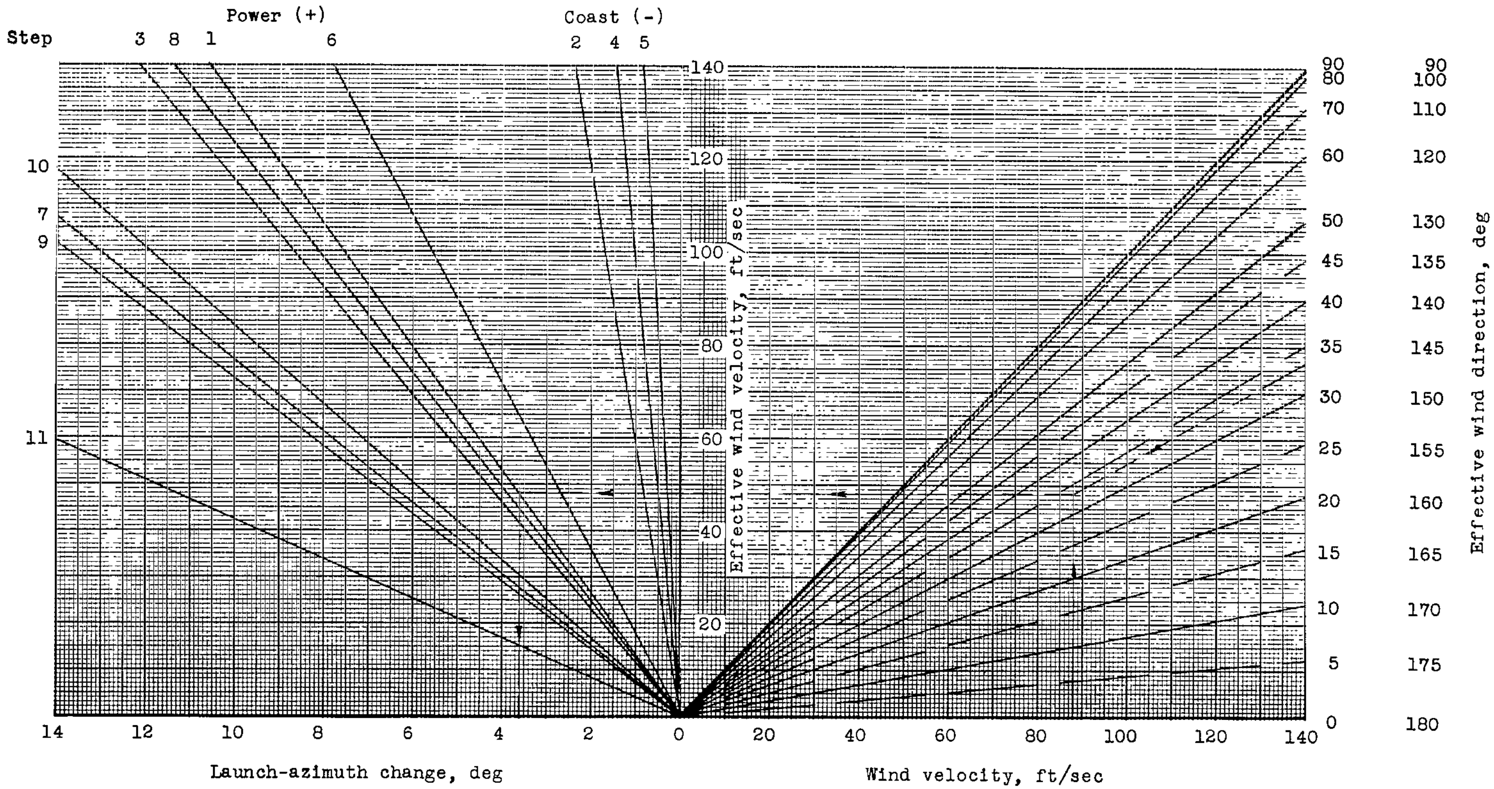
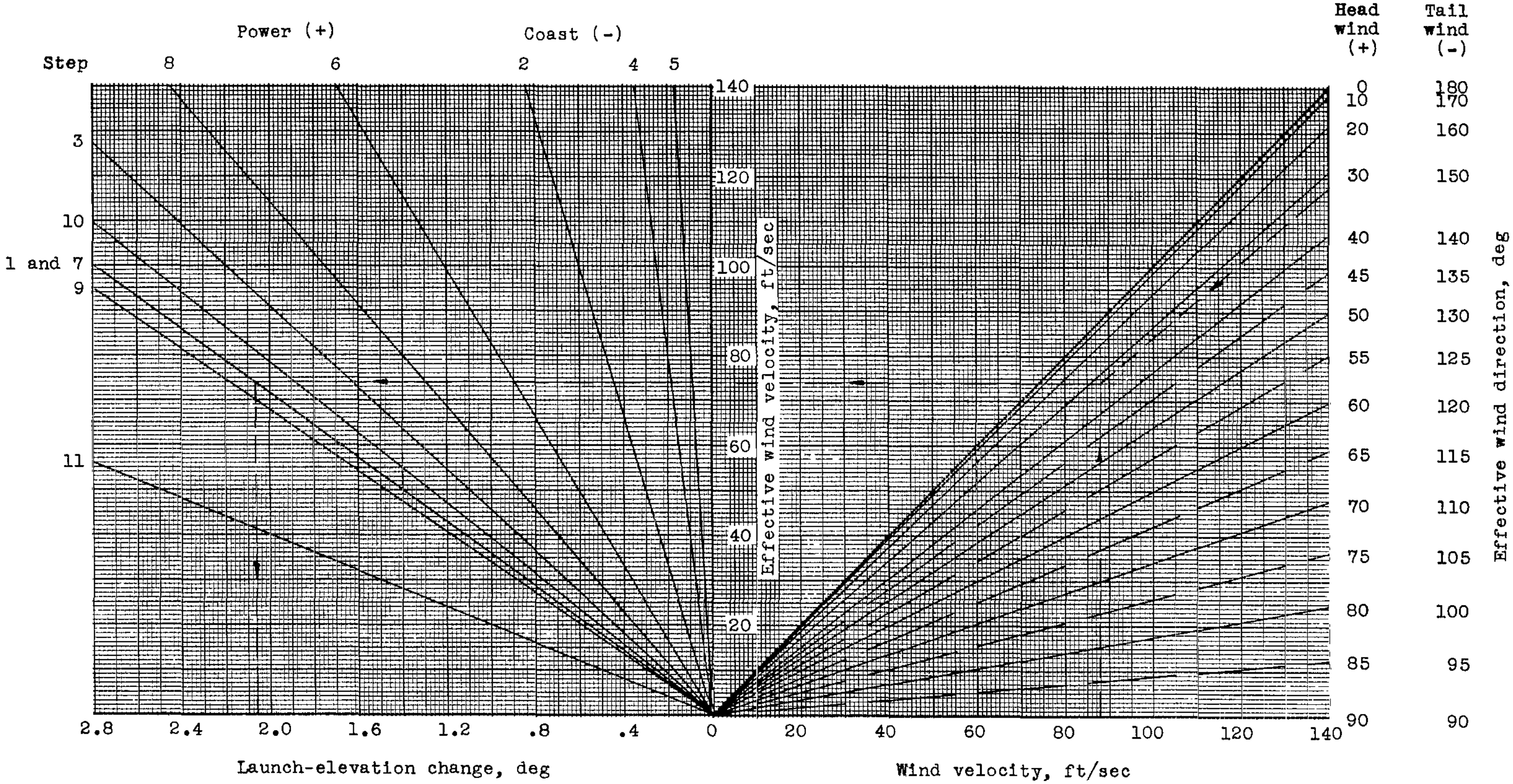


Figure 4.- Sketch of Trailblazer reentry research vehicles. (All dimensions and station locations are in inches unless otherwise noted.)



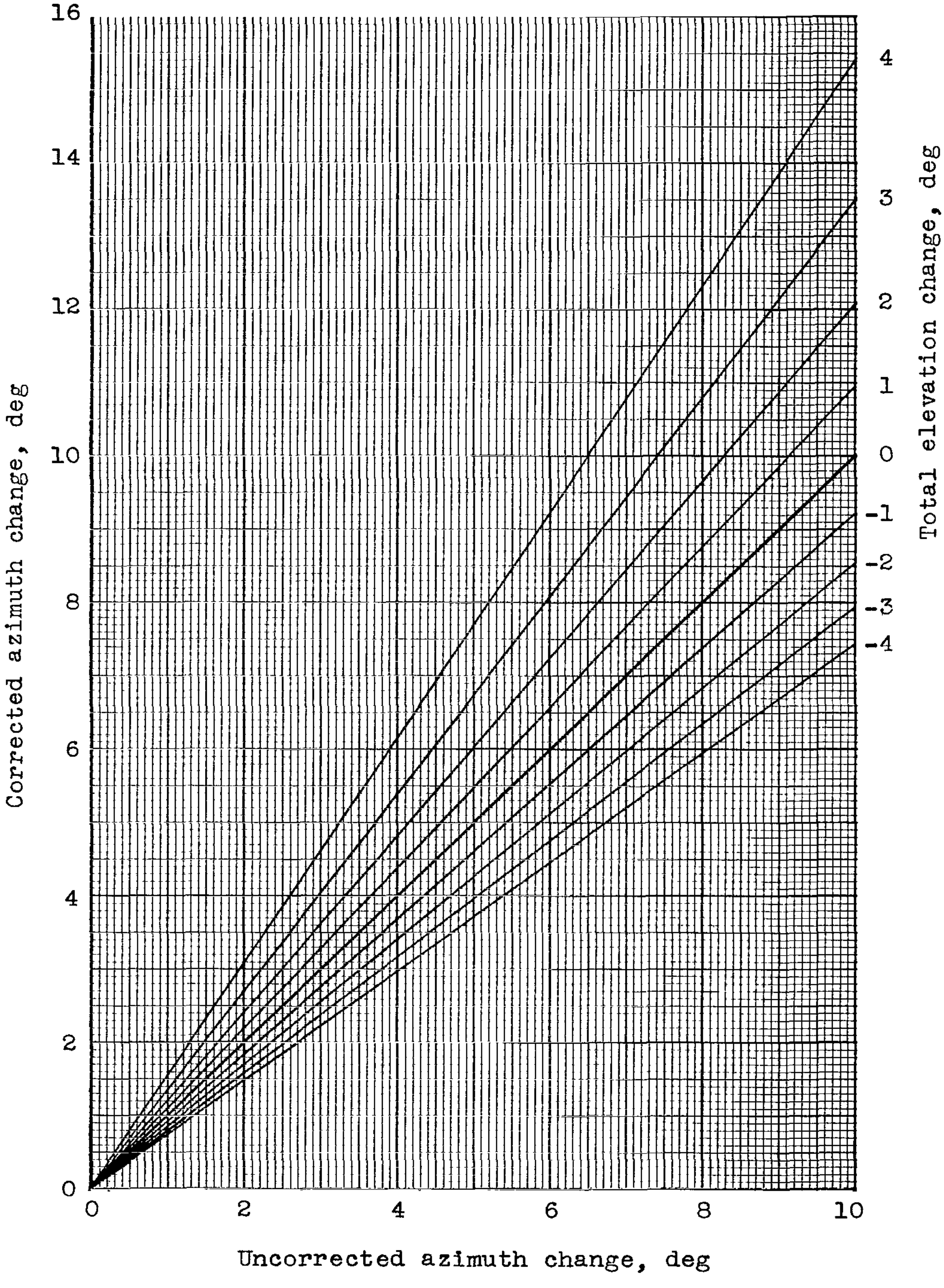
(a) Launcher-azimuth corrections. (Note: For effective wind direction, right wind is negative, left wind is positive.)

Figure 5.- Wind-compensation charts used for launcher corrections on Trailblazer I.



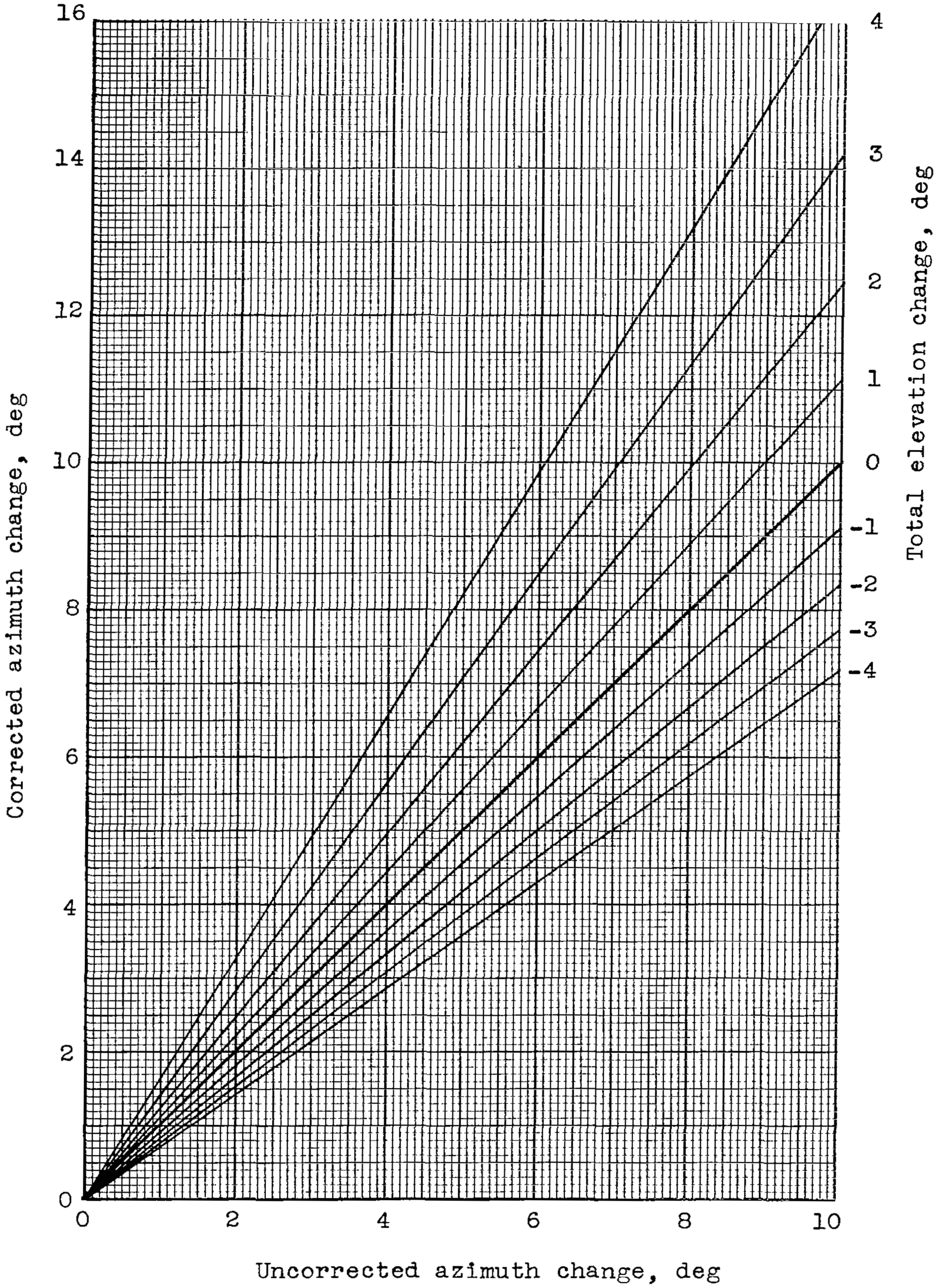
(b) Launcher-elevation corrections.

Figure 5.- Continued.



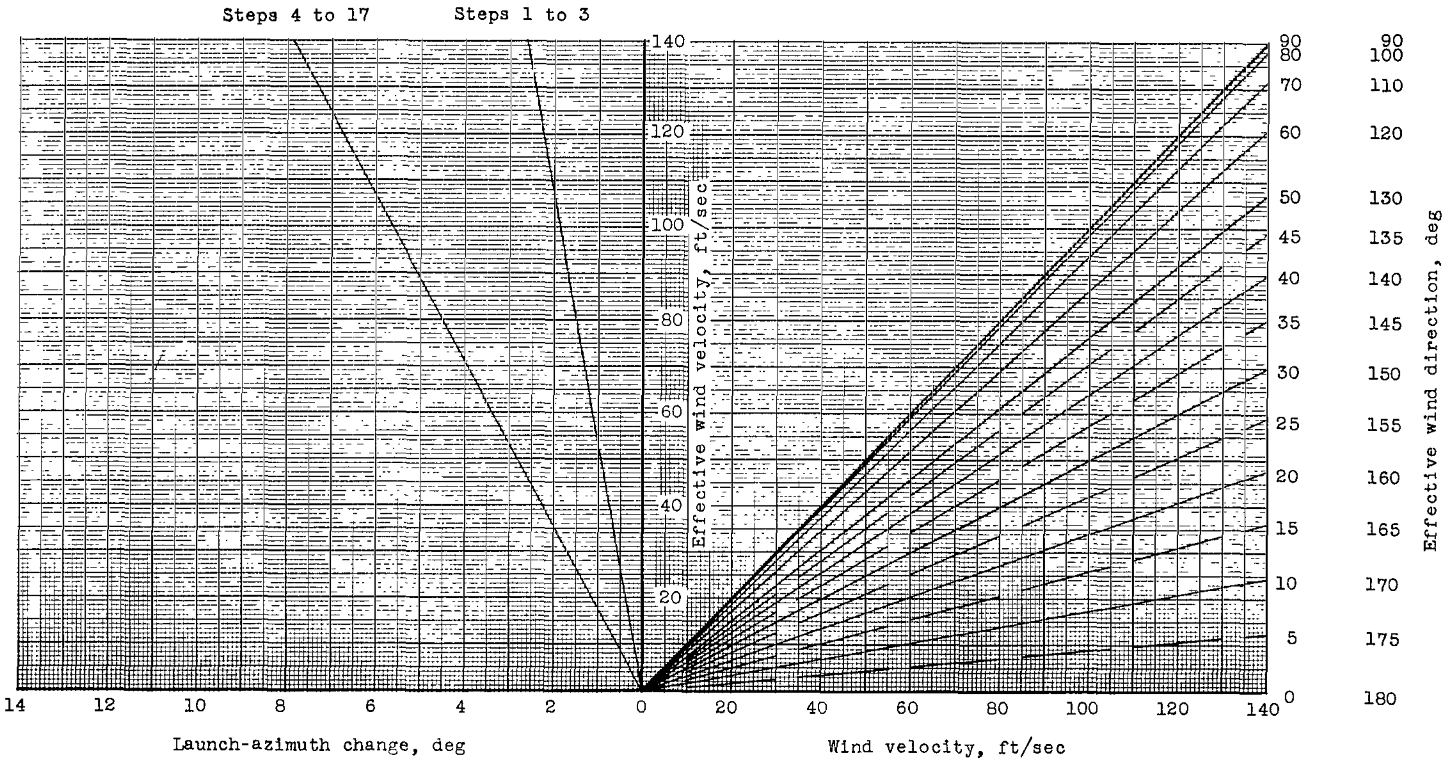
(c) Azimuth-change correction due to total elevation change, steps 6 to 9.

Figure 5.- Continued.



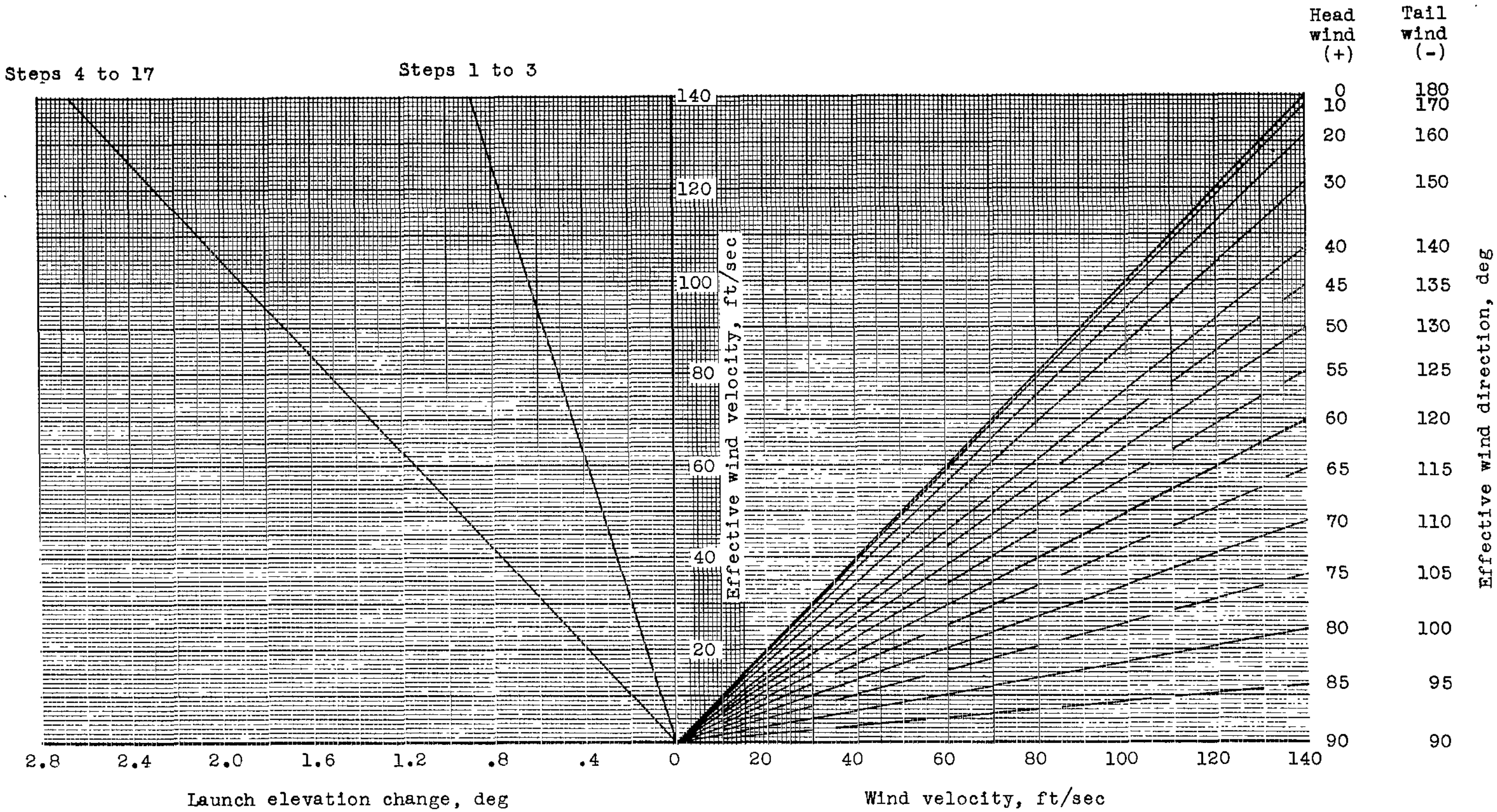
(d) Azimuth-change correction due to total elevation change, steps 10 and 11.

Figure 5.- Concluded.



