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PHOTOGRAPHIC AERIAL ASSESSMENT 53

Volume 1

SUPERVISOR'S MANUAL

NOa(s) 7632
Project 22, Northwestern University
Evanston, Illinois

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PHOTOGRAPHIC AERIAL ASSESSMENT.

Volume 1.

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GENERAL PREFACE

During the active life of the Project 14 at Northwestern University provision was made for the preparation of a series of monographs on the general subject of Photographic Aerial Assessment as developed for the Navy under OSRD Contract OEMsr 1276. It was felt that in its present highly specialized form a fairly comprehensive exposition of the theories of the various problems, the analytical procedures, the recording equipment and the unique devices used would be a timely undertaking, representing not only a general review of progress but also forming a point of departure from which to measure future developments.

The chief purpose held in view in preparing these Manuals has been to provide a reasonably adequate presentation of background theory, operational requirements and computing procedures as exploited by ~~the~~ Northwestern group.

To better suit the work to this main purpose, the first volume, The Supervisor's Manual, furnishes the reader with the elementary notions of the methods and resources of which use is made in the development of the theory. The treatment of the Bomber vs Fighter problem, with the bomber flying a straight line course at constant speed, has been developed in relatively extended form since it is the basic problem from which others may be handled by suitable modification and extension. The other problems discussed in similar but less detailed manner are four: (1) Bomber vs Fighter, with the Bomber undertaking Evasive Action; (2) The Fighter vs Bomber; (3) The Angle of Attack and Skid Problem; and (4) The Flight-Path Problem. The reader is given a geometrical interpretation of the different situations, a brief theoretical treatment is presented, and the analytical work is detailed with the aid of Flow Charts and associated Form Sheets. ~~The experimental~~ requirements of what information is necessary and how it may be obtained, ~~camera~~ calibration and synchronization, accuracy needed at various steps in the analysis, film handling, and description of the computing instruments are included, as well as suggestions and cautions based on several month's operational experience with the equipment and procedure.

Of the remaining volumes, two are very closely bound to the first. From the purely practical consideration of carrying out the assessment procedures the second volume is the Computer's Manual, which has been prepared for the non-technical people who will in the main do the actual computing work; it provides a summary of aerial gunnery terminology, provides Flow Charts indicating the operations necessary to obtain the desired assessment data from the film and computing machines, and provides a description of these devices. The third volume, the Theory Manual, supplements and extends the theory in the first volume.

Volumes 4 and 5 are Equipment Manuals, treating the Airborne and Ground Installations in comprehensive fashion, dealing with the subjects of mounting, aligning and adjusting the devices in addition to detailed instructions for maintenance and operation. Parts lists are included, giving specific reference to the drawing number and manufacturer of the detailed parts of the various units used in the program.

Certain general editorial features of the work may be noted as follows:

1. Symbols. No attempt has been made to maintain, in the treatment of the various volumes, an absolutely uniform system of notation. This was found to be quite impracticable.

Notation is peculiar to the special subject under treatment, and must be adjusted thereto. Furthermore, there is no generally accepted system of notation among the people working in the field. Each author has developed his system of symbols in accordance with his needs. However, tables are included giving the most frequently employed symbols with their meanings, and summaries of aerial-gunnery terminology are also provided.

2. General Plan of Construction. It should be noticed that definitions,

illustrations and charts included as a part of a volume are bound at the top of the left cover, and that the text material is bound at the top of the right cover. This makes for convenience of continued reference to a sketch, photograph or definition over the span of several pages of text material.

3. At times reference is made to a "Project 14", and also to a "Project 22"; it should be explained that the Northwestern University group working on the Aerial Gunnery Problem was known as Project 14 until 31 October 1945, after which date it became Project 22.

R. S. Hartenberg

Project 22
Northwestern University
Evanston, Illinois
November 1945

INTRODUCTION

Volume 1, the Supervisor's Manual, has been prepared primarily for the person who has charge of carrying out the computations which transform the raw experimental data into useful results. In addition, it will be adequate for the person who is merely interested in a brief glance at photographic aerial assessment and its methods. In either case the reader is assumed to be familiar with mathematics through the calculus and, what is even more important, to possess a mature viewpoint toward mathematical techniques plus good sense in applying them to physical situations and engineering problems. The equivalent of a college major in physical science, engineering, or mathematics should be sufficient, though not necessary, preparation for the understanding and application of the material presented in this volume.

Detailed step-by-step procedures for carrying out the various separate calculations are reserved for the Computer's Manual, and elaborate treatments and proofs which would interrupt the continuity are relegated to the Theory Manual. However, frequent references are made to both of these volumes, and the reader is presumed to have ready access to them and to the references mentioned in the text from time to time and collected in the bibliography at the end of each section. The general reader may not wish to study the Computer's Manual in detail, but the supervisor must be thoroughly familiar with it, since the computers working under his direction are expected to follow the procedures described therein.

BOMBER VS FIGHTER: BOMBER FLYING STRAIGHT AND LEVEL AT CONSTANT SPEED

CHAPTER A-1

THE THEORY - A BRIEF TREATMENT

A-1.01. Objectives and Methods. The objective of an assessment of a bomber's defensive armament is to measure the effectiveness of its fire control system against an attacking fighter (or fighters) under specified types of simulated combat conditions. Several different measures of this effectiveness have been proposed, among them the single shot probability of scoring a hit on the fighter at any instant during an attack, the probability of scoring at least one lethal hit during an attack, and the mean and standard deviation of the gun position errors during an attack. These and other measures have been defined and discussed in various papers*, from which an idea of their relative merits may be gleaned. Here we wish only to state that they all require the prior determination of the radial gun lead error (or suitable components) at any instant, where the radial gun lead error is defined to be the angular difference between the direction in which the gun under consideration was pointed and the direction in which it should have been pointed in order that a bullet fired at that instant would hit the fighter at some later instant. Because of this dependence of other measures on the radial gun lead error or its components and because it can itself be taken as a measure of effectiveness, the following discussions will be limited to the formulation of methods for calculating during "dry runs", i.e., attacks in which no actual firing occurs.

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* See, for example

AMG-C No. 370, "The Assessment of Gun-Camera Trials," by R. F. Bennett and A. Sard
SRG No. 360, "Estimation of Hit Expectancy or Bullet Density from Aim-Error Observations Known to Contain Observational Error", by R. F. Bennett
AMG-N No. 23, "Computation of Single Shot Probability in Camera Sight Assessment", by A. A. Albert
AMG-N No. 79 "Results of a Recomputation of Sight Evaluation Test Data", by W. Givens
AMG-N No. 83, "Optimum Dispersion with the Mark 23 Fighter Gunsight", by W. Givens

Two possible photographic assessment methods are discussed in Memos 3 and 10 of Project 14 at Northwestern University. The so-called transit-time or time-of-flight method (treated later in this Section), was considered in detail and the vector method was mentioned briefly. In developing the theory for the two methods it became apparent that the transit-time method possessed greater inherent flexibility and had a better chance of being made more accurate than the fire control system to be tested. It was, therefore, chosen as the most promising means for getting the desired results.

Having selected the transit-time method, the assessment is treated most naturally under the following cases:

(1) the special situation where the bomber flies a straight path at constant speed, and

(2) the more general condition where the bomber may deviate from such a path by taking various forms of evasive action.

The theory of the former is much simpler than that for the latter, and the present method developed for evasive action is based on the idea of reducing it to the case of straight, steady flight by applying appropriate corrections. Therefore, the special case, which is useful itself in spite of its restrictions, is described in detail first, after which the extensions to certain types of evasive action are considered in Section B of this Manual.

In the process of applying the transit-time method certain additional useful data are obtained, some of which are in the nature of by-products. Such data are principally (1) the gunner's ranging and tracking errors (at least when he is using a rate computing sight similar to the Mk 18), yielding information on the quality of his handling of the fire control system, (2) measurements of the bomber's attitude and change of attitude, (3) estimates of turret angular rates, and (4) certain information about the attacking fighter needed to determine its flight path (see Section E) and to assess its fixed gunnery (see Section C).

The following discussion is designed to explain intuitively the basic idea of the transit-time method. A rigorous analytical treatment is reserved for the Theory Manual, Chapter A-1.

A-1.02 Assumptions. The theory to be developed is based on three assumptions, viz.;

(1) that the bomber flies a straight path at constant speed, relative to some reference point, say a ground observation post or a free-balloon moving with the air mass;
(2) that a projectile fired from a bomber follows a straight path at constant speed, relative to the same reference point;
(3) that the bomber, projectile, and fighter may be treated as points in the air mass.

A-1.03 Basic Theorem. In Fig. 1.01, let the bomber move along the straight line $B_oB_1B_2$ and the attacking fighter along any path $F_oF_1F_2$ which need not be in a plane. Suppose that at the instant when the bomber is at B_o and the fighter at F_o, a projectile is fired from a gun pointing in the direction B_oG. The fundamental problem is to determine this direction such that the projectile will score a hit on the fighter.

First consider the projectile. When it leaves the gun its velocity vector is the resultant of its muzzle velocity with respect to the gun and the gun's, i.e., the bomber's, velocity. In Fig. 1.01 the direction of the projectile's path is B_oP, lying along the diagonal of a parallelogram whose sides, B_oG and B_oB, are proportional to the muzzle and bomber speeds, respectively. Note that only when the gun is pointed forward or backward along the bomber's path will the projectile travel in the direction the gun is pointing.

At some later instant, say one-tenth of a second after being fired, let the projectile be at P_1, the bomber at B_1 and the fighter at F_1. Assumptions (1) and (2) imply that the distances covered by the bomber and projectile in any given time are proportional to their speeds, so that $B_oB_1:B_oB = B_oP_1:B_oP$. This means that B_1P_1 is parallel to BP and hence to B_oG also.

Similarly, two-tenths of a second after firing, the projectile will be at P_2, the bomber at B_2, and the fighter at F_2, where B_2P_2 is parallel to B_oG. Applying the same argument to any instant of time, T seconds after firing, we see that B_TP_T is parallel to B_oG ; i.e., the direction from the bomber to the projectile is always the same as the direction the gun was pointed when it was fired.

Now the condition for a hit on the fighter at any time T is that P_T coincide with the fighter's position F_T , in which case B_TF_T is parallel to B_oG . Thus we have arrived at the following basic theorem:

Theorem: The direction in which the gun should be pointed when a projectile is fired in order that it shall hit the fighter at some later instant is the same as the direction from the bomber to the fighter at that instant.

This direction is called the true bore-line, and any convenient point (other than B_o) on it is called the true bore-point. Firing time, or present time, is the instant when the gun is fired and impact time, or future time, the instant when the hit is scored. The difference, T , between these times is called the bullet time-of-flight or transit time.

A-1.04. Discussion. The foregoing theorem provides the basic method for finding where the gun should have been pointed, by looking ahead to the assumed point of impact. Note that no restrictions on the fighter's path are required*, which is one of the chief advantages of the transit-time method. It means that no measurements need be made from the fighter during the attack to assess the bomber gunnery, although some are required if the fighter gunnery is to be studied simultaneously. (See Section C)

The effect of such factors as air resistance and gravity on actual projectiles usually invalidates Assumption (2) of Section A-1.02. It was convenient for the intuitive derivation but can be relaxed to meet practical situations. Suppose first that the projectile follows a straight path but that its speed is variable. If we know the time T for it to reach any point P_T , we can carry through the development in Section A-1.03 using an imaginary (or "ghost") projectile which coincides with the real projectile at firing time

* Unless they are imposed to facilitate ranging; see Section A-2.06 and the Theory Manual, Chapter A-2.

and impact time and travels with its average speed. Ballistic tables and formulas to fit them provide a means of calculating T , usually as a function of (future) range at impact time (B_TF_T in Fig. 1.01) and <u>angle-off</u> (θ in Fig. 1.01) for particular types of projectiles and specified flight conditions. (See AMP Memo No. 104.1 "Simple Formulas to Fit the Values Tabulated in the Firing Tables FT 0.50 AC-M-1," by George Piranian.)

Deviations of the projectile from a straight path are harder to handle in theory, but in aerial combat they are relatively small and can be applied with sufficient accuracy as a final correction to the true bore-line. Ballistic tables and formulas again furnish the necessary data, which have been reduced to a convenient graphical form called DOFOGRAPHS. A detailed description will be reserved for Chapter A-3 of the Theory Manual.

In passing, it should be noted that most ballistic formulas require <u>horizontal</u> bomber flight. This restriction is not serious, however, since in practice it is generally required in order to maintain constant bomber speed.

Actually, Assumption (3) of Section A-1.02 is unrealistic. The projectile is, of course, not a point, but its finite size will be neglected. For the fighter it is necessary to define a <u>target point</u> (F_T in Fig. 1.01), which has been taken to be the center of the propeller hub in the case of a single-engine fighter like an F6F. This procedure is satisfactory for computing the gun-lead error, but in calculating the probability of a hit it fails to take account of the finite size of the fighter. For this purpose it is customary to replace the fighter by a circle of equivalent lethal area with its center at the target point. A number of investigations have been concerned with the problem of establishing lethal areas for various fighters. (See, for example, AMG-C No. 370, "The Assessment of Gun-Camera Trials," by R. F. Bennett and A. Sard, Appendix 1, by Milton Friedman, and Appendix 2.)

On the bomber, the point B (Fig. 1.01) is defined as the center of rotation of the turret for which the assessment is being carried out, provided such a center exists. Usually there is no such center, since the axes of rotation of the turret and its guns do not in general intersect. However, the turrets which we shall consider are so constructed that these axes, while skew, are mutually perpendicular in the extended sense that for each axis there exists one plane which contains it and is normal to the other axis. In this case B is defined as the point of intersection of the turret's axis of rotation with its normal plane which contains the axis of rotation of the guns. We shall call B the <u>center of the turret</u>. These relations are shown schematically for two common turrets in Fig. 1.02. Note in both cases that when the turret rotates, the guns' axis moves in a plane normal to the turret's axis, thus maintaining the perpendicularity of the two axes. Note also that, as far as fundamental motions are concerned, the Erco turret is essentially a Martin turret turned on its side, and vice versa.

In connection with Assumption (1) of Section A-1.02 it should be noted that rotations of the bomber which take place about the turret center under consideration are permissible, provided that they do not ultimately cause a deviation from the required straight path or constant speed during bullet time-of-flight. In practice, large rotations would probably result in such a deviation, but the effect of small ones, say a few degrees in magnitude, is likely to be negligible in this respect. However, rotations of the bomber will generally take place about some point other than the turret center. Hence, they will produce <u>translations</u> of the turret center as well as rotations about it. Strictly speaking, the result of such translations is a deviation of the turret center from a straight path or from constant speed (or both), thereby violating Assumption (1). Physically however, the amount of rotation which will occur during time-of-flight is so limited that the translation effects are assumed to be negligible. For ease of assessment it is desirable to minimize all bomber rotations as much as possible, but slight ones are usually unavoidable even in straight flight, as a result of gusts, moving personnel, natural oscillations, pilot judgment, etc. The methods of measuring and correcting for such unavoidable rotations will be discussed in Section A-2.07 and in the Theory Manual, Chapter A-4.

So far the assessment has been applied to only a single instant, viz., the firing time defined in Section A-1.03. In assessing a fire-control system, its performance over an entire attack is usually more important than at any one instant. Hence, the analysis must be repeated for a sequence of firing times appropriately spaced throughout each attack. Motion picture cameras provide a running record of the required data, as described in Chapter A-2.

CHAPTER A-2

EXPERIMENTAL REQUIREMENTS

A-2.01. Measurements and Data. In using the transit-time method to determine the errors in gun lead or gun position at a specified turret on a bomber in defense against an attacking fighter, measurements of the following quantities as functions of time during the attack are needed:

(1) the direction in which the gun is pointed;

(2) the direction from the center of the turret to the target point;

(3) the range, or distance from the center of the turret to the target point;

(4) the bomber's attitude.

The following data which are not functions of time are also required:

(5) the bomber's TAS (true air speed);

(6) the bomber's altitude above sea level, or more precisely the relative air density, ρ , in the vicinity of the simulated attack;*

(7) the type of ammunition assumed to be fired from the bomber's gun.

(8) the fighter's wing span, or if it has special ranging lights or marks, the distance between them, for stadiametric ranging. (See Section A-2.06 and Theory Manual, Chapter A-2.)

If the single-shot probability of a hit is desired, the following additional data are required:

(9) the size of the attacking fighter;

(10) the standard deviation of the bullet dispersion pattern (assumed circular).

---

* Since no bullets are fired in these "dry runs", the value of ρ need not correspond to the actual altitude of the bomber as far as the behavior of its projectiles is concerned. However, the flight characteristics of the bomber and fighter will be somewhat artificial unless the actual altitude is used.

If the turret is equipped with some type of computing sight, it is desirable to measure the following quantities as functions of time in order to determine how well the sight is being used:

(11) the direction of the sight's "aiming pip", i.e., the point which the gunner attempts to hold in line with the target point by proper tracking. Any convenient point on this direction is called the sight-point;

(12) the range input if required by the sight.

It may happen that the target position data are most easily obtained from some other observation post on the bomber. The calculation procedure which relates them to the desired turret location is called parallax correction. Before this procedure can be carried out we require:

(13) measurements of the relative positions of pertinent turrets and other installations on the bomber.

A-2.02. Scope. The procedures to be described below for carrying out the transit-time method have been applied specifically to the case of a PB4Y-2 under attack by an F6F at Armament Test, U. S. N. A. S., Patuxent River, Md. Equipment needed to obtain the measurements described in Section A-2.01 has been installed in the Martin forward crown-turret, Erco port waist-turret, and Martin rear crown-turret of the PB4Y-2. (See Fig. 2.01). While the discussion will pertain directly to these turrets and aircraft, it should be borne in mind that the procedures themselves have general applicability in aerial assessment.

A-2.03. Turret Geometry. Before describing how the measurements are taken, it is necessary to define certain quantities and coordinate axes to which they refer. Figs. 2.02, 2.03, 2.04, 2.05 and 2.06 show the important relations.

On the Martin forward crown-turret the turret-axes (XYZ in Fig. 2.02) are defined to be a rectangular coordinate system having its origin O at the center of the turret, its Z-axis coinciding with the turret's axis of rotation, its Y-axis perpendicular to Z and parallel to the bomber's plane of symmetry*, and its X-axis perpendicular to Y and Z . Positive directions along X , Y , and Z are toward the starboard wing, toward the nose, and up, respectively, thus giving right-handed axes.

A given direction from O is specified by its <u>azimuth</u> (α) and <u>elevation</u> (ε), where α is the angle between the +Y-axis and the projection of the given direction on the XY-plane, and ε is the angle between this projection and the direction itself. (See Fig. 2.03). α is measured positively from the +Y-axis in a clockwise direction looking down on the XY-plane; ε is positive if the given direction is above the XY-plane and negative if below. The units for measuring α , ε , and other angles are the usual degree-minute system**, and the intervals for α and ε are $0^\circ \leqq \alpha < 360^\circ$ and $-90^\circ \leqq \varepsilon \leqq 90^\circ$.

It should be observed that when this turret is rotated its guns swing around in azimuth (see Fig. 1.02). However, since the guns' axis of rotation does not pass through O (B in Fig. 1.02), the guns do not raise and lower strictly in elevation as defined above. The investigation in P14E Memo No. 40, "Note on Error in Lead Due to Gun Camera's Displacement from Turret Center of Rotation" shows that the resulting errors are not serious under ordinary conditions at present.

The turret-axes for the Martin rear crown-turret are defined similarly and are parallel to those at the Martin forward crown-turret. The relative positions of their origins were found by surveying the bomber on the ground***.

On the Erco port waist-turret it is convenient to define three sets of axes, all of which have their origins at the center of the turret. One set (XYZ) is parallel to the turret-axes of the Martin forward crown-turret and is called the <u>bomber-axes</u> at the Erco

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* The vertical plane which divides the bomber into two symmetrical halves.

** A decimal system like degrees and hundredths would be preferable, but surveyor's transits used in some of the calculations (see Section A-3.02) were not obtainable with such scales.

*** See Drawing No. P14E-32-2, "Installation in PB4Y-2, A.T. No. 14". Since the bomber is not strictly a rigid body, the relative positions may change slightly in the air and under different loadings. See Section A-2.09.

port waist-turret (see Fig. 2.02). The turret's axis of rotation does not coincide with the Y-axis, but fortunately it does lie in the XY-plane (as closely as can be measured by ordinary methods), making an angle, σ , called the <u>off-set angle</u>*, with the Y-axis (see Fig. 2.04).

The second set of axes ($X_tY_tZ_t$ in Figs. 2.04 and 2.05) at the Erco port waist-turret differs from the bomber-axes only by being rotated about the Z-axis through the angle in the negative azimuth direction. Hence Z_t coincides with Z , and Y_t with the turret's axis of rotation. This second system is called the <u>turret-axes</u> at the Erco port waist-turret.

The third set of axes ($X_gY_gZ_g$ in Fig. 2.06) at the Erco port waist-turret is called the <u>gun-axes</u> because it moves with the guns. X_g is parallel to the bore line of the two guns (or of a chosen gun if they are not parallel to each other), and Y_g is perpendicular to X_g and parallel to the <u>traverse plane</u>, which is defined to be the plane of X_g and Y_t . It is the plane in which the guns move when rotated about their axis. Z_g is perpendicular to both X_g and Y_g . The positive direction on X_g is toward the muzzle and on Y_g is toward the bomber's tail when the gun is pointing along the beam. The positive direction on Z_g is chosen to form a right-handed system.

It is sometimes convenient to define a set of axes parallel to the turret axes of the Martin forward crown-turret but with its origin at some other location on the bomber. As in the case of the Erco port waist-turret, such a system will be called bomber-axes at the chosen location. An example which will be met later (Section A-2.05) is the bomber-axes at the tri-cameras.

In the following sections we shall give a brief description of the equipment by which the needed measurements are recorded. For detailed information on its design, construction, installation, and maintenance refer to the Equipment Manual, Airborne Installations.

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* By measurement the magnitude of σ was found to be $8^{o}52'$ on PB4Y-2, A.T. No. 14.

A-2.04. Direction of the Gun. On the Martin forward crown-turret is an installation called the RAZEL, its name standing for range, azimuth, and elevation. It consists of an azimuth scale scribed on the inside of the cylindrical turret-well, with an index which moves with the turret, and an elevation scale mounted on the elevation sector which moves with the guns, with an index and vernier which are stationary with respect to the turret. Readings from these two scales provide a direct measurement of the gun azimuth and elevation and are recorded by a motion picture camera installed in the turret expressly for this purpose. As originally constructed the RAZEL-camera also recorded readings from a third scale intended to give range input into the Mk 18 sight installed in the turret. Since this scale turned out none-too-successfully, it was later removed, thus reducing the RAZEL to what might be more correctly called an "AZEL". Fig. 2.07 shows a sample frame of RAZEL film.

On the Martin rear crown-turret an instrument called the deflectometer was originally installed for the purpose of measuring the gun position on that turret. It utilizes gears and flexible shafts to reproduce motions of the turret azimuth ring and the gun elevation sector on dials which are photographed in the edges of the gun camera film described in Section A-2.05. Fig. 2.08 shows a sample frame of this combined deflectometer and gun camera film.

Both the RAZEL-camera and the deflectometer-camera provide a running record of the actual directions in which the guns in their respective turrets were pointed. There is no analogous installation in the Erco port waist-turret. Here it is necessary to work back from the target position to locate the actual gun direction, as described in Section A-3.03.

A-2.05. Direction of the Targ Since the gun direction should always be within a few degrees of the target direction when an attempt is being made to aim the gun correctly, a camera rigidly attached to the gun will usually be able to keep the target in its field of view. Such a camera is called a gun-camera, and each turret to be assessed must be equipped with at least one. Its fundamental purpose is to relate the target direction to the gun direction, and vice versa. At first the gun-camera was boresighted, i.e., installed with its optical axis parallel to the gun-bore line. However, experience has shown that it is frequently advantageous to off-set the gun camera, i.e., to increase its useful field of view by rotating its optical axis an appropriate amount in the expected target direction. Fig. 2.08 and 2.09 show sample frames of gun-camera film.

Sometimes the direction of the target with respect to bomber-axes at some location other than a turret is desired. In this case it may be possible to mount one or more cameras, called target cameras, at the given location to cover the field of anticipated target directions. They give a panoramic view of the attacks. These cameras must remain fixed with respect to the bomber, at least during any one attack. An example is the bank of three, called the tri-camera, which is mounted in place of the navigator's astrodome just behind the Martin forward crown-turret, as shown in Fig. 2.01. A further example is a group of two, called bi-cameras. The mount is adjustable to allow for different types of fighter attacks.

A-2.06. Range. To determine the range by optical means at any desired instant during an attack, use is made of the fact that the apparent size of the fighter increases as it comes in closer. Derivations and discussion of various range formulas are given in the Theory Manual, Chapter A-2; here we merely state that under simplified conditions the range is inversely proportional to the wing span (or the distance between lights or marks placed on the wings to improve the visibility) as measured on the image of the fighter recorded by a suitable camera on the bomber.

With a given lens, the image size and density decrease with range, leading to a loss of accuracy at long ranges. A 2-inch lens has a field of view of approximately 28 degrees; a 10-inch lens has a field of about 6 degrees, with an image size five times as great as that of the 2-inch lens. It is not feasible to use a 10-inch lens in a gun-camera, since the leads are such that the attacking plane is likely to be out of the field. A 2-inch lens represents the limit in focal length with present aircraft speeds and ammunition; with the 2-inch lens range determination beyond 600 yards becomes too inaccurate.

The use of a long focal length lens in an independent camera, whose only function is to take pictures for ranging, has been successfully exploited in certain applications.

Recent developments in airborne radar promise a means of raising the effective upper limit to several times its present value. Radar has two advantages: (1) the fact that its accuracy is essentially independent of range, although it must be calibrated by, say, the optical method at short ranges; and (2) the fact that it can be used regardless of the path of the fighter. Its present difficulties are related to the additional equipment required in the bomber and the problems of maintenance.

A-2.07. Bomber's Attitude: Gyros. It was mentioned in Section A-1.04 that the bomber may experience undesirable rotations about its center of gravity even when it is flying level and steady. To measure these rotations, the attitude of the bomber relative to some fixed set of axes as a function of time during the attack is needed. One possibility is to photograph a background of clouds or horizon if available, and another is to employ gyroscopes carried in the bomber. Only the latter method will be discussed here.

A free gyroscope has the useful property that it will maintain the direction of its axis of rotation in space, regardless of the motion of the platform on which it is supported. Hence any rotation of the bomber, except about the gyro's own axis, may be measured by observing the apparent motion of this axis relative to the bomber. Since a single gyro cannot detect rotations which take place about its own axis, two gyros with their axes of rotation mutually perpendicular are used to cover all possible motions. The gyros actually employed were adapted from a C-1 autopilot with the addition of suitable scales to indicate the rotations and electrical-mechanical controls for starting, stopping, and aligning the axes to a desired initial position.

Fig. 2.10(a) shows the two gyros with temporary mountings and dials*, and Fig. 2.10(b) shows an actual gyro installation. In the PB4Y-2, A. T. No. 14, they were mounted under the Martin forward crown-turret and the scales photographed by a special camera, a sample frame of whose film is shown in Fig. 2.11. Instructions for reading these dials are included in the Computer's Manual, Section E.