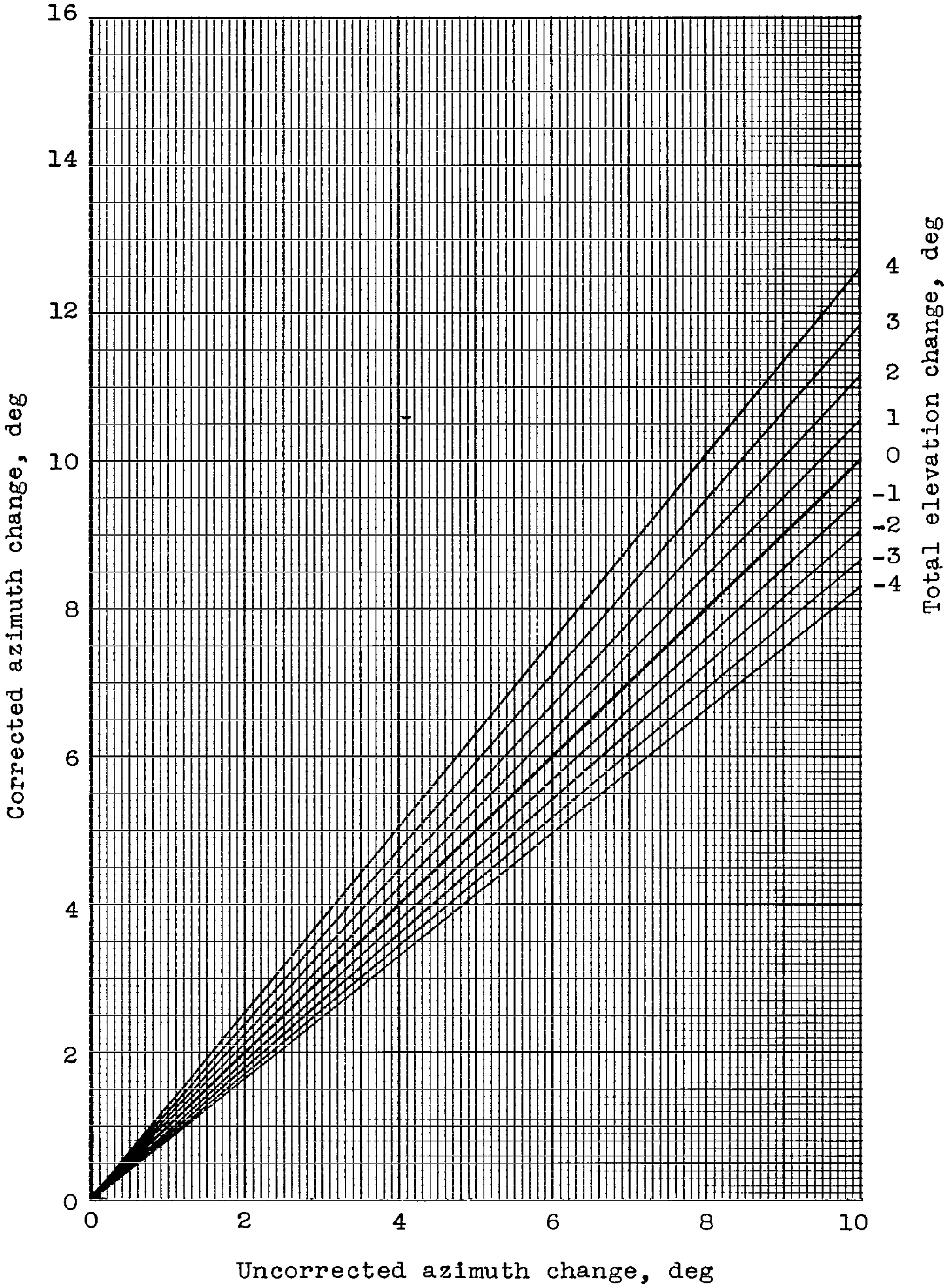
(a) Launcher-azimuth corrections. (Note: For effective wind direction, right wind is negative, left wind is positive.)

Figure 6.- Wind-compensation charts used for launcher corrections on Trailblazer II.



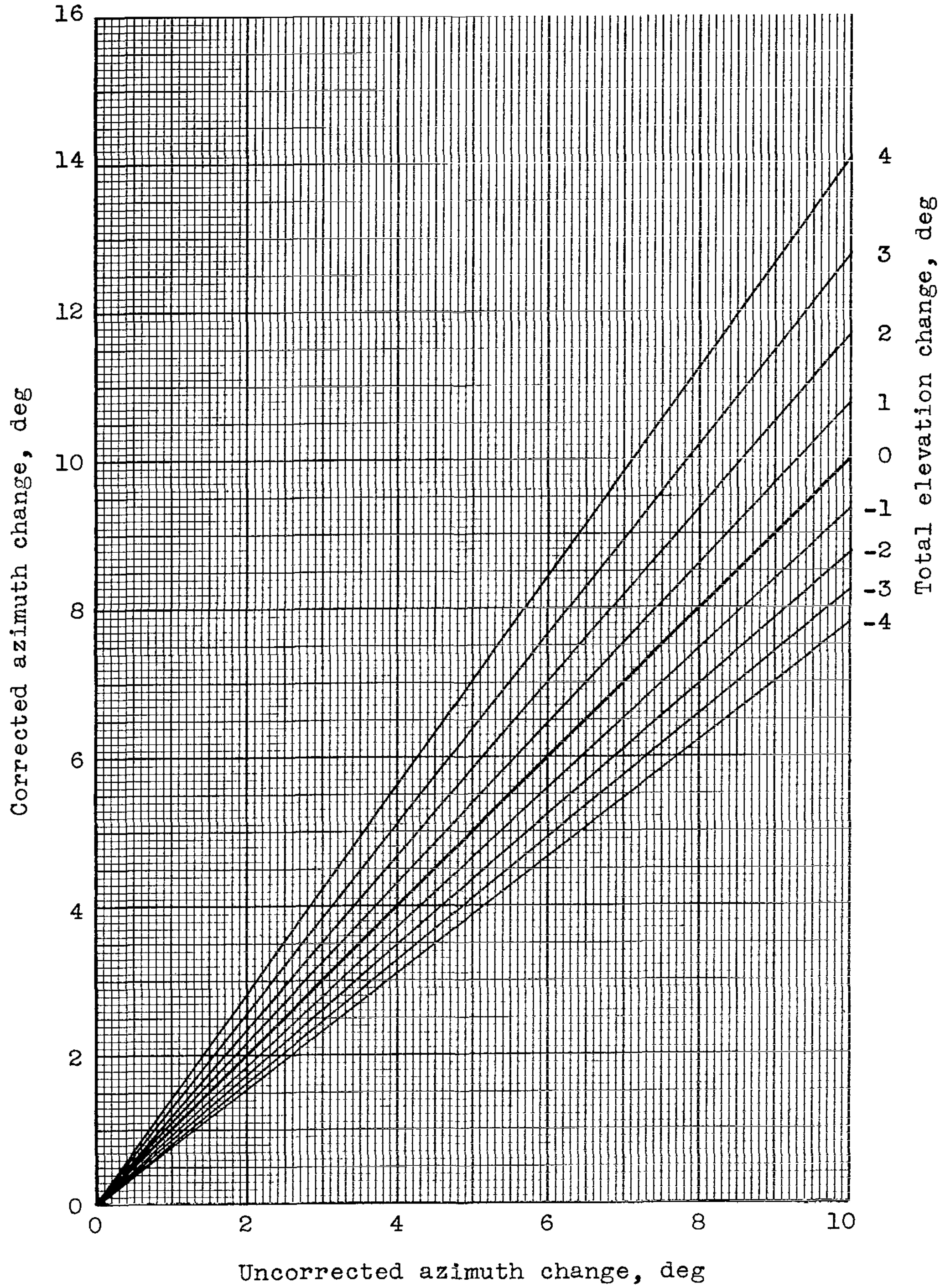
(b) Launcher-elevation corrections.

Figure 6.- Continued.



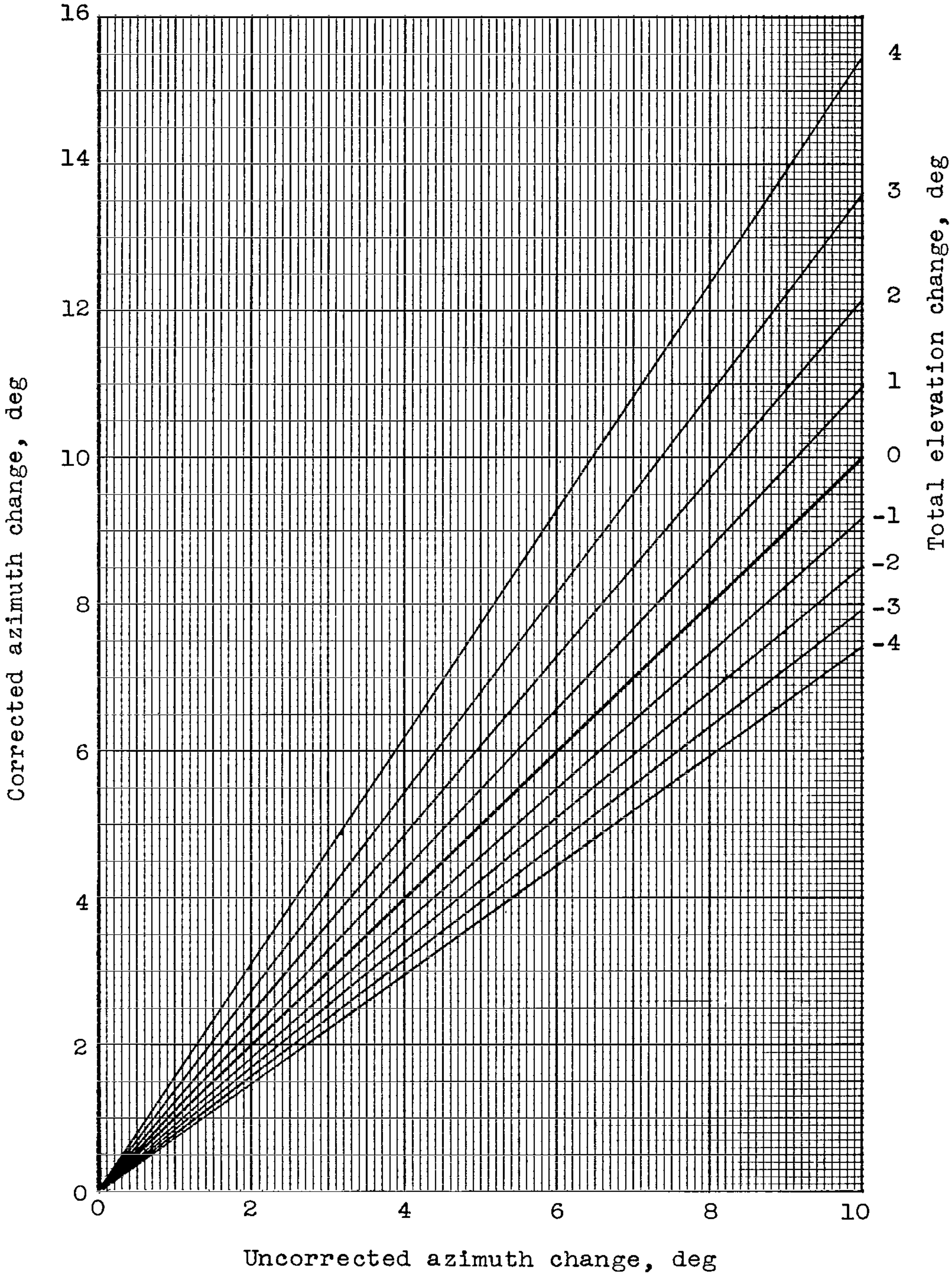
(c) Azimuth-change correction due to total elevation change, steps 1 to 4.

Figure 6.- Continued.



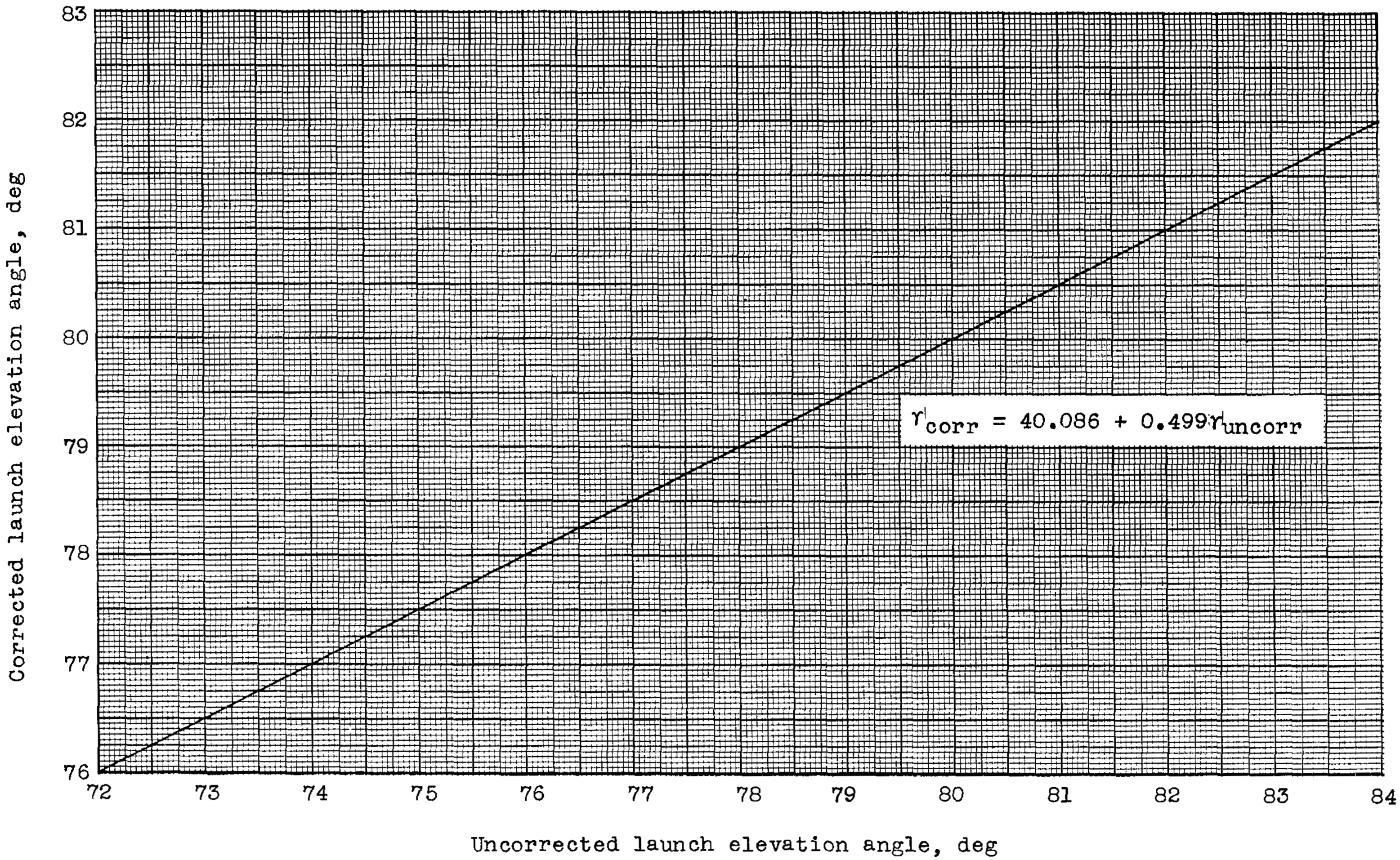
(d) Azimuth-change correction due to total elevation change, steps 5 to 10.

Figure 6.- Continued.



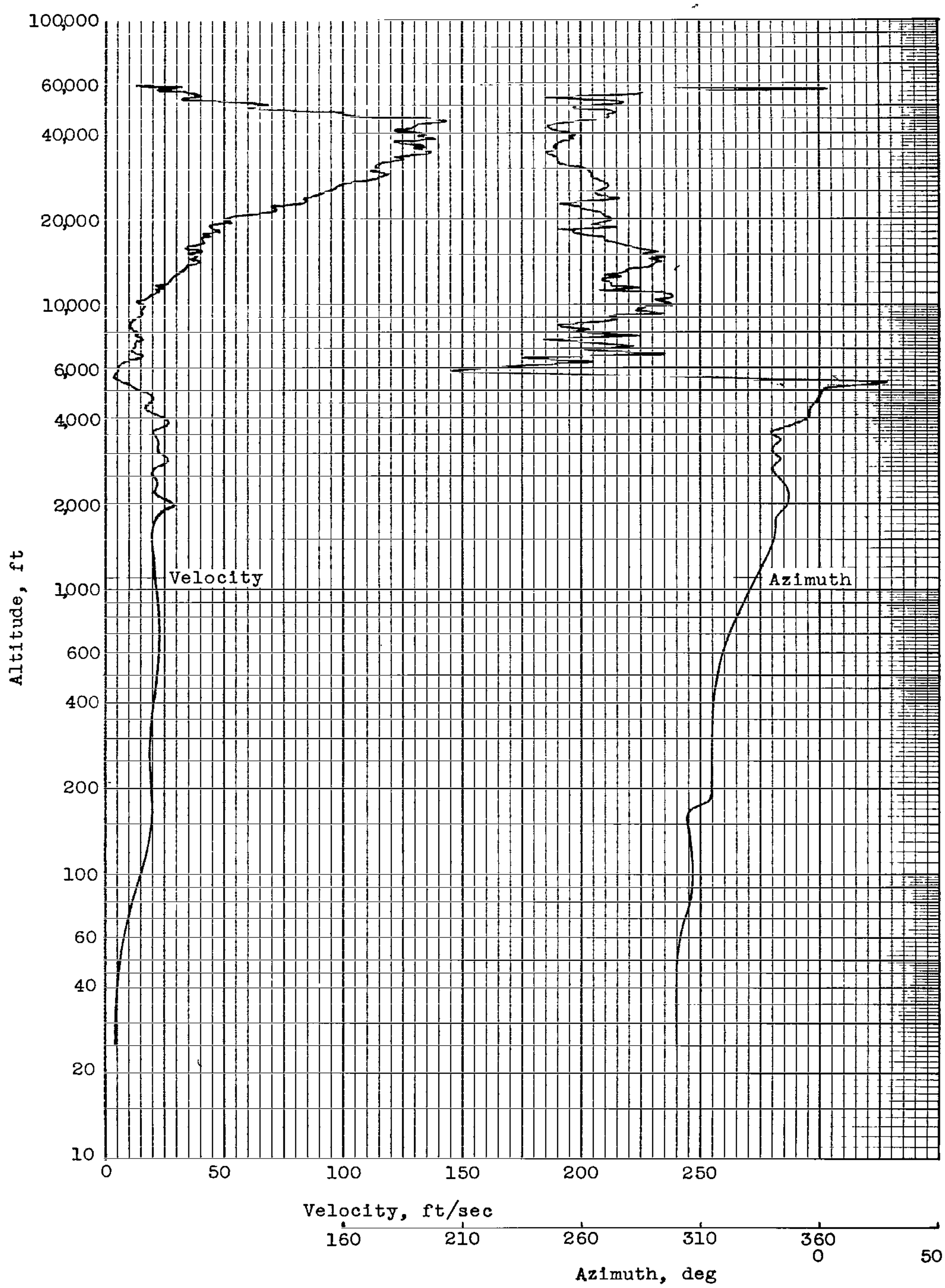
(e) Azimuth-change correction due to total elevation change, steps 11 to 17.

Figure 6.- Continued.



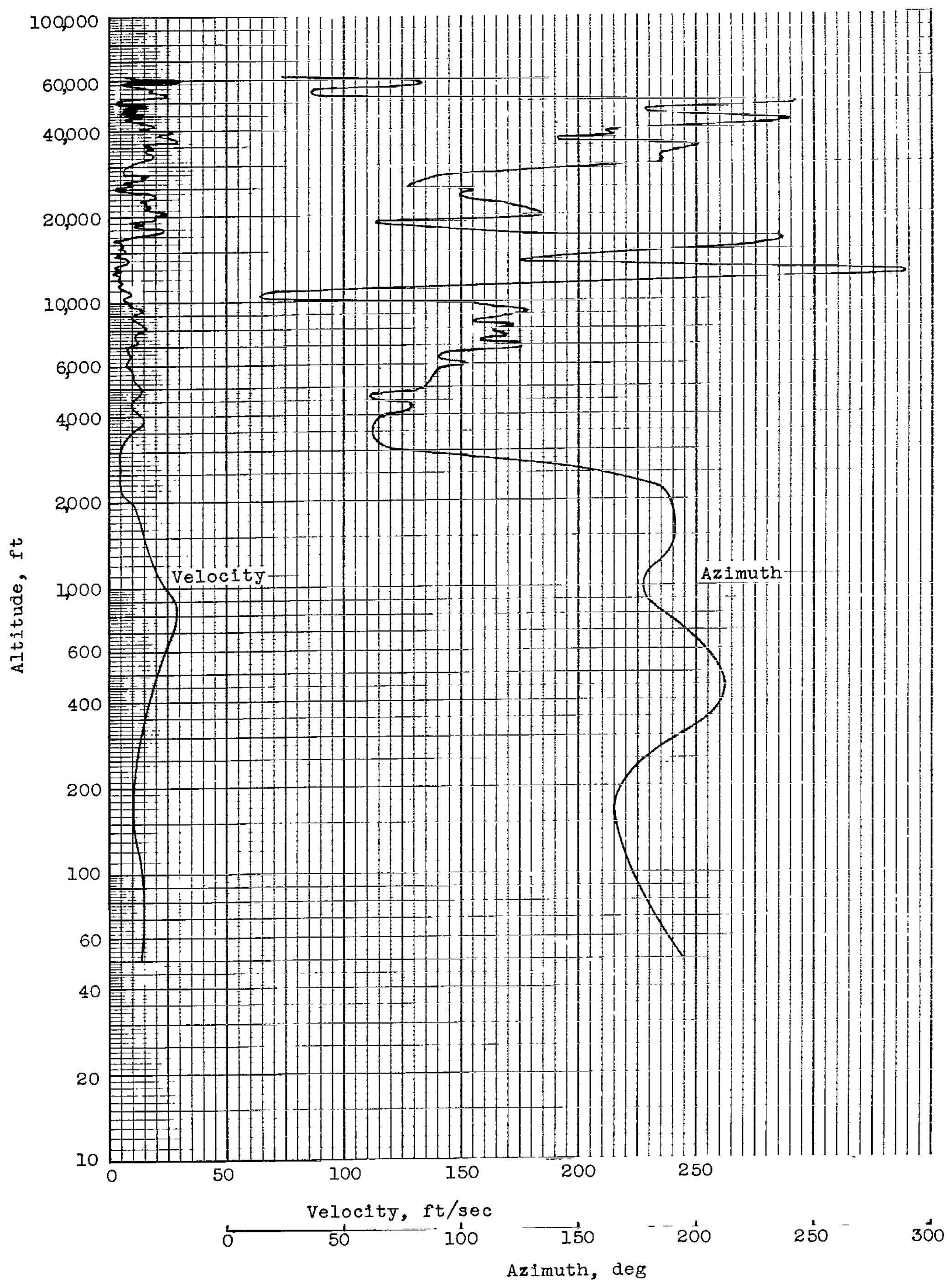
(f) Gravity correction.

Figure 6.- Concluded.



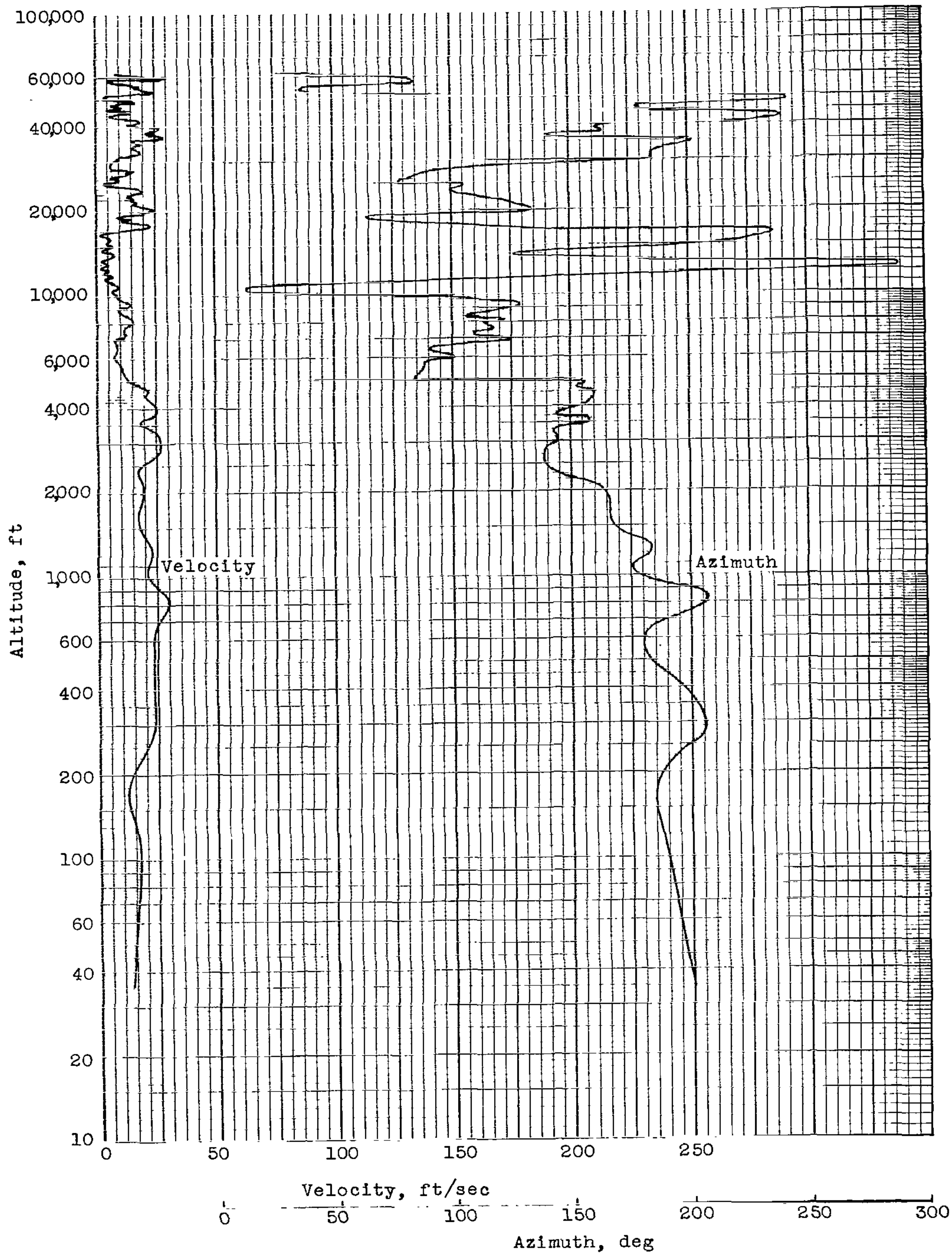
(a) Trailblazer Ib.

Figure 7.- Velocity and direction of wind prior to flights of each Trailblazer vehicle.



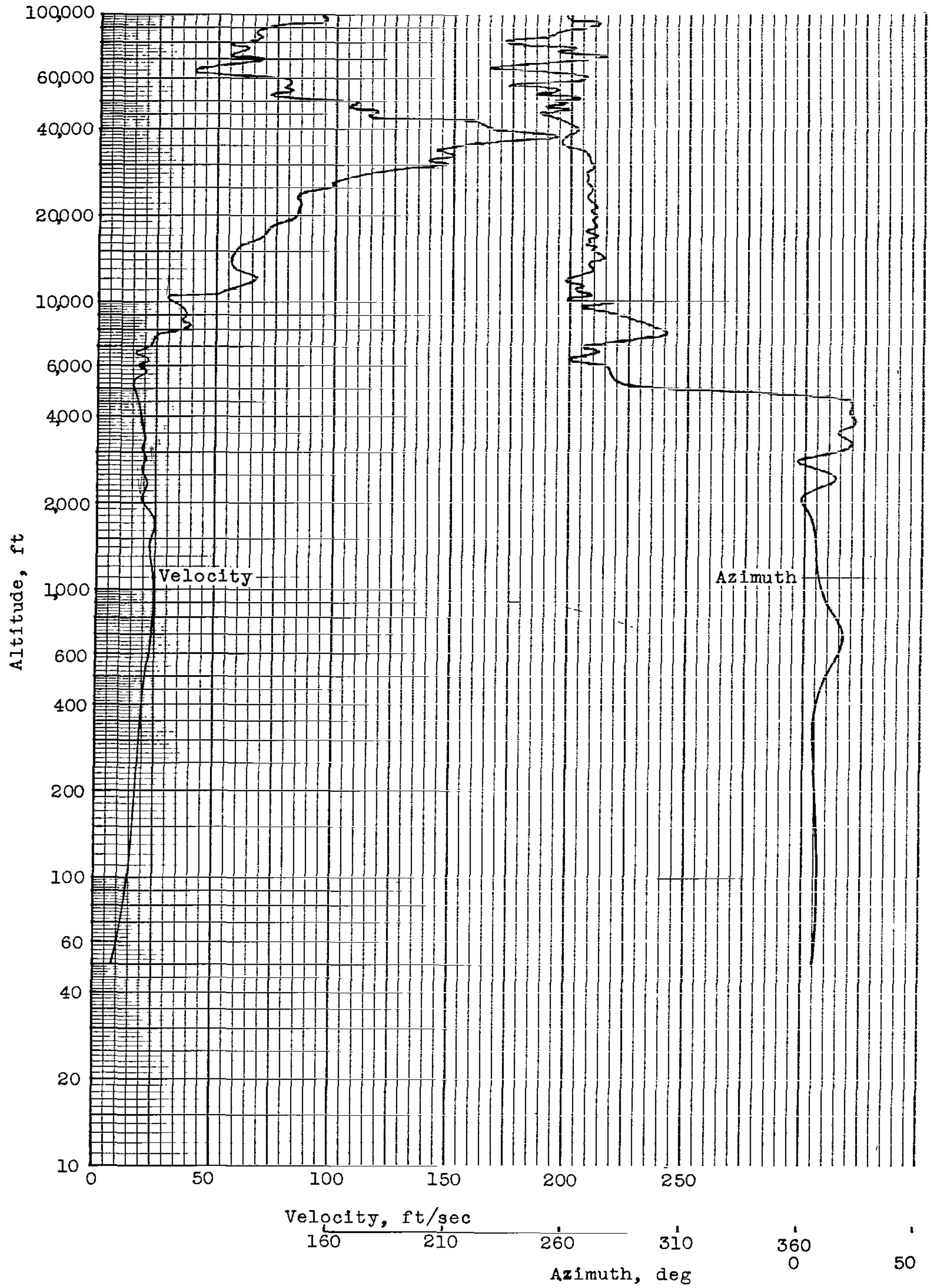
(b) Trailblazer Ic.

Figure 7.- Continued.



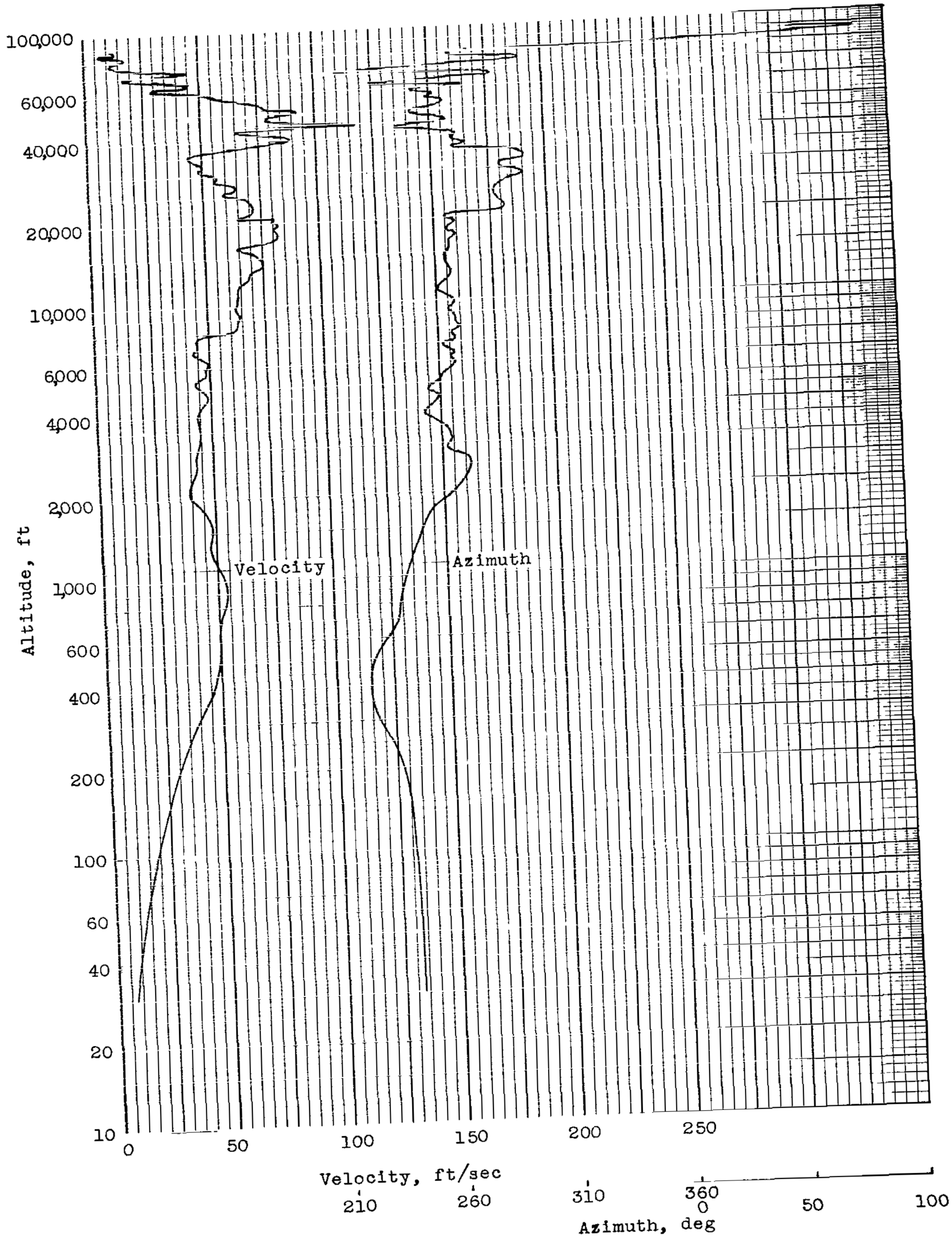
(c) Trailblazer Id.

Figure 7.- Continued.



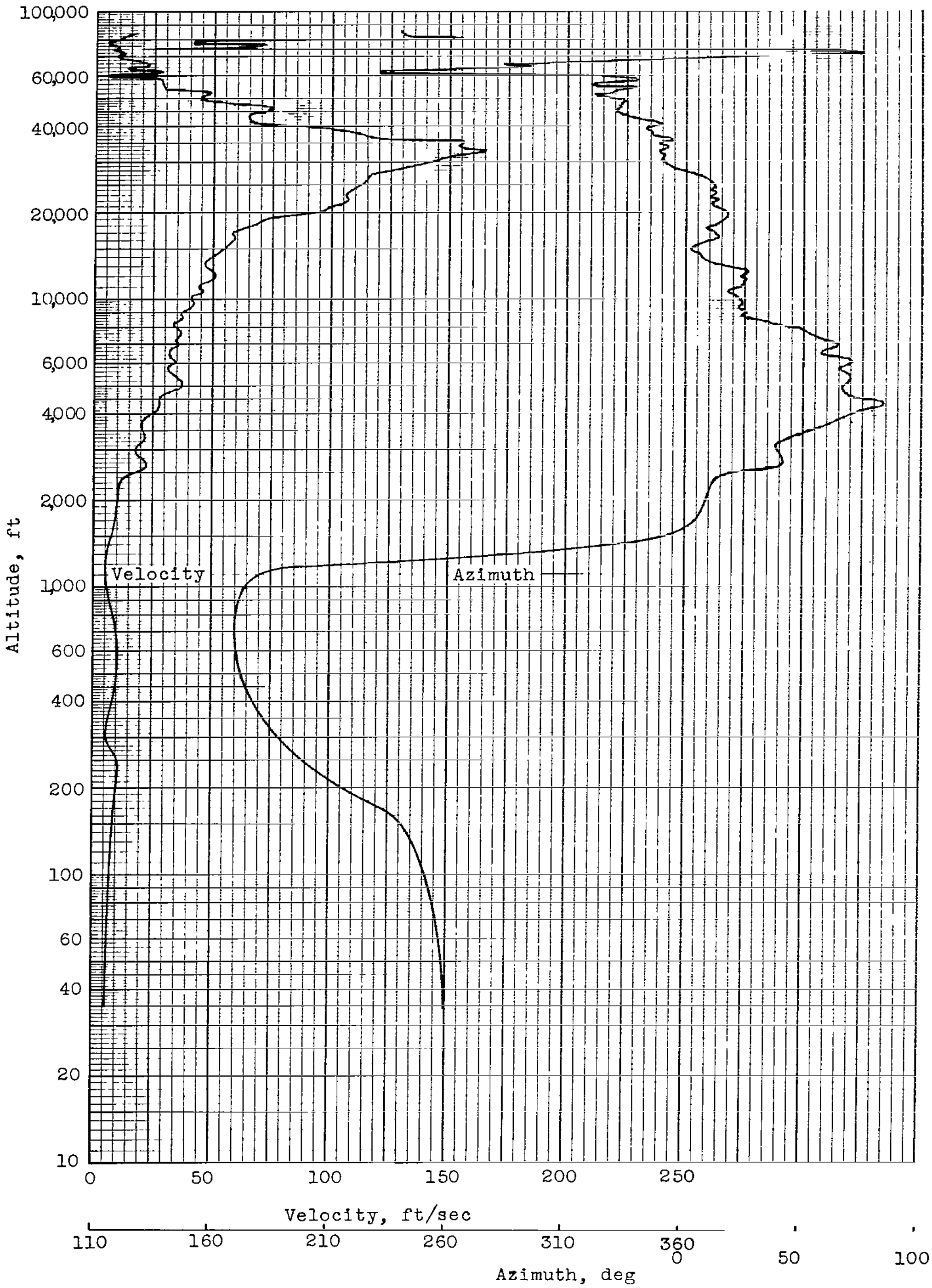
(d) Trailblazer Ie.

Figure 7.- Continued.



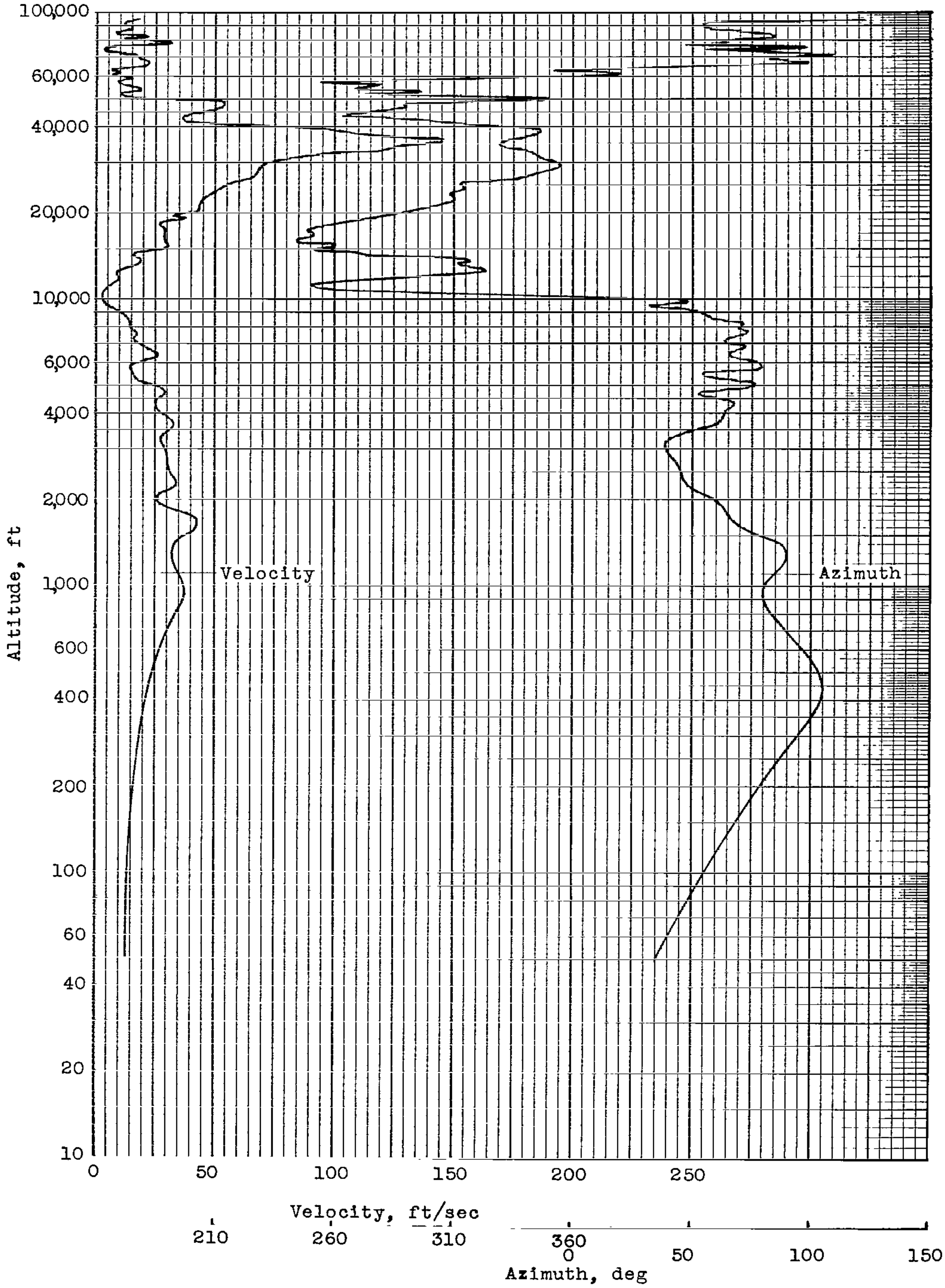
(e) Trailblazer If.

Figure 7.- Continued.



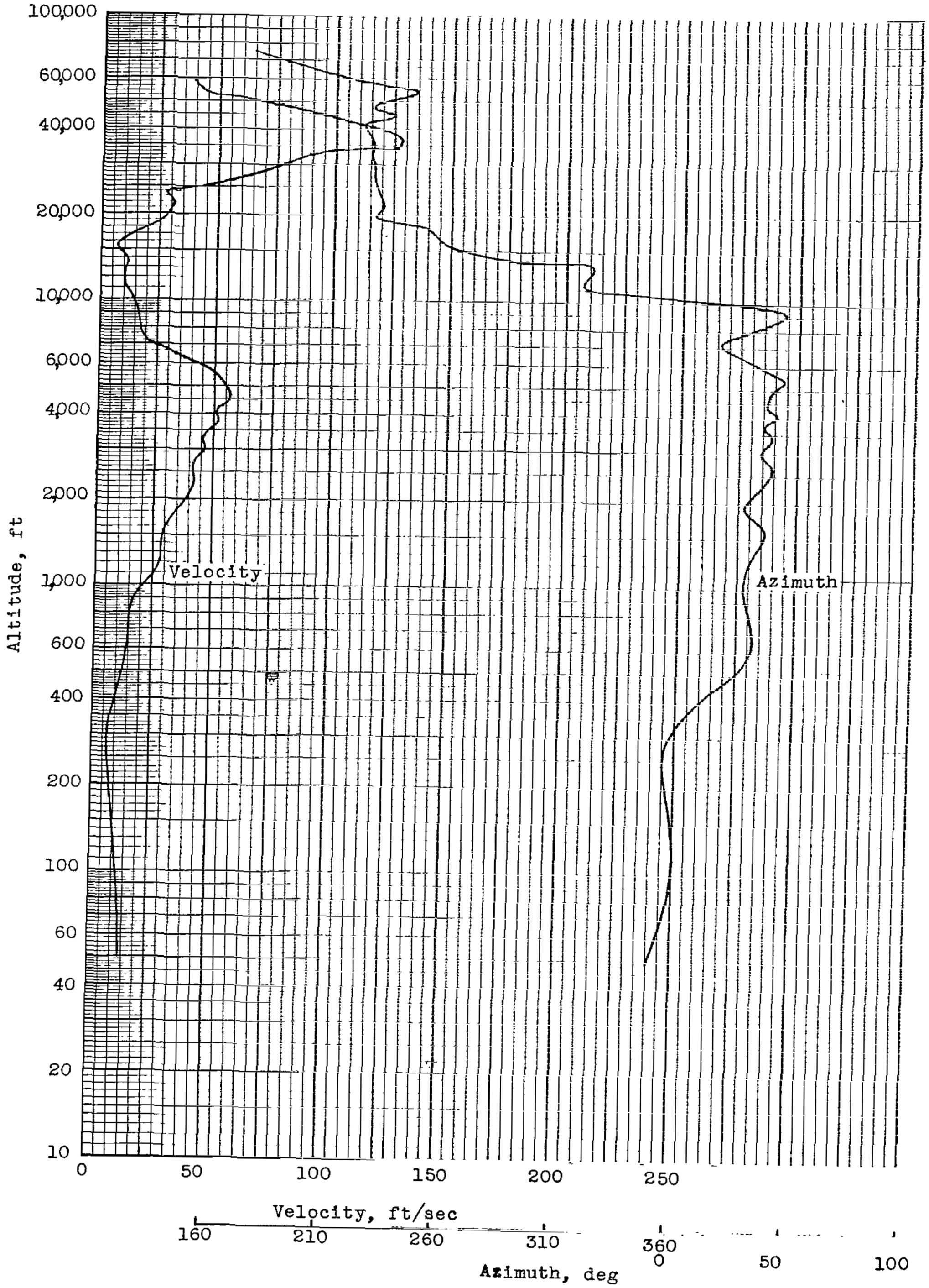
(f) Trailblazer Ig.

Figure 7.- Continued.