In order to make correct use of the gyro dial readings it is essential that the operation of the gyros be clearly understood, at least to the extent of the precise meaning of the angles they measure. The reader is advised to verify the statements made below by studying either the gyros themselves or a model which illustrates their essential parts and motions.

Referring to Fig. 2.12, where XYZ is a set of bomber axes at the center of gravity, suppose that the gyros are so mounted that when their axes are aligned and then freed the axis of rotation of one will be initially parallel to Z and the axis of the other will be initially parallel to Y . The first gyro is called the Z-rotor, the second the Y-rotor**. As shown in Fig. 2.10 the Y-rotor has only one dial, mounted parallel to the XY-plane, whereas the Z-rotor has two dials, one mounted parallel to the YZ-plane and the other parallel to the XZ-plane.

Starting from this initial position let the bomber rotate about Z only. The angle through which it turns is called yaw and will be indicated directly on the yaw dial of the Y-rotor. The dials on the Z-rotor will show no change, since a yaw takes place about an axis parallel to its axis of rotation.

Returning to the initial position let the bomber rotate about X only. Then the angle through which it turns is called pitch and is measured on the Z-rotor dial which is

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* Their actual dials and verniers read to minutes. (See Fig. 2.11.)

** On the autopilot they are called the vertical flight gyro and the directional stabilizer respectively.

parallel to the XZ-plane, called the pitch dial, without changing the other dials.

Similarly, returning to the initial position and letting the bomber rotate about Y only, it will turn through an angle called <u>roll</u>, measured on the Z-rotor dial which is parallel to the XZ-plane, called the <u>roll dial</u>, without changing the other dials.

In practice the bomber may have any combination of these three rotations. Let XYZ be the initial bomber-axes and X'Y'Z' the bomber-axes in an arbitrary new attitude. Then a study of the gyros or their model will show that:

(1) the yaw dial measures the angle between the positive Y'-axis and the projection of the positive Y-axis on the X'Y'-plane;

(2) the pitch dial measures the angle between the positive Z'-axis and the projection of the positive Z-axis on the Y'Z'-plane;

(3) the roll dial measures the angle between the positive Z'-axis and the projection of the positive Z-axis on the X'Z'-plane.

These angles are still called yaw, pitch, and roll, respectively. They reduce to the previously defined angles in the case of the corresponding single rotation only, since the projections of the primed axes are then identical with the axes themselves.

The sign conventions for yaw, pitch, and roll angles are as follows:

(1) yaw is positive if the nose turns to the left;

(2) pitch is positive if the nose turns up;

(3) roll is positive if the starboard wing rotates upward.

As a warning about the difficulty which will be met later, we state here the fact that the roll, yaw, and pitch as measured above are <u>not</u> in general the angles required by the calculation scheme. The theory of necessary corrections and various ways of performing them are treated in the Theory Manual, Chapter A-4.

In practice one needs a record of the roll, yaw, and pitch of the bomber as a function of time during each attack as provided by the gyro camera, and also what are known as <u>zero dial readings</u> and <u>initial readings</u>. The former means the three dial readings when the axes of rotation of the two gyros are aligned, i.e., when the axis of the Z-rotor is parallel to the intersection of the planes of its two dials and the axis of the Y-rotor is parallel to the intersection of the planes of the yaw and pitch dials. The zero dial readings can be obtained by a bench test before the gyros are installed in the bomber. The verniers should be adjusted to make all three of them zero, but this has not always been the case.

In an actual flight, the gyro axes of rotation should be aligned, or erected, just before each attack. If the erecting mechanism worked perfectly, the <u>initial readings</u> of the dials at the instant the gyros were freed would agree with the zero dial readings. The respective differences provide a measure of the accuracy of the erecting mechanism in correctly positioning the axes, except that the axis of the Y-rotor can have any direction parallel to the XY-plane and still show the correct initial readings. Hence they do not provide a complete check on the alignment of the Y-rotor.*

Before leaving the subject of gyros it should be observed that other orientations of the rotors are possible and sometimes desirable. In particular, Gyro Set No. 1 was at one time** so mounted that its coordinate axes $X_rY_rZ_r$ in Fig. 2.13 were rotated from the bomber-axes XYZ through an angle P_o in the YZ-plane. The reason for this orientation is based on the fact that the erecting mechanism for the Z-rotor depended on gravity and was designed to align its axis of rotation vertical with respect to the earth, whereas the erecting mechanism for the Y-rotor brought it parallel to the Y_r-axis. Hence unless Z_r is a true vertical, the two rotor axes will not be aligned perpendicular to each other. When the bomber is in level flight, Z is tilted back from the vertical by an

* That in general the axis of the Y-rotor should be aligned parallel to Y-axis and not merely parallel to the XY-plane may be shown by considering a rotation about the Y-axis, which should record a roll only. Unless the axis of the Y-rotor is parallel to the Y-axis, the yaw dial will also be affected.

** During flight tests for F. C. No. 9, 14, 15; Spring, 1945.

angle P_o , which is called the flight angle and amounts to an initial pitch. It depends on the speed and loading of the bomber and was found to average 2°18' for the PB4Y-2, A. T. No. 14, and in the tests conducted for F. C. No. 9, 14, 15, the extremes being about 1° and 3° for 170 knots and 140 knots, respectively, with the load originally carried. Hence P_o was taken to be 2°18' in order to minimize the deviations of Z_r from a true vertical. This procedure is not too satisfactory, however, and an electro-mechanical erecting mechanism independent of gravity has been installed in later gyro sets.

A-2.08 Gunner's Performance. In order to assess the gunner's tracking skill a running record of the sight reticle and its position relative to the target is needed. A sight-camera, mounted on the sight-head in such a way that it sees the same field as does the gunner, is used to provide this record. With most optical sights and in particular with the Mk 18 it is possible to mount the camera so that it looks down on the back of a half-silvered mirror and hence does not interfere with the gunner's vision in looking through it. A sample frame of the sight-camera film is shown in Fig. 2.14, and detailed instructions for its use are included in Section H of the Computer's Manual. Briefly, the gunner's tracking errors are obtained by computing the angular difference between the directions of the sight- and target-points on this film.

The Mk 18 sight requires that the gunner, in addition to tracking the target, must range it by framing its wing-tips in the circle formed by the six pips which surround the center aiming pip (see Fig. 2.14). As the fighter approaches, the gunner is expected to increase the diameter of this circle by means of foot controls to match the growing apparent size of the target. This reticle diameter is therefore a measure of the gunner's ranging, which is called sight range and which is inversely proportional to the reticle diameter for the same reason that range is inversely proportional to the target image size (see Section A-2.06 and the Theory Manual A-2.) The gunner's ranging error at any time is given by the difference between the sight range and the range at that time.

As mentioned in Section A-2.04, another estimate of the gunner's ranging was originally given by the third RAZEL scale. More recently a selsyn device which records a measure of the gunner's ranging derived from the sight's range circuit has been tried. Its reading has been dubbed remote range, since it records on a conveniently located instrument panel not necessarily in the turret.

It should be observed that the three estimates of gunner's ranging discussed above are not strictly equivalent. The remote range measures the range as fed into the computing mechanism, thus taking account of both the reticle diameter and the sight's initial setting for target wing span. On the other hand the sight range and RAZEL range are measures of the reticle diameters only and are used with the assumption that the initial setting was correct. The RAZEL range has further inaccuracies owing to lack of stiffness of available pulley- and support-brackets.

A-2.09 Additional Data. Pertinent information about a particular flight is recorded on its Flight Sheets, a sample set of which is shown in Figs. 2.15-2.19. Together they provide a log of flight conditions, equipment, and personnel. They must be filled in completely and accurately at the time of the flight and should be studied carefully before editing and assessing the film. In particular the flight sheets are the source of data on the bomber's IAS (indicated air speed)*, its altitude, and the outside air temperature, which are needed to compute TAS (true air speed)* and are involved in ballistic considerations.

Dimensions of the fighter required for stadiametric ranging and the calculation of the hit probability are to be obtained from direct measurement. Bullet dispersion patterns, also required for hit probability are usually found from jump card tests involving actual firing of the specified projectiles from the turret under consideration.

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* A circular slide rule is available for rapid calculation of TAS from IAS, altitude, and temperature.

The bomber dimensions required for parallax correction are given for the PB4Y-2, A. T. No. 14 in its Survey*. Of necessity they were measured with the bomber resting on the ground, and their use under actual flight conditions involves the tacit assumption that the fuselage deflections have a negligible effect on the relative positions of the points involved in the parallax correction. A preliminary test showed that this was surely true with respect to cantilever deflections between the bomb bay and tail and probably justified with respect to torsion as well. Apparatus for making more precise measurements has been installed but results are not yet available.

A-2.10 Calibration of Cameras and Lenses. Film from RAZEL, gyro, and other cameras which photograph only dials and scales may be read from a projected image of convenient size, the exact magnification being of no concern. However, in the case of gun-, sight-, and target-cameras, which are used primarily to determine relative directions, it is essential that the relation between the photographed angles and their projected images be accurately established.

If lens distortions are negligible, it can be shown that there exists a point on the projector's optical axis, called the true-angle point, from which angles as viewed on the (flat) screen are identical with the corresponding angles as photographed**. The distance from the true-angle point to the screen could be calculated from the projection distance and the focal length of the camera and projector lenses, but in practice these focal lengths may vary as much as 10% from their nominal ratings, so that a special test of each individual lens would be required. A much more direct test procedure is to photograph known angles with each camera lens, project its film with the particular projection system to be used, and then locate the true-angle point by trial. This procedure has been adopted for the alignment of the data-taking and computing devices to be described in Section A-3.06.

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* See Drawing No. P14E-32-2, "Installation in PB4Y-2, A. T. No. 14".

** This theorem is proved in the Theory Manual, Chapter A-5.

The first lens calibration-shots, or film test-strips as they are commonly called, were made after the cameras had been installed in the bomber. This necessitated an accurate and rather arduous leveling of the bomber on jacks, a time-consuming operation which had to be repeated whenever new equipment was to be calibrated. Moreover, since the film has a tendency to shrink with age, standard practice should require that new test-strips be taken at frequent intervals. Although the original test-strips were used successfully, the practical difficulties mentioned above, together with the desirability of showing more than the one or two known angles which appeared on the first films, motivated the development of an improved procedure, of which a detailed description is given in the Equipment Manual-Airborne Installations. Briefly, it involves setting up a special photo target range which can be photographed by each camera before installation in the bomber, in order to get the desired angle shots. Then the cameras are installed, after which a horizontal reference line and the direction of a reference point fixed relative to the camera, such as the bore-point in the case of a gun-camera, are established by means of level shots and position shots, respectively. Their use in aligning the computing devices is discussed in Section A-3.06 and in the Computer's Manual, Section F.

When the bomber is on the runway ready to take off on each flight, a check is made on the installations as follows. Each gunner is instructed to aim the fixed reticle of his (Mk 18) sight at some designated point*. Then a few frames are exposed in all cameras. This checks their mechanical operation and also each sight installation, since the designated point should appear at the bore-point of each gun-camera if the sight in the turret is properly boresighted**. Unfortunately, however, the fixed reticle does not show in the sight-camera, so that it is impossible to determine how well the gunner aimed it. Hence

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* Originally the top of a water tower was used, but more recently a special target has been erected beside the runway.

** This is true unless the fixed reticle has been boresighted with intentional super-elevation.

the cause of any discrepancy which may be observed between the designated point and the bore-point is uncertain.

Next the gunner is instructed to set the moving reticle at a specified range and wing span, usually the minimum for the former and the maximum for the latter, and a few more frames are exposed. This provides a means of calculating the constant which converts reticle diameter into sight range (see Section A-2.08). In practice, however, it was found that this constant could be determined more accurately by measuring the wing span on the sight film and using the corresponding range from the ranging-camera.

To determine the conversion constant for the ranging-camera itself, which may be a gun-camera, a ground test was carried out in which the fighter used in the flights was parked on the runway and photographed head-on by the ranging-camera at various measured ranges. This film was then viewed on the same projection system used to assess the actual flight film and wing measurements were taken from the screen.

A-2.11 Synchronization. Recalling that the transit-time method is based on a comparison of data at firing and impact times, it is clear that the instants at which the frames of each camera film are exposed must be recorded in some fashion. For simplicity of interpretation it would be even better if corresponding frames on the various cameras were exposed simultaneously at some specified and carefully controlled speed. Hence the problem of synchronization and timing of the cameras requires careful consideration. The many practical difficulties which arise will not be discussed here, but a brief history of past experience with the first "synch unit" will be included. For a detailed treatment of the instrumentation involved the reader is referred to the Equipment Manual-Airborne Installation.

The 35 mm and 16 mm motion picture cameras originally installed in the bomber were designed to run at nominal speeds of 24 and 16 frames per second, respectively. A mechanical governor and a vibrator-type voltage control were also provided in an attempt to hold the speeds close to these nominal ratings under load conditions which unavoidably vary from camera to camera. Each camera was also equipped with two tiny incandescent lamps which exposed when turned on a small portion of the film. These were controlled by a single timing source to give simultaneous flashes (timing marks) in all cameras at regular time intervals (see Figs. 2.07 and 2.09.) They were also used to catalog the several attacks on each roll of film by means of a series of flashes (cataloging marks) appearing in all cameras at the end of the attacks. A master control for starting and stopping all cameras simultaneously, inserting the timing and cataloging marks, aligning the gyros, and checking the operation of the equipment was installed at the observer's location, freeing the gunners from all responsibility for the operation of the cameras in their turrets.

In practice a number of difficulties have been encountered with this synch system. In the first place there is no way of controlling or even recording the relative phases of the shutter positions in the various cameras, which introduces an uncertainty of $\pm$ one frame in the correspondence between time scales from camera to camera. At 24 frames per second this uncertainty amounts to about $\pm$ 0.04 second, and at 16 frames per second it is approximately $\pm$ 0.06 second. It will be shown in Section A-2.12 that the time tolerance under operating conditions is only $\pm$ 0.001 second, so that this initial uncertainty is a serious shortcoming of the system.

At first some of the cameras had a tendency to run away, at speeds as high as 40 or 50 frames per second. This difficulty has been overcome, but it is still impossible to check the speeds in aerial operation, since the character of the timing marks varies from film to film. These variations are due largely to the different shutter phases and the differences between individual bulbs with regard to their heating time. In order to determine the best interpretation of the timing marks a bench test was conducted in which the cameras photographed a chronometer while running on the synch system. It was found that the individual frame times were most closely approximated by averaging the number of frames over the largest even number of seconds exposed in a particular attack. This test formed the basis for the so-called total-attack averaging method, details of which are given in the Theory Manual, Chapter A-6. It yields conversion tables which give the time corresponding to any specified frames for each film and attack.

Realizing the limitations of the first synch system, several possibilities for improving the accuracy to correspond with the expected tolerances are now under consideration and development.

A-2.12 Tolerances. Since measurements can never be made with absolute accuracy and since it is highly desirable to avoid the expense and effort involved in obtaining and maintaining instruments possessing an unnecessary degree of sensitivity and in carrying out calculations with unwarranted precision, no discussion of experimental requirements can be considered complete until the tolerances of the various steps are specified. The general method to be applied in such an analysis requires first that the individual contribution of an error in each step to the total error in the final product be estimated. In order to get an upper bound on these contributions, they are usually determined under the least favorable conditions to be met in practice, which requires a knowledge of the conditions and controls under which the experiment is to be carried out.

If a formula is available for the desired quantity as a function of the variables on which it depends, the contribution of an error in each variable separately, or even together, may usually be estimated by means of the differentials. (See any standard text on differential calculus). However, in some cases it may be simpler to resort to geometrical or physical reasoning, especially when the formulas required for an analytical estimate are not readily available. Sometimes it may be desirable to conduct a preliminary experiment to determine the sensitivity of the procedure to certain of the variables or to obtain data on the experimental conditions.

When the individual contributions have been determined, the sum of their numerical values will give an upper bound to the size of the total error. If it is within the desired limit of accuracy, the individual steps may all be considered sufficiently accurate. Usually, however, this condition puts unnecessarily close tolerances on the individual errors, since the probability that they will all combine additively is extremely small. If they are all independent, i.e., if a change in any one has no effect on any of the others, recourse may be had to the statistical theory of independent errors in which their variances are added to get the variance of the total error and this result is considered to be normal distribution.* In this way p , the probability that the total error will be less than any specified amount, can be estimated. If p is sufficiently close to one, the individual steps may again be considered satisfactory.

The procedure outlined above can be used either to estimate the total error from errors in the various steps or to specify tolerances for the latter in terms of the former, under the prescribed experimental conditions. It will also indicate which steps are most critical in the sense that they produce the largest contributions to the total errors. Thus those parts of the procedures most in need of refinement will be brought to light.

To get an idea of the tolerances in the bomber assessment problem, suppose that the desired result is the radial gun-lead error**, and that the experimental conditions of F. C. No. 9 and 14 prevail. Since this result is computed as the difference between actual and true gun directions, an error in either will carry over in itself as an equal error in the final result. These directions are specified by their respective components, azimuth and elevation, relative to bomber-axes at the turret under consideration and at each specified firing time. In the worst case for azimuth, where both elevations are zero, the radial gun-lead error equals the difference between the two azimuths, so that an error in either azimuth will carry over as an equal error in the result. Similarly, in the worst case for elevation, where the azimuths are equal, the radial gun-lead error equals the difference between the two elevations, so that an error in either elevation will appear as

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* See, for example, Jones, "A First Course in Statistics", pp. 236-243, where the case of normally distributed independent errors is considered, and the more general treatment in Uspensky, "Introduction to Mathematical Probability", Chapter XIV.

** This use of the term "error" is not to be confused with that above.

an equal error in the result. Hence the tolerances on the components of actual and true gun-directions are certainly no greater than those of the radial gun-lead error. To be safe, each should be considerably less. For example, if the radial gun-lead error is desired to an accuracy of ± 10 minutes (of arc), then each azimuth and elevation should be held to, say, ± 3 or 4 minutes.

Considering the possible sources of error in the actual gun direction when measured by the RAZEL, it appears that the RAZEL scales should be scribed to an accuracy of ± 1 minute, they should have verniers permitting easy reading to ± 1 minute, and they should be photographed sharply with enough frames per second to detect significant variations in the gun-direction. Experience indicates that twenty frames per second are an adequate and convenient number.

All graphs of azimuth and elevation must be accurately plotted on an ordinate scale large enough to permit reading the curves to ± 1 minute and an abscissa time scale which permits ready detection of the smallest time interval corresponding to an azimuth or elevation change of ± 1 minute. This interval depends essentially on the rate of change of the gun and target directions during the attack. At long ranges this rate is generally low, but it usually increases rapidly as the fighter presses the attack home. As would be expected, the azimuth changes on the flat side attacks of F. C. No. 9 and 14 are far greater than the elevation changes. An average azimuth rate is perhaps 20° per second although it has been observed to reach as high as 60° or 70° per second just prior to the breakaway. Since 20° per second is 1.2 minutes per thousandth of a second, the timing should be correct to ± 0.001 seconds and the azimuth abscissa scale large enough to permit readings to that accuracy*.

The final accuracy of the true gun-direction is the result of several factors. Recalling

* Under expected future conditions the average angular rate is likely to exceed considerably the 20° per second used in this analysis, in which case timing accuracy should be increased accordingly.

that it is obtained by applying ballistic corrections to the target direction at impact time, it appears in the first place that the target direction itself should be correct to ± 1 minute. Hence the computing instruments and procedure for calculating target azimuth and elevation should be consistent with this required accuracy. If they are to be found from gun-camera and RAZEL data, the relative timing of these two cameras should be known to ± 0.001 second, as stated above. The problem of synchronizing cameras and controlling their speeds was discussed briefly in Section A-2.11.

Secondly, the impact time corresponding to a chosen firing time should be correct to ± 0.001 second, which implies the same tolerance on time-of-flight. It in turn depends on the range, muzzle velocity and ballistic characteristics of the projectile, relative air density, bomber TAS, and direction of fire. However, only the first two quantities are critical. As for muzzle velocity, the standard for the projectile should be accepted, although it will actually vary considerably with such factors as temperature and age. Since the API M-8 projectile travels at an average speed of 800 to 900 yards per second for ranges up to 1000 yards, the tolerance on range measurements to give time-of-flight to ± 0.001 second is no greater than ± 1 yard.

As discussed in Section A-2.07, the attitude of the bomber-axes at impact time may differ from that at firing time, so that measurements of the roll, yaw, and pitch must be taken and applied. If the target is abeam, an error in roll will carry over as an equal error in true gun elevation; if it is at azimuth 0° or 180°, pitch will do likewise; and if it is at elevation 0°, an error in yaw will appear as an equal error in true gun azimuth. Hence the tolerances on the measurements of and calculations with roll, yaw and pitch should be individually correct to ± 1 minute.

Finally the ballistic corrections which allow for the projectile's deviation from a straight path should be accurate to ± 1 minute, since they apply directly to the true gun direction.

The preceding discussion of tolerances is not intended to be complete in all details but rather to indicate the sort of analysis required. A more complete listing of known sources of error in the F. C. No. 9 and 14 experiments will be given later.

CHAPTER A-3

COMPUTING INSTRUMENTS

A-3.01 Motivation for the CRADLE, GLOOK, and PLAXIE. In order to use the information on the relative positions of the target- and bore-points provided by the gun-camera film it is necessary to project or view it in some fashion and take measurements from its image on the screen. One way is to scale the position of the target with respect to the bore-point in linear dimensions. Since the desired data are usually the target azimuth and elevation relative to turret axes knowing the gun azimuth and elevation, or vice versa, additional computations, either numerical or graphical or both, are required. An economy can therefore be effected if these results can be read directly from the screen, thus combining the measurements and computation into one step. An instrument called the CRADLE (Figs. 3.01, 3.02, and 3.03) has been constructed for this purpose and is described in Section A-3.03. Mathematically it merely performs the special rotation of axes involved in converting screen position into the desired azimuth and elevation.

The necessity of compensating for changes in the bomber's attitude, usually over the time-of-flight interval, was mentioned in Section A-1.04, and the roll, yaw, and pitch which specify the attitude at any instant were discussed in Section A-2.07. To carry out these corrections without recourse to lengthy numerical calculations involving trigonometric formulas, an instrument called the GLOOK (Figs. 3.04 and 3.05) has been built. It is described in Section A-3.04*. Like the CRADLE it performs a rotation of axes, but it has more degrees of freedom and hence will handle more general rotations, as are required in roll, yaw, pitch corrections and also in reading target data from tri-camera film when the tri-camera mount has an arbitrary position.

Likewise, to carry out parallax corrections without recourse to extensive numerical

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* The AMG-N gnomonic chart provides an alternate, graphical method of performing these and other calculations. See AMG-N No. 38, "Gnomonic Charts", by A. A. Albert, and AMG-N No. 62, "A Manual for the Use of Gnomonic Charts", by A. A. Albert.

or graphical computations, an instrument called the PLAXIE (Fig. 3.06 and 3.07) has been constructed. It is described in Section A-3.05. Mathematically it performs the translation of axes involved in moving from one position on the bomber to another.

A-3.02 Features in Common. With regard to their uses as calculating machines, the CRADLE, GLOOK, and PLAXIE all belong to the analogue type; i.e., they "reenact the crime" or set up in miniature a geometrical situation similar to that which existed at the flight time under consideration and from which the desired data may be extracted. It has been found most helpful in devising and understanding the procedures for using the instruments to keep this fact in mind and to interpret each step geometrically in terms of the corresponding actual situations in the air.

The heart of each of these three instruments is a surveyor's transit (Fig. 3.08), which is admirably suited to the measurement of a direction in terms of its azimuth and elevation as defined in Section A-2.03. A thorough understanding of the operation of a transit is requisite to the successful use of the CRADLE, GLOOK, and PLAXIE. Therefore the reader is advised to become familiar with Section G of the Computer's Manual, where the operating parts and adjustments of the transit are explained. For convenience the transit's eyepiece has been replaced by a light cell which projects an image of the telescope's crosshairs onto the screen, thus eliminating the necessity of looking through the telescope.

No attempt will be made here to discuss the details of the design and construction of the CRADLE, GLOOK, and PLAXIE. Important as these matters are, one need not understand them to use the instruments successfully, although a general appreciation of the engineering features will help avoid harmful and incorrect practices.

As stated in Section A-3.01, the CRADLE, GLOOK, and PLAXIE were first conceived to meet special assessment needs. However, in view of the fact that they perform the basic mathematical transformations of rotation or translation of axes, it is not surprising that other uses should arise. Step-by-step procedures for these applications, insofar as they apply to assessment problems considered to date, are included in the Computer's Manual.

A-3.03 Theory of the CRADLE. To understand the manner in which the CRADLE is constructed and installed, consider the problem of assessing film from a boresighted gun-camera mounted in a turret whose guns move in azimuth and elevation*. Assume that the optical center of the camera is at the turret center O (Fig. 3.09), and let its optical axis have the direction OG . Then suppose that the gun azimuth α_G and elevation ϵ_G are known at an instant when a picture is taken showing the fighter attacking the bomber. This picture may be visualized as recording the intersection T of the line of sight from O to the target (fighter) with a plane tangent at G to a sphere whose center is at O and whose radius is some convenient length OG . The problem is to find the target azimuth α_T and elevation ϵ_T .

Now suppose that the film has been developed and is projected onto a flat screen as shown in Fig. 3.03, with the CRADLE slid out of the way. To avoid distortion, it is necessary that the projector's optical axis be perpendicular to the screen and that the point G , which was on the camera's optical axis, be also on the projector's optical axis. In addition, to specify the position of the picture completely, the coordinates of some other point or the direction of some line on the film must be known. Suppose that the "horizontal" line AB through G is used for this purpose and that its image has been made to coincide with the horizontal screen line passing through the screen center, which is defined as the intersection of the projector's optical axis and the plane of the screen** With the picture in this position let the target point be marked on the screen and the projector then turned off.

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* Except for the fact that the two axes of rotation do not quite intersect, the Martin crown-turret is an example of this type (see Section A-2.03).

** In practice the proper positioning of the images of the point G and the line AB on the screen is accomplished by aligning the picture to the black framing marks shown in Figs. 3.02 and 3.03, using the projector adjustments. The way in which these framing marks are obtained is discussed in Section A-3.06.

Next, imagine a transit installed with its center* at the true-angle point (see Section A-2.10) and aligned so that its azimuth and elevation scales both read 0^o when the telescope is pointed at the screen center. Also suppose it to be leveled so that its elevation axis lies in a horizontal plane and its azimuth axis is vertical. In this position the telescope will trace the image of the horizontal line AB on the screen when the elevation scale is set to read 0^o and the transit is rotated in azimuth only. Fig. 3.09 can be used to represent the geometry of this situation if the transit center is taken at O and the screen is imagined to be tangent to the sphere at C instead of G and with AB lying in the XOY-plane. In this position the transit can be used to read correct angular locations of points on the screen relative to the <u>center</u>, but it does <u>not</u> yet read the desired <u>azimuth</u> and <u>elevation</u> of any point, in particular the target point T . One way to make it do so would be to hold the transit fixed and revolve the whole screen first through the azimuth angle α_G and then through the elevation angle ε_G , keeping its center on the sphere and the line AB parallel to the horizontal XOY-plane, thus bringing it to the position shown in Fig. 3.09. Then the transit scales would read α_G and ε_G , respectively, if the telescope were pointed at G (now the screen center), and the desired α_T and ε_T could be read from the scales after pointing the telescope at T . Thus the problem would be solved, but a moment's reflection will bring to mind the difficult mechanical problem involved in constructing either a spherical screen of sufficient size or a flat screen which can be moved around on a sphere. It is much simpler to keep the screen fixed and reposition the coordinate system, first by rotating the transit azimuth axis through the angle $-\varepsilon_G$ and about O in the OGZ-plane and then rotating the line of 0^o azimuth about the azimuth axis through the angle $-\alpha_G$. The first rotation of the transit must take place about an axis through O and parallel to AB , which is precisely what the CRADLE is designed to do. The second

* The <u>transit center</u> is the intersection of the transit <u>azimuth and elevation axes</u>, which are its axes of rotation in azimuth and elevation, respectively.

rotation is accomplished by means of the transit's lower azimuth adjustment*, which rotates the telescope in azimuth without altering the scale reading.