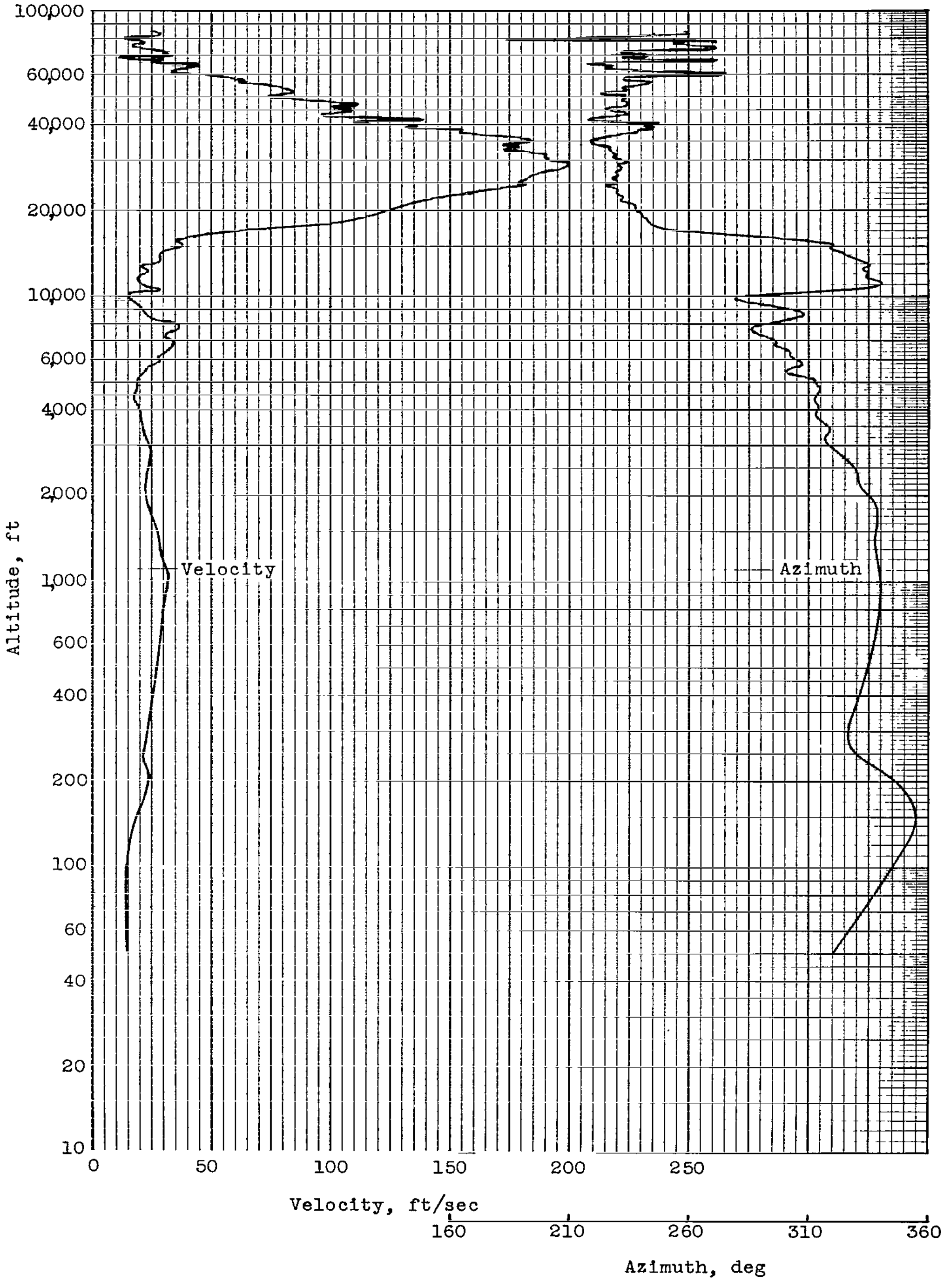
(g) Trailblazer Ih.

Figure 7.- Continued.



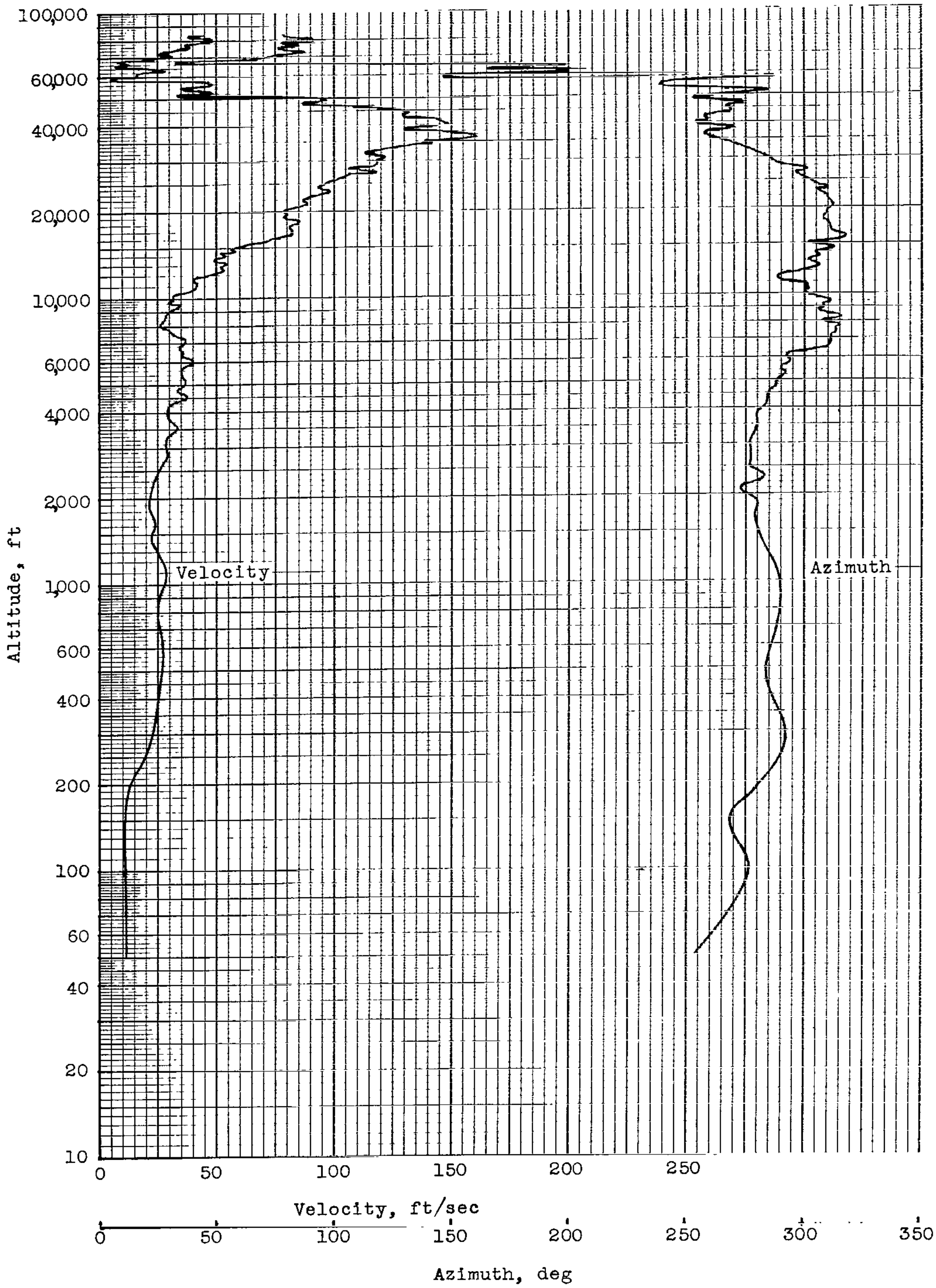
(h) Trailblazer Ii.

Figure 7.- Continued.



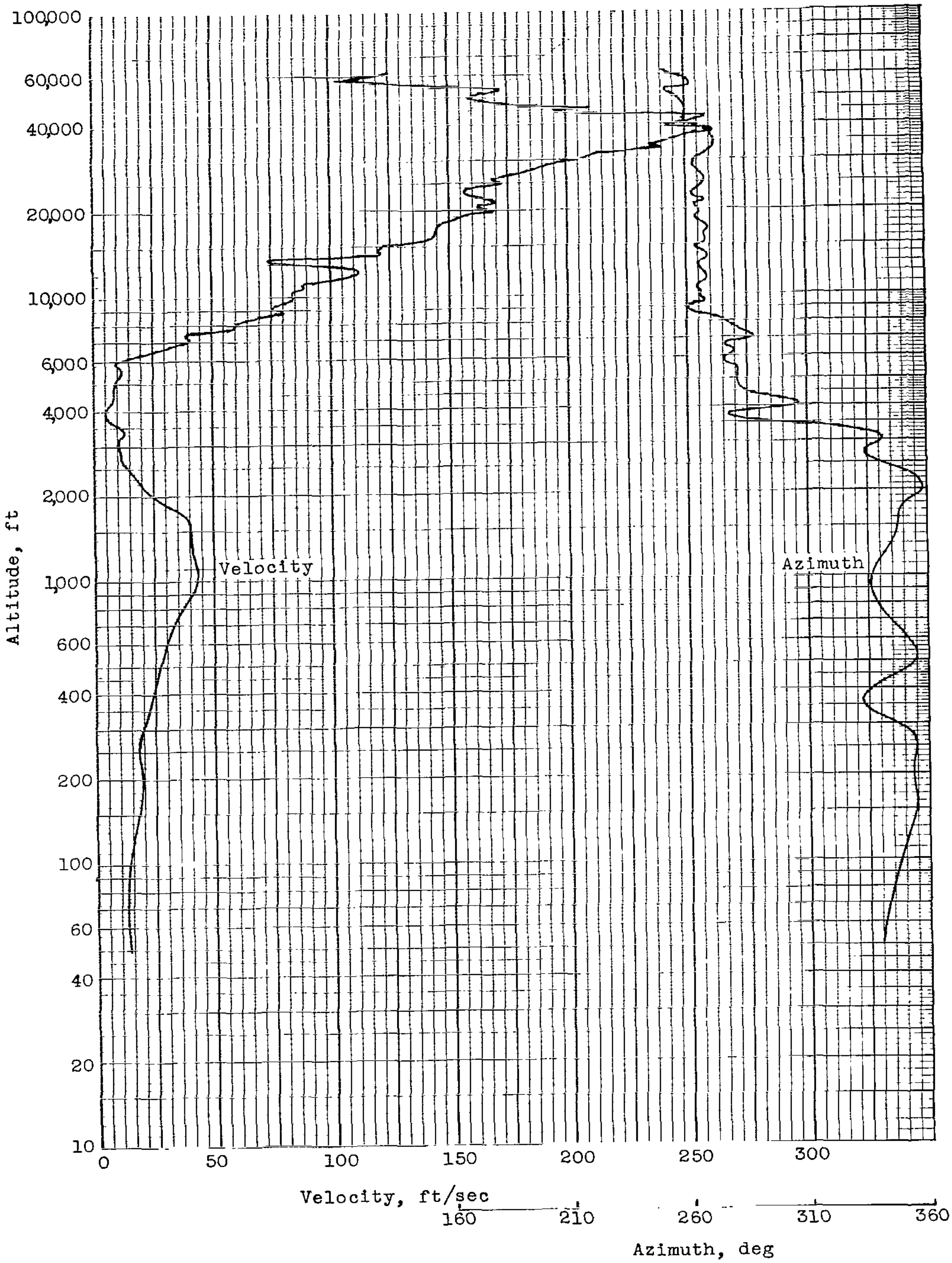
(i) Trailblazer Ij.

Figure 7.- Continued.



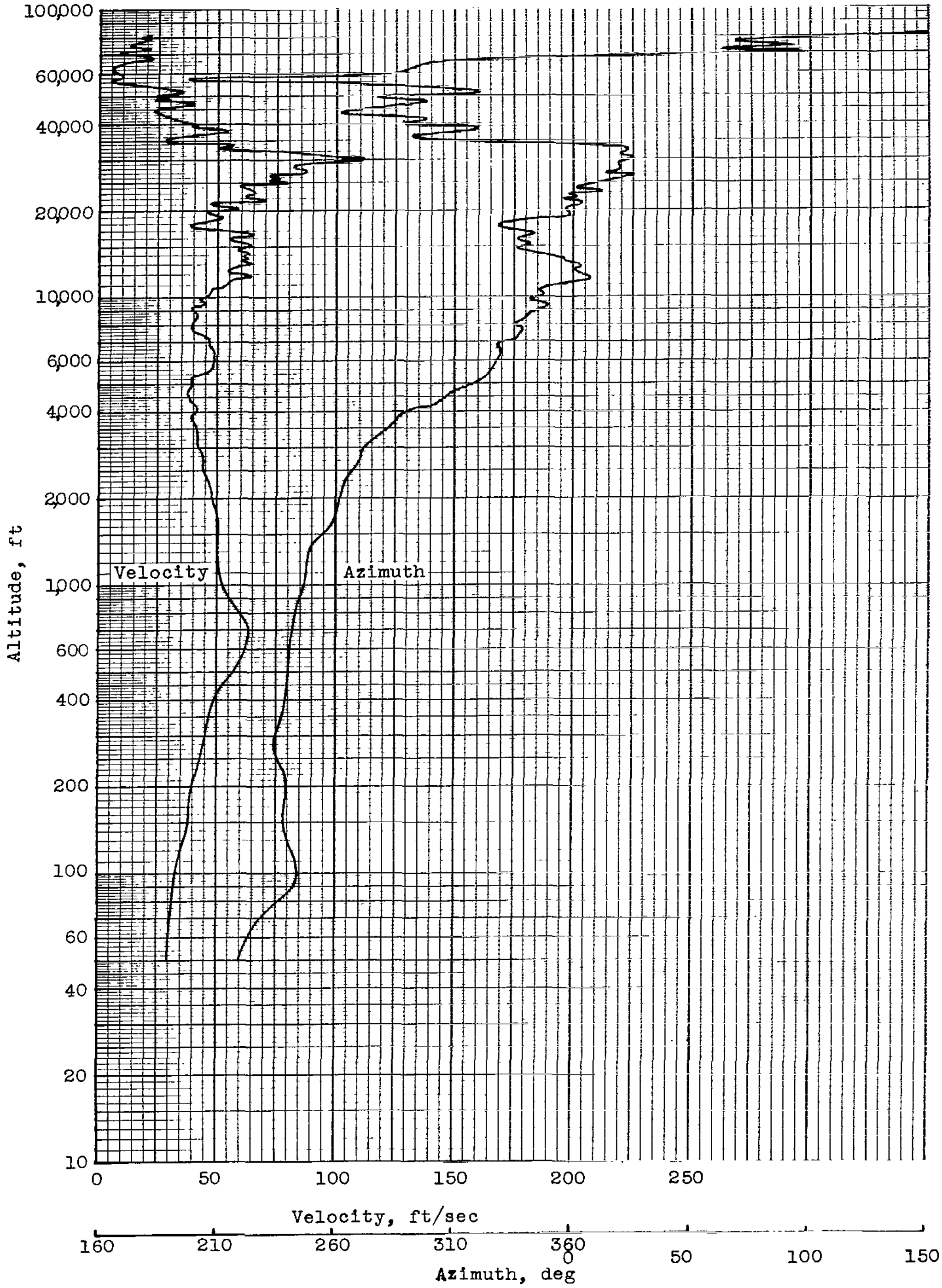
(j) Trailblazer Ik.

Figure 7.- Continued.



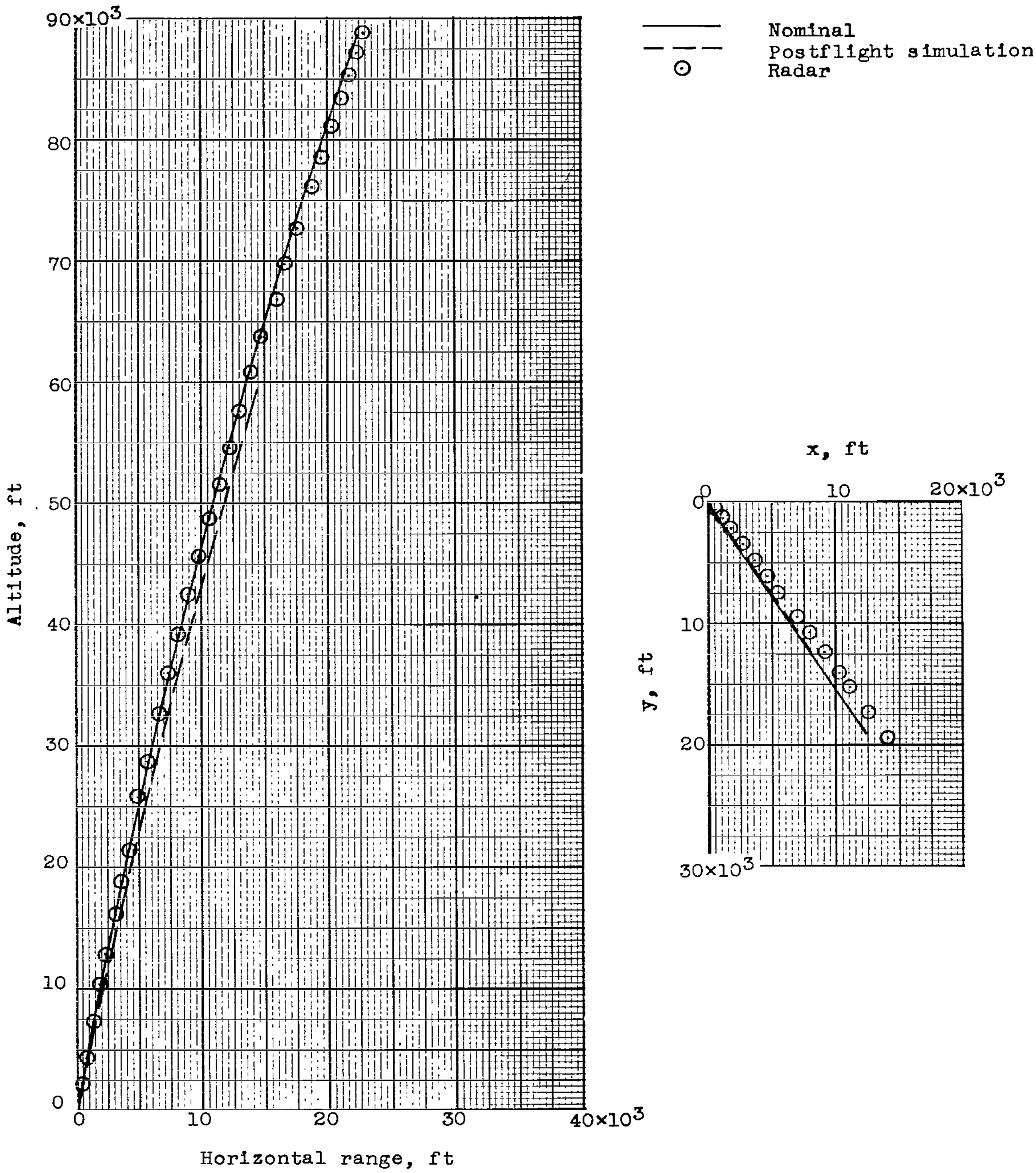
(k) Trailblazer IIa.

Figure 7.- Continued.



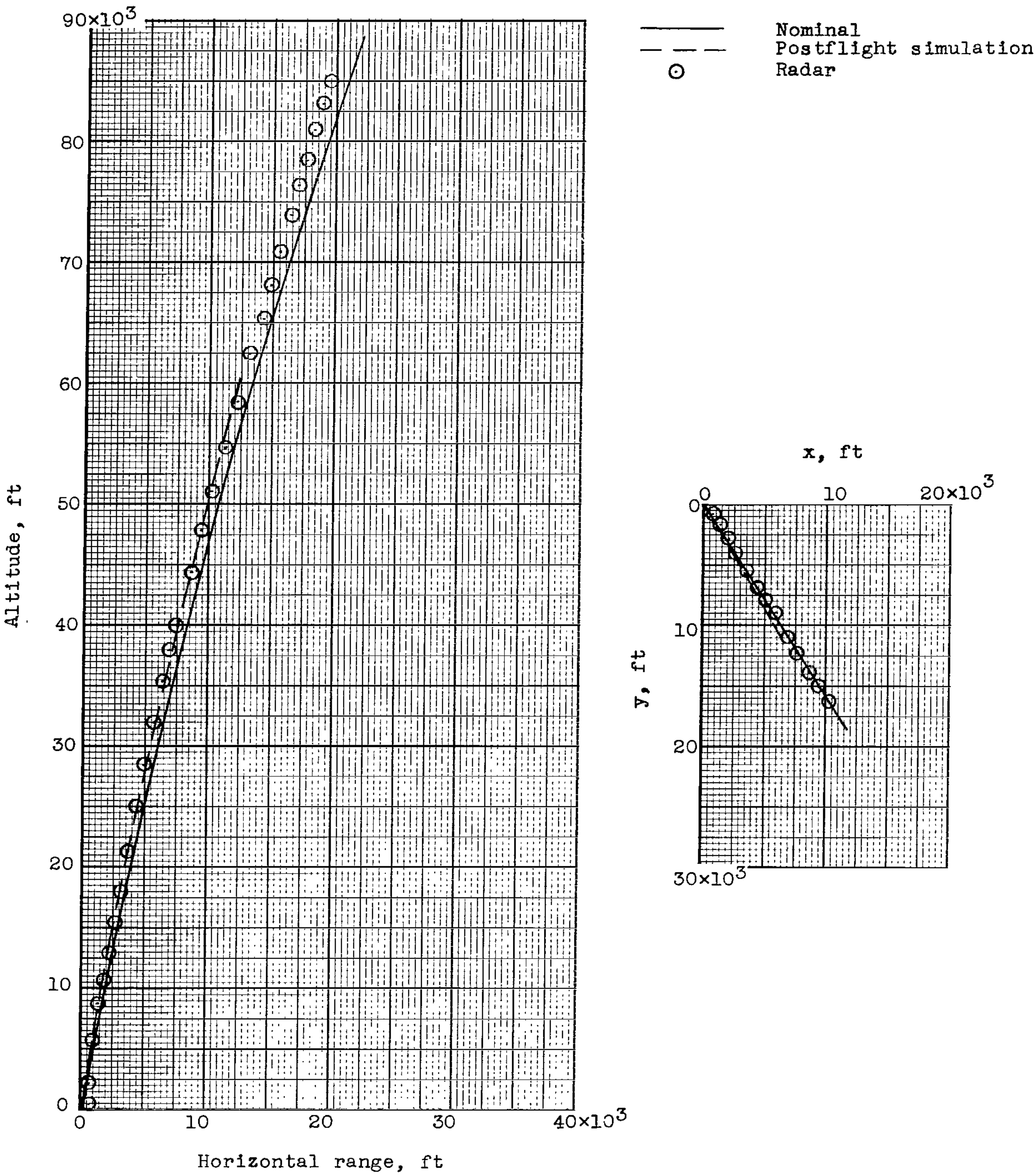
(l) Trailblazer IIb.

Figure 7.- Concluded.