To meet the requirements stated above, the CRADLE possesses a transit mounted in a swing or cradle (whence the name) permitting the whole transit to be rotated about a fixed horizontal axis called the CRADLE axis when the lower elevation control wheel is turned (see Fig. 3.01). This axis is designed to pass through the transit center and to be perpendicular to its azimuth axis. Note that the transit center remains fixed regardless of the direction in which the telescope is pointed, unless the carriage (Fig. 3.01) is moved.

When the CRADLE is installed in the operating position shown in Fig. 3.02, the transit center is located at the true-angle point and the CRADLE axis is not only horizontal but also parallel to the screen, so that it will be parallel to AB. Detailed procedures for setting the CRADLE, projector, and screen in their proper relative positions are given in the Equipment Manual-Ground Installations.

In practice the transit is brought into the proper position for reading the correct azimuths and elevations by setting the azimuth scale to read α_G and the elevation scale to read ε_G and then using the lower azimuth adjustment and the lower elevation control to aim the telescope at G without altering the azimuth and elevation scale readings. This effectively fixes the coordinate system. Then the telescope may be aimed at any point on the screen using the upper azimuth and elevation adjustments (which change the scale readings but do not alter the coordinate system) and the desired azimuth and elevation of that point read directly from the scales. Complete details will be found in the Computer's Manual, Section H, together with the directions for solving other problems by means of the CRADLE.

It was assumed above that α_G and ε_G were given. However, the CRADLE may also

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* See Section G of the Computer's Manual

be used in problems where they are not known, provided the azimuth and elevation of some other point, say T , on the screen are given. In this case the coordinate system is fixed as described above but with T , α_T, ε_T, substituted for G , α_G, and ε_G, respectively, after the film has been properly positioned on the screen. This procedure is useful, for example, in finding α_G and ε_G when α_T and ε_T are known.

It should be emphasized that the CRADLE was designed especially for analyzing film from a boresighted gun-camera mounted on a turret whose guns move in azimuth and elevation. In Section A-2.05, the fact that it is often desirable to "offset" the gun-camera by rotating its optical axis an approximate amount in the expected target direction was mentioned. The problem of assessing film from such an offset camera is considered in the Theory Manual, Chapter A-7. If the offset happens to be an angle e in elevation only, the CRADLE can still be used if ε_G is replaced by $\varepsilon_G + e$ in the operations described above. Usually, however, the offset will be partly in azimuth as well as in elevation. As shown in Chapter A-7 of the Theory Manual, a rotation of the whole CRADLE about a vertical axis through the transit center (true-angle point) is then required. This leads to the suggestion that the CRADLE be mounted on a horizontal turntable. Such a modified CRADLE is called a SEMI-GLOOK, since it lacks only one rotation of being a GLOOK. Therefore a GLOOK itself could be used for this purpose.

In the case of a turret whose guns do not move in azimuth and elevation the problem of an offset gun-camera will be handled somewhat differently. For example, a procedure using both a CRADLE and a GLOOK has been worked out for an Erco port waist-turret whose gun-camera is offset in the traverse plane only. The details are described in the Computer's Manual, Section I.

One practical difficulty with the CRADLE analysis is that the gun-camera cannot ordinarily be mounted with its optical center at the turret center. Instead it may be displaced by as much as four feet. An investigation of the errors introduced will be found in P14E Memo 40, where it is shown that they are negligible for the cases commonly encountered in practice.

A-3.04. Theory of the GLOOK. The GLOOK, shown in Fig. 3.04, was first conceived as a computing instrument to correct the measured α_T and ϵ_T for the unavoidable rotations of the turret-axes $X_t Y_t Z_t$ caused by changes in the bomber's attitude during flight. (Section A-2.07.) To see how these corrections are handled, imagine a set of rectangular coordinate axes with their origin at the turret center O and fixed in the sense that they do not rotate with the bomber but always remain parallel to their original directions, which are taken as the directions to which gyros are initially aligned. Hence, these fixed axes are called the gyro-axes $X_G Y_G Z_G$. They translate with the bomber, keeping their origin always at the turret center, but they do not rotate.

Now α_T and ϵ_T are measured with respect to the turret-axes, whose orientation with respect to the gyro-axes at a given instant is measured by the readings on the three gyro dials at that instant. The principle of the GLOOK is merely to duplicate this orientation, then locate and hold the target direction with respect to the turret-axes, and finally read off the desired azimuth and elevation of this direction with respect to a set of fixed axes, say the gyro-axes themselves to be specific. For this purpose the GLOOK first of all has a transit to measure azimuth and elevation (Fig. 3.04). To get this transit into the desired orientation with respect to the $X_G Y_G Z_G$-axes, it is mounted on a partial circular bearing called the rocker, which permits a rotation of the whole transit about an axis through its center. This axis is called the rocker axis. The rocker in turn is mounted on another partial circular bearing called the saddle, which permits a rotation of the rocker and transit about an axis (the saddle axis) through the transit center and perpendicular to the rocker axis*. Finally, the saddle rides on a circular plate called the turntable, which permits a rotation of the saddle, rocker, and transit about an axis (the turntable axis) through the transit center and perpendicular to the saddle axis. When

* Circular bearings are used instead of gimbals on the GLOOK to minimize the probability that the telescope will point at some solid part of the GLOOK. The motion obtained would be the same in either case, except that the length of the partial circular bearings restricts the amount of rotation possible.

installed for operation (Fig. 3.05) the turntable axis is vertical, so that the saddle axis is horizontal. Rocker, saddle, and turntable all have scales and verniers for measuring their angular positions to the nearest minute. Their order from top to bottom may be easily remembered by noting that their first letters (r s t) form an alphebetical sequence.

From the fact that rotations in space are not commutative, i.e., rotations performed in one sequence are not in general equivalent to the same rotations performed in a different sequence*, it follows that great care must be taken to carry out the rotations in the proper order. Let us illustrate by a specific example. Suppose that the orientation of the turret-axes with respect to the gyro-axes is specified by three angles, viz., yaw, roll, and pitch in the order YRP . This means that the gyro-axes would be transformed into the turret-axes by a yaw through the angle Y , followed by a roll through the angle R , followed by a pitch through the angle P **. Note carefully that first the yaw takes place about Z_G and carries X_G and Y_G into new axes which will be called X'_G and Y'_G respectively. (See Fig. 3.10). In this set of rectangular axes Z'_G is coincident with Z_G . Next the roll takes place about Y'_G and carries X'_G into X''_G and Z'_G into Z''_G , where Y''_G is coincident with Y'_G . Finally, the pitch about X''_G rotates Y''_G and Z''_G into new axes which must be Y_t and Z_t respectively. Also X''_G is coincident with X_t . In passing it may be worth noting that the procedure just described was used by Euler to derive the formulas for the coordinates of a point with respect to one set of axes in terms of its coordinates with respect to a rotated set of axes and angles equivalent to Y , R , and P ***. The GLOOK eliminates the rather lengthy calculations which would be involved in using these formulas.

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* See, for example, Lamb, "Higher Mechanics", p.4.

** As mentioned in Section A-2.07, these angles are not in general equal to those measured on the gyro dials but are obtainable from them.

*** See, for example, Ames and Murnaghan, "Theoretical Mechanics", pp. 80, 81.

To perform this transformation on the GLOOK, imagine the common origin of both sets of axes to be at the transit center, let Z_G coincide with the turntable axis and Y_G initially with the saddle axis, and set the rocker axis perpendicular to the turntable axis by moving the saddle if necessary, so that X_G can be made to coincide initially with the rocker axis. In this position the rocker, saddle, and turntable scales should all be set to read 0^o, the transit must be levelled so that its azimuth axis coincides with the turntable axis, and its azimuth scale must be set to read at 0^o with the telescope pointing along the saddle axis in the positive Y_G direction. Starting from this position, rotate the turntable through the angle Y . Since the rocker and saddle ride on the turntable, their axes will be brought thereby into coincidence with X'_G and Y'_G , respectively. The transit azimuth axis will remain coincident with Z_G or Z'_G , but its telescope now points along Y'_G . The next rotation, the roll about Y'_G , can then be performed by turning the saddle through the angle R . Since the rocker and transit ride on the saddle, the rocker axis will be carried into coincidence with X''_G and the transit azimuth axis into Z''_G . Finally, the pitch about X''_G can be accomplished by turning the rocker through the angle P , thereby bringing the transit azimuth axis into coincidence with Z_t and its telescope with Y_t . In these three steps the transit is brought into position to read azimuth and elevation with respect to the turret-axes.

The next step is to set the given α_T and ε_T on the transit azimuth and elevation scales, respectively, in which case the telescope will point along the target direction. To hold this desired direction, it is only necessary to mark the point where the projected transit crosshairs strike a convenient screen, since the transit center is fixed regardless of the setting on its scales or those of the rocker, saddle, and turntable. At first thought a screen completely surrounding the GLOOK would seem to be required in order to cover all possible target directions, but a far simpler alternative is to use a narrow screen and provide a means of rotating the turntable and everything above it about a vertical axis through the transit center. For this purpose the GLOOK possesses a ring

(Fig. 3.04) whose axis coincides with that of the turntable, on which the latter can be rotated until the crosshairs fall on the circular center line* of the narrow curved screen shown in Fig. 3.05. Next this point is marked, most conveniently by merely aiming an auxiliary transit so that its crosshairs intersect the same point on the screen. If the rocker, saddle, and turntable are then returned to their original zero positions without moving the ring, the desired stabilized azimuth and elevation, i.e., the azimuth and elevation with respect to the gyro-axes, can be read from the transit scales when the telescope is re-aimed at the marked point on the screen.

In practice the stabilized azimuth and elevation can be obtained with fewer GLOOK motions if they are read from the ring scale and the auxiliary transit's elevation scale respectively, which eliminates the final zeroing of the rocker, saddle, and turntable. To perform this task correctly, the auxiliary transit must be aligned with its azimuth axis parallel to the turntable axis and its elevation axis always coincident with the line through the GLOOK transit center perpendicular to the plane of the circular center line of thecurved screen. Hence the azimuth adjustments of the auxiliary transit are used only in the process of bringing the elevation axis into proper adjustment and are not touched thereafter. The distance between the centers of the auxiliary and GLOOK transits is immaterial and may be determined purely by convenience. Since the telescope of the auxiliary transit moves in a plane parallel to but not coincident with the plane of the screen's circular center line, a flat mirror is attached to the objective lens in order to reflect the crosshairs onto the curved screen. This mirror must be adjusted so that its plane is perpendicular to the plane through both transit telescopes when they are parallel to each other. The latter plane will then contain the reflected beam from the auxiliary transit so that it will read correctly the stabilized elevation of any point on the screen. In practice the mirror adjustment is checked by comparing the elevation of any screen point as read from

* The center of this circular arc is the transit center.

the auxiliary and GLOOK transits when the latter's azimuth axis coincides with the turntable axis.

Once the order YRP was prescribed as above, these angles had to be set on the turntable, saddle and rocker, respectively, although which setting is made first is of no consequence. To illustrate the fact that no other arrangements of the setting are possible, suppose that we try to set the roll on the rocker instead of the saddle, after first aligning Y_G with the rocker axis and X_G with the saddle axis. As before, the yaw will carry these axes into Y'_G and X'_G, respectively, so that the rocker axis will now be in the correct position to handle the roll about Y'_G. However, since the saddle is <u>below</u> the rocker, its axis does <u>not</u> rotate into X''_G during the roll, so that the saddle axis is <u>not</u> carried into the correct position for the pitch, which must take place about X''_G. Therefore, this arrangement is not permissible. However, the reader should verify that it would have been correct if the specified order had been YPR instead of YRP. In that case the only other change in the procedure would have been to set the transit with its line of 0^o azimuth coincident with the rocker axis instead of the saddle axis.

Theoretically, by aligning the transit in other ways initially, it is possible to use the GLOOK in any of the other four orders (PRY, PYR, RPY, and RYP). Note that all four start with either P or R, which would require that the transit azimuth axis be set initially perpendicular to the turntable axis, in order to align the latter coincident with either X_G or Y_G. This would involve tipping the transit on its side by turning the rocker or saddle through 90^o from the initial position required by the order YPR or YRP. As the GLOOK is now constructed, the rocker and saddle motions are limited to 90^o or less on each side of the transit's level position. Hence to tip the transit on its side would either put the GLOOK in an awkward operating position or be impossible. Cantilever deflection of the transit telescope, likely in this position, is another practical difficulty. For these reasons, only the orders YRP and YPR can be considered satisfactory. In passing it may be noted, however, that the orders PRY and RPY could be conveniently handled if the transit's lower azimuth ring were equipped with a scale similar to that on its upper azimuth ring. Then yaw, which is last in order, would be set on this scale instead of the turntable.*

Instead of stabilizing to the gyro-axes as described above, it is often desirable to find the azimuth and elevation of the target direction with respect to the turret-axes at a chosen firing-time when they are known with respect to the turret-axes at the corresponding impact-time. This problem is called <u>local stabilization</u>, since the results are referred to a set of axes which are generally changing with time. The procedure is identical with that given above up to the marking of the point on the screen, using the known values of Y, R, P, α_T, and ε_T at impact-time. Then the GLOOK is reset to the values of Y, R, and P at firing-time, its transit telescope re-aimed at the screen point, and the desired azimuth and elevation read from the transit scales.

The GLOOK may also be used to read certain data directly from film projected onto its flat screen (Fig. 3.05). For this purpose it must be aligned in a manner similar to that employed for the CRADLE (Section A-3.03). In fact, it can be used to perform the same functions as the CRADLE by using only the saddle or the rocker. If the turntable is used with either the saddle or the rocker, the GLOOK is equivalent to the SEMI-GLOOK mentioned in Section A-3.03.

Because of its versatility in handling general rotations, the GLOOK has many uses in addition to those already discussed. For example, it can be employed to read target azimuth and elevation with respect to bomber-axes at the tri-camera location directly from tri-camera film projected onto the flat screen, no matter how the position of the mount was set. The operating details of this and other problems in which the GLOOK has been used to date are given in Section I of the Computer's Manual. Routines for other problems involving rotations of axes can be worked out as needed.

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* Certain additional modifications in the procedure would also be required.

A-3.05. Theory of the PLAXIE. It has been stated above that the CRADLE and GLOOK are designed to handle problems involving rotations of axes without translations, since these instruments keep the transit center, the origin of the axes, fixed during all operations carried out in reaching the desired solutions. On the other hand, the parallax corrector, nicknamed the PLAXIE (Fig. 3.06), is designed to perform translations of axes without rotations. The necessity for such translations arises characteristically in cases where the direction to some point (usually the target point on the fighter) in space is known at some bomber location and desired at another.

A typical example of this kind of problem is shown in Fig. 3.11(a), where α'_T and ε'_T, the azimuth and elevation respectively of the target direction O'T, are assumed known with respect to bomber-axes X'Y'Z' with origin at the optical center of one of the tri-cameras. The azimuth and elevation, α_T and ε_T respectively, of the target direction OT are to be calculated with respect to the XYZ-axes of the Martin forward crown-turret, where it will be recalled that the X'Y'Z'-axes are respectively parallel to the XYZ-axes (Section A-2.03).

By surveying the bomber the rectangular coordinates (a, b, c) of O' with respect to the XYZ-axes are determined, and from them the corresponding spherical coordinates $(h, \alpha_1, \varepsilon_1)$ can be easily computed, using the formulas.

$$h = \sqrt{a^2 + b^2 + c^2}$$

$$\tan \alpha_1 = a/b \quad ,$$

$$\sin \varepsilon_1 = c/h \quad ,$$

where care must be taken to put α_1 and ε_1 in the proper quadrants. Assuming the bomber to be a rigid body, these quantities are all constant. Also needed is the range r of T from O or O', say the former as shown in Fig. 3.11(a). It is not constant but in general varies with time.

The PLAXIE solves this problem basically by establishing the triangle OO'T of

Fig. 3.11(b) similar to the triangle OO'T of Fig. 3.11(a). To this end it has a transit mounted on a block which can be slid along an arm which can be inclined at the angle ε_1 to the horizontal (Fig. 3.06). After the arm has been set at this inclination, the transit can be levelled and its azimuth scale adjusted to read α_1 when its telescope is pointed in the O'OZ-plane*. In this position the transit will read correctly the azimuth and elevation of its telescope direction with respect to axes parallel to XYZ .

Like the GLOOK, the PLAXIE installation (Fig. 3.07) includes a narrow curved screen, whose center line is a circle with center at O and radius ℓ (Fig. 3.11(b)). The next step is to locate the transit center at O , by sliding the transit along the arm and, if necessary, raising or lowering the turntable base (Fig. 3.06) by means of the gearing provided**. In this position the adjustable linear scale on the arm should be set to read zero.

The transit is now in position to read the desired α_T and ε_T , but first the point T specifying the target direction must be located on the screen center line. For this purpose the transit must be slid along the arm a distance d to O' (Fig. 3.11(b)), where it will be located properly to read α'_T and ε'_T . From the similarity of the triangles it follows that $d/\ell = h/r$, so that $d = K/r$ where $K = h\ell$. Since K is constant, d varies inversely with r .

With the transit center at O' , its azimuth and elevation scales are set to read α'_T and ε'_T, respectively. As in the case of the GLOOK, the necessity for an extensive screen is eliminated by mounting the PLAXIE arm on a turntable (Fig. 3.06) which permits rotation about a vertical axis through O until the telescope crosshairs fall on the screen

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* ...ctice this alignment is accomplished by setting α_1 on the azimuth scale and then ... the elevation and lower azimuth adjustments to point the telescope at a line scribed along the center of the arm. Thereafter the lower azimuth adjustment is not altered.

** The details of this adjustment are described in the Equipment Manual, Ground Installations.

center line. This point T (Fig. 3.11(b)) is then marked, again most conveniently by an auxiliary transit (Fig. 3.07), after which the transit is slid back to O , the telescope re-aimed at T , and the desired α_T and ε_T read from its scales. Thus the parallax correction problem is solved for a given instant of time. The procedure may now be repeated for other times, where r , d , α'_T , and ε'_T will in general be different. Note however, that the settings for α_1 and ε_1 and the constant K are fixed for a given parallax problem.

In the problem just described the azimuth and elevation were known at one point (O') while the range was given from the other (O). Sometimes the parallax problem is met in a slightly modified form, in that the azimuth, elevation and range will all be given at the same point, say O , and the azimuth and elevation at O' are desired. An example is the problem of parallaxing target data from the Martin forward crown-turret to the Erco port waist-turret, with range, azimuth, and elevation of T given at the former. Here the procedure must be altered by setting the given azimuth and elevation into the transit at O instead of O' , marking T as before, and then moving the transit out to O' , from which position the desired azimuth and elevation may be read after re-aiming the telescope at T . Care must be taken to analyze each parallax problem encountered to determine the type to which it belongs. A convenient criterion is obtained from the observation that side must correspond to side r in the similar triangles OO'T of Figs. 3.11(b) and 3.11(a). This implies that the center O of the curved screen must correspond to the point on the bomber from which range is given.

It must be emphasized that the PLAXIE can be used to correct only directions and not distances for parallax. Thus in either of the problems described above it could not be used to find the range r' from O' to T (Fig. 3.11(a))*. It should be observed in

* This statement is true as the PLAXIE is now constructed. If it were equipped with an attachment for measuring the distance ℓ from O' to T (Fig. 3.11(b)), r' could be calculated from $r' = r\,\ell'/\ell$.

this connection that the difference between r and r' is small, being at most the distance h between the two positions, and that in practice the side h of triangle OO'T (Fig. 3.11(a)) is also small compared to r and r' . These facts led to the thought that a sufficiently accurate correction to convert r into r' can be obtained without elaborate calculation. This topic is discussed in the Theory Manual, Chapter A-8, where tables of this correction for particular parallax problems are given.

The step-by-step procedures for some specific PLAXIE problems are given in the Computer's Manual, Section J.

A-3.06. <u>The Use of Film Test-Strips</u>. In connection with the problem of taking data directly from a projected film by means of the CRADLE or GLOOK, it has been mentioned that the proper alignment of the picture on the screen was accomplished by using the so-called framing-marks (Section A-3.03). It was also pointed out that the projector , screen, and CRADLE or GLOOK must occupy correct positions relative to each other (Sections A-2.10 and A-3.03). Some of the requisite adjustments are made in the course of installing and checking the equipment, so that they are properly the responsibility of the maintenance crew. The remainder, including the location of the framing [illegible], will now be described with the CRADLE and gun-camera film as a specific example. [illegible]st be made by the computing staff under the direction of the supervisor before the data-taking begins.

In the first place the supervisor must be satisfied that the equipment has been installed and checked by the maintenance crew to comply with the following conditions:

(1) The flat screen is in a vertical plane.

(2) The projector's optical-axis is horizontal and perpendicular to the screen at its center, as defined in Section A-3.03.

(3) The screen center is marked and sharp horizontal and vertical lines are drawn through it on the screen.

(4) The projector is at approximately the distance from the screen which will

result in the largest image which is still sharp, clear, and entirely on the screen*.

(5) The cradle axis is horizontal and parallel to the screen, i.e., this axis is parallel to the horizontal screen line through the screen center.

(6) When in operating position, the CRADLE'S transit center lies on the projector's optical axis and is approximately at the true-angle point for the problem to be solved, withing the extent of the adjustment on the projector which permits it to be translated along its optical axis**.

Detailed procedures for installing the equipment in accordance with these requirements and routine checks to assure that it remains there are given in the Equipment Manual-Ground Installations.

The next step is to locate the transit center exactly at the true-angle point, using the angle-shots (Fig. 3.12) for the particular camera and lens under consideration. For convenience, the CRADLE is kept fixed and the projector adjusted by moving it along its optical-axis (Fig. 3.03), so that the process really involves bringing the true-angle point into coincidence with the transit center rather than the other way around. The following sequence of operations shows how this can be done:

(1) Starting with the CRADLE in operating position (Fig. 3.02) and its transit reading 0 in both azimuth and elevation when the telescope points at the screen center, lay off angles in azimuth equal to those between the center target and the other targets, as measured directly on the photo target-range. (These values should accompany the angle-shot film). Each angle will thus

* For 35 mm film photographed with a 2 inch lens and projected with a 3 inch lens, this projection distance should be about 150 inches.

** The distance from the true-angle point to the screen can be estimated by applying the condition that its ratio to the projection distance very nearly equals the ratio of the focal lengths of the camera and projector lenses, respectively. (This fact is proved in the Theory Manual, Chapter A-5). Thus for the case mentioned in the footnote to (4) above, the transit center should be about 100 inches from the screen, which is the installation shown in Fig. 3.02.

determine a point on the horizontal screen line; mark and label it in the same way that the corresponding target was designated on the photo target-range.

(2) Slide the CRADLE out of the way and project the angle-shot film onto the screen. Use the projector adjustments to focus the picture, to bring the line of targets onto the horizontal screen line, and to make the center target coincide with the screen center. If, as should have been the case, the camera was pointed toward the center target when the angle-shot was taken, the image of this target will now appear near the center of the picture. Strictly speaking, the picture should be centered on the screen, but the distortion is negligible for a displacement not exceeding a few inches. In doubtful or more extreme cases, the target points marked on the screen in (1) should be translated so that the picture can remain centered.

(3) Move the projector forward or backward on its base and adjust the position of the picture as required until the images of the targets coincide with the corresponding target points marked on the screen. In this process the picture must be kept in as sharp focus as possible. It is worth a little extra time and effort at this stage to get the best focus, since it must not be changed hereafter.

(4) Carefully tighten the focusing set-screws and the lock-nuts which clamp the projector to its base. Also mark this projector position, so that it can be reset without repeating the angle-shot procedure. Check the position of the picture on the screen to be sure that it has not changed.

(5) Next use the projector adjustments to realign the picture until it is centered on the screen and its longer sides are vertical. Then return the CRADLE to the operating position and measure the angles to the points where the edges of the picture cross the horizontal and vertical screen lines.

Tabulate these angles for future reference; they can be used to test film shrinkage if the process is repeated from time to time.

Having used the angle-shots to locate the projector properly, the framing-marks (Section A-3.03 and Figs. 3.02 and 3.03) are put on the screen in the following steps:

(1) Project onto the screen the level-shot film (Fig. 3.13) for the particular lens and camera, say a gun-camera, under consideration. This film shows a picture of the horizon taken when the turret azimuth ring, i.e., the XY-plane was level and the guns were approximately level. Hence the horizon will appear near the center of the picture although not necessarily passing through it. The image of the horizon only specifies a direction on the picture which must be parallel to AB (Fig. 3.09) since both are parallel to the XY-plane.

(2) Rotate the picture until the image of the horizon is parallel to the horizontal screen line. Then center it by means of the translation adjustments on the projector, keeping the horizon level.

(3) Outline the edges of the frame carefully and uniformly with strips of black adhesive tape* to form the framing-marks. Short strips of tape, spaced at intervals, are better than a solid boundary, because the edge of the picture can be seen between them. In addition, it is usually desirable to trace the fiducial marks on the screen in pencil.

If the gun-camera was boresighted, the bore-point on the screen should now be at its center. To check the boresighting accuracy or to locate the bore-point on the screen in the case of an off-set camera, a position-shot (Fig. 3.14) is generally taken just prior to each flight. The procedure is to aim the gun at a specified target and expose a few feet of film in the gun camera. This film is the position-shot and is used as follows:

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* Photographer's binding tape has been found more satisfactory than ordinary friction tape for this purpose, since the former does not gum up the screen.

(1) Project the position-shots onto the screen and align its image to fit the framing-marks.

(2) Mark the position of the specified target on the screen and label it to identify its camera and the flight to which it belongs. This gives the screen bore-point needed in the CRADLE or SEMI-GLOOK problem solutions. As stated in Section A-3.03, the former can be used with strict accuracy only if the bore-point falls on the vertical screen line. Otherwise the SEMI-GLOOK is required.

The alignment of the CRADLE and associated equipment is now complete. Film from the camera and lens corresponding to the test-strips used above may now be assessed. The test-strip procedure need not be repeated unless film from different cameras or lenses is to be assessed* or unless the alignment of the equipment is disturbed. However, if only the focus of the projector lens is altered, it may be reset properly by merely focusing the picture to the size of the framing-marks, which should result in a distinct image as well. Modification of the test-strip procedure to adapt it to other cameras, such as the tri-cameras, are described in the Equipment Manual-Ground Installations. Attention should also be called to the Test-Strip Film Procedure in the Computer's Manual, Section F. It refers to the original method in which only a single film was used. The Test-Strip Procedure II, also described there, is a condensed version of the improved method discussed above.