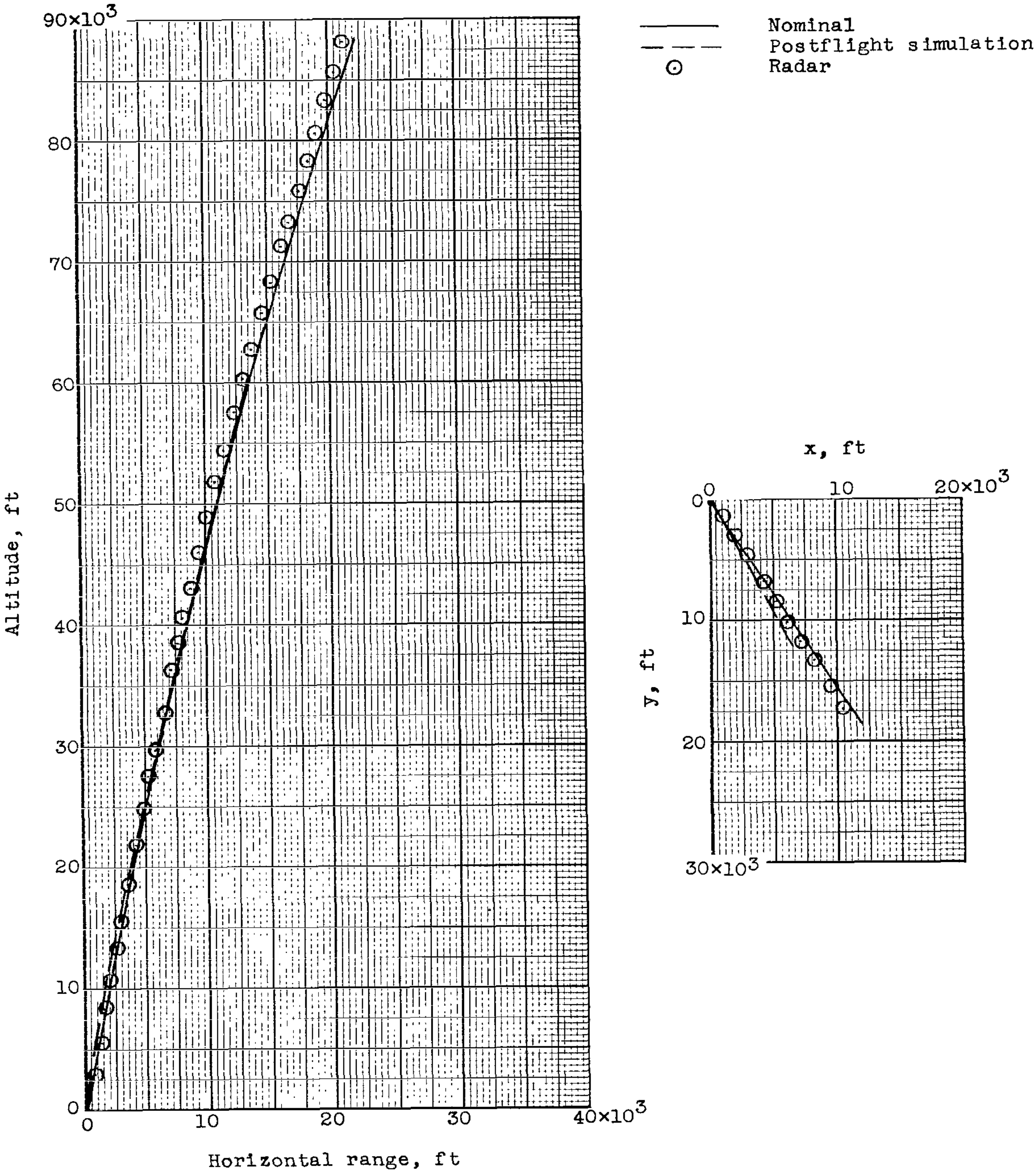
(a) Trailblazer Ib.

Figure 8.- Variation of altitude with horizontal range and of x with y for a comparison of nominal trajectory without wind, theoretical six degrees of freedom with wind, and radar-tracking data from flight.



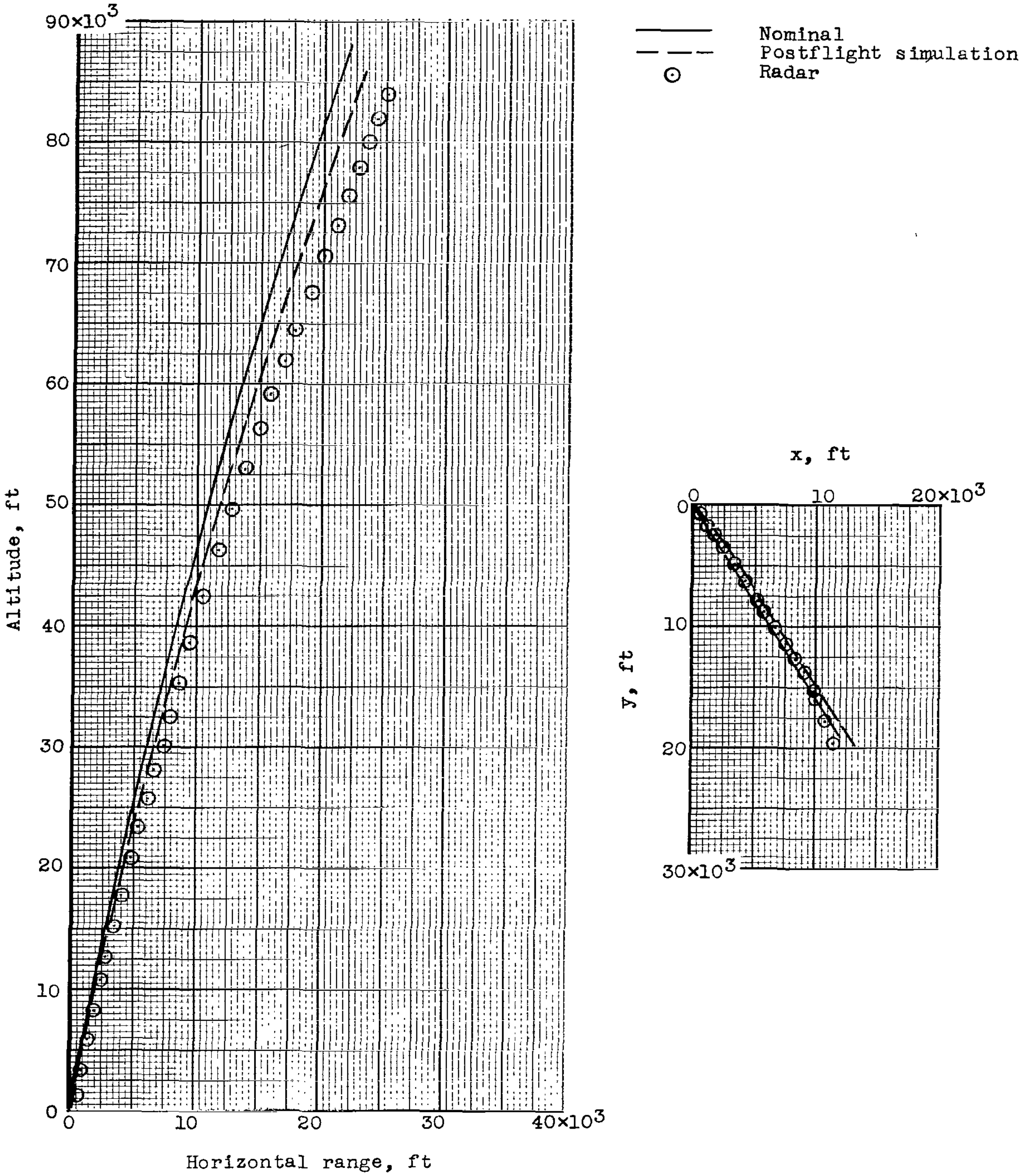
(b) Trailblazer Ic.

Figure 8.- Continued.



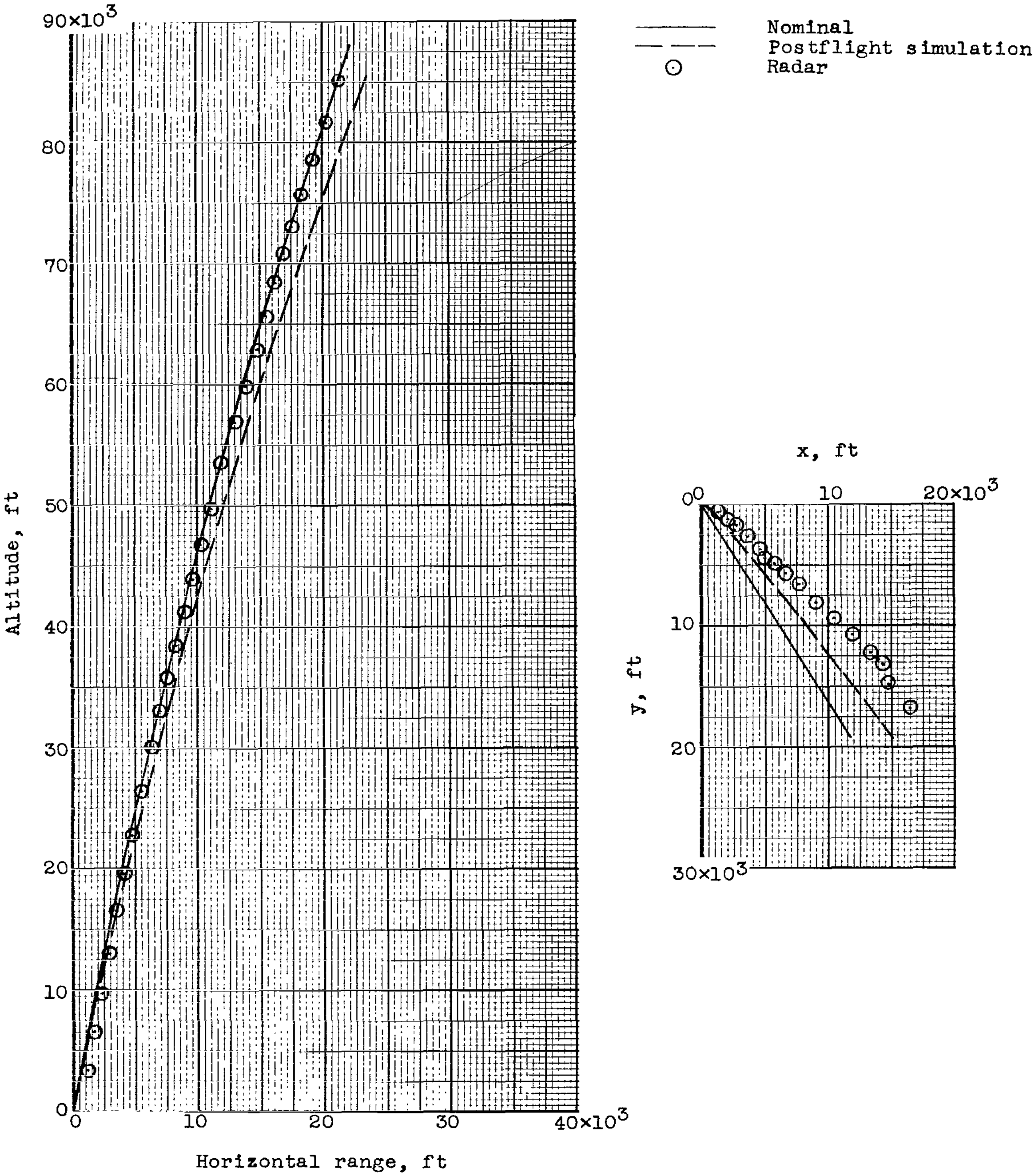
(c) Trailblazer Id.

Figure 8.- Continued.



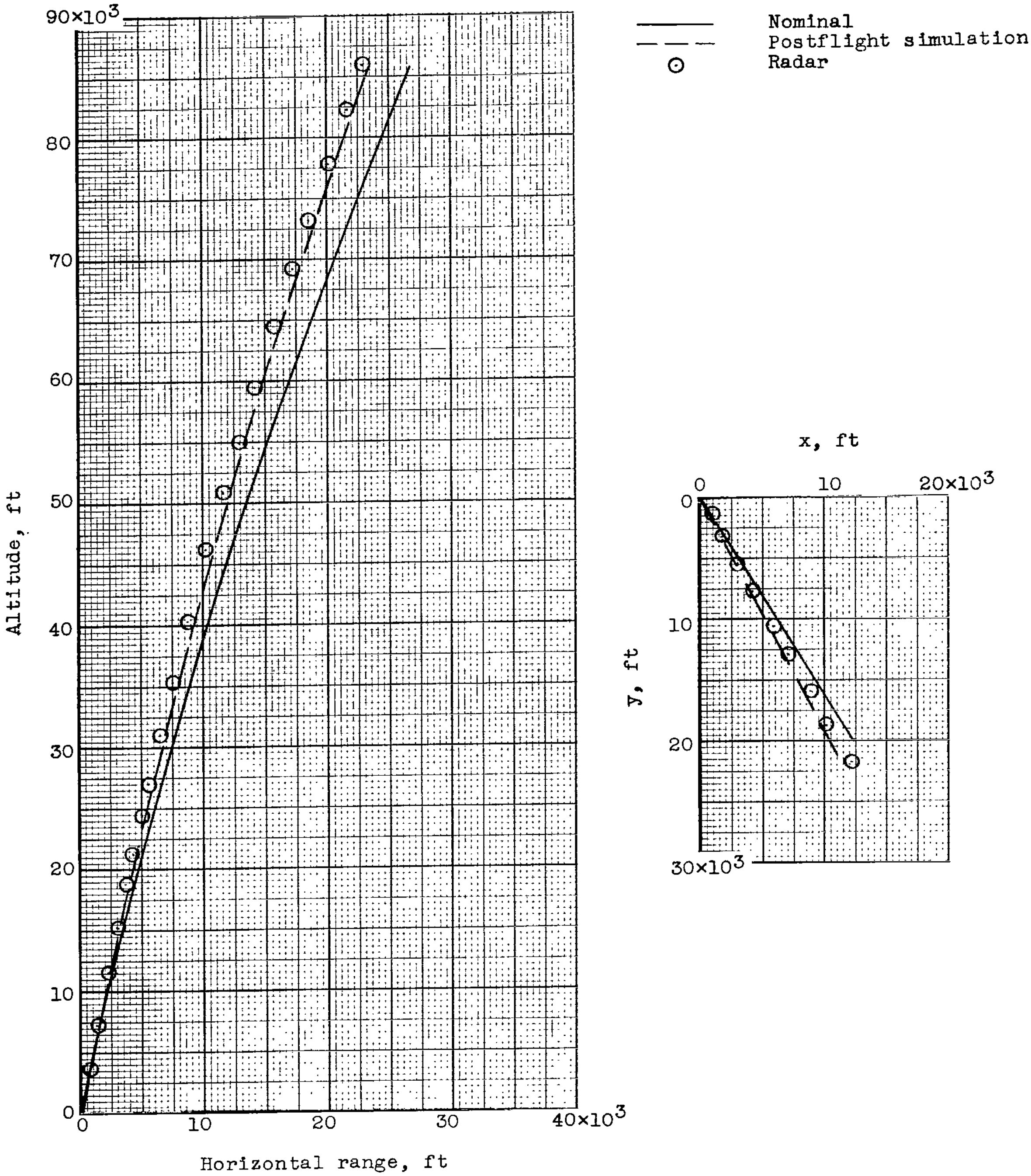
(d) Trailblazer Ie.

Figure 8.- Continued.



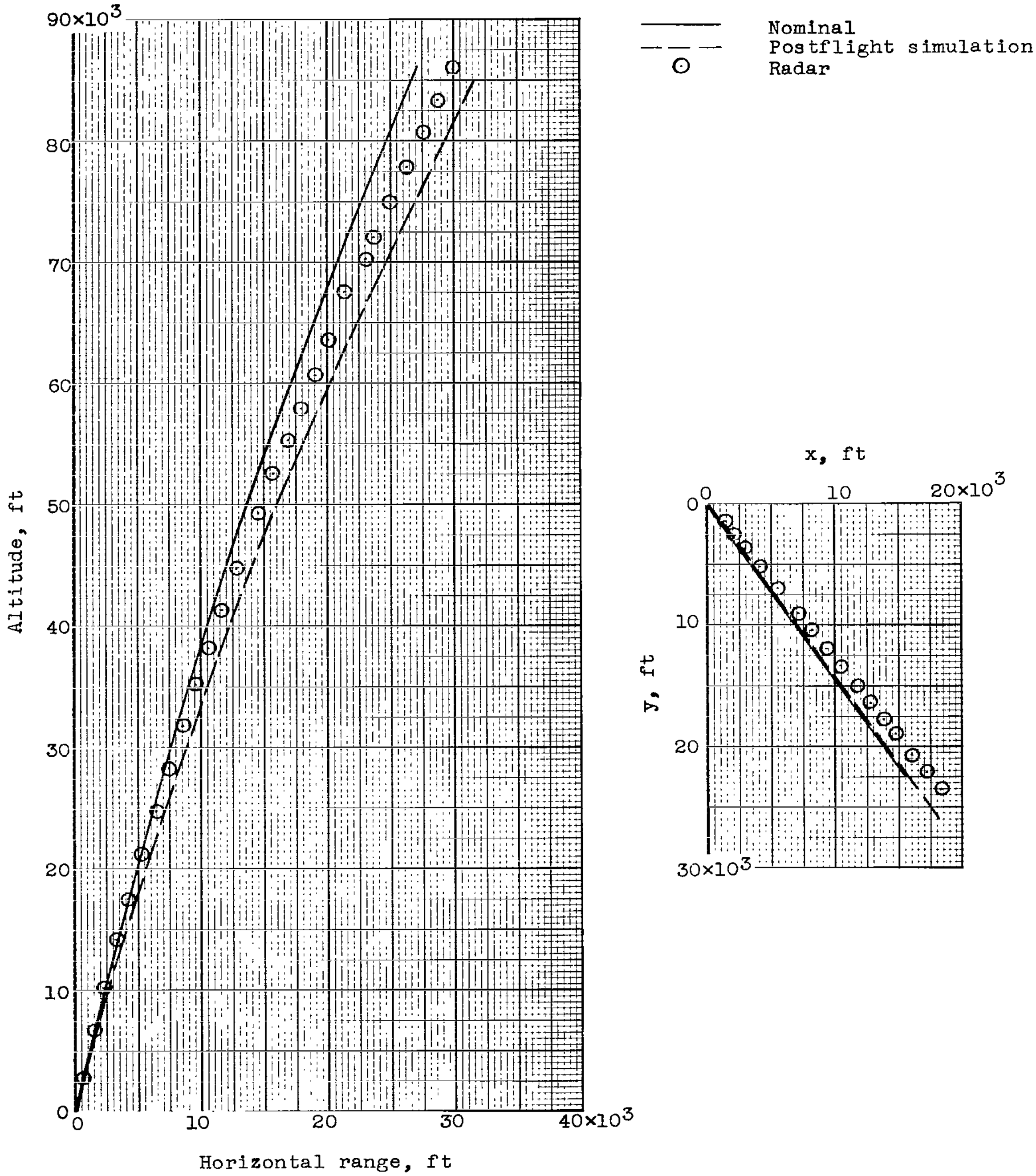
(e) Trailblazer If.

Figure 8.- Continued.



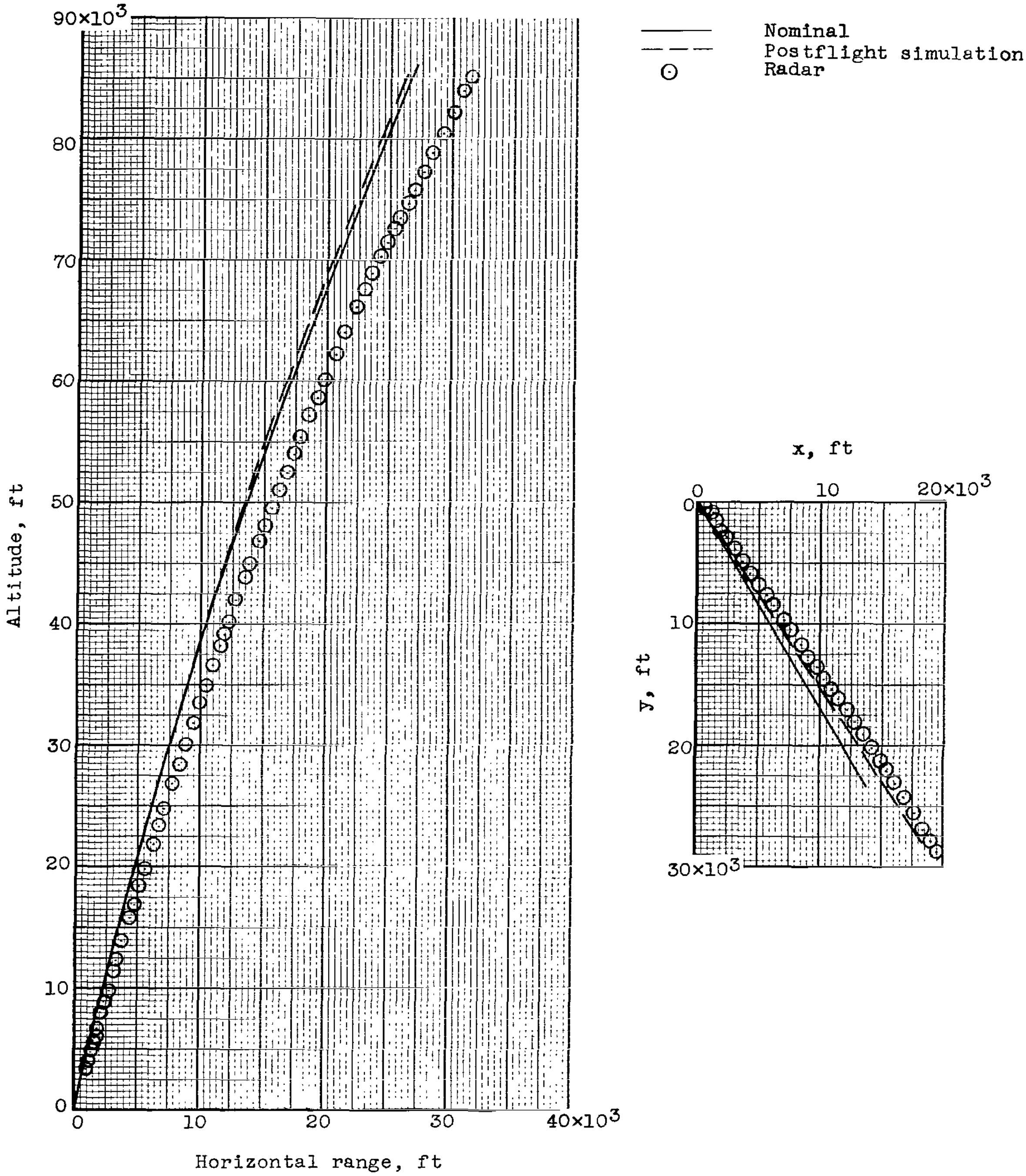
(f) Trailblazer Ig.

Figure 8.- Continued.



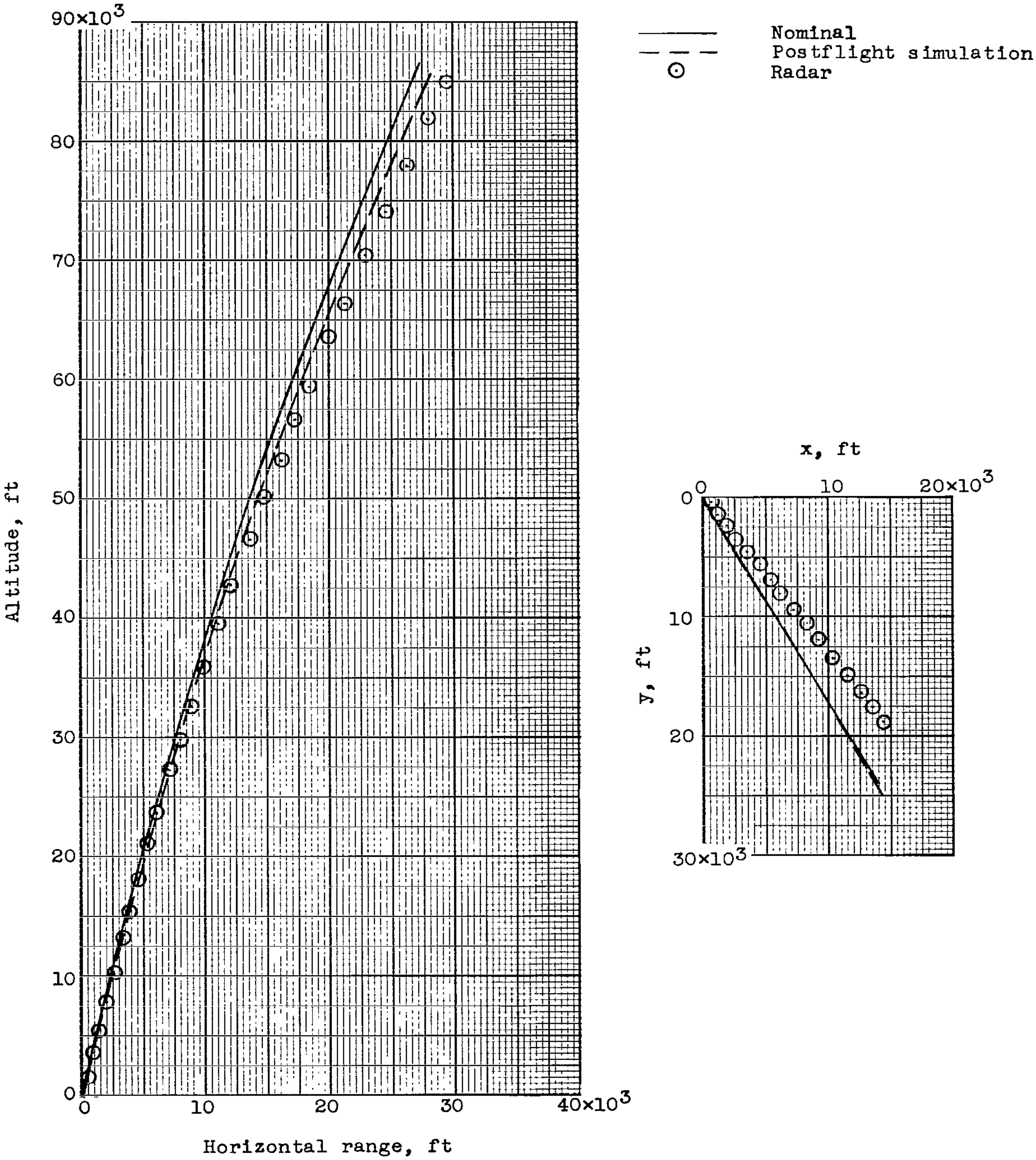
(g) Trailblazer Ih.