A-3.07. Precautions in the Use of Instruments. The computing instruments and their associated equipment are massively constructed and are securely bolted down to minimize deflections and displacements from the correct alignment. Nevertheless, some members, especially the transits, are not too rigid. For this reason it is imperative that all operators exercise great care in handling the instruments, rugged as they may appear. The

* More than one set of framing-marks may be left on the screen as long as no confusion will result therefrom. Two sets are shown in Figs. 3.02 and 3.03.

following seven commandments deserve special consideration:

(1) Do not lean on the equipment. This applies especially to the transits and projectors, where even a light pressure can cause deflection of a minute or two. Hence magnifiers used to assist in reading scales must not be allowed to rest on the transits.

(2) Do not bump against any piece of equipment. Its alignment requires considerable time and effort, a fact which the operator may be inclined to forget. The auxiliary transits are particularly susceptible to misalignment from unintentional jolts.

(3) When tightening the various clamps, set-screws, and lock-nuts, do so gently and smoothly. Jamming them home will cause distortion and excessive wear.

(4) When bringing a CRADLE or GLOOK into operating position, ease it against the stop-screw gently. It must not be brought up with a sudden bump.

(5) Do not "diddle" with any adjustments, especially those set in aligning the equipment. This practice not only causes unnecessary wear and tear but may also necessitate a lengthy and arduous realignment of the equipment.

(6) Always focus the image of the telescope cross-hairs sharply on the screen. Since the distance from the transit center to the screen depends on the direction in which the telescope is pointed, refocusing should always follow positioning of the telescope. Otherwise the telescope line is likely to be displaced and a corresponding error introduced.

(7) Once the focus of the projector has been fixed in the Test-Strip Procedure (Section A-3.06), do not change it. To do so would alter the size of the picture and hence the location of the true-angle point. Operators are tempted to try changing the focus to get a more distinct picture, but this practice must be forbidden.

Essential care and basic alignment should be left to the maintenance crew. They should make all repairs, unless specific permission to the contrary is granted. However, it will be advantageous for the supervisor to be as familiar as possible with the alignment and maintenance procedures described in the Equipment Manual-Ground Installations.

CHAPTER A-4

PRELIMINARY PROCESSING OF FILM

A-4.01. Care in Developing, Handling, and Storing Film. On finishing a flight, the various films should be developed and delivered to the supervisor as soon as possible. The developing process itself should conform to the best practice, taking particular care to prevent damage to the film, especially scratching, and to minimize distortion and shrinkage.

Unnecessary handling of the film should be avoided in the interests of keeping it clean and undamaged. It should be kept rolled up on a reel or core as much as possible. When unrolled, the free end should fall into a flannel-lined cutting barrel designed for the purpose, never on the floor. Since film is subject to damage from heat and certain types are highly inflammable, smoking and other fire hazards should not be permitted in rooms where film is handled. Adequate emergency exits and fire extinguishers must also be provided.

Every effort should be made to assess the film with a minimum of delay after developing. When storage is necessary, even for short periods, the film should be kept in metal cans in a special fire-proof vault, with controlled temperature and humidity if possible. In case these ideal conditions cannot be provided, the film cans should be sealed with tape and stored in a cool place.

A-4.02. Inspecting, Editing, and Cutting. Detailed procedures for inspecting and editing the film and cutting it into separate attacks are given in the Computer's Manual, Section D. The inspection especially should be carried out as soon as the film for a particular flight is received, the primary objective being to determine whether or not sufficient data in the form of usable film have been obtained for enough attacks to satisfy the assessment requirements. Since this decision requires a thorough knowledge of the desired results and of the possibilities and limitations of the assessment techniques, it should be entrusted only to the supervisor or an experienced computer.

If some data on the flight sheets are missing, the persons responsible should be consulted at once in the hope that it can still be obtained. If some films are missing or not usable, the supervisor must decide whether data from other films can be successfully substituted or whether the flight will have to be reflown. In the latter case, the retake should be scheduled for the earliest possible time and under the same experimental conditions, including personnel and equipment.

As soon as the inspection shows that the film can be assessed, the editing may be started. Here the main object is to number enough frames on the various films for a given attack to provide a convenient reference system for later identification of data taken from different films. Frame number 201 in Figs. 2.08 and 2.09 is an example of this method of identification.

During the editing any irregularities or gaps in the data should be discovered and their significance noted. Great care must be taken with the editing to avoid misinterpretation of timing and cataloging marks and to prevent mistakes in frame numbering. This is especially important for frame number 001 on each film. It represents zero time, so that labelling it on the wrong frame would produce a translation of the time axis for that film relative to the others. The supervisor should approve all editing before the films are processed further.

The next step is to cut each roll of film into separate attacks, wind each strip onto a core, attach a label identifying the experiment, flight, attack, and camera, and store in a film-strip can. The film is now ready for the actual assessment to start.

A-4.03. <u>Synchronization of Films</u>. Before the data taken from different films can be correlated, the time corresponding to each frame number on each film, measured from an arbitrarily chosen instant which is the same for all films, must be found. In Section A-2.12 it was shown for a typical case that the tolerance on this time for any frame is only about $\pm$ 0.001 second, and the difficulties in the way of obtaining such precision were treated briefly in Section A-2.11.

For film from cameras controlled by the first or Mk I synch system, e.g. in F. C. 9 and 14, the total-attack averaging method is applicable. It is discussed more fully in the Theory Manual, Chapter A-6, and amounts in practice to finding the average number of frames per second over the largest even number of timing-mark intervals in the attacks*. Assuming constant camera speed, the reciprocal of this average gives the time interval, i , between frames. Then the time, t , corresponding to the nth frame after the one marked 001 is given by t = ni , where t should be listed to the nearest thousandth of a second. This simple calculation yields the desired conversion table from each frame number to its corresponding time for the film and attack under consideration. A consequence of this procedure is that frames 101, 201, etc., which nominally mark the beginning of successive seconds, may not correspond exactly to times 1.000, 2.000, etc., seconds, respectively.

In the actual construction of the conversion table it is not necessary to list every frame but only those to be assessed, which depends on the conditions of the experiment. For F. C. 9 and 14 it was found that every third frame for 35 mm film and every other frame for 16 mm film were convenient and yielded enough data. The standard practice called for reading the frame at the beginning of each timing-mark (e.g., 101, 201, etc.) and regularly spaced frames thereafter until the beginning of the next mark. Thus if there were exactly 24 frames between the second and third marks, the ones to be read would be 101, 104, 107, ---, 122, 201, 204, ---, all evenly spaced. If frame 124 were missing, the same frames would be read, but 122 and 201 would be separated by only one frame, viz., 123. On the other hand, if an extra frame were present, it would be number 125 and would also be read, since it is the third frame beyond 122. Then 201, which is adjacent to 125, would be the next

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* A knowledge of the length of each pair of intervals to the nearest thousandth of a second is required here.

frame read. All such irregularities must be carefully noted, marked with an asterisk, and taken into account in computing the entries in the conversion table. The supervisor should check the computations, especially at the beginning and end of each timing-mark interval, before the table is used.

CHAPTER A-5

DETAILED PROCEDURES FOR THE MARTIN FORWARD CROWN-TURRET (F. C. NO. 14)

A-5.01. Purpose. The assessment of a particular turret requires the analysis of data from recording equipment by means of reading devices, computing instruments, arithmetical operations, and graphs. The theory for such an assessment, the methods for gathering the data, and the motivation for the various computing instruments have been discussed in the preceding chapters of this Manual, but it is often a far cry from these prerequisites to the step-by-step outline and form sheets for handling the data efficiently and accurately. Furthermore, once a satisfactory pattern for one type of assessment has been established, the modifications necessary to adapt it to other types of turrets are not too difficult to devise. For these reasons a description of the procedures worked out thus far is deemed advisable. The present chapter will be concerned only with the assessment of the Mark 18 sight installed in the Martin forward crown-turret of the PB4Y-2, A. T. No. 14, according to the specifications prescribed for F. C. No. 14. During these tests data for a similar assessment (F. C. No. 9) of the Mark 18 sight installed in the Erco port waist-turret of the same bomber were gathered simultaneously; their analysis is discussed in Chapter A-6. A separate experiment to determine the flight path of a particular fighter attacking a bomber is treated in Section E of this manual.

Flow charts have been prepared for the various assessments to provide a pictorial outline of the steps in the analysis and to show the interdependence and order of precedence of the operations. They are included with the Figures* and should prove useful to the supervisor in explaining the procedure and in scheduling the computations. It is desirable for the computers also to understand the flow charts as far as possible, although

* In addition, a simplified Flow Chart for F. C. Nos. 9 and 14 is shown in Fig. 5.11

individual operations can be explained as separate problems when needed. Specific directions for the computers' use are stated on the sample form sheets which are reproduced in the Computer's Manual as well as here. They do not attempt to explain the reasons for the steps, nor do they repeat directions given in the Computer's Manual for reading data from the recording equipment, for using the computing instruments, or for performing arithmetical and graphical operations. In several instances there is more than one acceptable way to proceed, but for the sake of explicitness only the most satisfactory method has been prescribed. The purpose of this chapter and the next is to discuss the sample form sheets from the supervisor's standpoint, emphasizing the motivation for the steps and possible alternatives.

A-5.02. Brief Description of F. C. Nos. 9 and 14. In the experiments designated by F. C. Nos. 9 and 14 the PB4Y-2, A. T. No. 14, was flown on a straight, level course at a constant speed of about 140 or 170 knots and at an altitude of about 6000 feet. Gunners in the Martin forward crown- and Erco port waist-turrets used their Mark 18 sights in simulated defense against an F6F fighter which executed specified types of pursuit curve attacks on the port side of the bomber. The required assessment data were recorded by the RAZEL-, gun-, and sight-cameras in the forward crown-turret, the gun- and sight-cameras in the port waist-turret, and the gyro-camera*. Both sight-cameras were 16 mm GSAPs, whereas the other cameras were all 35 mm Bell and Howell A-4s. The assessment of the port waist-turret was designated F. C. No. 9 and that of the forward crown-turret F. C. No. 14. Much of the data gathered for the latter was useful in the former, as explained in Chapter A-6. The step-by-step procedure for F. C. No. 14 will now be discussed in detail, with reference to the sample form sheets.

A-5.03. Form 10**. This data sheet is used to record the gun position relative to turret axes as obtained from the RAZEL film.

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* Tri-camera data were generally not available and were never used in the assessment.

** Form sheets bearing numbers below 10 are obsolete.

Cols 10-A and 10-H*. The numbers of the frames to be read are listed in Col 10-A. In general every third frame is sufficient, except where the turret motion is very fast, in which case it may be desirable to read every frame. Next, the time corresponding to each entry in Col 10-A may be read from the proper conversion table (see Section A-4.03) and recorded in Col 10-H, or this step may be postponed until the entries in the rest of the columns are complete.

Cols 10-B, 10-C, and 10-D. As each frame of RAZEL film is viewed, the readings from the azimuth and elevation scales are recorded in Cols 10-C and 10-D, respectively. If a RAZEL range scale is present, its reading may be recorded in Col 10-B. Since the azimuth and elevation scales were marked only every 30 minutes, without satisfactory verniers (see Fig. 2.07), it was impractical to attempt to read them closer than about ± 3 minutes. Until these scales are improved, this is the working tolerance. To minimize reading errors it is advisable to have each film read by two different persons and to check all corresponding entries which differ by as much as the prescribed tolerance.

When the turret is turning at a high rate, the lines on the azimuth dial will blur into bands, while the stationary index remains clear. Under such circumstances the center of the blurred band may be used as the azimuth line. The numbers will also blur, but they can be determined with practice by comparison with other numbers, by estimating the value from the rate at which the azimuth is changing, and by utilizing the distinguishing marks which appear near certain of the numbers.

Cols 10-E, 10-F, and 10-G. Because of practical difficulties in scribing the turret scales, the zero azimuth and elevation position of the gun does not coincide exactly with the zero azimuth and elevation on the scales. This discrepancy has been neglected, since a small, constant error is of no consequence. However, it is known

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* To denote each column it will be convenient to write the form number followed by the letter for the column; e.g., Col 11-G means Column G of Form 11.

that the azimuth scale reads 2 degrees low because the index was intentionally moved that amount to center it on the film. Hence 2 degrees should be added to Col 10-C. The result may be recorded in Col 10-F, but if this is the only correction, it is easier to add the 2 degrees when the gun data are plotted (see below).

A more serious source of error is the non-uniformity of the half-degree spacings on the turret scales. A check on the azimuth scale has revealed errors as large as 9 minutes at one point but not exceeding 6 minutes elsewhere*. These errors have been indicated on the scale itself, but since there is some uncertainty about the corrections to be applied and since they are generally less than the present reading accuracy, no attempt has yet been made to use them. However, as the reading accuracy improves, the scale corrections should be verified and then applied before listing the entries in Col 10-F.

Possible scribing errors on the elevation scale are not known. When they become available, they should be applied to Col 10-D and the results tabulated in Col 10-G. At present these columns are identical, and the former may be omitted to save copying.

Col 10-E is for the range input converted to yards if it is desired. Since the RAZEL range scale has never been satisfactory, both Cols 10-B and 10-E are now omitted.

<u>P10-F and P10-G</u>**. The gun data (azimuth and elevation) are graphed to provide a visual check and to permit graphical interpolation if required. Detailed instructions for scales and conventions for labelling which have been found satisfactory in practice are stated in the Computer's Manual, Section L. A sample working graph, reduced from its original 21 x 33 inch size is shown in Fig. 5.01. Any points that appear out of line should be checked for accurate plotting and reading from the film. If a point is

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* This test is described in a letter to Lt. Comdr. R. J. Teich from W. R. Payne, S 2/c, and L. L. Pokorny, S 2/c, dated 20 Sep 1944.

** P before a column designation stands for "plot" and denotes the graph composed of straight-line segments drawn through successive points obtained by plotting the column vs the corresponding time column. Similarly, S means "smooth" and denotes the smooth curve which sometimes replaces the straight-line graph; e.g., S11-G.

in doubt, it may be advisable to read more frames in its vicinity in order to determine the behavior of the data more closely.

Interpolation arises most frequently from the necessity of synchronizing the gun data with the gun-camera frames, as will be discussed in Section A-5.04. Because the gun motions are relatively rough or capable of fairly rapid changes, smoothing of gun data is not considered justifiable. This leaves the interpolation to be carried out along the straight-line graphs and casts considerable doubt on its accuracy. Therefore it is highly desirable to eliminate the interpolation by proper synchronization of the RAZEL- and gun-cameras. In passing it should be noted that this difficulty is absent in the case of deflectometer film, where the gun data are recorded directly on the gun-camera film, and is reduced in the case of tri-camera film, where the interpolation is performed in the relatively smooth target data.

A-5.04. Form 11. This form sheet is used in the determination of the range and target position from measurements on the boresighted gun-camera film.

Cols 11-A and 11-H. The numbers of the frames to be assessed on this film, generally every third, are listed in Col 11-A and the corresponding times from the proper conversion table in Col 11-H.

Cols 11-B and 11-D. The problem of calculating the range is treated in the Theory Manual, Chapter A-2. Form 11 is designed only for the simplest case where the range is inversely proportional to the length of the screen image of a known base line on the fighter, such as the distance between winglights or marks. This formula has been found to be satisfactory in view of the accuracy to which the screen lengths can be measured in practice. The proportionality constants, K_1 and K_2, are to be found from test films which show the target at known ranges; these pictures must be taken by the same camera and lens used in the actual flights, and the film must be projected in the identical manner employed in the assessment.

Great care must be exercised in scaling the screen lengths. A scale with 1/50 inch divisions, reading directly in inches, is most satisfactory, and it should be equipped with a suitable handle for ease of holding it flat against the screen. To avoid the contradictory lighting conditions involved in best projection and easiest reading of the scale, it has been found advisable to mark the ends of the screen length carefully on the screen or a piece of paper held against it and then to turn on sufficient light to permit accurate scale readings. Of course, this procedure introduces an additional step, with the consequent possibility of more error. The computer must be impressed with the necessity of cooperating to reduce these reading errors to a minimum at their source.

Cols 11-F and 11-G. When a particular frame of gun-camera film is projected onto the screen, it must first be aligned to fit the framing marks (see Sections A-3.03 and A-3.06). Then the screen lengths are scaled as described above and the target point (chosen to be the center of the propeller hub) is marked on the screen and labelled with the frame number. This marking must also be done with great care. These steps are then repeated for a sequence of frames, including all those to be assessed for the attack unless they become too dense on some portion of the screen. Then the projector is turned off, the lights turned on, and the CRADLE slid into operating position, where it is used with the gun data for the same times as the gun-camera frames in the "Bore-Point to Target-Point Operations". (See the Computer's Manual, Section H, Cradle Problem No. 2.) This yields the target azimuth and elevation for each frame assessed, which are recorded in Cols 11-F and 11-G, respectively. Either of the following cases may occur:

1. If the RAZEL- and gun-cameras are correctly synchronized, Cols 10-H and 11-H are identical. Then the gun data in Cols 10-F and 10-G may be fed directly into the CRADLE, which is the simplest and most desirable case since it requires no interpolation.
2. If the RAZEL- and gun-camera are not synchronized, interpolation is unavoidable. The interpolated gun data read from their graphs at the times of Col 11-H should be recorded on unused columns of Form 11 if such are available or on a special sheet, such as another Form 10, properly labelled for the purpose. The CRADLE problem then proceeds as before. An alternative to Case 2 which is sometimes convenient is described in Section A-5.06.

P11-F and P11-G. The target data are graphed for two reasons: to check the CRADLE computations and to permit smoothing. In order to correct mistakes with a minimum of inconvenience, it is desirable to plot the target data as soon as they are read from the CRADLE. Then points which are out of line can be checked while the target points are still marked on the screen. Experience shows that target data can be expected to be quite smooth unless the bomber experiences sudden roll, yaw, or pitch. Target azimuth and elevation graphs should be obtained in acceptable form before the CRADLE computation is considered complete.

S11-F and S11-G. A discussion of techniques for fitting a smooth curve to the target data using French- or ship-curves is included in the Computer's Manual, Section L. The method requires skill and practice to be successful.

Cols. 11-C and 11-E. Having the values of K_1 and K_2, Cols 11-B and 11-D can be converted into range by a simple calculation. For a large number of range determinations it is worthwhile to construct a range conversion table listing range vs screen length. Range may then be read from this table, or a graph drawn from it, and recorded in Cols 11-C or 11-E, depending on which screen measurements are used. The use of both winglights and marks for ranging provides a check, but it should be noted that the accuracy is greater the longer the base-line on the fighter. On the F6F this means that better results will be obtained from the wingtip lights than from the marks, which are only about half as far apart as are the lights. Since the lights are also generally visible at a longer range, the marks are often disregarded.

P11-C and S11-C. Like the target data, range is graphed to check the values and to permit smoothing. Since on a pure pursuit curve the range decreases almost linearly with time, the range graph is expected to be very smooth and nearly straight. Actually it is in general slightly concave upward, especially at short ranges (see Fig. 5.01).

In practice, the range data appears to be reliable up to about 600 yards. Beyond that range the fighter tends to be too faint and small to permit accurate screen measurements, resulting usually in erratic range values. Therefore, it is deemed more satisfactory to extrapolate the smooth range curve out to the desired 800 yard maximum. However, recent improvements in the winglights have resulted in range curves which are themselves smooth out to about 800 yards.

P11-E and S11-E. If measurements of wingmarks are to be used instead of or in addition to the lights, the same procedure applies.

A-5.05. Form 12. This sheet is used to calculate the bullet time-of-flight and the corresponding firing time. If the Erco port waist-turret is to be assessed from data taken on the same attack, certain economies can be affected by using Form 12 in combination with Form 18, as discussed in Section A-5.06. The case where Form 12 is used by itself will now be described.

Cols 12-A and 12-B. Experience has shown that an appreciable amount of time can be saved and the accuracy of reading data from the working graphs improved by choosing points on the time axes at successive tenths of a second apart, all corresponding to vertical lines on the graph (Fig. 5.01). Then it is easy to locate the abscissas quickly. The chosen times are to be listed in Col 12-B; the reason that it is headed "Impact Time (Initial)" is explained below.

Col 12-A is for frame numbers in case it is desirable to have the time correspond to the gun-camera frame numbers instead of the tenths of a second recommended above Otherwise it may be omitted.

Cols 12-D, 12-G, and 12-H. From the smooth curves of target range, azimuth, and elevation (S11-C or S11-E, S11-F, and S11-G, respectively) the corresponding values are read at the times of Col 12-B and recorded in Cols 12-D, 12-G, and 12-H, respectively. As shown by Formula (1) of AMP Memo No. 104.1 (see Section A-1.04 for a complete reference to this paper), the bullet-time-of-flight, T , for the case of an aircraft flying and firing horizontally depends on the type of gun and projectile, its muzzle velocity, the range at impact time, the relative air density, the constant true air speed of the aircraft, and the angle-off (the angle between the direction of flight of the aircraft and the bore-line of the gun). For non-horizontal fire a correction term is given in Equation (A-11) of AMP Memo No. 104.1. However, its maximum value is about 0.007 cos z seconds, where z is the angle between the zenith and the bore-line, for ranges out to 800 yards*. Since it is much less for shorter ranges, it was neglected in F. C. 9 and 14, in which all attacks were flat-side with z rarely under 75 degrees. In cases where z is smaller or the range longer, this correction term must be considered.

Since T varies almost directly with the range, the tolerance on the latter is very small, of the order of one yard (see Section A-2.12). Stadiametric ranging does not ordinarily permit the attainment of such accuracy except at very short ranges, so that this is a weak link in the computation. Every effort must be made to plot, smooth, and read the range graph with the greatest possible care. A good check on Col 12-D is to compute the first differences and be sure that they are smooth.

Col 12-C. Inspection of Formula (1) mentioned above or tables computed from it (see Figs. 5.02 and 5.03) reveals the fact that the dependence of T on angle-off, θ , is not critical, errors up to 2 degrees being negligible for ranges out to 1000 yards. Hence, for convenience θ is listed only to the nearest degree in Col 12-C.

The theory of the transit-time method (see Chapter A-1 and Fig. 1.01) implies that θ is given by the direction of the target at impact time, except for small ballistic deflections which may be neglected in view of the large tolerance stated above. For the same reason the fact that the zero azimuth and elevation direction does not ordinarily coincide exactly with the bomber's line-of-flight may also be neglected.

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* See AMG-N No. 21, "Prospectus on Ballistic Charts for Caliber 0.50 Projectiles Fired from Moving Aircraft", by George Piranian, page 2.

Then Θ may be computed from the formula* $\cos \Theta = \cos \alpha_T \cos \epsilon_T$, where α_T = azimuth and ϵ_T = elevation of the target, or more readily from the angle-off table (Fig. 5.04) which has been computed from this formula. Note that for this purpose α_T and ϵ_T need be read only to the nearest degree. If ϵ_T is small, α_T may be used for Θ , thus making it possible to tabulate Θ directly from the target azimuth working graph and to omit Cols 12-G and 12-H altogether. Also, if Cols 12-B and 11-H are identical and if the smoothing did not alter α_T and ϵ_T more than about 1 degree, Cols 11-F and 11-G may be used instead of Cols 12-G and 12-H for finding Θ .

Col 12-E. A more complete discussion of the theory for the determination of T is given in the Theory Manual, Chapter A-3. The result is a double-entry table giving the range r in terms of T and Θ . A separate table is needed for each type of projectile and gun, relative air density (determined by the altitude under assumed standard atmospheric conditions), and true air speed of the bomber. A set of such tables has been computed by AMG-N (Fig. 5.02), each giving r to the nearest yard for T-intervals of 0.05-second and Θ-intervals of 10 degrees. To facilitate the computation the particular tables needed for F. C. 9 and 14 have been interpolated for T at intervals of 0.01 second (Fig 5.03). Entering with r (Col 12-D) and Θ (Col 12-C), T can be found to the nearest 0.005 second by mental interpolation and is then recorded in Col 12-E. To calculate T any closer would probably require more complicated interpolation. Although hardly justified by the accuracy of the tables themselves, it may be desirable to calculate T to the nearest 0.001-second in the interest of getting a smooth curve.

Col 12-F. It was inferred above and should be emphasized again that the range used in the time-of-flight table is the distance between the moving gun platform and

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* The angle Θ is the hypotenuse of a right spherical triangle whose legs are α_T and ϵ_T . For the solution of such triangles see any standard text on spherical trigonometry.

the projectile T seconds after firing. Since the only range which can be measured (Col 12-D) is the distance from the bomber to the fighter at the times listed in Col 12-B, the use of this range in the time-of-flight table implies that the projectil must coincide with the fighter (i.e., a hit is scored) at the corresponding time in Col 12-B. Hence this must be impact time and not firing time. However, the corresponding firing time is obtained by simply subtracting T (Col 12-E) from the corresponding entry in Col 12-B and is recorded in Col 12-F. All these times carry the designation "Initial" to distinguish them from "Final" times which will be introduced in connection with Forms 13 and 14 (see Section A-5.07).

P12-E and S12-E. Col 12-E is plotted vs Col 12-F to provide a visual check, and it is smoothed to permit reading the time-of-flight at chosen final firing times. The points should lie very close to the smooth curve, and the latter should be nearly linear. The supervisor must check and approve this curve before the computations are carried further.

A-5.06. Form 12 combined with Form 18. The following modifications of the procedure described in Section A-5.05 will eliminate unnecessary repetition of data when it is to be parallaxed to the Erco port waist-turret later:

1. List the time in tenths of a second also in Col 18-B.
2. Record smoothed target range, azimuth, and elevation in Cols 18-E, 18-C, and 18-D, instead of Cols 12-D, 12-G, and 12-H, respectively, which are then left blank. For purposes of parallax correction the azimuth and elevation must be read to the nearest minute. The data recorded on Form 18 are used in computing Col 12-E and are also ready for parallax correction.

In using any two form sheets together care must be taken, here and elsewhere, to be certain that the time columns are correctly aligned.

A-5.07. Final Firing and Impact Time. It will be recalled that the initial impact times (Col 12-B) were generally chosen for convenience at evenly spaced intervals (see

Section A-5.05). Since the corresponding time-of-flight (Col 12-E) usually decreases steadily as the attack is pressed home, the initial firing times (Col 12-F) will not be evenly spaced. In particular it is only a coincidence if they correspond to either the RAZEL- or the gun-camera frame times. Hence in general the use of the initial firing times for the comparison of true and actual borepoints would require interpolation in the gun data as found from the RAZEL. It has already been pointed out (see Section A-5.03) that such interpolation is hardly justified in view of the relative roughness of the gun data.

This difficulty can be avoided by noting that the time-of-flight graph is very smooth, so that no serious error is introduced by interpolating between calculated values of T . Hence the standard procedure is to choose new firing times identical with the RAZEL times (Col 10-H); these are designated as <u>final</u> firing times and are listed in Col 14-A. Then the corresponding values of T , the final time-of-flight are read from S12-E and recorded in Col 13-F. The sum of corresponding entries in Cols 14-A and 13-F is Col 13-A, the final impact time*. Cols 14-B and 14-C are then identical with Cols 10-F and 10-G, respectively, and the undesirable interpolation in the gun data has been avoided**.