Figure 8.- Continued.



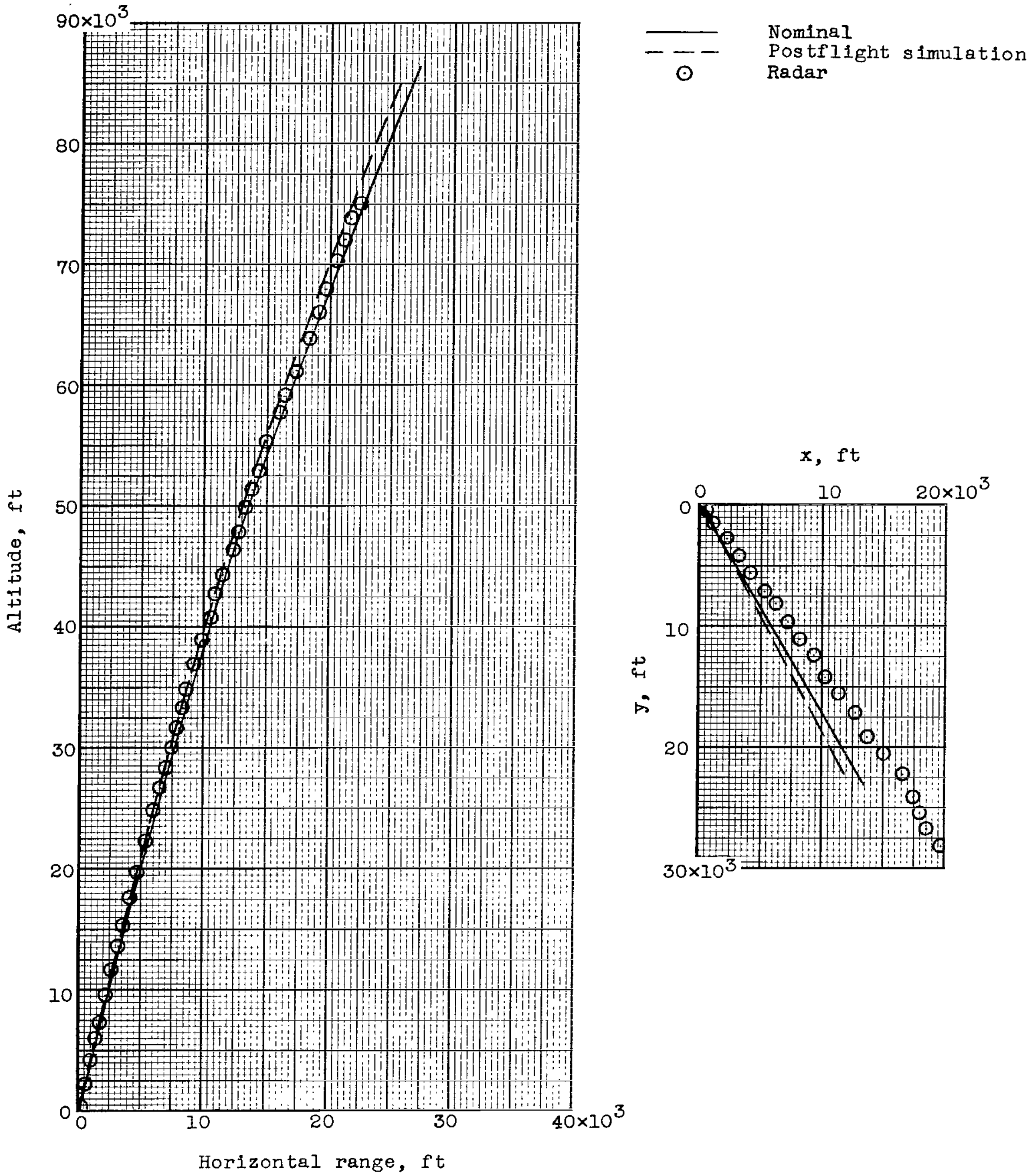
(h) Trailblazer Ii.

Figure 8.- Continued.



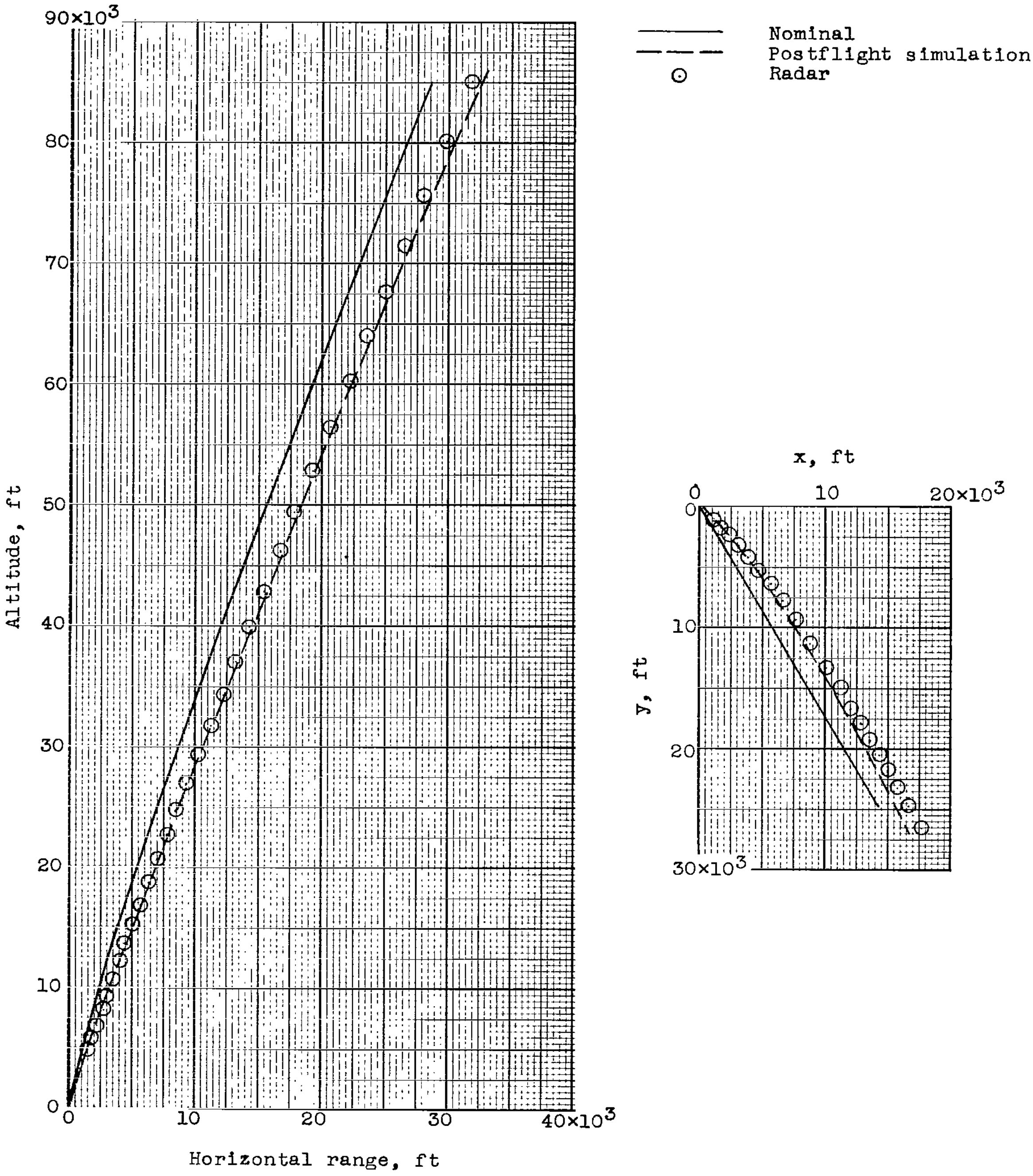
(i) Trailblazer Ij.

Figure 8.- Continued.



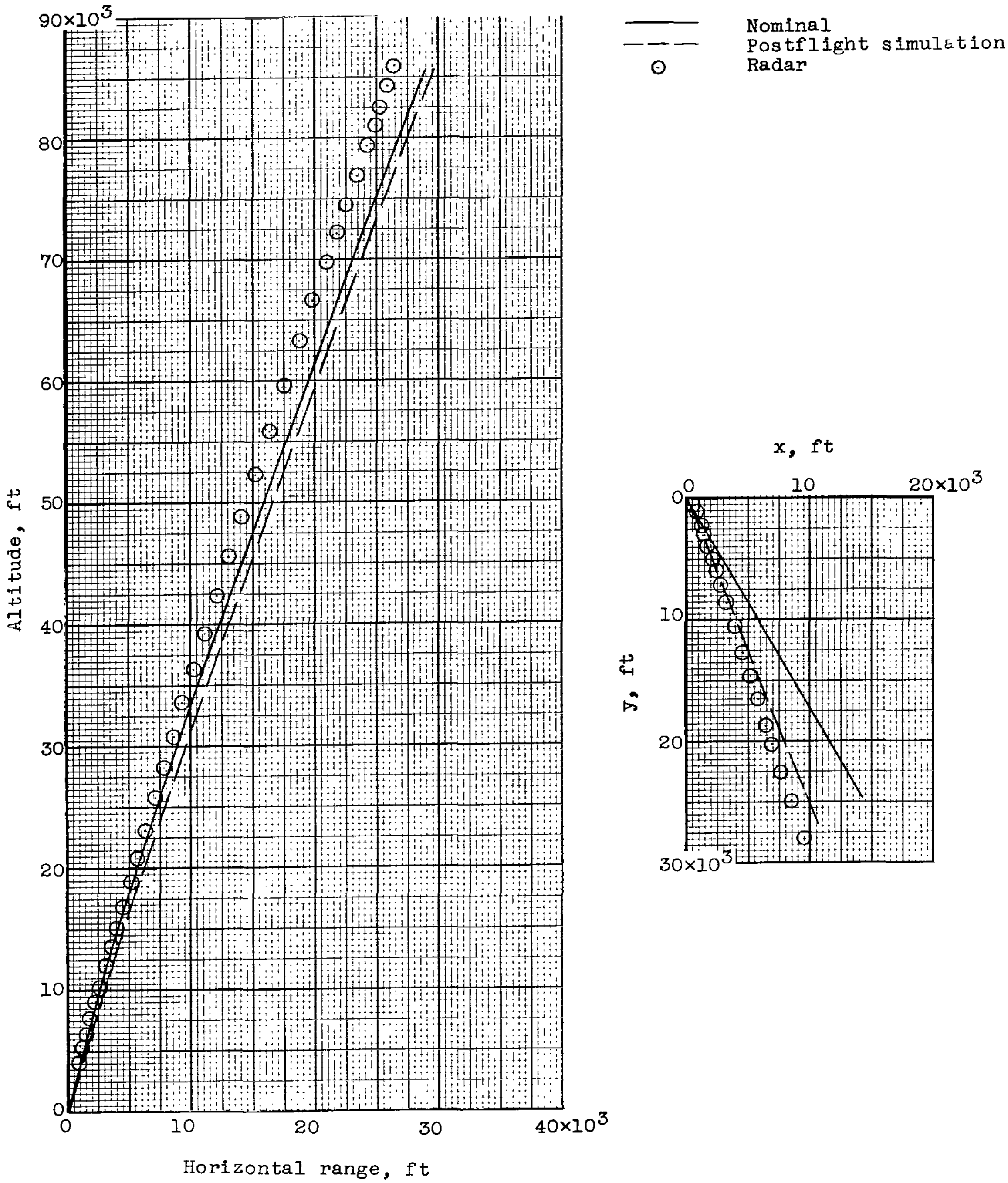
(j) Trailblazer Ik.

Figure 8.- Continued.



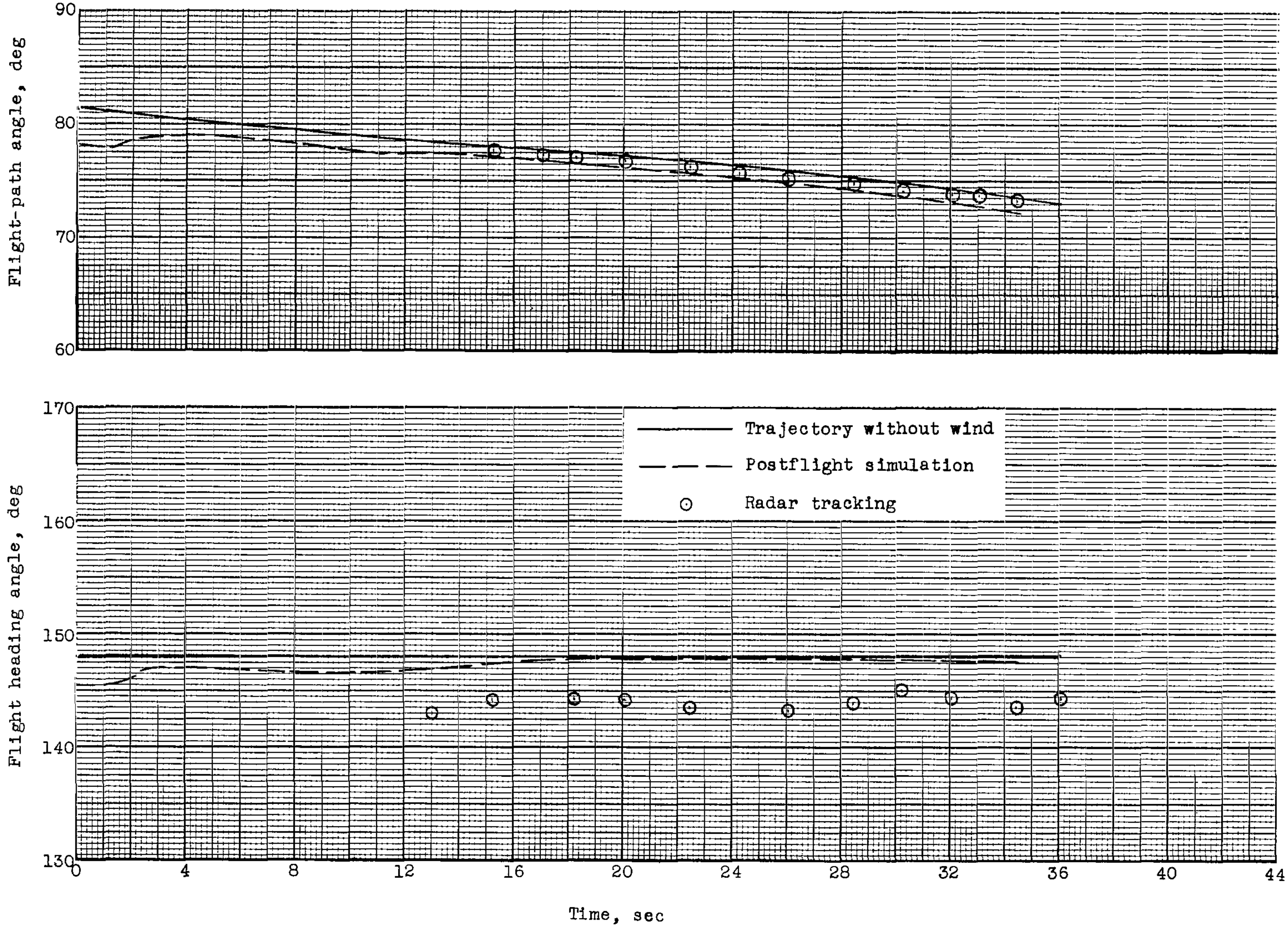
(k) Trailblazer IIa.

Figure 8.- Continued.



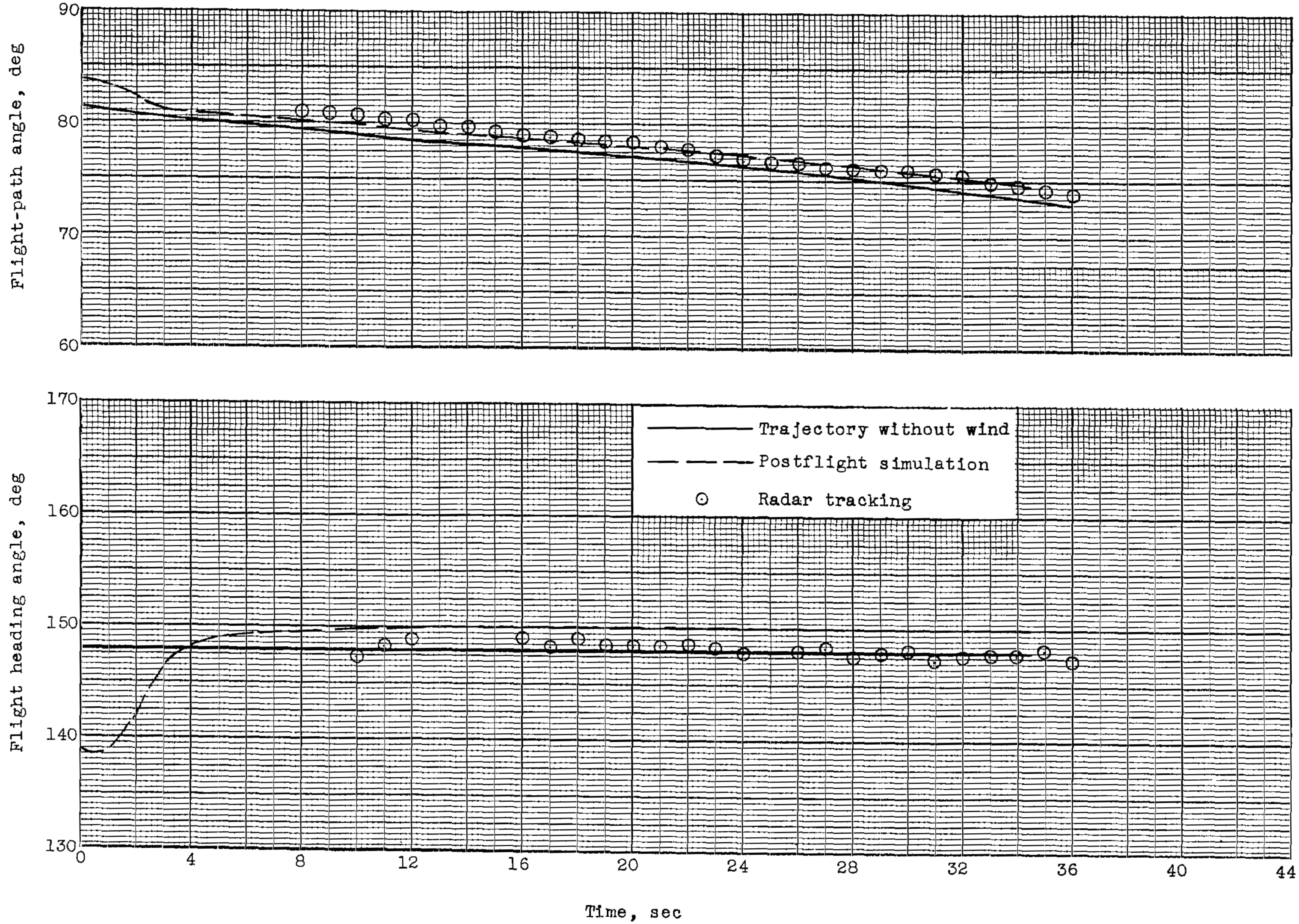
(l) Trailblazer IIb.

Figure 8.- Concluded.



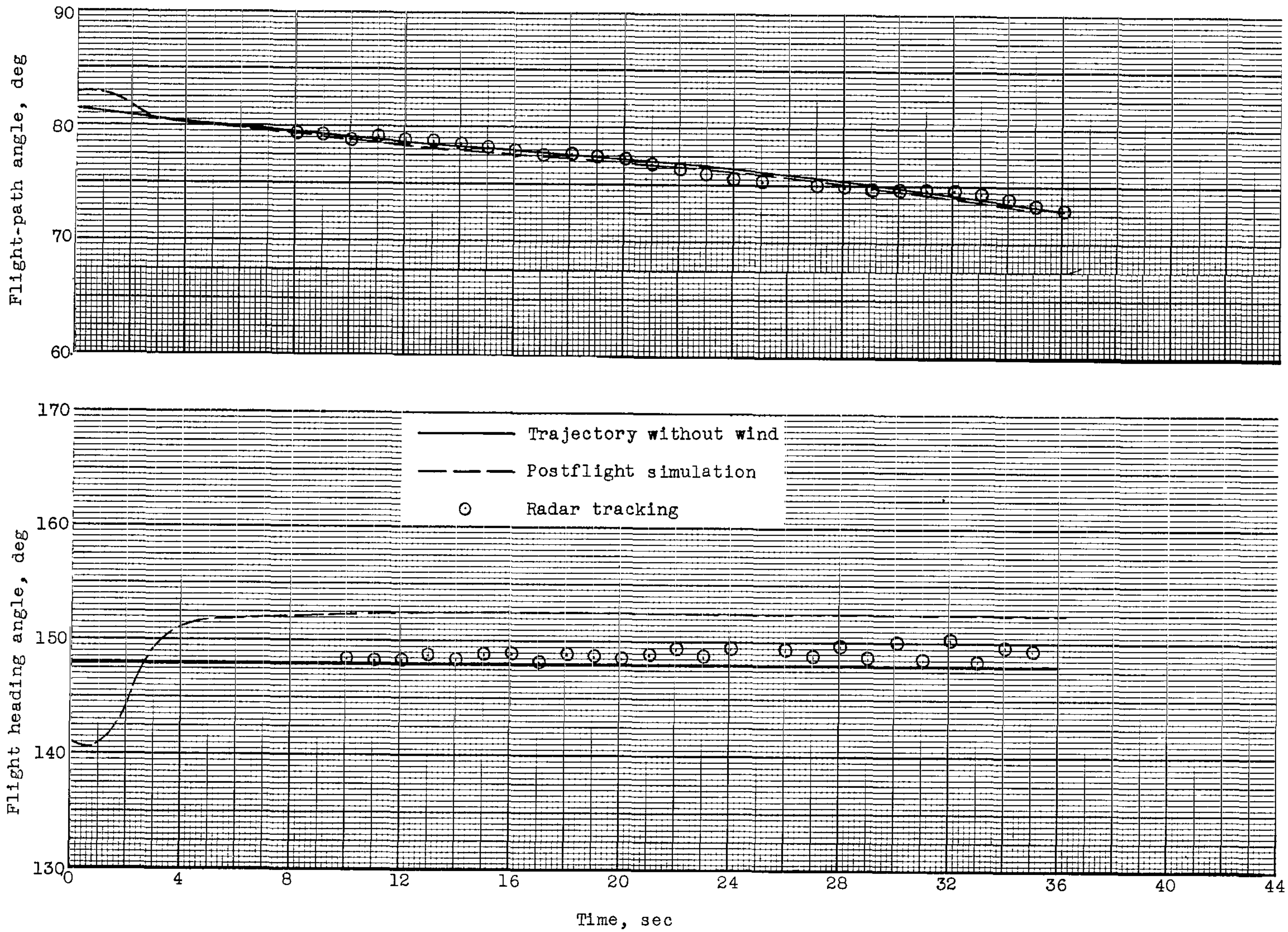
(a) Trailblazer Ib.