If desirable and convenient, the gun-camera times, instead of RAZEL times, may be chosen for final firing times. Then Col 14-A is identical with Col 11-H and Cols 14-B and 14-C will be used to record the interpolated gun data used with the CRADLE problem. This alternative procedure avoids any additional interpolation in the gun data and eliminates the need for a special sheet on which to record the interpolated gun data.

A-5.08. <u>Necessity for Roll, Yaw, Pitch Corrections</u>. If the turret axes at all impact times are respectively parallel to those at the corresponding firing times, the target data

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* The reason for this apparently reverse listing of final firing and impact times will be seen when Forms 13 and 14 are discussed (see Section A-5.12 and A-5.13).

** The suggestion for this improved procedure is due to AMG-N. See AMG-N No. 47, "A Modified Computation Procedure for Camera Bomber Sight Assessment", by A. A. Albert. It should be emphasized that the terms "initial" and "final" have no intrinsic physical significance. They are used merely to distinguish the first set of firing times and corresponding impact times from the second. Both sets are taken from the same firing and impact time data but at different time intervals, for convenience of computation.

at the former may be corrected for ballistic deflections, as described in Section A-5.12, and then compared directly with the gun data at the firing times to obtain the desired gun lead errors, as discussed in Section A-5.13. In this case Cols 13-B and 13-C are read from S11-F and S11-G, respectively, at the times of Col 13-A, and the phrase "corrected for RYP" is deleted from the headings of Forms 13 and 14. Since the target data are relatively smooth, this graphical interpolation is justified.

Usually, however, the gyro data show that the turret axes rotated (see Sections A-1.04 and A-2.07) during the time-of-flight. To remove the effect of these rotations, the gyro data must be recorded, interpreted in the light of the theory treated in Chapter A-4 of the Theory Manual, and finally applied in the proper calculation procedure. The practical completion of these steps is discussed in the next two sections.

A-5.09. Form 21. This sheet is used to record the gyro data from the film and to correct it for initial misalignment and offset of the gyro axes, as well as changes in sign if required.

Cols 21-A and 21-B. The numbers of the gyro-camera frames to be assessed are recorded in Col 21-A and the corresponding times from the proper conversion table in Col 21-B. In practice the gyro data change relatively slowly, so that their time conversion and synchronization are not nearly so critical as in the case of gun data.

Cols 21-C, 21-D, 21-E. The yaw, pitch, and roll angles which specify the bomber's attitude at any time were defined in Section A-2.07. Their values as read from the gyro film (Fig. 2.11) are recorded in Cols 21-C, 21-D, and 21-E, the respective initial readings being listed in the space provided in the heading to those columns. It should be noted that the range of angles scribed on the gyro dials is within the interval from 0 to 360 degrees to avoid possible confusion over negative angles.

Cols 21-F, 21-G, and 21-H. The chosen sign conventions for yaw, pitch, and roll were also established in Section A-2.07. Each gyro installation must be observed to determine whether or not its dial angles conform to these conventions. For Gyro

Set No. 1 installed with its camera pointing toward the nose of the bomber, the yaw dial reads positive in the correct direction but the other two dials do not. In effect this means that the sign of the pitch and roll readings should be changed, but this correction is combined with others now to be considered.

The erecting mechanism on Gyro Set No. 1 is partially gravity-erecting and does not permit a complete determination of the positions of the gyro rotor axes (see Section A-2.07). Hence one cannot be sure of the proper interpretation of the film data, but if the initial readings are used as a zero reference, the difference between them and the respective dial readings during the attack represent deviations of the bomber's attitude from its initial position. To compute these corrected values, including the changes of sign established above, the initial yaw is subtracted from each entry in Col 21-C, each entry in Col 21-D is subtracted from the initial pitch reading and each entry in Col 21-E from the initial roll reading. Any negative angles resulting therefrom should be converted to the corresponding positive angles by adding 360 degrees. These corrected angles are then recorded in Cols 21-F, 21-G, and 21-H, respectively.

Col 21-J. As mentioned in Section A-2.07 and shown in Fig. 2.13, the gyro coordinate axes for Set No. 1 were rotated through the flight angle $P_0 = 2^\circ\ 18'$ in the YZ-plane. In Chapter A-4 of the Theory Manual it is shown that this fixed offset is properly taken into account by adding it to the corrected pitch (Col 21-G), when the GLOOK is to be used in the order YRP. This result may be tabulated in Col 21-J if desired, but a little time can be saved by combining it with the previously described corrections or adding it mentally in the course of graphing the corrected values.

P21-F, P21-H, and P21-J. As with other readings, the corrected gyro data are plotted vs time to provide a check and to permit interpolation for intermediate values of time (see Fig. 5.05). The data can be expected to be smooth, but in practice they usually change so slowly that the straight-line graph is sufficiently accurate for interpolation. In fact it is frequently satisfactory to use merely the nearest observed values. If this can be foreseen from an inspection of the data, the graphing may be omitted.

A-5.10. Form 22. This sheet was designed for use in converting the corrected gyro readings into the corresponding GLOOK angles in the order YRP (see Section A-3.04) for the mildly restricted case where Cols 21-F, 21-H, and 21-J are all within 8 degrees of 0 or 360 degrees. The formulas for this conversion are given in the Theory Manual, Chapter A-4, where it is also shown that they produce a negligible effect if Cols 21-F, 21-H, and 21-J are all within 4 degrees of 0 or 360 degrees. Since the gyro data in F. C. No. 9 and 14 all conformed to these latter conditions, Form 22 was never needed and hence is not treated in detail here.

A-5.11. Form 23. This sheet is used to provide the data needed in using the GLOOK to correct the target data at impact time for rotations of the turret axes over the time-of-flight. The idea is to calculate what the target azimuth and elevation at impact time would have been if the turret axes had remained parallel to their position at firing time. As mentioned in Section A-3.04, this process is called local stabilization, since the turret axes are in general slightly different at various firing times.

Cols 23-A and 23-G. Col 23-A is identical with Col 13-A, and Col 23-G is identical with Col 14-A.

Cols 23-B and 23-C. The target azimuth and elevation are read from S11-F and S11-G, respectively, at the times in Col 23-A and recorded in Cols 23-C and 23-B, respectively. Note that elevation is recorded to the left of azimuth, which is the opposite of the usual custom. The reason for this reversal is to make the order of columns, from left to right, agree with the order in which the data are set into the scales on the GLOOK and its transit, from top to bottom.

Cols 23-D, 23-E, 23-F, 23-H, 23-J, and 23-K. In the case where Form 22 is omitted, the gyro data are read from P21-F, P21-H, and P21-J at the times of Col 23-A and recorded in Cols 23-F, 23-E, and 23-D, respectively. Then they are read again at the times of Col 23-G and recorded in Cols 23-K, 23-J, and 23-H, respectively.

For each row the entry in Col 23-G is less than that in Col 23-A, but an entry in a later row of Col 23-G can usually be found which is nearly equal to the given entry in Col 23-A. Hence a check on all but the first few rows of Cols 23-H, 23-J, and 23-K is obtained by comparison with the entries in the row of Cols 23-D, 23-E, and 23-F, respectively, for which the impact time (Col 23-A) is approximately equal to the firing time (Col 23-G). Since on pursuit attacks the firing time decreases during the attack, the rows to be compared will get closer together as the attack progresses.

Form 23 is now ready for use in the GLOOK Problem Solution No. 1 (see Section I of the Computer's Manual). The results of this computation, as read from the GLOOK transit scales, are recorded in Cols 13-B and 13-C, where care must be taken to line up Col 13-A correctly with Col 23-A.

Rough checks on this GLOOK operation can readily be devised from the following observations:

(1) When Col 23-B is near 0 degree, the principal part of the correction to Col 23-C is the difference in yaw, Col 23-F minus Col 23-K.
(2) When Col 23-C is near 0 or 360 degrees, the principal part of the correction to Col 23-B is the difference in pitch, Col 23-D minus Col 23-H.
(3) When Col 23-C is near 90 or 270 degrees, the principal part of the correction to Col 23-B is the difference in roll, Col 23-E minus Col 23-J.

These facts are usually sufficient to provide qualitative checks by noting the signs of the roll, yaw, and pitch differences and comparing with the signs of the corrections, keeping in mind the sign conventions for roll, yaw, and pitch (Section A-2.07). Thus, under condition (1) above, if Col 23-F is greater than Col 23-K, Col 13-B should be less than Col 23-C. Similarly, if under condition (2) Col 23-D is greater than Col 23-H, Col 13-C should be greater than Col 23-B when Col 23-C is near 0 degrees and less when it is near 360 degrees. Finally, if under condition (3) Col 23-E is greater than Col 23-J, Col 13-C should be greater than Col 23-B when Col 23-C is near 90 degrees and less when it is near 270 degrees*.

Approximate quantitative checks may also be derived from these same facts by estimating the corrections from the magnitude and signs of the differences. Experience shows that this procedure gives the correct results within ± 3 minutes when the differences are each no larger than about 10 minutes, the roll, yaw, and pitch are within ± 3 degrees of zero, and Col 23-B is within ± 15 degrees of zero. When Col 23-C is between the values listed in conditions (2) or (3), the correction to Col 23-B may be estimated as a linear combination of the pitch and roll differences, where the weighting coefficients are between zero and unity and are assigned from inspection of Col 23-C.

These methods of checking are useful in detecting doubtful results which should be recalculated on the GLOOK. The checks themselves can sometimes be used in place of a GLOOK calculation, but the method does not generally possess sufficient accuracy.

A-5.12. Form 13. The use of Cols 13-A, 13-B, 13-C, and 13-F has already been discussed (see Sections A-5.07, A-5.08, and A-5.11). The remainder of this sheet is used in correcting the target direction for ballistic deflections in order to get the true borepoint, i.e., the azimuth and elevation of the direction in which the gun should have been pointing at firing time in order that its projectile would score a hit at impact time.

Cols 13-D and 13-E. It is beyond the scope of the present treatment to discuss the many factors which produce deflections of the projectile from a straight path. The only two which are large enough to warrant consideration in assessment, at least for ranges no greater than 800 yards and with present accuracy, are the gravity drop

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* All of these statements require appropriate modification in case the yaw, pitch, or roll happens to pass through 0 or 360 degrees, in view of the sudden change of 360 degrees in the readings there.

and the trail*. The former acts in a vertical plane and the latter in the plane of action, i.e., the plane of the gun boreline when fired and the direction of the bomber's flight at that instant. Formulas for both of these angular deflections are given in AMP Memo No. 104.1 for M-2 projectiles and in AMG-N No. 8 for M-8.

In applying these corrections it is first necessary to convert them into azimuth and elevation components. AMG-N has devised an ingenious graphical representation called DOFOGRAPHS, which give $\Delta\alpha/T$ and $\Delta\epsilon/T$, the sum of the respective components of both gravity drop and trail angles per unit time-of-flight (see the Theory Manual, Chapter A-3). A sample pair of DOFOGRAPHS is shown in Fig. 5.06. Note that a different pair is needed for each ammunition, altitude, and true air speed, although deviations of a few hundred feet in altitude and a few knots in speed from the specified values are tolerable.

Detailed instructions for using the DOFOGRAPHS are included in the Computer's Manual, Section L. The graphs are entered with the data in Cols 13-B and 13-C rounded mentally to the nearest degree, and the results listed in Cols 13-D and 13-E. The supervisor must be sure that the interpolation between DOFOGRAPH curves is properly carried out to obtain the results accurate to the nearest minute per second. A check should also be made to see that the listings from the α dofograph are negative when the azimuth α, is between 180 and 360 degrees. Since the corrections should change slowly with time, any large error in a single entry can be detected by inspection of the adjacent entries in its column.

Col 13-G and 13-H. Multiplication of Col 13-F by Col 13-D yields the azimuth ballistic deflection $\Delta\alpha$ and by Col 13-E the elevation deflection $\Delta\epsilon$, which are recorded in Cols 13-G and 13-H respectively, the entries are to be rounded off to the nearest minute.

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* By "trail" is meant the apparent deflection of the projectile from a straight path with respect to the (moving) turret axes, caused by its slow-down. This effect has also been called the "trail due to relative wind" (see AMP Memo No. 104.1).

Cols 13-J and 13-K. Stated more precisely, the DOFOGRAPHS provide the following information. If α and ϵ are respectively the azimuth and elevation of the gun with respect to a coordinate system whose azimuth plane is horizontal and whose zero azimuth line coincides with the bomber's line-of-flight, then $\Delta\alpha/T$ and $\Delta\epsilon/T$ are the angular rates at which the projectile is deflected in azimuth and elevation because of trail and gravity drop. Hence, strictly speaking, the α and ϵ with which the DOFOGRAPHS are entered should be the true gun boreline azimuth and elevation. Since these quantities are the objective of this computation, the procedure stated above really amounts to successive approximations, in which the target azimuth (Col 13-B) and elevation (Col 13-C) are taken as first approximations to α and ϵ. This being the deflected direction of the projectile if a hit is scored, the second approximation for the desired α is given by subtracting Col 13-G from Col 13-B, and for ϵ by subtracting Col 13-H from Col 13-C. These values are listed in Cols 13-J and 13-K, respectively. Technically, they should now be used as entries in the DOFOGRAPHS for obtaining refined values of $\Delta\alpha/T$ and $\Delta\epsilon/T$. In practice, however, the second approximation is usually sufficient, since $\Delta\alpha$ and $\Delta\epsilon$ rarely exceed 1 degree and are essentially unchanged when α and ϵ take on increments numerically that large or less.

There is also an error in assuming that the turret axes at firing time, to which all azimuths and elevations have been referred, coincide with the axes defined above. Actually the turret XY-plane is generally tipped up a few degrees above the horizontal and the zero azimuth line only approximates the bomber's line-of-flight. However, these errors can be tolerated in view of the relatively slow variations of $\Delta\alpha/T$ and $\Delta\epsilon/T$ with changes in α and ϵ. These matters are discussed in greater detail in the Theory Manual, Chapter A-3.

A-5.13. Form 14. The use of Cols 14-A, 14-B, and 14-C was treated in Section A-5.07. The remainder of this sheet is devoted to the calculation of component and radial gun lead errors. Since the true gun direction differs from the target direction by an angle called the true lead, gun direction or position errors are the same as gun lead errors. This flexibility in interpretation is sometimes advantageous.

Cols 14-D and 14-E. To provide a uniform meaning for the signed quantities involved, the gun errors are defined to be the actual position minus the true position. [illegible] a positive elevation error means that the gun was pointed too high, and a negative azimuth error means that its azimuth was too low at that firing time. Note that the latter implies that the gun was too far toward the tail on a port attack but too far toward the nose on a starboard attack.

The component gun errors are found by simply subtracting Col 13-C from Col 14-B and Col 13-K from Col 14-C, these results being recorded in Cols 14-D and 14-E, respectively. The supervisor must take special care to see that Forms 13 and 14 are correctly lined up with respect to rows during this operation. There are no identical time columns for this purpose, the test being that Col 14-A plus Col 13-F must equal Col 13-A.

Cols 14-F and 14-G. Like all angles employed thus far, the units for Cols 14-D and 14-E are degrees and minutes. In gunnery parlance it is customary to measure comparatively small angles in mils, a much-abused term since one mil may mean a milliradian (0.001 radian) or arc tan 0.001 or a circular mil (1/1600 of 90°), to mention some of its common definitions. Although they are not equivalent, the various mils are nearly equal. In standard Navy usage, the mil means arc tan 0.001. Since 1 milliradian = 1.0000003 Navy mils, for practical purposes the latter may be replaced by the milliradian, which is desirable because standard tables for converting degrees and minutes to radians, and therefore to milliradians by merely pointing off three places to the right, are readily available*.

* See, for example, "Mathematical Tables from the Handbook of Chemistry and Physics", 7th Edition, page 158.

When these tables are applied to Cols 14-D and 14-E, Cols 14-F and 14-G, respectively, are obtained*.

Cols 14-H and 14-J. Fig 3.09 will serve to illustrate the relation between the azimuth, elevation, and radial errors, with the following reinterpretation of symbols: OG is the actual gun bore-line and OT'T the true gun boreline. Then $\alpha_G - \alpha_T$ is the azimuth error and $\varepsilon_G - \varepsilon_T$ is the elevation error. The radial error is, by definition, angle GOT' , which can be found exactly by solving the spherical triangle GZT' for the side GT' = angle GOT' , where the sides GZ = $90^\circ - \varepsilon_G$ and T'Z = $90^\circ - \varepsilon_T$ and angle GZT' = $\alpha_G - \alpha_T$ are known. In practice, however, ε_T and ε_G are nearly equal and $\alpha_G - \alpha_T$ is fairly small, so that the radial error can be computed more simply by a procedure equivalent to the dead reckoning method in plane sailing. Here the radial error is given by the formula**:

$$\text{Angle GOT'} = \sqrt{(\varepsilon_G - \varepsilon_T)^2 + (\alpha_G - \alpha_T)^2 \cos^2 \varepsilon_T} \quad .$$

The quantity $(\alpha_G - \alpha_T) \cos \varepsilon_T$ is called the traverse error. It and the elevation error form what amount to rectangular components of the radial error, whereas the azimuth and elevation errors do not. For this reason the traverse error is sometimes preferable to the azimuth error, and Col 14-H is provided for its tabulation. It is found by multiplying Col 14-F by the cosine of Col 13-C, or the cosine of Col 14-C if preferred. Then the radial error (Col 14-J) is merely the square root of the sum of the squares of Cols 14-G and 14-H. It can also be found from the radial error chart (Fig 5.07), which was designed to give Col 14-J directly from Cols 14-D, 14-E, and 13-C. The details of its use are given in the Computer's Manual, Section L.

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* The abbreviation "millirad" means, of course, milliradian. "Rad" is not to be confused with its use in connection with sight reticles, where it refers to the radius of a given deflection circle.

** This relation is stated in AMG-N No. 50, page 65, Cos ε_G may be used instead of cos ε_T if desired, since the formula is not sufficiently accurate unless ε_G is near enough to ε_T to make the effect of their difference negligible.

A-5.14. Form 27. Although the primary objective has been reached when the radial gun-lead error has been computed (Section A-5.13), Form 27 for use in calculating the single shot probability is included here for the sake of completeness. The theory has been discussed in various papers*; the required data are range at impact time, radial gun-lead error at firing time, radius of the target, (assumed circular), and standard deviation of the bullet dispersion pattern (also assumed circular). This information is then used with the probability tables given in AMP Report 10.2 R, "Scatter Bombing of a Circular Target", by H. H. Germond and Cecil Hastings, Jr., or in graphs constructed therefrom. Form 27 provides columns for recording the various steps in this process and the results. The details will not be discussed further here.

A-5.15. Form 15. The desirability of assessing the gunner's performance in handling the fire control apparatus was discussed in Section A-2.08. There it was pointed out that with the Mark 18 sight the desired information concerns the gunner's ranging and tracking errors. Form 15 is designed for use in measuring the former and Form 16 the latter.

Cols 15-A and 15-B. The frames to be assessed on the sight-camera film are listed in Col 15-A and the corresponding times from the proper conversion table in Col 15-B. Since this 16 mm film runs at a nominal speed of 16 frames per second, standard practice calls for assessing every other frame in order to approximate the one-eighth second intervals which are the nominal spacings of the frames assessed from the gun and RAZEL films.

Cols 15-C, 15-D, and 15-E. The sight film is projected onto the screen in much the same fashion as the gun-camera film but using its own test-strips and framing-marks (see Section A-3.06). Since the nominal focal length of the sight-camera lens was 1.375 inches, the projector with a nominal 3-inch lens should be about twice as

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* See, for example, AMG-N No. 23, "Computation of Single Shot Probabilities in Camera Sight Assessment", by A. A. Albert, and AMG-N No. 50, "Camera Evaluation of Bomber Gun Sights", by the same author.

far from the screen as the CRADLE transit center is. To get a screen image of convenient size, the projector should be about 100 inches away, so that the CRADLE transit center is set 50 inches from the screen.

Fig. 2.14 shows sample frames of sight-camera film, in which the fighter and the sight reticle are visible. On a Mark 18 sight the latter consists of a center aiming-pip surrounded by six ranging-pips equally spaced on a circle whose center is the aiming-pip. To estimate the gunner's ranging the three diameters formed by pairs of opposite pips are scaled and recorded in Cols 15-C, 15-D, and 15-E. Since the gunner uses the <u>inside</u> of these pips in framing the fighter, these measurements should be taken between the pip edges nearest the center. In case one pip of a pair is not visible, the radius to the visible aiming-pip is to be measured and recorded with and indicated multiplication by 2. As a rough check it is advisable to record whether the gunner was <u>overranging</u> (reticle diameter smaller than wingspan) or <u>underranging</u> (reticle diameter greater than wingspan), noting especially all points of crossover from one to the other.

Before proceeding to the next frame, the target and sight points are marked on the screen, as will be described in Section A-5.16.

<u>Cols 15-F and 15-G</u>. Ideally Cols 15-C, 15-D, and 15-E should all be equal. To minimize the inevitable scaling errors, the arithmetical mean of these three columns is computed and recorded in Col 15-F. This average is inversely proportional to the gunner's estimate of range, called <u>sight-range</u>, which is calculated and recorded in Col 15-G. The proportionality constant K_3 for this computation is found from the so-called <u>ranging shot</u>, which should follow the boresight shot at the beginning of each flight. It shows the reticle when set at a specified range, r_0 , preferably its minimum of 200 yards, and a specified wingspan setting, w_0 , preferably at its maximum of 120 feet, in order to get as large an image as possible for reasons of accuracy. The constant K_3 is computed from these data and the measured reticle

diameter, s_o , on the screen by means of the formula $K_3 = K_3'w$, where $K_3' = r_o s_o / w_o$ and w is the wingspan setting during the attack (42.33 feet for the F6F fighter's winglights). This formula is basically the same as the one for actual ranging, which is derived in the Theory Manual, Chapter A-2*. In practice it is usually worth while to compute a sight-range conversion table, giving sight-range vs average reticle diameter.

Cols 15-H and 15-J. If the RAZEL range was read and graphed (see Section A-5.03), it can be recorded at the times of Col 15-B in Col 15-H. However, this column is usually omitted.

The smoothed range itself is read from S11-C at the times of Col 15-B and recorded in Col 15-J. If the gunner ranged perfectly and all calculations were accurate, Cols 15-G and 15-H would both equal Col 15-J.

Cols 15-K and 15-L. A comparison of Col 15-J and Col 15-G, or with Col 15-H, gives the gunner's range error. As in the case of the gun-lead errors, the range error is defined to be the actual range minus the true range, so that a positive range error means that the gunner was overranging. Thus Col 15-K is Col 15-G minus Col 15-J, and Col 15-L, if used, is Col 15-H minus Col 15-J. The signs in Col 15-K and 15-L should be checked to see if they agree with the indications of over or underranging obtained in connection with Cols 15-C, 15-D, and 15-E, particularly at the crossover points, if any. A discrepancy will indicate mistakes or a lack of sufficient accuracy.

Col 15-M. For some purposes it is more significant to exhibit the percent range errors rather than these errors themselves. Col 15-M provides a place to record these percentages, which are simply 100 times the ratio of Col 15-K to Col 15-J in the usual

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* See also Section A-2.10, where mention is made of the possibility of checking K_3 by using it to compute the actual range from winglight measurements on the sight film and then comparing with the range from the gun-camera film. Discrepancies may be due to incorrect settings for r_o , w_o , or w .

case where the sight range is employed. A similar percentage can be calculated from the RAZEL range, if desired, by merely substituting Col 15-L for Col 15-K.

A-5.16. Form 16. As mentioned above, this sheet is used in the calculation of the gunner's tracking errors, i.e., the measure of his accuracy in holding the aiming-pip on the target.

Cols 16-A and 16-B are identical with Cols 15-A and 15-B, respectively.

Cols 16-C and 16-D. One purpose of the sight film is to record the position of the aiming-pip, whose center is called the sight point, relative to the target point, defined as before to be the propeller hub on the F6F. From this information and the previously determined position of the target point (see Section A-5.04), it is possible to find the azimuth and elevation of the sight point. Differencing the azimuths and elevations, respectively, of these two points then yields the desired component tracking errors, from which the radial tracking error can be computed in the same manner as the radial gun-lead error (see Section A-5.13) was found from its components.

Cols 16-C and 16-D provide spaces for recording the smoothed target azimuth and elevation as read from S11-F and S11-G, respectively, at the times of Col 16-B. In this connection, it should be noted that these readings will be sufficiently accurate if correct to the nearest degree, since the difference in azimuth and elevation are not critically dependent on the values themselves. Furthermore, the radial error formula (see Section A-5.13, where the subscripts G and T now refer to the sight and target points, respectively) involves the elevation of one of the points as well as the difference in elevation, but only the difference in azimuth appears. This being the case, the construction of the transit and CRADLE permits the starting azimuth (α_T) to be prescribed at will without altering the results, which means that the target azimuth need not be read and Col 16-C can be omitted.

Marking Target and Sight Points. Since the tracking errors are to be found from a comparison of the positions of the aiming-pip and the target, these points in general must be marked on the screen in a manner similar to that used with the gun-camera film (see Section A-5.04). However, when the gunner's tracking is good, as is frequently the case, it will often be impossible to distinguish the sight point from the target point on the screen. Then the tracking errors are all zero, and it is unnecessary to mark either the sight or target point. This situation is recorded in writing $S = T$ in Col 16-F to indicate that the sight and target points coincide. Since the measurements of the reticle diameter, which are also performed while each frame is being projected, are not measurably affected by moderate mis-alignment of the film, it is not necessary to align it accurately when $S = T$. This results in a considerable saving of time and effort.

When the sight and target points do not coincide, the film image must be carefully aligned to the framing-marks and the sight and target points accurately located on the screen. They are again distinguished by the letters S and T, respectively, followed by the frame number. It should be noted that the lateral and vertical alignment is not so critical here as it was in the case of gun-camera film (Section A-5.04), since both points to be compared appear on each frame. However, the rotational alignment must be accurate to avoid distortions of azimuth and elevation readings. Even so the radial error, i.e., the angular distance between sight and target points, would not be distorted; in fact, if the component errors are not desired, the radial error could be read directly by rotating the film, keeping it centered on the screen until the sight and target points both lie on either the horizontal or the vertical screen line and using the CRADLE transit in azimuth or elevation only.

Cols 16-F and 16-G. Unless they become too dense on some portion of the screen, the sight and target points for all frames to be assessed in the given attack are marked and the reticle diameters scaled at the same time, before the CRADLE is used. When the screen marking is complete, the projector is turned off and the CRADLE slid into operating position. It is then used with each pair of target and sight points in the "Target-Point to Sight-Point Operations for Martin Forward Crown-Turret" (see the Computer's Manual, Section H, CRADLE Problem No. 4), entering with Cols 16-C (which may be taken always zero) and 16-D and recording the azimuth and elevation of the sight point so obtained in Cols 16-F and 16-G, respectively.

Cols 16-H and 16-J. Following the convention adopted for the gun-lead errors (Section A-5.13), the tracking errors are defined to be the actual position (sight point) minus the true position (target point). Thus Col 16-H is obtained by subtracting Col 16-C from Col 16-F, and Col 16-J by subtracting Col 16-D from Col 16-G.

Cols 16-K, 16-L, 16-M, 16-N, and 16-E. The conversion of Cols 16-H and 16-J to milliradians and to traverse and radial tracking errors proceeds in the same fashion as with the gun lead errors (Section A-5.13). If desired, Col 16-E may be used for tabulating the cosine of Col 16-D, needed in finding the traverse error, although this information can usually be taken directly from a table of cosines when needed, without the necessity of recording it.

A-5.17. Final Graphs. The results of the assessment are the radial and component gun-lead errors on Form 14, the actual and percent range errors on Form 15, and the radial and component tracking errors on Form 16, all as functions of time measured from the starting point near the beginning of the attack (frame number 001). If a statistical analysis is to be performed, these tabular data will suffice, but to interpret them as they stand it is desirable to plot them conveniently. The following graphs were constructed for each attack of F. C. No. 14, where the time scale was shifted so that its zero occurs when the range is 800 yards:

1. on the same sheet: radial gun lead error, radial tracking error, and percent range error, forming a summary sheet;

2. on another sheet: gun-lead and tracking traverse errors and gun-lead and tracking elevation errors, thereby assembling all component errors in one place;
3. target range and input (sight) range, for comparison.

For ready reference, a range scale at intervals of 100 yards was superimposed on all abscissa time scales. Samples of final graphs are shown in Figs. 5.08, 5.09, and 5.10.

CHAPTER A-6

DETAILED PROCEDURES

FOR THE ERCO PORT WAIST-TURRET (F. C. NO. 9)

A-6.01. Dependence on Target Data Elsewhere. During the experiments for F. C. No. 9, the Erco port waist-turret was equipped with gun- and sight-cameras, but it did not possess a RAZEL. Hence it was necessary to obtain basic target data from some other location on the bomber, either the tri-camera or another turret. The target azimuth, elevation, and range with respect to the Martin forward crown-turret, which was assessed simultaneously, were used for this purpose.

A-6.02. Form 18. This sheet is used with the PLAXIE for the parallax correction of target azimuth and elevation from the Martin forward crown-turret to the Erco port waist-turret. Cols 18-B, 18-C, 18-D, and 18-E have already been discussed (Section A-5.06). Col 18-A is ordinarily omitted.

Col 18-F. In Section A-3.05 the position of the PLAXIE transit on the arm was shown to be given by $d = K/r$, where $K = h\ell$. For this parallax problem $h = 10.9$ yards and $\ell = 60$ inches, so that $K = 654$*. If desired, a table could be constructed for the conversion from r to d . A useful though not complete check on d results from the observation that d becomes larger as r gets smaller.

Cols 18-G and 18-H. All needed data have now been assembled to use the PLAXIE as described in the Computer's Manual, Section J, PLAXIE Problem No. 2. The supervisor must make certain that it has the proper initial settings for α_1 and ε_1 (see Section A-3.05) and that the computers set the given data into the PLAXIE when the transit is at O (Fig. 3.11 (b)) and not at O' , which is the most likely systematic error.

The results are recorded in Cols 18-G and 18-H and should be checked before being plotted. For flat-side attacks it is easy to tell from the physical picture

* To keep the units correct, d and ℓ are measured in inches and h and r in yards.

whether Col 18-G should be larger or smaller than Col 18-C, the former being true for an attack from port and the latter from starboard. No such simple check has been devised for Col 18-H, but it should differ relatively little from Col 18-D. Another useful check is to compute the difference between Cols 18-G and 18-C and between Cols 18-H and 18-D to be sure that they are smooth. Any points which are still out of line will be discovered when Cols 18-G and 18-H are plotted vs Col 18-B on an Erco working graph similar to that for the Martin turret shown in Fig. 5.01. Minor variations are removed by smoothing, although the chief purpose of this graphing is to permit interpolation of these target data at the Erco gun-camera frame times (see Section A-6.03).

A-6.03. Form 19. In spite of its misleading and obsolete title, which should be changed to read "Gun Position" instead of "Actual Gun Lead", this sheet is used in taking target data from the Erco gun-camera film and in combining it with the parallaxed target position found on Form 18 to compute the gun position relative to bomber axes at the Erco turret. The details of the CRADLE and GLOOK operations involved are given in the Computer's Manual, Section I, GLOOK Problem No. 2.

Cols 19-A and 19-B. The Erco gun-camera frames to be assessed, generally every other one, are listed in Col 19-A and the corresponding times obtained from the proper conversion table are recorded in Col 19-B.

Cols 19-C and 19-D. To visualize the steps in finding the gun position relative to bomber axes at the Erco turret, it is necessary to understand the motions of the Erco turret and its guns and the definitions of the gun, turret, and bomber axes. The motions may be implied from a study of Fig. 2.01 (b) and are indicated schematically in Fig. 1.02. The axes are shown in Figs. 2.02, 2.04, 2.05, and 2.06.

In order to get a larger effective field of view for the gun-camera shown in Fig. 2.01 (b), it is usually offset a few degrees toward the nose of the bomber in the traverse plane (the X_gY_g-plane of Fig. 2.06). This offset causes no difficulty as long as the borepoint on the gun-camera film is given by the position-shot. When the gun-camera film is analyzed with the CRADLE, as described in the Computer's Manual, Section I, GLOOK Problem No. 2, Part I, the azimuth and elevation of the target with respect to the gun axes (Fig. 2.06) are obtained and recorded in Col 19-C and 19-D, respectively. Note that these are components of the actual gun lead and that they are found without the use of gun position data, in contrast to the method of analyzing Martin gun-camera (see Section A-5.04).

If desired as a check on the ranging, the distance between winglights and/or marks may be scaled at the same time that the target point is marked on the screen. However, the results are generally not satisfactory in view of the characteristically poorer quality of the photography obtained with the 16 mm cameras.

Cols 19-G and 19-H*. In addition to the components of actual lead of the target azimuth and elevation relative to bomber axes at the Erco turret are required. These data are read from S18-G and S18-H at the times of Col 19-B and recorded in Cols 19-G and 19-H, respectively.

Cols 19-E and 19-F. The GLOOK solves the problem of finding the gun azimuth and elevation relative to bomber axes at the Erco turret, using the data in Cols 19-C, 19-D, 19-G, and 19-H, by reproducing the geometry of the turret, its gun, and the fighter at each instant of assessment. To visualize the steps in the solution given in the Computer's Manual, Section I, GLOOK Problem No. 2, Part III, the following facts should be kept in mind:

1. The vertical turntable axis on the GLOOK represents the coincident Z- and Z_t-axes of Fig. 2.06.
2. The Y_t-axis is represented by the rocker axis, so that the rocker motion represents inclination of the turret.
3. The saddle is not needed and must be always set to read zero, in order to keep the rocker-axis always horizontal, i.e., perpendicular to Z_t .
4. The Y-axis is also always horizontal and, since it differs from Y_t by the offset angle δ , the ring is rotated through δ from its initial setting.

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* It would be preferable to interchange Cols 19-G and 19-H with Cols 19-E and 19-F, respectively; the present order arose by a process of evaluation.

5. Azimuth and elevation with respect to the bomber axes are measured by the turntable scale and the auxiliary transit elevation scale, respectively.
6. When the GLOOK transit's elevation scale is set at zero, the telescope rotates in a traverse plane when moved in azimuth.
7. When the GLOOK transit's azimuth and elevation scales are both set at zero, the telescope represents the gun.
8. When the GLOOK transit's azimuth and elevation scales are set to read the values in Cols 19-C and 19-D, respectively, the telescope represents the line of sight to the target, i.e., it duplicates the orientation of the CRADLE transit's telescope when the data were read from the gun-camera film.

The results of the GLOOK problem are the gun azimuth and elevation relative to the bomber axes. From the standpoint of the GLOOK operation itself it is more convenient to record them in Cols 19-E and 19-F, respectively, although it would save copying later to record them directly in Cols 14-B and 14-C (of a Form 14 for the Erco turret). Col 14-A is identical with Col 19-B, except that values of time for which there are no data in Cols 19-D and 19-C or 19-G and 19-H may be omitted.

A-6.04. Forms 12, 23, 13, and 14. Having obtained the basic target and gun data, both with respect to the bomber axes, the assessment proceeds in essentially the same fashion as with the Martin turret (see Sections A-5.05, A-5.07, A-5.11, A-5.12, and A-5.13), but with certain modifications which will now be described.

Col 12-A will not be used, and Col 12-B is the same as Col 18-B, except that times outside the interval for which data are complete on Form 19 may be omitted.

To compute θ , Cols 18-G and 18-H are used instead of 18-C and 18-D, again rounding off mentally to the nearest degree.

The range in Col 12-D must refer to the Erco turret and not the Martin. It can be found from scaling the winglight or mark distances on the Erco gun-camera film, but experience has shown that it is more satisfactory to obtain it by correcting the range at the Martin forward crown-turret for parallax. The corrections are small, never exceeding the distance between the two turrets (about 11 yards). In the Theory Manual, Chapter A-8, it is shown that this correction is independent of range, for practical purposes, and therefore is a function of θ only. A simple table is given, from which Col 12-D can be computed from Col 18-E and Col 12-C.

Col 12-G and 12-H are to be omitted.

Gyro data for Form 23 are read from the same graphs constructed for the Martin assessment (see Section A-5.09 and Fig. 5.05) under the assumption that the bomber rolls, yaws, and pitches as a rigid body. In other words, fuselage deflection is assumed to be negligible between the two turrets (see Section A-2.09).

Entries for Cols 23-B and 23-C are read from S18-H and S18-G, respectively, instead of S11-G and S11-F.

There is no change in the method of handling Forms 13 and 14.

A-6.05. Forms 15 and 16. The procedure for Form 15 is the same for the Erco turret as for the Martin (see Section A-5.15) but the following modifications should be noted.

The constant, K_5 for converting Col 15-F to Erco sight range is probably not quite equal to K_3 , due to variations between the lenses. However, K_5 is computed in the same manner as K_3 (see Section A-5.15).

RAZEL range never enters in the Erco assessment, so Col 15-H can be used to record the smoothed range at the Martin turret from S11-C, at the times of Col 15-B. Then this range is corrected to the Erco turret as described in Section A-6.04, where θ may be taken from Col 12-C. Even though Cols 15-B and 12-B do not agree exactly, they will usually be near enough to give θ as closely as required.

On Form 16 the chief difference is that both target and sight points are to be measured relative to gun axes, since to convert them to bomber axes would entail a considerable amount of unnecessary computation. The needed borepoint may be found from the sight-camera position-shot. Then the azimuth and elevation of the target and sight points are measured with the CRADLE as described in the Computer's Manual, Section H, CRADLE Problem No. 5 and recorded in Cols 16-C, 16-D, 16-F, and 16-G. Col 16-E is not needed. The word "smoothed" should be deleted from the heading of Cols 16-C and 16-D.

The errors are computed in the same manner as in the Martin assessment, but it must be remembered that each row is referred to the instantaneous gun axes. In practice the elevations are so small that the traverse error (Col 16-N) is essentially the same as the azimuth error (Col 16-K). For the flat side attacks of F. C. No. 9 these errors have effectively the same significance as before, since the traverse plane is nearly parallel to the Martin turret's azimuth plane, but this will not be ture in genera.

A-6.06. <u>Final Graphs</u>. The Erco turret results were exhibited in the same form as those for the Martin turret (see Section A-5.17).

CHAPTER A-7

MISCELLANY

A-7.01. Necessity. In the discussions contained in the preceding chapters a number of separate topics related to the assessment have been omitted from time to time in the interest of avoiding excessive detail which would tend to interrupt the continuity. These subjects will be included in the present Chapter, their order of presentation being irrelevant.

A-7.02. Additional Responsibilities for the Supervisor. Many points which the supervisor must watch have been noted in the preceding chapters. The following additions have been dictated by experience.

1. When two or more form sheets are used together, be sure that their rows are correctly lined up. A common column of time or frame numbers is the usual guide, but Forms 13 and 14 are exceptions, as pointed out in Section A-5.13.
2. Insist that the headings on all form sheets and col[illegible]s be properly and completely filled in. Computers have a tendency to omit what appears to be superfluous, especially after an operation has become routine. In particular the computer's initials must be recorded in the space provided, together with the data and time the operation was started and completed.
3. Impress the computers with the importance of following all directions explicitly, asking questions until they understand thoroughly the work assigned, and noting on the form sheets all irregularities and omissions in the data with their exact cause. Such remarks are often vital to a correct interpretation of results and may furnish a clue to some trouble which has developed. They should be brought to the supervisor's attention as soon as possible.
4. Determine the proper starting and stopping points for all operations to avoid both loss of data and unnecessary copying and computing.

5. See that all film is properly projected. Unless a demonstration is given, there is danger that the film will be projected upside down or backwards.
6. Check all computing instruments before they are used to be sure that they are in satisfactory adjustment and are set in the proper positions for the problem at hand.
7. Be sure that algebraic operations are carried out with proper regard for the correct signs and rules. Careless computers have been known to ignore the signs and treat the operations arithmetically. As their title suggests, the computers should be persons with an understanding of elementary algebraic methods and a flair for accurate calculation.
8. Institute adequate and frequent checks throughout the assessment. In some cases a repetition of the operation by different persons may be required, although independent conditions which the data must satisfy should be used as checks insofar as possible. It is also important to apply the checks as the data are received or as soon thereafter as possible especially in operations involving the projection of film. This saves the time required in reloading the projector at a later date, and more important, avoids the possibility that incorrect data may be processed further, which would be a complete waste of time and effort. The importance of adequate checking at each step cannot be overemphasized, and time so spent is an economy in the long run.

A-7.03. Additional Form Sheets. Besides the data sheets described in Chapters A-5, A-6, and E-2 of this Manual, two others have been devised for special purposes. Since these may be useful in the future, they will now be discussed briefly.

Form 17. This sheet is for use in the parallax correction of target position data from one location to another. Its format is similar to that of Form 18 (see Sections A-5.06 and A-6.02); Form 18 is merely a special case of Form 17. Spaces are provided in the headings for recording the values of α_1 , ε_1) , and the conversion constant for computing d , and for listing locations at which the data are known and for which they are to be found by using the PLAXIE (see the Computer's Manual, Section J). Special note must be taken of the location from which the range is measured, as explained in Section A-3.05. One example of the use of Form 17 is in parallaxing target data obtained from the tri-camera to the Martin forward crown-turret.

Form 20*. This sheet is for use with a scheme which avoids parallax correction from the Martin forward crown-turret to the Erco port waist-turret by assuming that the difference in true lead at the two turrets is negligible. Furthermore the true lead can be expected to be smooth, so that graphical interpolation is justified. Hence Form 20 has columns for forward crown-turret firing time and corresponding azimuth and elevation components of true lead, which are then graphed and smoothed. Columns are also provided for the waist-turret firing times and corresponding components of true lead read from the smooth curves.

This procedure was not followed, because of uncertainty about the validity of the basic assumption for turrets so far apart. It was first devised by AMG-N and used for parallaxing between turrets located much closer together**.

A-7.04. Suggested Revisions of Form Sheets. As a result of experience in using the form sheets several desirable revisions have become apparent, some of which have already been mentioned (see Section A-6.03). The chief addition to this list is to consider replacing Forms 13 and 14 by a single sheet, even though it would have to be larger than the standard size, in order to avoid mistakes in aligning their rows correctly. This source of difficulty was also mentioned in Section A-7.02.

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* No sample of Form 20 is given.

** See AMG-N No. 47, "A Modified Computation Procedure for Camera Bomber Sight Assessment", by A. A. Albert.

It would be more natural to place the time columns on Form 10 and 11 next to the respective frame number columns instead of at the right as at present.

On Form 11 it would be desirable to provide columns for the gun azimuth and elevation in the case where they must be read from P10-F and P10-G at the times of Col 11-H. This would eliminate the possible need for a separate sheet for these data, as mentioned in Section A-5.04.

Other revisions of existing form sheets and drafting of new ones may be required for processing data from similar or entirely different assessments.

A-7.05. List of Constants for F. C. Nos. 9 and 14. The following list of important constants used in the assessment of data for F. C. 9 and 14 is included for completeness. It must be emphasized that they apply only to these particular experiments as analyzed at Northwestern University during the summer of 1945. Any changes in recording or assessing equipment, including their installation, may well alter some of the values given below.

Distance between centers of wing-lights on F6F, A. T. No. 5 = 42 ft 4-1/8 in.
Distance between centers of wing-marks on F6F, A. T. No. 5 = 24 ft 5-1/2 in.
Offset angle, δ , of Erco port waist-turret's axis of rotation on PB4Y-2, A. T. No. 14, = 8° 52' in the negative azimuth direction (Section A-2.03).
Flight angle, P_0 , for gyro set No. 1 = 2° 18' in the negative pitch direction (Sections A-2.07 and A-5.09 and Fig. 2.13).
Distance from CRADLE to screen in Bay #1 = 50 inches.
Distance from 16 mm projector to screen in Bay #1 = about 100 inches.
Distance from 35 mm projector to screen in Bay #1 = about 150 inches.
Distance from CRADLE to screen in Bay #2 = 100 inches.
Distance from 35 mm projector to screen in Bay #2 = about 150 inches.
Intentional offset of RAZEL azimuth index = 2° in the positive azimuth direction (Section A-5.03).
Ranging constant to convert F6F, A. T. No. 5, wing-light measurements (inches) on the screen of Bay #2 to range (yards), K_1 = 1400 (Section A-5.04).
Ranging constant to convert F6F, A. T. No. 5, wing-mark measurements (inches) on the screen of Bay #2 to range (yards), K_2 = 809.
Ranging constant to convert diameter (inches) of Mk 18 sight reticle on Martin forward crown-turret, measured on the screen of Bay #1, to sight range (yards), K_3 = 716.8 (Section A-5.15).
Ranging constant to convert diameter (inches) of Mk 18 sight reticle on Erco port waist-turret, measured on the screen of Bay #1, to sight range (yards), K_5 = 706.1 (Section A-6.05).
Distance between centers of Martin forward crown-turret and Erco port waist-turret on PB4Y-2, A. T. No. 14, h = 10.9 yards (Fig. 2.02).
PLAXIE settings for parallax correction of target data from Martin forward crown-turret to Erco port waist-turret, α_I = 185° 39' and ε_I = 5° 48' (Sections A-3.05 and A-6.02).

Constant to convert range (yards) into distance (inches) which PLAXIE slider moves for the above parallax problem, $K = h\ell = 654$, where $h = 10.9$ yards and $\ell = 60$ inches (Fig. 3.11 (b) and Sections A-3.05 and A-6.02).

A-7.06. List of Known Errors in F. C. Nos. 9 and 14. The terms "mistake" and "error" are often used synonymously, but a distinction is made here. By a mistake is meant an incorrect use of some instrument, process, or operation, i.e., a wrong move on the part of a computer or other person, even though unintentional. On the other hand an error is a shortcoming of some piece of equipment or method which introduces inaccuracy into the assessment. The mistakes can be discovered by checking the data, whereas to eliminate the errors, refinements in the sensitivity of the instruments used or more precise methods of handling the data or both are generally required.

A list of known individual errors and the best estimates of their maximum magnitudes, insofar as they are available, is included here to indicate the present state of the assessment techniques and to set off the features most in need of improvement. By far the most serious errors are related to synchronization, ranging, and RAZEL scale reading. Errors inherent in the airborne recording equipment and its installation are not included, and it is assumed that the data obtained are reliable. Otherwise the errors in attempting to handle incomplete or erratic data are likely to be larger than listed below. It should also be noted that only the estimated maximum magnitudes are given. Thus an error listed as 2 minutes, for example, means that the actual value obtained is estimated to be within 2 minutes of the correct value, plus or minus.

Source of Error		Estimated Maximum Magnitude (±)	
Computing frame times		0.007	second
Synchronizing various films		0.04	second
Reading RAZEL scales		6	minutes
Scaling wing distances		0.02	inch
Using simplified range formula		1	yard
Plotting position data	(on regular scale	1	minute
	on double scale	2	minutes
Plotting range data		1	yard
Smoothing positive curves	(on regular scale	3	minutes
	on double scale	6	minutes

Source of Error (continued)	Estimated Maximum Magnitude (±)
Smoothing range curves	2 yards
Reading from position curves (on regular scale)	1 minute
(on double scale)	2 minutes
Reading from range curves	1 yard
Interpolation in gun data (depending on curvature of gun data curves)	6 to 12 minutes
Setting and reading transit scales	1 minute
Basic alignment of CRADLE, GLOOK, PLAXIE	3 minutes
Locating true angle-point	1 minute
Locating framing-marks on screen	2 minutes
Centering film on framing-marks	2 minutes
Marking target-, sight-, or bore-point	2 minutes
Aiming telescope at screen points	1 minute
Setting and reading GLOOK scales	0.5 minute
Calculating bullet time-of-flight (if range is accurate)	0.005 second
Calculating bullet time-of-flight (effect of range error)	0.001 sec/yard error
Plotting time-of-flight	0.001 second
Smoothing time-of-flight curves	0.001 second
Reading from time-of-flight curve	0.001 second
Reading gyro scales	0.5 minute
Plotting gyro data	0.5 minute
Reading from gyro curves	0.5 minute
Ballistic deflections from DOFOGRAPH	0.5 minute
Scaling reticle diameters	0.02 inch
Parallax correction of range	0.5 yard
Parallax correction of position (effect of range error)	1 min/yard error
Fuselage twist	unknown*
Film Shrinkage	unknown*

A-7.07. Time Estimates for F. C. Nos. 9 and 14. The following estimates of the time required to carry out various steps in assessing one attack of F. C. Nos. 9 and 14 are based on experience at N. U. P14E during the summer of 1945. They cannot, however, be taken literally, since a great deal depends on such variable factors as the type and length of the attack, the quality of photography, irregularities in the film data, status of computing equipment (assumed in working order below), the working conditions, and the ability of the computers. The figures are for an average attack having 50 readings, i.e., lasting about 6 seconds with a reading every 1/8 second. Two persons are assumed to be working together on all CRADLE and GLOOK operations, which is more efficient than having

* But probably quite small.

only one operator. One or two persons may be employed on the PLAXIE, the total man hours being about the same either way.

F. C. No. 14

Operation or Step	Man Hours per Attack
Inspecting, editing and cutting film	8
Constructing time conversion tables	2
Gun position (graphed RAZEL data)	2
Target position (via CRADLE)	8
Range determination	2
Time-of-flight (including plotting)	12
Gyro data	1
Local stabilization (via GLOOK)	4
Gun lead errors	2
Range errors	3
Tracking errors	5
Final form	6
Checking	15
TOTAL	70

F. C. No. 9

(assuming target data available from F. C. No. 14)

Operation or Step	Man Hours per Attack
Inspecting, Editing, and cutting film	4
Constructing time conversion tables	1
Parallaxed target position (via PLAXIE)	5
Target position (via CRADLE	3
Gun position (via GLOOK)	8
Parallaxed range	2
Time-of-flight (including plotting)	12
Local stabilization (via GLOOK)	4
Gun lead errors	2
Range Errors	3
Tracking errors	5
Final form	6
Checking	15
TOTAL	70

Hence the time required to assess one average attack for one turret is about 70 man hours. It should be noted that this does not include supervising time spent in organizing, scheduling, and expediting the work or maintenance time necessary to keep the computing equipment in working order and alignment.

CHAPTER A-8

BIBLIOGRAPHY

The following references form a fairly complete bibliography of the subject as used by the present research group. Those given will aid the reader in becoming acquainted with some of the papers which have made important contributions to the subject treated. In addition to those papers containing the results of basic investigations, an attempt has been made to list also papers which develop the investigations in further detail than was possible because of space limitations. The papers listed are given in chronological order for each grouping.

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BOMBER VS FIGHTER: BOMBER IN EVASIVE ACTION

CHAPTER B-1

THE THEORY - A BRIEF TREATMENT

B-1.01. Content. The transit-time procedure for straight line flight at constant speed has been developed and used to assess several different turrets. This Section will develop the necessary additional procedures that will permit the same sights, turrets, and aircraft to be assessed in evasive action as well as in straight line flight. No attempt will be made to include procedures for parallax correction or any other problems common to both linear and evasive flight.

B-1.02. Possible Solutions. One possible solution to the problem of assessing free gunnery during evasive action would be to neglect any deviation from a straight line, constant speed flight and correct only for change in attitude. This is the solution used by Eglin Field and is identical in principle to the method of making roll, pitch and yaw corrections described in Section A and the Computer's Manual. For mild and gentle evasive tactics (perhaps a normal acceleration of ten ft/sec^2) this procedure is not too much in error, but for the expected maneuvers in which the normal accelerations may approach sixty ft/sec^2 (or about two g net) the error in correct gun bore-point introduces by neglecting deviation from straight line flight may be as great as forty minutes of arc.

Since the present assessment program has been aimed at an accuracy of about one minute for any single operation and has hoped for an over-all accuracy of the order of one mil (about three minutes of arc), this possible error of forty minutes is much too great to overlook. To develop an accurate method of evasive action assessment, two courses were available;

(1) To modify the existing equipment and procedures for straight line flight as necessary for evasive action,

(2) Develop a different method.

A preliminary study showed the former alternative to be simpler and more direct.

B-1.03. Chosen Solution. The method presented in this Section utilizes all of the devices required for straight line assessment, with the addition of a three-component accelerometer (including synchronized camera) and one supplementary computing instrument. The operating procedure is based on the straight line assessment with roll, pitch and yaw corrections, modified to include the magnitude and direction of evasive action.

The theory of evasive-action assessment of a bomber is more easily understood by creating a fictitious or ghost bomber. The ghost bomber is defined as coinciding with the real bomber at firing time and travelling thereafter with a constant vector velocity equal to the vector velocity of the real bomber at firing time. In other words, during the bullet flight-time the ghost bomber is always in the position the real bomber would have occupied if it had continued on a straight course at constant speed after the firing time. If the observed target (attacking fighter) data, as seen from the real bomber, could be corrected to data as would be seen from the ghost bomber, these latter data could be used in the present straight line assessment procedure. The major part of this report is devoted to the development and explanation of methods of converting the observed data as seen from the real bomber to the target data as would be seen from the ghost.

In Fig. 1.1 are shown the real (and ghost) bomber O at firing time, the real bomber B at impact time, the ghost bomber G at impact time, and the fighter F at impact time. The vector $\overrightarrow{BF}$ is obtained at present from photographic data. The vector $\overrightarrow{GF}$ is required to apply the straight line assessment procedure. One way of obtaining the vector $\overrightarrow{GF}$ is to let the GLOOK represent the bomber B, with a point on the GLOOK screen representing the fighter F; on moving the GLOOK through the vector distance $\overrightarrow{BG}$ to a position corresponding to the ghost G and sighting on the point F, $\overrightarrow{GF}$ would be established. Since the GLOOK is a large and heavy instrument it would not be practical to translate it from B to G; a feasible solution is to hold the GLOOK stationary and construct an attachment to fit on the screen. In Fig. 1.1 the parallelogram FBGS is constructed on the triangle FBG with $\vec{FS} = \vec{BG}$ and $\vec{GS} = \vec{BF}$. The more convenient method of obtaining the vector $\vec{GF}$ is to let the GLOOK represent the ghost bomber G and from photographic data locate point S on the GLOOK screen. Instead of moving the GLOOK through the distance $\vec{BG}$, locate the fighter F at the distance $\vec{SF} = \vec{GB}$ from the point S with the aid of an auxiliary computing instrument, called the MONKEY. The vector $\vec{GF}$ can now be obtained by sighting the GLOOK on the fighter F . It is the principal purpose of this report to derive and develop methods of calculating the vector $\vec{BG}$ and to indicate how the MONKEY can be used with the GLOOK to represent the vector $\vec{FS}$.