Figure 9.- Variation of flight-path angle and flight heading angle with time for comparison of nominal trajectory without wind, theoretical six degrees of freedom with wind, and radar tracking data from flight.



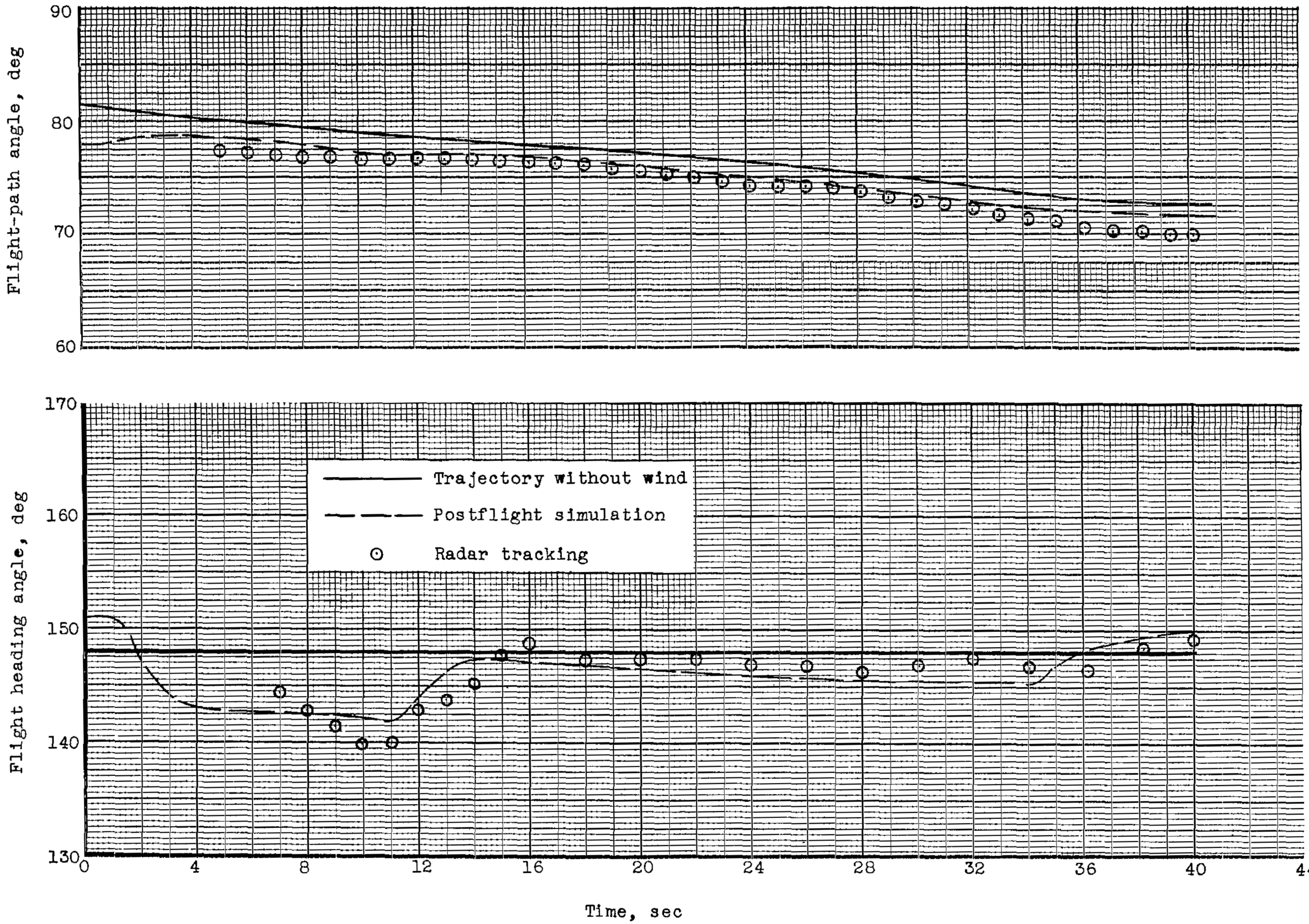
(b) Trailblazer Ic.

Figure 9.- Continued.



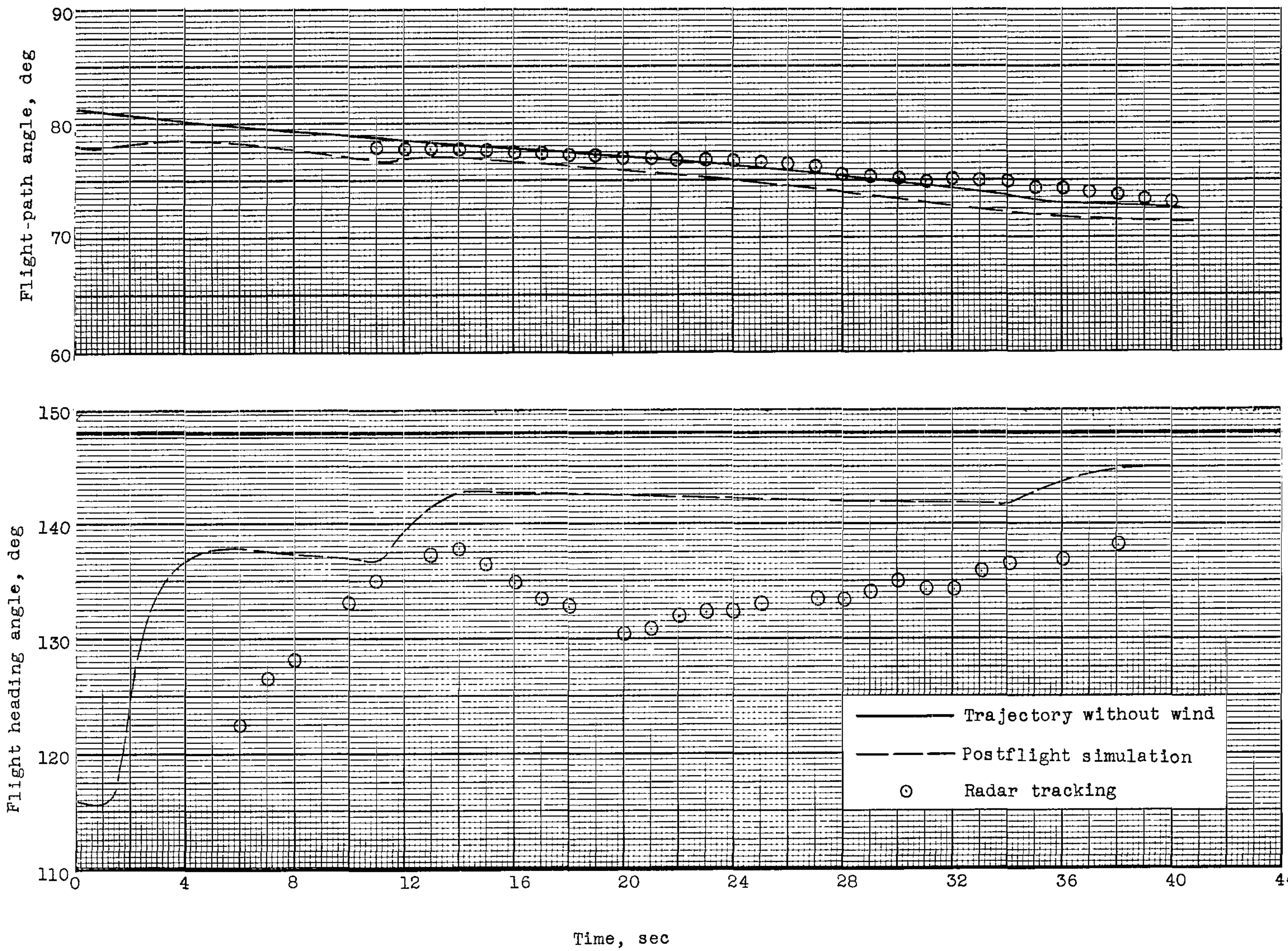
(c) Trailblazer Id.

Figure 9.- Continued.



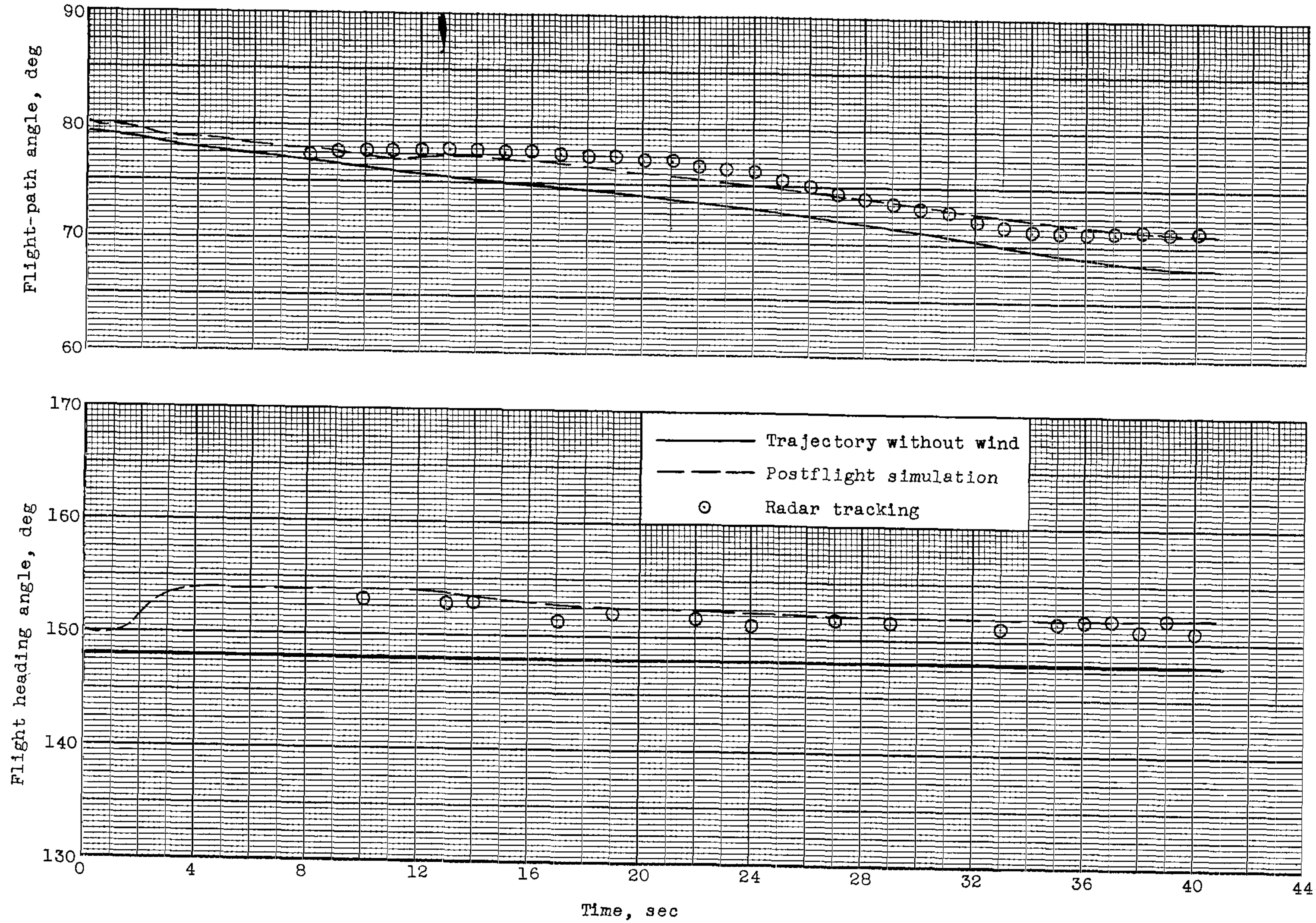
(d) Trailblazer Ie.

Figure 9.- Continued.



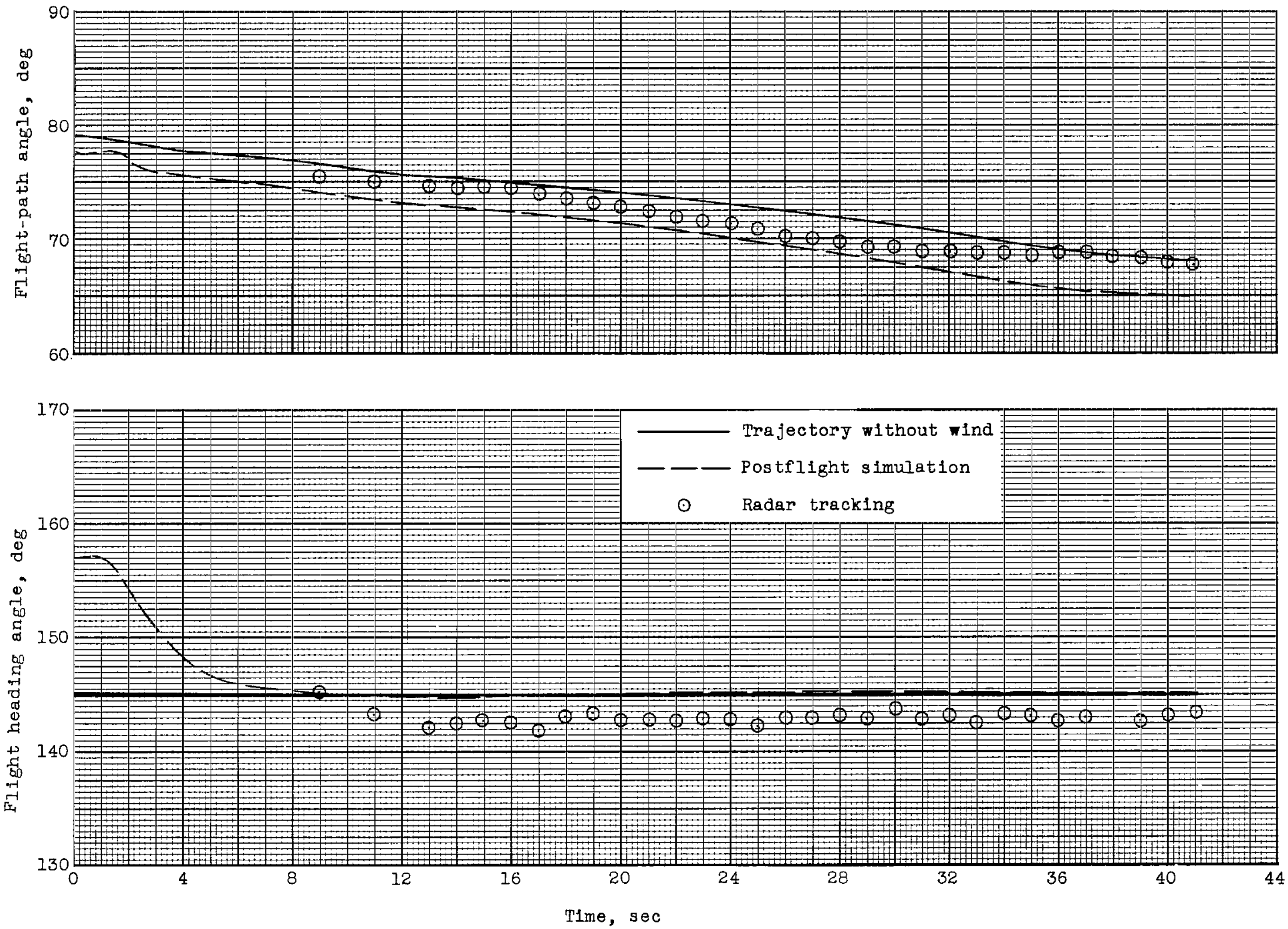
(e) Trailblazer If.

Figure 9.- Continued.



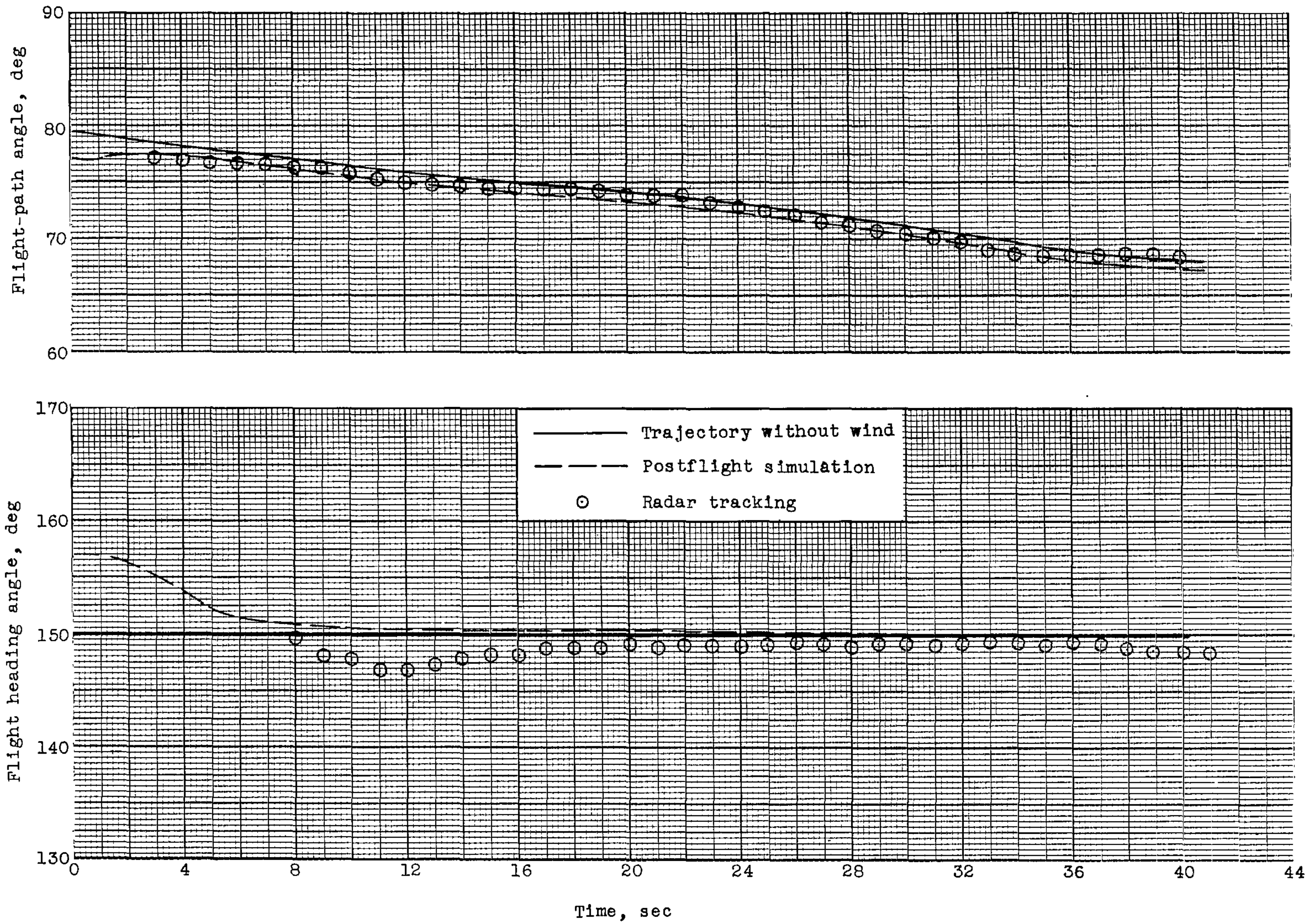
(f) Trailblazer Ig.

Figure 9.- Continued.



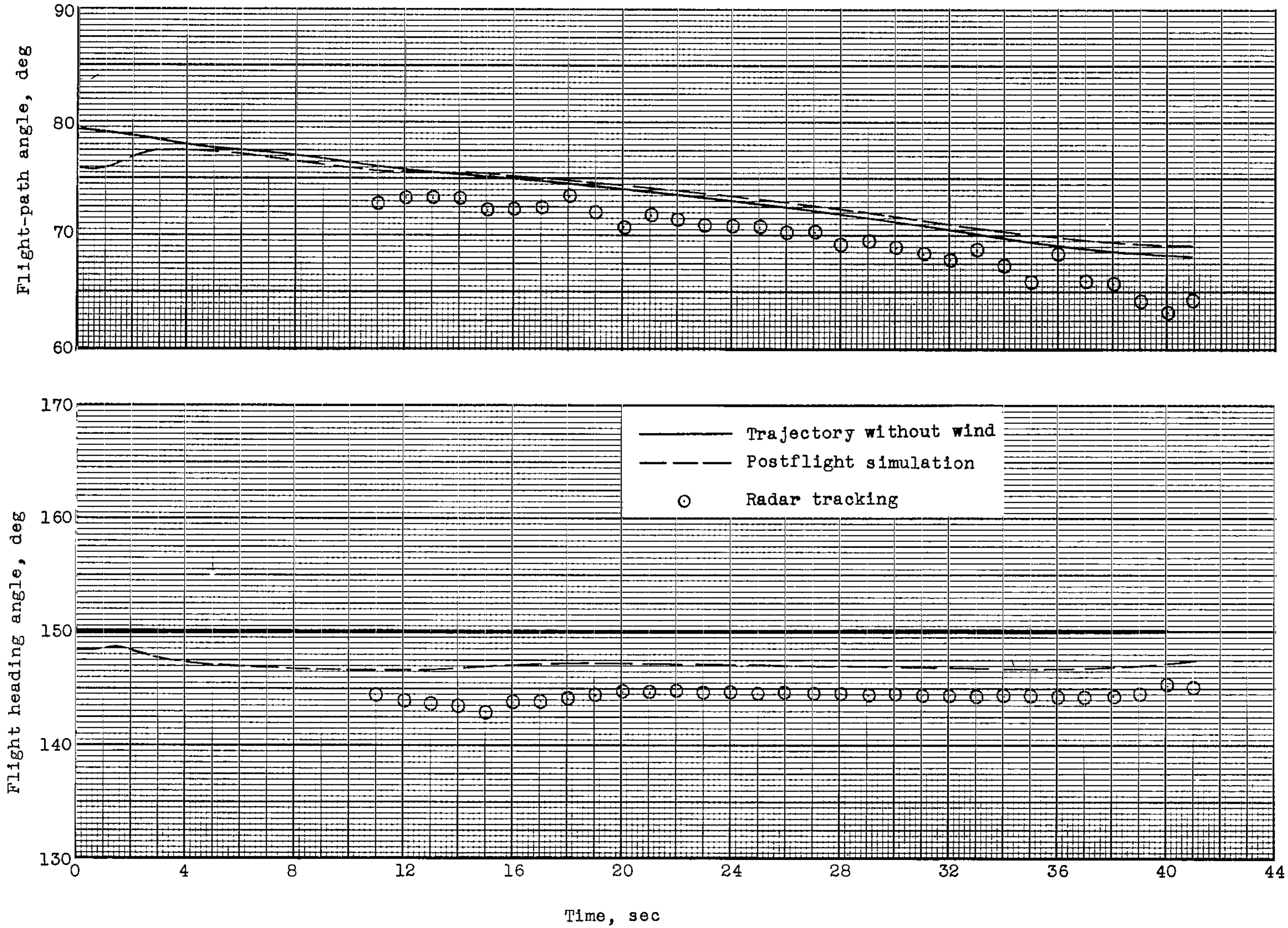
(g) Trailblazer Ih.

Figure 9.- Continued.



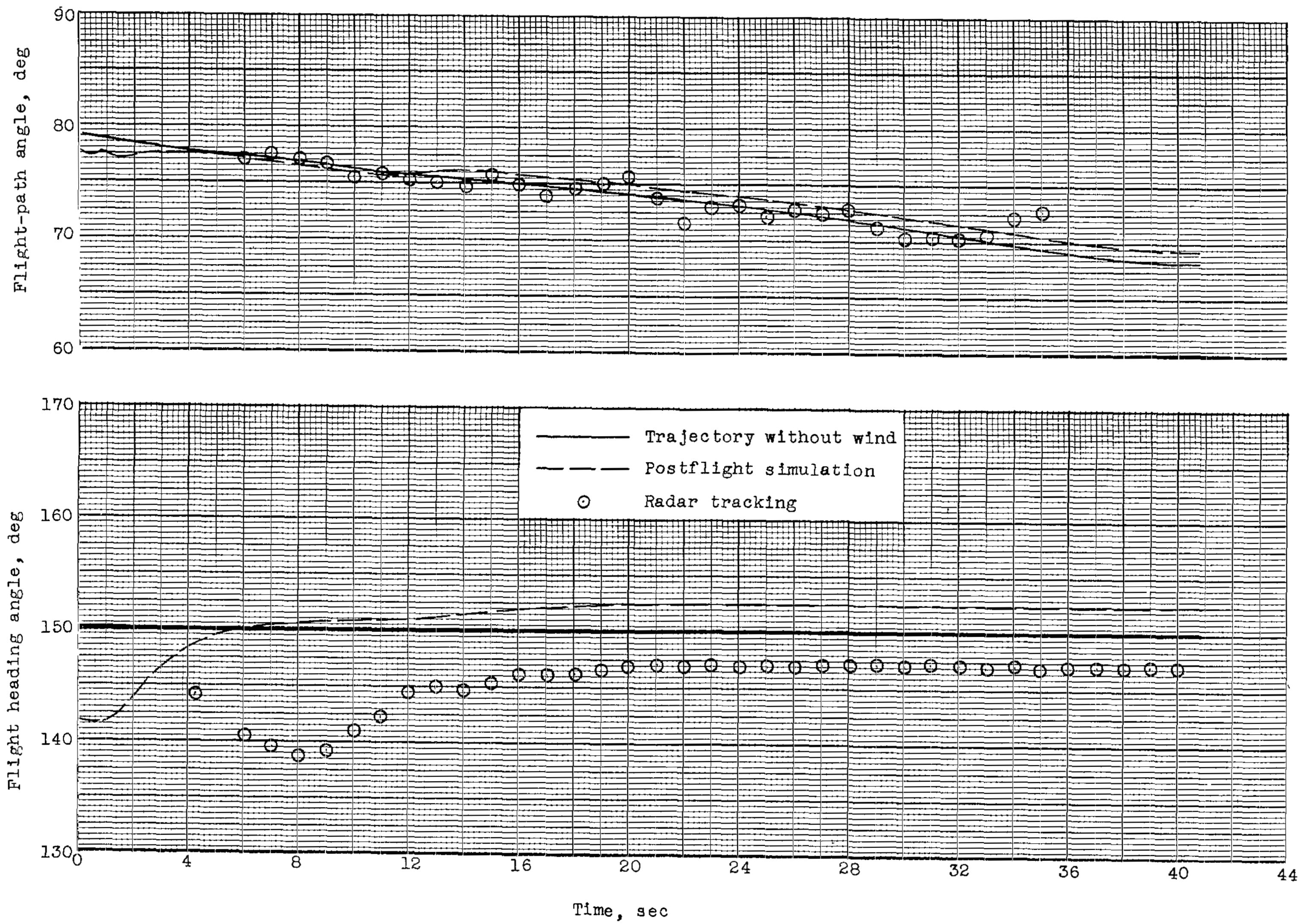
(h) Trailblazer Ii.

Figure 9.- Continued.



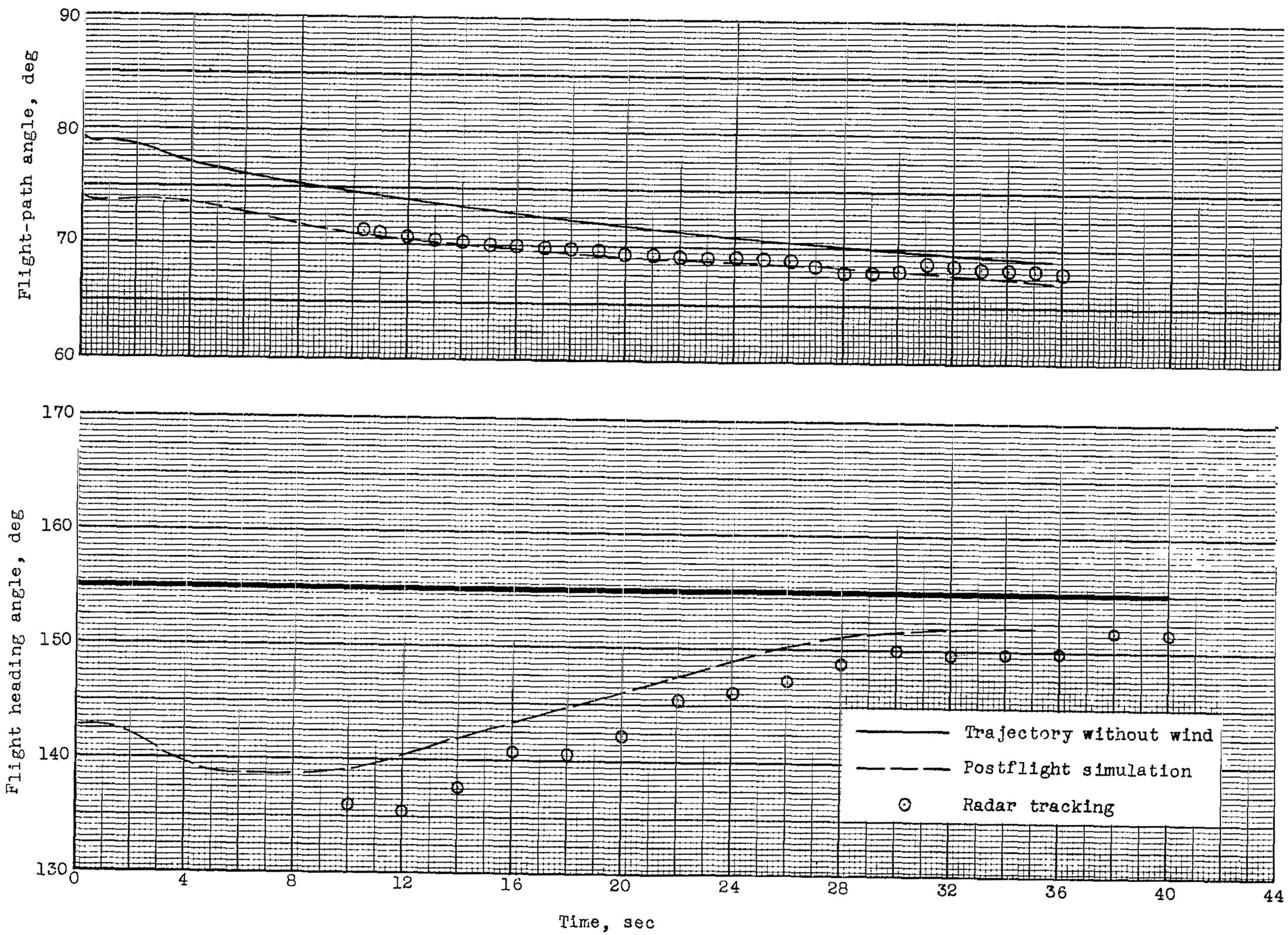
(i) Trailblazer Ij.

Figure 9.- Continued.



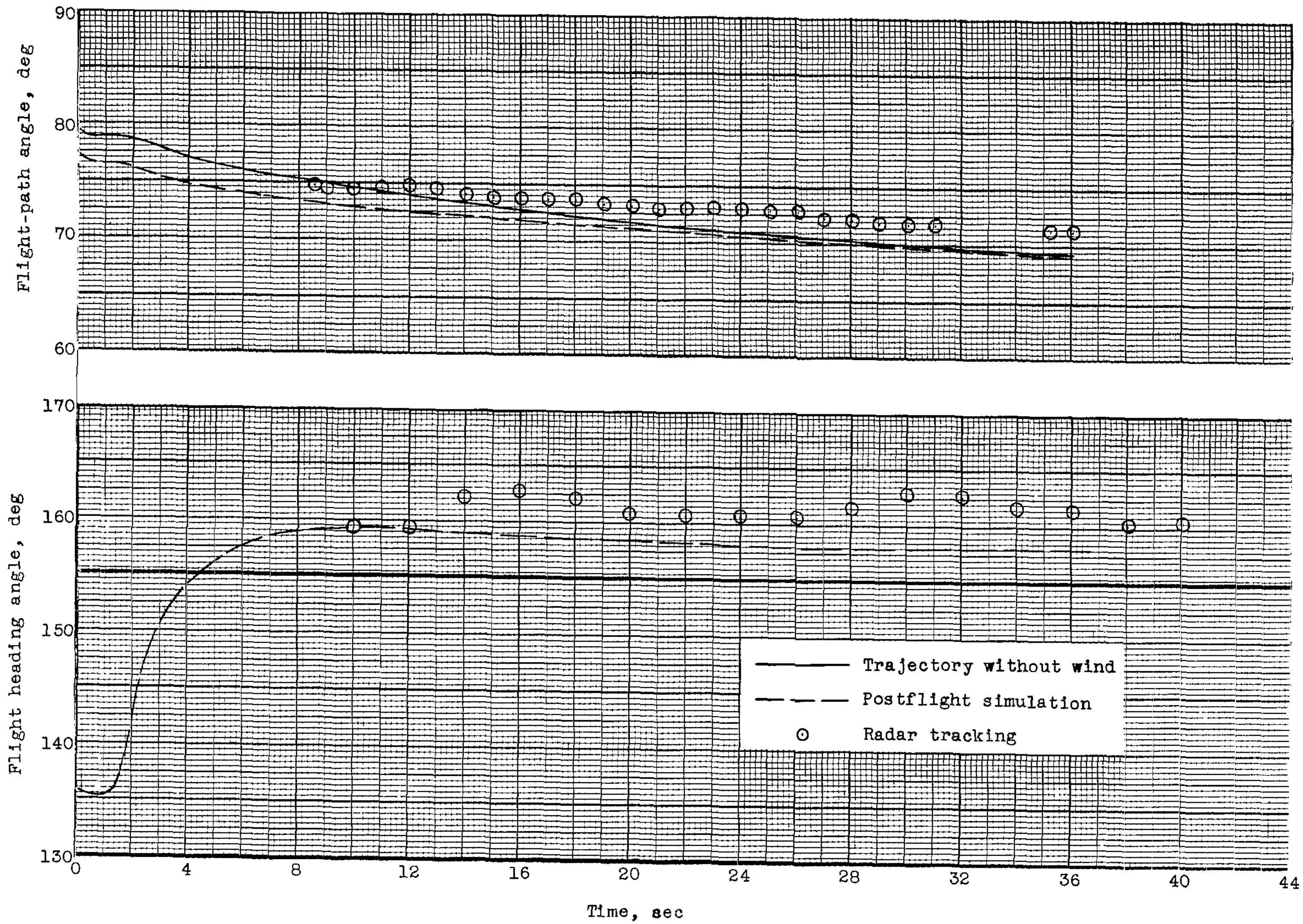
(j) Trailblazer Ik.

Figure 9.- Continued.



(k) Trailblazer IIa.

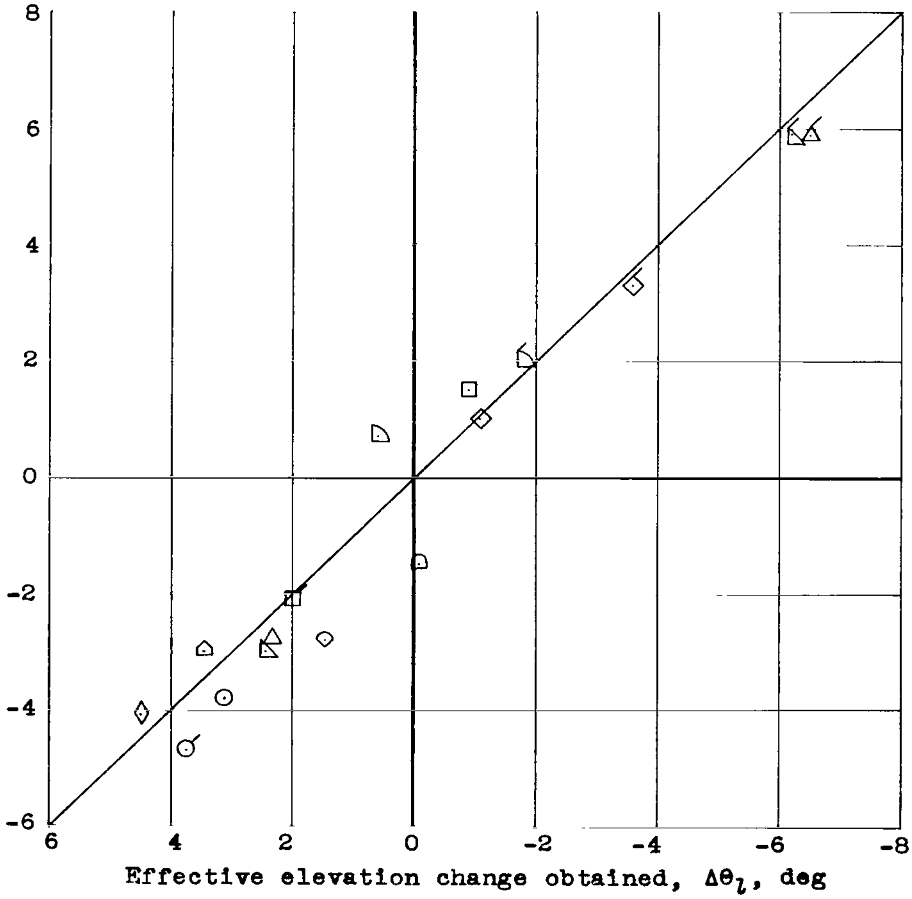
Figure 9.- Continued.



(l) Trailblazer IIb.

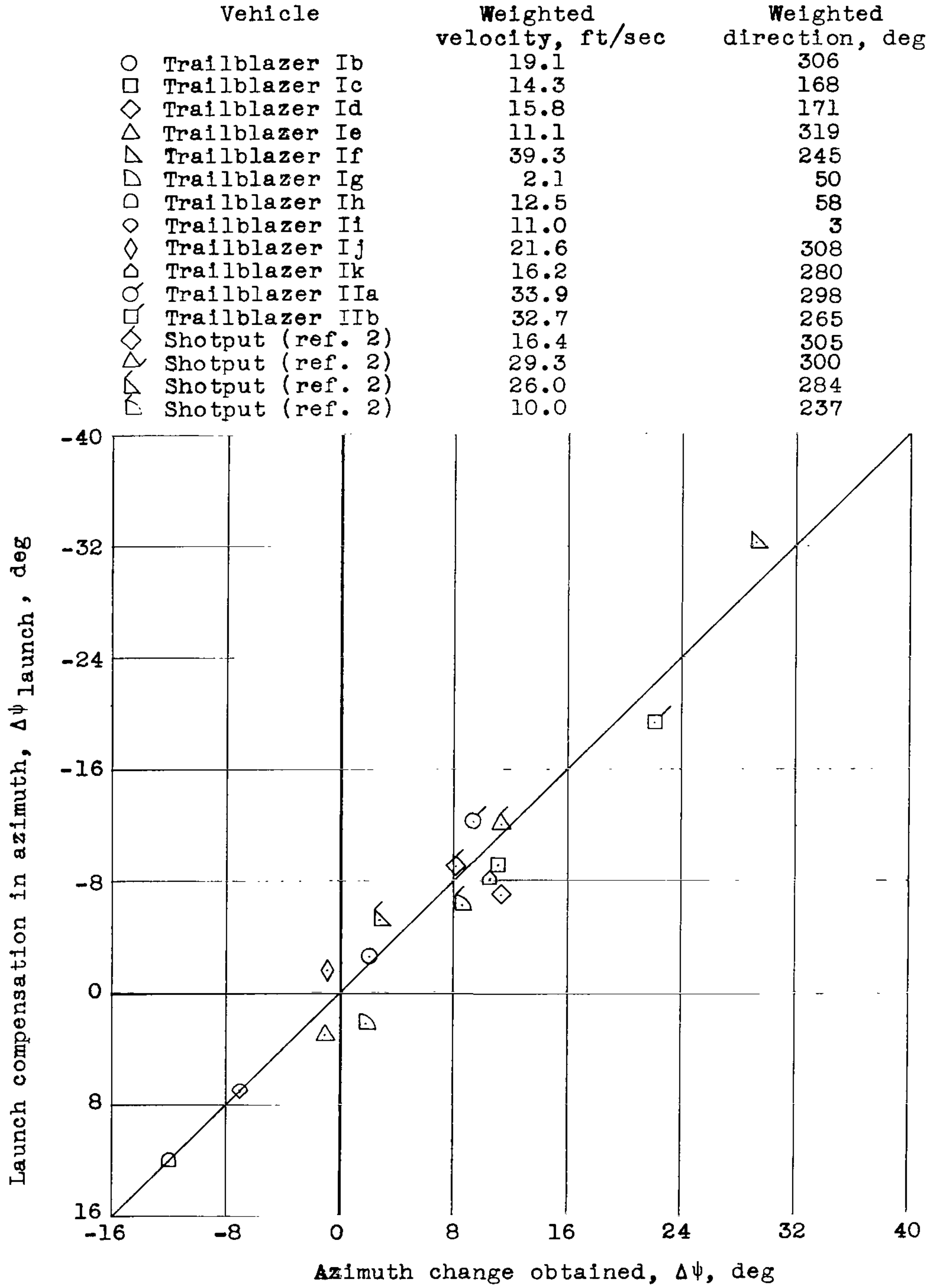
Figure 9.- Concluded.

Vehicle	Weighted velocity, ft/sec	Weighted direction, deg
○ Trailblazer Ib	19.1	306
□ Trailblazer Ic	14.3	168
◇ Trailblazer Id	15.8	171
△ Trailblazer Ie	11.1	319
Trailblazer If	39.3	245
Trailblazer Ig	2.1	50
Trailblazer Ih	12.5	58
Trailblazer Ii	11.0	3
Trailblazer Ij	21.6	308
Trailblazer Ik	16.2	280
Trailblazer IIa	33.9	298
Trailblazer IIb	32.7	265
Shotput (ref. 2)	16.4	305
Shotput (ref. 2)	29.3	300
Shotput (ref. 2)	26.0	284
Shotput (ref. 2)	10.0	237



(a) Comparison in elevation.

Figure 10.- Comparison between correction applied to launcher and change due to wind obtained from postflight calculations.



(b) Comparison in azimuth.

Figure 10.- Concluded.

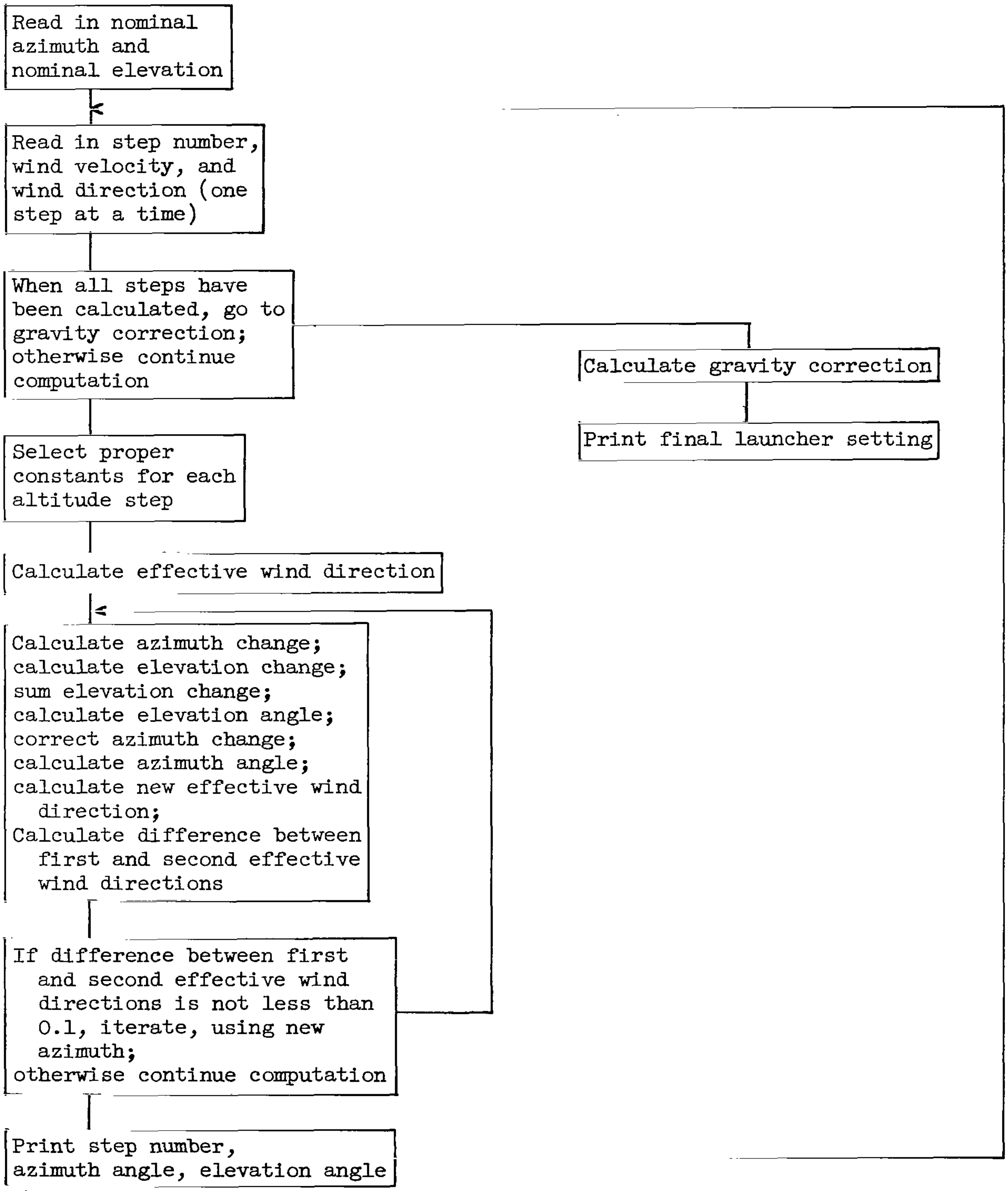


Figure 11.- Block diagram of computer program as used for Trailblazer II.

2/1:1/

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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