B-1.04. Device MONKEY. Before proceeding to the methods of calculating the vector quantity $\vec{BG}$, it will be helpful to have the idea of the MONKEY and its relationship to the existing GLOOK set-up. The MONKEY is shown at about half-size in Fig. 1.2(a); this is a photo of a wood mockup. Basically the MONKEY consists of two sections; (1) a flat surface (tail) suitable for marking with a light-pencil, and (2) several auxiliary motions to locate this tail in the desired orientation. The tail will contain the two points F and S . The point S wil lie on a circular arc whose center will always be at a constant distance from the center of the GLOOK (see Fig. 1.2(b)), while F will be moved around so that a line joining the two points represents the vector $\vec{FS}$. The auxiliary motions which locate the tail in the desired position are similar to those of the GLOOK. The successive motions given the tail are elevation, azimuth, roll, pitch, yaw, and rotation about GLOOK. The sliding motion of the MONKEY'S tail is three inches (for use with an arm swinging a forty-five inch arc), and the other mechanisms are as small as convenient around the tail. In order to insure one minute accuracy at the GLOOK (one minute accuracy in correct bore-point) the distance between the two points on the tail must be known to 0.01 inch and the various angles to one-half degree.

B-1.05. Assumptions and Limitations. In developing the theory for evasive-action assessment several assumptions have to be made. The three major assumptions are:

(1) That the bomber's path during the bullet time-of-flight can be closely approximated by a reasonably simple curve;
(2) That instruments such as accelerometers and air speed indicators of sufficient accuracy to determine the bomber's path are available or can be developed;
(3) That angle of attack or skid of bomber can be measured, assumed, or neglected.

Two alternative procedures are presented for calculating the deviation of the bomber from straight line flight at constant speed. These procedures are designated as METHOD A and METHOD B. The only differences between the two methods are (1) the type of curves chosen to represent the bomber's path and (2) the resulting calculation procedures. Since the evasive tactics which present heavy bombers can undertake are limited to maneuvers in which the total normal acceleration is less than about ± 2.5 or 3.0 g, and since the present maximum assessable bullet time-of-flight is less than about 1.5 seconds, it may be shown that for purposes of assessment, the bomber's path is closely approximated by a space curve whose two radii of curvature are constant, or even by a portion of a circular arc. A later section (Art. B-3.07) discusses the errors of assuming either of these curves.

B-1.06. Geometry of Flight Paths. METHOD A assumes that during the bullet flight-time the path of a bomber undergoing evasive action can be satisfactorily approximated by a space curve which lies on the surface of a vertical right circular cylinder and which becomes a circular arc when the cylindrical surface is developed. Fig. 1.3 shows a curve xy which can be defined by two constant radii, R_H the radius of the cylinder, and R_V the radius of the curve on the developed surface. In this method of representation, an airplane making a turn in the horizontal plane has R_H equal to the radius of the turn and R_V equal to infinity. Likewise an airplane making a loop in the vertical plane has R_V equal to the radius of the loop and R_H equal to infinity. A spiral dive in the path of a helix is shown in Fig. 1.4.

METHOD B assumes that during the bullet flight-time the path of the bomber can be approximated by a circular arc of constant radius R. The plane containing this arc xy makes an angle ψ with the horizontal plane as shown in Fig. 1.5. For a horizontal turn, $\psi = 0$ and R corresponds to the R_H of METHOD A. For a vertical loop, $\psi = 90^\circ$ and R corresponds to the R_V of METHOD A. For other values of ψ the circular arc of METHOD B cannot be represented exactly by METHOD A. On the other hand, a spiral dive and certain other curves lying on the cylinder of METHOD A cannot be represented exactly by METHOD B.

B-1.07. Determination of Flight Path for METHOD A. In a preceding paragraph concerning METHOD A, the bomber's path was described in terms of two radii of curvature. These radii can be expressed in terms of measurable quantities and the vector deviation of the actual flight path from a straight line path at constant speed can be calculated from the following values*:

$$R_H = \frac{V^2 \cos^2 \gamma}{A_H g} \qquad (1); \text{ and}$$

$$R_V = \frac{V^2}{A_V g} \qquad (2);$$

where
- R_H = radius of cylinder, ft,
- R_V = radius of arc on developed surface of cylinder, ft,
- V = speed of bomber, relative to air mass, ft/sec,
- γ = climb angle, or angle between horizontal plane and tangent to line of flight, positive if climbing, degrees,
- A_H = normal acceleration in horizontal plane, g,
- A_V = normal acceleration in vertical plane (perpendicular to both line of flight and A_H), g.

It is proposed to obtain the speed V from an air speed indicator, the angle of climb γ from gyros and angle of attack information, and the normal accelerations from accelerometers and gyros. Since the accelerometers are to be fixed in the bomber and will be

* For detailed mathematical derivation see Theory Manual.

influenced by gravity, the observed readings must be corrected to obtain the desired linear and normal accelerations.

If N_x, N_y, N_z = observed accelerometer readings, g, (positive if acceleration occurs in direction of positive X, Y, or Z axis where positive X-axis is along right wing, positive Y-axis is forward along fuselage, and positive Z-axis is up and normal to X and Y. See Fig. 1.6).
A_F = linear acceleration, g,
R, P = roll and pitch angles (roll about line of flight, positive if right wing is up; pitch in a vertical plane, positive if nose is up), degrees,

then approximate equations for the normal and linear accelerations, which are rigorous if the Y-axis of the bomber or of the gyros and accelerometer units correspond to the tangent to the line of flight, are*:

$$A_H = N_x \cos R - N_z \sin R \qquad (3);$$

$$A_F = N_y - \sin P \qquad (4);$$

$$A_V = N_x \sin R + N_z \cos R - \cos P \qquad (5).$$

With the knowledge of the bomber's attitude, speed and three accelerations throughout the bullet flight-time, it is possible to calculate the vector quantity by which the real bomber is removed from the ghost at the end of bullet flight-time. In this METHOD A the location of the bomber is calculated with reference to a coordinate system whose origin is located at the ghost at impact time and whose orientation is determined by the horizontal component of the tangent to the line of flight at firing time. See Fig. 1.6. The line OB lies on the surface of the cylinder and represents the path of the bomber. The line OG lies in the tangent plane and represents the path of the ghost. Based on geometric principles the magnitude of the vector $\overrightarrow{GB}$, δ , is found to be approximately

$$\delta = \frac{(\Delta T)^2}{2} g \left(A_H^2 + A_F^2 + A_V^2\right)^{\frac{1}{2}} \qquad (6)$$

where ΔT = bullet time-of-flight, sec.

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* For derivation and rigorous equations when Y-axis is not along the tangent to the line of flight, see Theory Manual.

This equation is accurate to within one percent at high speeds or low accelerations such that

$$V > 2(\Delta T)g(A_H^2 + A_F^2 + A_V^2)^{\frac{1}{2}}$$

The direction of the vector $\vec{GB}$ is expressed in terms of azimuth α , and elevation ε , where

$$\tan \alpha = \frac{x}{y} \quad \text{and} \quad \tan \varepsilon = \frac{z}{(x^2 + y^2)^{\frac{1}{2}}}$$

These angles are approximately represented by

$$\tan \alpha = \frac{A_H}{Q} \quad , \qquad (7)$$

where $Q = A_F(1 - \frac{\gamma_0^2}{2}) - A_H \frac{m}{3} - A_V(\gamma_0 + \frac{n}{3})$, (γ_0 in radians)

$\gamma_0 = \gamma$ at firing time,

$$m = \left(\frac{A_H}{V\cos^2 \gamma}\right)_{av} \Delta Tg \qquad n = \left(\frac{A_V}{V}\right)_{av} \Delta Tg \quad ;$$

and

$$\tan \varepsilon = \frac{A_V(1 - \frac{\gamma_0^2}{2}) + A_F \gamma_0}{(A_H^2 - Q^2)^{\frac{1}{2}}} \qquad (8)$$

Charts have been prepared (see Appendix) to facilitate calculations of δ , α , and ε . Once calculated these values can be used in the MONKEY to obtain the target data as viewed from the ghost as indicated earlier in this report. Of the seven possible motions on the MONKEY, this method uses five. The MONKEY is swung up or down around the GLOOK to the desired position , yawed around to be in the proper orientation, and then the three calculated values δ , α , and ε locate the tail in correct position.

B-1.08. <u>Determination of Flight Path for METHOD B</u>. In introducing METHOD B the bomber's path was described in terms of a single radius lying in a slant plane making an angle ψ with the horizontal plane. In terms of measurable quantities the radius may be defined as

$$R = \frac{V^2}{Ag} \quad , \tag{9}$$

where R = radius of arc, ft,

V = speed of bomber as in METHOD A, ft/sec,

A = resultant normal acceleration (in slant plane), g,

$= (A_H^2 + A_V^2)^{\frac{1}{2}}$

The speed and accelerations are obtained as described above in METHOD A, but the vector quantity by which the real bomber is removed from the ghost at the end of bullet flight-time is calculated in a different manner. In METHOD B the bomber's path is assumed to lie in a plane (slant plane) and consequently the path of the ghost lies in the same plane. This simplification permits calculation of both the magnitude δ, and the direction ξ, of the vector $\overrightarrow{GB}$ to be carried out in a plane, once the location of the plane is established. See Figs. 1.7 and 1.8.

Although the slant plane has been described as making an angle ψ with the horizontal plane, it is more convenient for our purposes to define this plane by the angles φ and γ_T. The slant plane (Fig. 1.7) contains the tangent to the line of flight at impact time (Y-axis) and the radius CB of the circular arc (along the X-axis). The angle γ_T is the angle between the horizontal plane and tangent to the line of flight at impact time. It is measured in the vertical plane and is a pitch angle. The angle φ is the angle between the slant plane and the horizontal plane and is measured in the normal plane (plane perpendicular to the tangent to the line of flight at impact time) and is a roll angle. The angle γ_T is obtained from gyros and angle of attack information while $\tan \varphi = A_V/A_H$. The angles γ_T and φ are then put into the MONKEY as pitch and roll angles to get the MONKEY'S tail into the slant plane.

With the MONKEY'S tail located in the correct plane, the angle ξ, which is put in as an azimuth angle, and the magnitude δ locate the vector $\vec{GB}$. As in METHOD A, δ is approximately defined as

$$\delta = \frac{(\Delta T)^2}{2} g (A_H^2 + A_F^2 + A_V^2)^{\frac{1}{2}} \qquad (6)$$

The angle ξ * can be expressed as a function of p and x where

$$p = \frac{A_F \Delta T}{V} g \text{ , and}$$

$$x = \frac{A \Delta T}{V} g \text{ ;}$$

this function has been calculated for the most frequent values of p and x and is given in the " ξ - Function Table", (Chart VIII).

* $\tan \xi \doteq \left(\frac{p}{1-p}\right)\frac{1}{x} + \left(\frac{8 - 5p + 6p^2}{12}\right)x + \frac{x^3}{10}$

CHAPTER B-2

EXPERIMENTAL REQUIREMENTS

B-2.01. Instrumentation. In addition to the instruments required for straight line assessment, the assessment of gunnery during evasive action requires the use of the following instruments and data or their equivalent:

(1) A three-component accelerometer (linear) with synchronized camera;
(2) A speed indicator (including outside air temperature and altitude, for giving TAS);
(3) Angles of attack and skid*;
(4) A MONKEY.

Other instruments which might be used to give pertinent information but which are not required in the procedures presented here:

(1) Angular accelerometers;
(2) Highly sensitive air speed indicators for one or three directions;
(3) Angular velocity meters;
(4) Any of several instruments for determining flight characteristics and for aiding pilots.

B-2.02. Accelerometers. As pointed out in Art. B-1.05, the path of a bomber undergoing evasive action can be expressed in terms of normal accelerations and forward velocity. Although there are other ways of expressing the path of the bomber, this method appears to be the most favorable. This is true since only moderately accurate and sensitive accelerometers are needed to determine the bomber's path with the required precision, while the other methods require highly accurate and sensitive instruments (precision type requiring extensive development and perhaps not suitable for airborne operation). A more detailed discussion of the accuracy required is presented later. In order to obtain data of the required precision, each of the three accelerometers should be accurate at all times to $\pm$ 0.05 g and readable to

* In this section the angle of attack is defined as the pitch angle minus the climb angle, where all three angles are measured in vertical planes. The angle of skid is defined as the angle between the horizontal projection of the tangent to the line of flight and the Y-axis of the gyro box. The climb angle is defined as the angle between the tangent to the line of flight and the horizontal plane.

$\pm$ 0.01 g. The three accelerometer units should be located as near as possible to the center of gravity of the bomber, and be of convenient access. The following equations give the errors which may be expected if the units are located away from the center of gravity.

$$\Delta A_X = y\ \alpha_Y + z\ \alpha_R + x(\omega_R^2 - \omega_Y^2)\ ,$$
$$\Delta A_Y = z\ \alpha_P + x\ \alpha_Y + y(\omega_P^2 + \omega_Y^2)\ ,$$
$$\Delta A_Z = x\ \alpha_R + y\ \alpha_P + z(\omega_P^2 + \omega_R^2)\ ,$$

where ΔA_X, ΔA_Y, ΔA_Z = errors in X , Y and Z accelerometer readings, ft/sec^2,

x, y, z = distance from center of gravity, ft,

α = angular acceleration, rad/sec^2,

$\underline{\omega}$ = angular velocity, rad/sec,

subscripts

Y, P, R = yaw, pitch and roll, respectively.

In addition to the above specifications more points should be considered. The accelerometer readings must be synchronized with the gyro and the other films. If a camera is used to record accelerations, the airspeed indicator should be in this camera's field of view. For heavy bombers like a PB4Y-2, structural, mechanical, and operational features limit the permissible maneuvers. In view of these limitations the range of the Z-accelerometer should be about -1 g to +3 g and the range of the X- and Y-accelerometers should be about $\pm$1 g.

B-2.03. Air Speed Indicator. Although not as important as an accelerometer, an air speed indicator also is required for accurate determination of the bomber's flight path. With a Y-axis accelerometer available to record changes in forward speed, the necessity for a highly sensitive air speed indicator is eliminated. However a moderately accurate air speed indicator with little time lag, which gives results to within 10 mph of the correct speed relative to the air mass is good enough for this purpose. If an indicated air speed meter is used, the auxiliary instruments such as outside temperature recorder and altimeter should be included in such a way that the true air speed (TAS) can easily be obtained correct to ±10 mph. To simplify camera operation and film reading, the necessary information to obtain TAS should be recorded on one of the available films—perhaps on the accelerometer film.

B-2.04. Angles of Attack and Skid. In order to stabilize the accelerations to axes determined by the tangent to the line of flight and by the horizontal, it is necessary to know both the angle of attack and the skid angle. For extreme accelerations these angles should be known to one-half degree. An error of one-half degree in either angle together with an acceleration of two g may easily cause an error which is greater than the specified limit of "one minute accuracy per operation as referred to target position". It may be entirely possible to determine these angles with sufficient accuracy from loading data and speed together with the bomber's flight characteristics.

If the accelerations are stabilized to the bomber axes corrected for roll only, then the angle of attack and skid can be used to determine velocity components normal to the bomber's Y-axis. This method is under development and may prove superior to the method of stabilization to the line of flight.

CHAPTER B-3

COMPUTING INSTRUMENTS AND PROCEDURES

B-3.01. Device MONKEY. As indicated in B-1.04 the MONKEY (see Fig. 1.2(a)) consists of two parts, a flat surface (tail) suitable for marking with a beam of light, and several auxiliary motions to locate the flat surface (tail) in the desired orientation. The tail contains two points representing the F and S in Fig. 1.1. These two points are indicated by crossed lines for ease in aiming a beam of light containing cross-hairs. One point, S , is always at a fixed distance from the center of rotation of the GLOOK, but it rotates around the GLOOK in a vertical plane as the entire MONKEY rotates. This point is also the center of rotation for the several MONKEY motions described below. The other point, F , is capable of being placed at various specified distances and directions from the first point S . The distance from F to S is regulated by sliding the tail out the required distance. The means of orienting the tail is described in the next paragraph.

The auxiliary motions which are necessary to locate the tail in the desired orientation are seven in number:

(1) The flat surface containing the two points rotates about the line passing through the two points. This motion permits maximum visibility of the flat surface from the GLOOK transit. The inclination of the surface can be changed without altering the location of the two points.
(2) The flat surface rotates in elevation about an axis through the first point, S . As in a transit, the normal position of the tail at zero elevation is horizontal. If the tail is extended (point F slid away from point S) positive elevation places point F up from the horizontal while negative elevation places it below the horizontal with respect to point S .
(3) The tail and elevation mechanism rotate about the azimuth-axis in a manner similar to that of a transit. Azimuth is measured positive in a clockwise direction as viewed from above. If all of the MONKEY'S scales of rotation are set at zero and the center of the MONKEY is in the same horizontal plane as the center of the GLOOK, then the center of the GLOOK, the point S and the point F all lie along a horizontal line with S in between the other two points. Furthermore, if all the GLOOK scales are set at zero, then the transit is pointed at the MONKEY along this same horizontal line.
(4) The azimuth mechanism rotates about the roll-axis.
(5) The roll bearing rotates about the pitch-axis.
(6) The pitch bearing rotates about the yaw-axis.

(7) The yawing mechanism rotates in a vertical plane about the center of the GLOOK in such a manner that the yaw axis remains (or can be set) in a vertical position and the point S on the tail (center of all the above MONKEY rotations) remains at a fixed known distance from the center of the GLOOK rotations.

The above seven motions of rotation together with the sliding tail describe all the MONKEY'S motions. Additional comments and specifications are given in the following paragraph.

The general comments and specifications are:

(1) Since the purpose of the flat tail surface is to receive a beam of light from the GLOOK transit, all yokes, dials and other mechanisms and devices should obstruct the beam of light from the GLOOK as little as practicable.
(2) It is expected that both attacks from above and from below will be assessed. For this reason the MONKEY should operate easily in both normal and upside down position. All adjustments will have to be made and dials read in both normal and upside down positions.
(3) Most changes in settings on the MONKEY will consist of successive small adjustments. The order of making the settings is theoretically immaterial and will be determined on the basis of ease of operation.
(4) Overall dimensions and weight should be as small as practicable.
(5) In order to retain "minute accuracy per operation" all dials should be able to be set accurately to one-quarter degree. It is recommended that graduations on all dials be made to five degrees with vernier to one-quarter degree.
(6) Overall precision, including deflections and play, should be such that the angle between the two points, F and S , as viewed from the GLOOK is at all times correct to within one minute.

In addition to the general comments and specifications listed above, the following specific requirements must be met:

(1) The tail must be (a) wide enough to accept the projected cross-hairs of the transit on each point, (b) long enough to extend the second point, F , three inches from the first point, S , and (c) graduated to 0.10 inch with a vernier to 0.01 inch.
(2) The elevation, azimuth, roll and pitch and yaw mechanism dials should be graduated from 0 to 360 degrees in both directions.

B-3.02. Supplementary Data Needed. In addition to the photographic data and instruments required for straight line assessment with corrections for roll, pitch and yaw, evasive-action assessment requires these additional data and computing instruments:

(1) Accelerometer film. This film contains pictures of three accelerometer dials and one air speed meter together with the usual timing marks or means of synchronizing the information on this film with other films

(2) Angles of attack and skid information. Some means of determining or estimating the angles of attack and skid should be available.
(3) MONKEY. In place of the present GLOOK screen and auxiliary transit to indicate single points, a means of indicating two specified points to high accuracy is required. The MONKEY satisfies this requirement.

B-3.03. Flow Charts and Step-by-Step Solutions. The step-by-step computation procedure for METHOD A and B are outlined in the accompanying Flow Charts VII and VIII. A comparison of these flow charts with Flow Chart III (straight line flight with corrections for roll, pitch, and yaw) shows the following major differences:

(1) In addition to the RAZEL film, gun-camera film, and gyro film, an accelerometer film is required.
(2) The GLOOK is operated yaw-pitch-roll and therefore the pitch and yaw gyro readings are corrected for use in the GLOOK instead of correcting the roll and yaw readings.
(3) In between gun-camera Step 5, gyro Step 5 and Step 6, many steps, based on the accelerometer film are inserted, and they include operation of the MONKEY.
(4) Correction tables are required for use with the DOFOGRAPH.

B-3.04. Computation Steps Common to METHODS A and B. Since the computations of the stabilized accelerations and MONKEY tail are the same for both METHODS A and B, these computations will be discussed first.

Gyro Film, Step 5. Also record roll and pitch at impact $time_F$ in Columns 32-E, 32-F, (and 34B-G for METHOD B only).

Gyro Film, Step 6. Obtain angles of attack and skid from any available reliable source. Perhaps the flight characteristics of the bomber are known and angle of attack (or skid angle or combination of the two) can be obtained from speed, altitude, and loading data. For impact times compute the climb angle γ from Column 32-F and angle of attack and record in Column 34-I.* Using Columns 32-E and 32-F and trig tables compute sin R, cos R, sin P, cos P to the nearest 0.01 and record in Columns 32-G, 32-H, 33-B, and 33-C.

Caution: At this step the computation of these four trig functions is sufficient if the accelerations can be calculated to the required accuracy by means of simplified formulas. This simplification is valid only when the angles of attack and skid are small. See discussion under Acc. Film 6 and in appendix for further information.

* Form Sheets 34A, 34B, 35A, 35B, and 36A indicate their association with either METHOD A or B. In notes on computing procedures, reference is sometimes made to only a Form 34 or 35; it is to be understood that Form 34A or 34B, etc., whichever is consistent with the chosen Method, is to be used.

Acc. Film, Step 1. In the same manner as for the gyro film, read the accelerometer and speed dials at selected intervals and record speed to one mph and X , Y , Z accelerations to 0.01 g in Columns 31-C, 31-D, 31-E and 31-F.

Acc. Film, Step 2. The air speed reading may have to be corrected for any of several reasons. A TAS meter may have calibration or time lag corrections. An IAS meter must be corrected for outside air temperature and altitude in addition to calibration corrections. Make necessary corrections and record corrected speed to one mph in Column 31-G. The X , Y , Z accelerations will probably require calibration corrections of some kind. Make these corrections and record to nearest 0.01 g in Columns 31-H, 31-I and 31-J.

Acc. Film, Step 3. For convenience in interpolation, smoothing, and averaging, the corrected speed and acceleration readings are plotted against frame numbers and corresponding time scale.

Acc. Film, Step 4. Read graph (Acc. Film, Step 3) at values of impact time_F obtained from Gun-Camera Film, Step H and record accelerations to 0.01 g in Columns 32-B, 32-C, and 32-D. Record speed to one mph in Column 33-K.

Acc. Film, Step 5. From Gyro Film, Step 6 and Acc. Film, Step 4 compute the products $N_x \cos R$, $N_z \sin R$, $N_x \sin R$ and $N_z \cos R$ to nearest 0.01 g and record in Columns 33-D, 33-E, 33-F, and 33-G.

Acc. Film, Step 6. From Gyro Film, Step 6 and Acc. Film, Step 5 compute the accelerations A_H , A_F , A_V and record in Columns 33-H, 33-I and 33-J. These accelerations are obtained from the following approximate equations.

$$A_H = N_x \cos R - N_z \sin R$$

$$A_F = N_y - \sin P$$

$$A_V = N_x \sin R + N_z \cos R - \cos P$$

Caution: These equations are sufficiently accurate only when the angle of attack and angle of skid are less than one-half degree. If the angle of skid, λ , is less than one-half degree, and the angle of attack, ρ , is less than five degrees, then

$$A_H = N_x \cos R - N_z \sin R$$

$$A_F = N_x \sin \rho \ \sin R + N_y - N_z \sin \rho \cos R - \sin \gamma$$

$$A_V = N_x \sin R - N_y \sin \rho + N_z \cos R - \cos \gamma$$

If either λ is greater than one-half degree or ρ is greater than five degrees these equations become more complex, (see Theory Manual for complete equations).

Acc. Film, Step 7. Compute average values (averaged over transit time) of A_H A_F , A_V , V and P . The best method of averaging has not been determined If the variations are close to linear, the arithmetic average of initial and end values might be accurate enough. Perhaps reading the graphs (Acc. Film, Step 3) at an average time value (average between firing time and impact time) would be satisfactory. Record these average values in Columns 34-C, 34-D, 34-E, 34-F and 34A-G.

Note: For METHOD B the average value of pitch, P , is not required. Column 34B-G will contain pitch at impact time.

Acc. Film, Step A. Compute the resultant normal acceleration, A , from the average normal accelerations, A_H and A_V , (Columns 34-C and 34-E) by the equation

$$A = (A_H^2 + A_V^2)^{\frac{1}{2}}$$

This calculation can be made with the aid of Chart II. Record A to nearest 0.01 g in Column 35-B. Be sure that A is given the same sign that A_H has.

Acc. Film, Step B. Compute $A_\delta = (A^2 + A_F^2)^{\frac{1}{2}}$ to the nearest 0.01 g from Columns 35-B, 34-D with the aid of Chart II and record in Column 35-C. Note that A_δ is always positive.

Acc. Film, Step C. Compute the magnitude of the deviation of the bomber from the ghost by the following equation

$$\delta = \frac{1}{2} A_{\delta} (\Delta T)^2$$

This calculation can be made with the aid of Table III. Note that for consistent units A_{δ} must be multiplied by 32.2 to get δ in feet. The value of δ should be calculated as accurately as is required to get L in Acc. Film, Step E to 0.005 inch (see below). This may be about 0.05 feet or one percent whichever is the larger.

Acc. Film, Step D. Read plot of range data (Gun-Camera Film, Step C) at values of impact time$_F$ and record these ranges, D , in Column 36A-E. (35B-J for METHOD B).

> Note: In these instructions the observed range data-observed from bomber-are used in the determination of transit time and in the calculation of the length of the MONKEY'S tail - see next step. The correct procedure would be to obtain range as would be observed from the ghost and use these corrected values of range for transit time and tail length calculations. This correction, however, is difficult to make and the magnitude of it is small enough to neglect. A comprehensive discussion of this correction is presented in the Theory Manual.

Acc. Film, Step E. Compute the length, L , to which the MONKEY'S tail must be extended by the equation

$$L = \frac{K\delta}{3D}$$

where K = radius of MONKEY rotation in inches,

δ = distance from bomber to ghost, feet,

D = range of target, yards.

This length should be computed to the nearest 0.005 inch and recorded in Column 36A-F. (35B-K for METHOD B).

B-3.05. Computation Steps Unique for METHOD A. In the preceding paragraphs the detailed computation steps which are the same for both METHOD A and B were given. In these next paragraphs the steps which are for METHOD A only are described.

Acc. Film, Step 8. From average values of P as recorded in Column 34A-G and angle of attack information compute

$$\gamma_{av} = P_{av} - \beta_{av}$$

and record to nearest one-half degree in Column 34A-H.

Acc. Film, Step 9. Compute m and n from Column 34A-C, 34A-E, 34A-F, 34A-H and 34A-J, where

$$m = \left(\frac{A_H}{V \cos^2 \gamma}\right)_{av} \Delta T \qquad \text{and} \qquad n = \left(\frac{A_V}{V}\right)_{av} \Delta T$$

These calculations can be made on Chart IV and the results recorded to the nearest 0.001 in Columns 35A-E and 35A-F. Notice that m and n have respectively the same signs as A_H and A_V. The chart includes conversion to consistent units. As the equations are written, A_H and A_V should be in ft/sec^2, V in ft/sec, γ in radians and ΔT in seconds.

Acc. Film, Step 10. Compute Q from Columns 34A-C, 34A-D, 34A-E, 34A-I, 35A-E, and 35A-F where Q is defined approximately by

$$Q = A_F\left(1 - \frac{\gamma_0^2}{2}\right) - A_H \frac{m}{3} - A_V\left(\gamma_0 + \frac{n}{3}\right)$$

This calculation can be made on Chart V and Q recorded to the nearest 0.01 g in Column 35A-G. Since the chart incorporates conversion to consistent units, γ_0 is used in the chart in degrees. If direct calculation of Q from the above equation is attempted, γ_0 should be converted to radians. (See Theory Manual for rigorous equation for Q).

Acc. Film, Step 11. Compute W from Columns 34A-D, 34A-E and 34A-I where W is approximately defined by

$$W = A_v \left(1 - \frac{\gamma_0^2}{2}\right) + A_f \gamma_0$$

This calculatio
This calculation can be made on Chart VII and W recorded to the nearest 0.01 g in Column 36A-B. As with Q (see above) the chart uses γ_0 in degrees although it must be converted to radians if the equation is used directly. (See Theory Manual for rigorous equation).

Acc. Film, Step 12. Compute S from Column 34A-C and 35A-G where

$$S = (A_h^2 + Q^2)^{\frac{1}{2}}$$

This calculation can be made with aid of Chart II and S recorded to the nearest 0.01 g in Column 36A-C. Note that S is always positive.

Acc. Film, Step 13. Compute $\tan \epsilon$ from Columns 36A-B and 36A-C where

$$\tan \epsilon = W/S$$

and record $\tan \epsilon$ in Column 36A-D and ϵ to the nearest one-quarter degree in Column 36A-C.

Acc. Film, Step 14. Compute $\tan \alpha$ from Columns 34A-C and 35A-G where

$$\tan \alpha = A_h/Q$$

and record $\tan \alpha$ in Column 35A-H and α to the nearest one-quarter degree in Column 36A-H.

Acc. Film, Steps 15 and 16. Use GLOOK and MONKEY to compute target azimuth and elevation at impact-time$_F$ with respect to turret axes at firing-time$_F$. Record in Columns 13-B and 13-C. This operation is carried out as follows:

(1) Set GLOOK at elevation = ϵ_{obs} - Col 23-B

azimuth = α_{obs} - Col 23-C

roll $= R_T$ - Col 23-E

pitch $= P_T$ - Col 23-D

yaw $= Y_T$ - Col 23-F

Note: For this setting the pitch is put on the saddle and the roll on the rocker. The zero azimuth is along the roll axis. The MONKEY or screen should be in line with the transit beam when all GLOOK scales (azimuth, yaw, and ring, especially) are at zero. The MONKEY'S tail should be pointing directly away from the GLOOK if all of its scales (yaw and azimuth especially) are at zero.

(2) Rotate ring and MONKEY to bring transit beam onto zero point of MONKEY'S tail or onto screen.

(3) Read angle on ring. Record in Column 36A-I.

Note: In this procedure it is assumed that the ring reads positive for a clockwise motion and that the conditions above in Note for (1) regarding the GLOOK scales are valid.

(4) Calculate (α_3 + ring - Y_o) and record in Column 36A-J. The value of α is obtained from 36A-H, ring from 36A-I, and Y_o from 23-J.

(5) Set MONKEY at

$\alpha_m = (\alpha_3 +$ ring $- Y_o)$ - Col 36A-J

$\epsilon_m = \epsilon_3$ - Col 36A-G

Tail $= L$ - Col 36A-F.

Note: In this setting the yaw, pitch and roll scales of the MONKEY are all set at zero.

(6) Adjust MONKEY until zero of tail is in line with transit beam. This may require some rotation of GLOOK ring.

(7) Set GLOOK at

Roll $= R_o$ - Col 23-I

Pitch $= P_o$ - Col 23-H

Yaw $= Y_o$ - Col 23-J.

(8) Sight transit on tip of MONKEY'S tail by changing GLOOK azimuth and GLOOK elevation. Read off desired values of target azimuth and elevation. Record in Columns 13-B and 13-C.

B-3.06. Computation Steps Unique for METHOD B. In the preceding paragraphs were given the detailed steps which are the same for both METHOD A and B and those which are unique for METHOD A. In the next paragraphs the steps which are only for METHOD B are described

Acc. Film, Step 8. For impact-time$_F$ values of P as recorded in Column 34B-G and angle of attack compute $\gamma_t = P_T - \rho_t$ and record to nearest one-quarter degree in Column 34B-H.

Acc. Film, Step 9. Compute x and p from Columns 35B-B, 34B-F and 34B-J, where

$$x = \left(\frac{A}{V}\right)_{av} \Delta T \qquad \text{and} \qquad p = \left(\frac{A_F}{V}\right)_{av} \Delta T$$

x -

These calculations can be made on Chart IV and the results recorded to the nearest 0.001 in Column 35B-E and 35B-F. Notice that x and p have the same signs as A and A_F respectively. The chart includes conversion to consistent units. As the equations are written, A and A_F should be ft/sec^2, V in ft/sec, and ΔT in seconds.

Acc. Film, Step 10. Compute ξ from x and p in Columns 35B-E and 35B-F. This calculation can be done with Chart VIII and recorded to the nearest one-quarter degree in Column 35B-G

Acc. Film, Step 11. Compute tan φ and φ from Column 33-H and 33-H, where

$$\tan \varphi = \frac{\Delta V}{\Delta H}$$

Record tan φ and φ in Column 35B-H and 35B-I. The angle φ should be obtained to the nearest one-quarter degree.

Acc. Film, Steps 12-16. Follow the procedure for METHOD A, Steps 15 and 16, with the following changes:

(1) and (2) Same;

(3) Record in Column 35B-L instead of 36A-I;

(4) Calculate (Y_T - ring) and record in Column 35B-M. Y_T is obtained from Column 23-F and ring from Column 35B-L.

(5) Set the MONKEY at:

Tail	= L	, or Col 35B-K,
Elevation	= 0	
Azimuth	= $-\varepsilon$	, or Col. 35B-G,
Roll	= Φ_T	, or Col 35B-I,
Pitch	= γ_T	, or Col 34B-H,
Yaw	= (Y_T - ring),	or Col 35B-M;

(6), (7) and (8) Same.

Art. B-3.07. Ballistic Corrections. In the assessment theory which has been developed it was assumed that the projectile traveled in a straight line. The validity of this assumption will depend upon the type of projectile which was fired. In most cases it would be necessary to apply a correction to allow for the deviation of the projectile from a straight line. In the assessment work so far it has been found most convenient to apply these corrections to the target position.

A series of graphs giving the ballistic corrections per second time-of-flight as a function of target azimuth and elevation for different airspeeds and altitudes of the airplane has been prepared by AMG-N. These graphs, called DOFOGRAPHS, are valid only when the airplane flies in a horizontal plane.

Dr. George Piranian has developed a method for calculating corrections to these DOFOGRAPHS for the case when the airplane does not remain in a horizontal plane (see AMG-N 172).

The following are some suggestions for computing the corrections described in AMG-N 172:

1. Determine the azimuth, α , and elevation, ε , of the target with respect to a horizontal plane from the azimuth, α' , and elevation, ε' , of the target with respect to the bomber which is pitched, P^o , and rolled, R^o , from a horizontal plane.
2. Find the direction A' , E' of the axis $\alpha - 90^o$, 0^o with respect to unstabilized bomber coordinates by pitching through P^o and rolling through R^o
3. Compute the corrections which are given at the end of AMG-N 172 as a function of α' , ε' , A' , E' and α .
4. To the ballistic corrections corresponding to α' , ε' on the DOFOGRAPH add the correction given under Step 3.

In performing the roll and pitch in Steps 1 and 2 either a GLOOK or a gnomonic chart may be used. It would probably be most convenient to make a chart or graph of the evasive action corrections as a function of α' , ε' , R and P .

B-3.08. Discussion and Limitations. In the preceding sections the theory was presented in brief form and the computation steps described in detail. In this Section explanations and limitations of some of the points will be presented.

First of all, the two computation procedures (METHOD A and METHOD B) were based on different geometric assumptions and can easily give different results. METHOD A assumes that two normal radii of curvature are constant (or rather that the use of average values introduces negligible error). METHOD B assumes that one resultant radius of curvature is constant and remains in a plane. These assumptions can easily be checked for any given problem to determine which method is nearer to the actual case. If both $\frac{A_V}{V^2}$ and $\frac{A_H}{V^2 \cos^2 \gamma}$ remain constant (see Section B-1.07) during the bullet flight-time, then the actual path of the evading bomber corresponds to the assumptions of METHOD A. If both $\frac{A_H^2 + A_V^2}{V^4}$ and $\left[\frac{A_V^2}{A^2} + \sin^2 \gamma\right]$ remain constant (see Section B-1.08) during the bullet flight-time, then the assumptions of METHOD B are identical with the actual conditions. As seen from Eq. (9) on page 8, $\frac{A_H^2 + A_V^2}{V^4} = \frac{A^2}{V^4} = \frac{1}{(Rg)^2}$. When this term is constant the resultant radius of curvature is constant and one of the conditions of METHOD B is obtained. The other condition (planar path of bomber) is usually satisfied when $\left[\frac{A_V^2}{A^2} + \sin^2 \gamma\right]$ is constant. This condition is sufficient when $A_V \neq 0$, but when $A_V = 0$, γ must also be zero to have planar motion. This second condition is sufficient to specify planar motion of the bomber when the resultant radius, R, is constant since $\frac{A_V^2}{V^2} = \sin^2 \phi$, (note that $\tan \phi = \frac{A_V}{A_H}$) and both ϕ and γ vary between $\pm \psi$. (When $\phi = \pm \psi$, $\gamma = 0$ and when $\phi = 0$, $\gamma = \pm \psi$). Another way of putting this is $\sin^2 \gamma + \sin^2 \phi = \sin^2 \psi$, and in order to have planar motion ψ must be constant and therefore $\left[\frac{A_V^2}{A^2} + \sin^2 \gamma\right]$ must be constant.

In the development presented here transit-time was obtained from actual range data instead of the desired range (range from ghost bomber). This introduces some error but it is never large. In the Theory Manual means are presented for obtaining the range data from the ghost bomber. During operation of the MONKEY and the GLOOK the range from the ghost is easily seen as represented by the distance (GF in Fig. 1.1) from the GLOOK center to point F on the MONKEY's tail, while the range from the real bomber is represented by the distance (GS or BF in Fig. 1.1) from the GLOOK center to point S .

CHAPTER B-4

EVASIVE ACTION ON GNOMONIC* CHARTS

B-4.01. Scope. The general problem of evasive action and methods of solution have been discussed in the preceding chapter. It is the purpose of this section to describe an alternative "instrumentation", i.e., a procedure not making use of the GLOOK and MONKEY, but a procedure utilizing a gnomonic chart —— a chart on which are drawn curves such as a GLOOK might trace with its light-pencil on a fixed flat screen properly oriented.

In evolving the gnomonic chart procedure for the Evasive Action Problem, it is very helpful to give first a pictorial description of the gnomonic chart from which a correspondence between the GLOOK rotations and the chart coordinates may be derived. This correspondence is first illustrated by the roll, yaw, pitch problem and then applied to the Evasive Action Problem.

B-4.02. Description of Gnomonic Chart. Imagine a GLOOK, Fig. 1.9 aligned as usual, in front of a large vertical screen whose center has the position $a = 270^\circ$, $\acute{\varepsilon} = 0^\circ$, on the GLOOK transit when the GLOOK roll, yaw and pitch are all zero. To any point on the screen a unique azimuth and elevation may be assigned by pointing the GLOOK transit at that point using only the upper transit adjustments. Conversely, corresponding to a given azimuth and elevation the transit beam intersects the screen in only one point if it does so at all.

With roll, yaw, and pitch still zero, rotate the GLOOK transit in azimuth, leaving the elevation constant. The transit beam will then trace a curve of constant elevation on the screen. These curves are hyperbolas.

If the GLOOK transit, with roll, yaw, and pitch zero, is rotated in elevation leaving the azimuth constant, the transit beam will trace a curve of constant azimuth on the screen.

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* A general treatment is given in "A Manual for the Use of Gnomonic Charts", by . A. Albert, AMP Note 23, (AMG-N No. 62), October 1945.

These curves are vertical straight lines.

If enough such curves are drawn it is possible to determine the azimuth and elevation of a point on the screen by means of the curves of constant azimuth and of constant elevation which pass through or near that point.

When the GLOOK saddle is rolled, with yaw and pitch zero and with the transit azimuth and elevation fixed but not necessarily zero, the GLOOK transit beam traces a curve of constant angle-off on the screen. These curves are hyperbolas rotated 90° from the elevation hyperbolas. To see this, imagine the GLOOK to be pitched through -90° on the rocker. A roll on the saddle would then rotate the GLOOK transit in azimuth leaving the elevation constant.

If the transit of the GLOOK is rotated in azimuth with yaw, pitch, and the transit elevation zero, and with a fixed roll not necessarily zero, a curve of constant inclination will be traced on the screen. These curves are horizontal straight lines.

The screen together with the curves of constant azimuth, elevation, inclination, and angle-off is known as the gnomonic chart. For convenience the chart is sometimes cut into four equal parts, one corner of each containing the center of the chart. Such is the case with the chart designed by AMG-N and drawn by the U. S. Coast and Geodetic Survey.

B-4.03. Roll, Yaw, and Pitch Problem on Gnomonic Charts. Assume that the gnomonic chart is rigidly attached to the GLOOK so that it always has the position $\alpha = 270^{\circ}$, $\varepsilon = 0^{\circ}$, with respect to the GLOOK transit. Imagine also a light-pencil located at the center about which the GLOOK motions rotate, but which maintains its position in space constant, i.e., it is in no way attached to the GLOOK. In mathematical language it is a constant vector whose direction with respect to a rotated coordinate system we wish to find.

With the situation as described above let the GLOOK be yawed, rolled, and pitched in that order through angles Y, R, and P respectively and the point where the light-pencil strikes the gnomonic chart noted. If the GLOOK is pitched through an angle $-P$

back to zero the fixed light-pencil will travel on a circular arc about the origin of the chart an amount +P . Roll the GLOOK through -R back to zero and the light-pencil will travel along a line of constant angle-off an amount -R as measured between the lines of constant inclination. Yaw the GLOOK through -Y back to zero and the light-pencil will travel a distance -Y along a line of constant elevation as measured between the lines of constant azimuth. After the GLOOK has been pitched, rolled, and yawed the azimuth and elevation of the light-pencil with respect to the GLOOK may be either read from the gnomonic chart or measured with the GLOOK transit. In practice the GLOOK would represent the bomber and the light-pencil the vector from the bomber to the fighter.

It is not necessary to locate the center of the gnomonic chart at the position $\alpha = 270^\circ$, $\varepsilon = 0^\circ$, with respect to the GLOOK transit. It might also be located in any one of the positions $\alpha = 360^\circ$, $\varepsilon = 0^\circ$; $\alpha = 90^\circ$, $\varepsilon = 0^\circ$; $\alpha = 180^\circ$, $\varepsilon = 0^\circ$; $\alpha = 270^\circ$, $\varepsilon = 90^\circ$; $\alpha = 270^\circ$, $\varepsilon = -90^\circ$. If one constructed a chart as described above at any of these positions he would find that all of the charts were exactly like the one which has already been described except that the chart coordinates would correspond to different GLOOK rotations in each of the different chart positions. To derive the GLOOK-chart correspondences it is only necessary to follow a line of reasoning analagous to that for the position $\alpha = 270^\circ$, $\varepsilon = 0^\circ$. Below is a table of GLOOK chart correspondences for all chart positions.

GLOCK-CHART CORRESPONDENCES

Center of Chart at $\alpha = 270^\circ$, $\varepsilon = 0^\circ$

GLOOK Rotation	Effect on Position of Light-Pencil on Chart
Yaw through +Y	Increases azimuth by +Y ; elevation remains constant.
Roll through +R	Increases inclination by +R ; angle-off remains constant.

GLOOK-CHART CORRESPONDENCES (Continued)

Pitch through $+P$	Rotates point about center of chart $-P$.
Center of Chart at $\alpha = 360^\circ$, $\varepsilon = 0^\circ$	
Yaw through $+Y$	Increases azimuth by $+Y$; elevation remains constant.
Roll through $+R$	Rotates point about center of chart $-R$.
Pitch through $+P$	Increases inclination by $-P$; angle-off remains constant.
Center of Chart at $\alpha = 90^\circ$, $\varepsilon = 0^\circ$	
Yaw through angle $+Y$	Increases azimuth by $+Y$; elevation remains constant.
Roll through $+R$	Rotates point about center of chart $-R$.
Pitch through $+P$	Rotates point about center of chart $+P$.
Center of Chart at $\alpha = 180^\circ$, $\varepsilon = 0^\circ$	
Yaw through $+Y$	Increases azimuth by $+Y$; elevation remains constant.
Roll through $+R$	Rotates point about center of chart $+R$.
Pitch through $+P$	Increases inclination by $+P$; angle-off remains constant.
Center of Chart at $\alpha = 270^\circ$, $\varepsilon = 90^\circ$	
Yaw through $+Y$	Rotates point about center of chart $+Y$.
Roll through $+R$	Increases inclination by $+R$; angle-off remains constant.
Pitch through $+P$	Increases azimuth by $+P$; elevation remains constant.

GLOOK-CHART CORRESPONDENCES (Continued)

Center of Chart at $\alpha = 270^\circ$, $\varepsilon = 90^\circ$

Yaw through +Y	Rotates point about center of chart -Y .
Roll through +R	Increases inclination angle by -R ; angle-off remains constant.
Pitch through +P	Increases azimuth by -P ; elevation remains constant.

Note: The terms azimuth, elevation, inclination, and angle-off are used to refer to those coordinates which would represent these angles if the center of the chart were at $\alpha = 270^\circ$, $\varepsilon = 0^\circ$. A positive yaw is to the left, a positive roll is right wing up, and a positive pitch is nose up. If other conventions are adopted, suitable changes should be made in the above table.

For azimuth and elevation angles which differ from those of the center of the charts by more than 45° the size of the chart becomes too large for convenience. It is then necessary to consider the center of the chart to be located at one of the other positions described above. It is always possible to locate a point on the chart by considering its center to have one of these positions. One of the most frequent sources of error is the failure of the computer to interpret correctly the chart coordinates for different positions of the chart.

If during a rotation a point goes off the chart in a given position it is necessary to consider the chart to be located at another position and to complete the rotation in the correct way for the new chart position.

In any one of the chart positions where the elevation of the center of the chart is zero the lines of constant azimuth and elevation are the same as for the position $\alpha = 270^\circ$, $\varepsilon = 0^\circ$. However, when the center of the chart has $\varepsilon = \pm 90^\circ$ the curves of constant azimuth are radial straight lines from the center of the chart, and the curves of constant elevation are concentric circles with their centers at the center of the chart. To locate a point on the chart in one of these positions use one of the scales at one side of the chart to set the marker on the rotating arm a distance equal to 90° minus the elevation angle of the point from the center of the chart. Then rotate the arm through the azimuth angle of the point. The direction of this last rotation will be different for the two positions of the chart and will depend upon the direction of positive azimuth rotation.

B-4.04. Evasive Action Problem on Gnomonic Chart. Imagine the GLOOK and gnomonic chart situation previously described, i.e., the GLOOK with roll, yaw, and pitch zero, and with the chart rigidly attached to it so as to maintain the position $\alpha = 270^\circ$, $\varepsilon = 0^\circ$ on the GLOOK transit. Let a lead pencil be erected with its point on the spot where the light and pencil strikes the screen. The direction of the lead pencil remains fixed in space although it is free to translate along the light-pencil.

The Evasive Action Problem is to find the azimuth and elevation of the tail of the lead pencil, knowing the azimuth and elevation of the light-pencil and the space orientation of the lead pencil.

One way to do this is to sight the GLOOK transit on the tail of the lead pencil; the beam of light from the GLOOK transit will then project the tail of the lead pencil onto the gnomonic chart. The azimuth and elevation of the tail of the lead pencil may be read from either the transit scales or directly from the chart as the azimuth and elevation of projection of the tail of the lead pencil onto the chart.

If it is possible to determine the projection of the lead pencil onto the chart without the use of the GLOOK transit, the Evasive Action Problem may be solved entirely by means of the gnomonic chart. This is possible if the lead pencil lies in the plane of the chart, since in this case the pencil and its projection onto the chart coincide. If the lead pencil does not lie in the plane of the chart rotate the GLOOK and with it the chart until the plane of the chart is parallel to the lead pencil. Then translate the lead pencil along the light-pencil until it lies in the plane of the gnomonic chart. The only effect of the translation will be to make a correction necessary for the length of the lead pencil.

Let the space orientation of the lead pencil be specified by its azimuth and elevation. Now since the azimuth of the lead pencil and the GLOOK yaw are measured in parallel planes, it is only necessary to rotate the GLOOK in yaw through the lead pencil azimuth angle to make the gnomonic chart parallel to the lead pencil. If the GLOOK is then pitched through the lead pencil elevation angle the lead pencil will be parallel to the line $\varepsilon = 0^{\circ}$ of the gnomonic chart. Now translate the lead pencil along the light-pencil until it lies in the plane of the chart. During these rotations the azimuth and elevation of the light-pencil have changed. The new azimuth and elevation of the light-pencil may now be found by performing the above yaw and pitch on the gnomonic chart. If a line is measured on the chart parallel to the line $\varepsilon = 0^{\circ}$ and with its initial point on the new azimuth and elevation of the light-pencil, its terminal point will be the projection of the lead pencil onto the chart (if a correction for length is made which will be described later). If the chart is now rotated back to its initial position, i.e., yaw and pitch zero, the initial point will go back into the old azimuth and elevation of the light-pencil and the terminal point will still be the projection of the lead pencil onto the screen. The Evasive Action Problem is then solved.

B-4.05. Brief Theory of Gnomonic Charts. In this section the statements made in the preceding section will be proven in as pictorial a manner as is consistent with mathematical rigor.

In order to derive the equations of the various curves which compose the gnomonic chart, it is necessary to make use of the methods of analytical geometry. Imagine a system of axes as pictured in Fig.1.10 whose directions coincide with the axes about which the GLOCK rotates. Let ε be the elevation angle of the GLOCK transit and at the point $x = b$ imagine a plane perpendicular to the x-axis. If the GLOCK transit is rotated in azimuth and the elevation is kept constant the transit beam will generate a conical surface whose equation is

$$x^2 \tan^2\varepsilon + y^2 \tan^2\varepsilon = z^2 ,$$

and the intersection of this surface with the plane $x = b$ is

$$b^2 \tan^2\varepsilon + y^2 \tan^2\varepsilon = z^2$$

or the equation of one of the elevation hyperbolas is

$$z = \pm \tan\varepsilon \sqrt{y^2 + b^2}$$

If the GLOCK transit is rotated in elevation while the azimuth is kept constant the transit beam will generate the plane

$$y = x \tan\alpha \quad ;$$

and its intersection with the plane $x = b$ will be the line

$$y = b \tan\alpha$$

This is a vertical line on the plane, a distance $y = b \tan \alpha$ from the center of the plane.

To derive the equation of the hyperbolas of constant angle-off rotate the y- and z-axes through 90°, or in other words interchange y and z in the equation for the elevation hyperbolas, i.e.,

$$y = \pm \tan \theta \sqrt{z^2 + b^2}$$

Similarly the lines of the constant inclination are

$$z = b \tan \varphi$$

In Fig. 1.11 there are two coordinate systems, (1) the x'y'z'-coordinate system about whose axes the CLOCK motions rotate, and (2) the xyz-coordinate system whose axes are parallel to the x'y'z'-axes and whose origin is at the point 0 where the light-pencil strikes screen. $\overrightarrow{P_1O}$ is the light-pencil, OP_2 the lead pencil, and P_3 the projection of the tail of the lead pencil, P_2, onto the screen.

The problem is to find the coordinates of P_3 in the xyz-system, knowing the orientation of $\overrightarrow{P_1O}$ in the x'y'z'-system, the orientation of OP_2 in the xyz-system, the length of OP_2 and b.

To solve this problem find the equation of the line P_1P_2 in the xyz-system and then calculate its intersection with the zy-plane. This point will be P_3.

Let α_1 and ε_1 be the azimuth and elevation of $\overrightarrow{OP_1}$, with r with respect to the x'y'z'-coordinate system and r_1 the length of $\overrightarrow{OP_1}$; similarly let the subscript 2 refer to the corresponding quantities for OP_2.

The x'y'z'-components of $\overrightarrow{OP_1}$ are

$$x_1' = r_1 \cos\varepsilon_1 \sin\alpha_1 \quad ,$$
$$y_1' = r_1 \cos\varepsilon_1 \cos\alpha_1 \quad ,$$
$$z_1' = r_1 \sin\varepsilon_1 \quad ;$$

and the xyz-components of $\overline{OP_1}$ are

$$x_1 = - r_1 \cos\varepsilon_1 \sin\alpha_1 \quad ,$$
$$y_1 = - r_1 \cos\varepsilon_1 \cos\alpha_1 \quad ,$$
$$z_1 = - r_1 \sin\varepsilon_1 \quad .$$

The xyz-components of $\overline{OP_2}$ are

$$x_2 = r_2 \cos\varepsilon_2 \sin\alpha_2 \quad ,$$
$$y_2 = r_2 \cos\varepsilon_2 \sin\alpha_2 \quad ,$$
$$z_2 = r_2 \sin\varepsilon_2 \quad .$$

The equations of the line through P_1 and P_2 in the xyz-system are

$$\frac{x + r_1 \cos\varepsilon_1 \sin\alpha_1}{r_2 \cos\varepsilon_2 \sin\alpha_2 + r_1 \cos\varepsilon_1 \sin\alpha_1} = t \quad ,$$

$$\frac{y + r_1 \cos\varepsilon_1 \cos\alpha_1}{r_2 \cos\varepsilon_2 \cos\alpha_2 + r_1 \cos\varepsilon_1 \cos\alpha_1} = t \quad ,$$

and $$\frac{z + r_1 \sin\varepsilon_1}{r_2 \sin\varepsilon_2 + r_1 \sin\varepsilon_1} = t \quad .$$

When $x = 0$

$$t = \frac{r_1 \cos\varepsilon_1 \sin\alpha_1}{r_2 \cos\varepsilon_2 \sin\alpha_2 + r_1 \cos\varepsilon_1 \sin\alpha_1} \quad ,$$

whence $$y = \frac{r_1 \cos\varepsilon_1 \sin\alpha_1 \, (r_2 \cos\varepsilon_2 \cos\alpha_2 + r_1 \cos\varepsilon_1 \cos\alpha_1)}{r_2 \cos\varepsilon_2 \sin\alpha_2 + r_1 \cos\varepsilon_1 \sin\alpha_1} - r_1 \cos\varepsilon_1 \cos\alpha_1 \quad ,$$

$$= \frac{r_1 r_2 (\cos\varepsilon_1 \cos\varepsilon_2 \sin\alpha_1 \cos\alpha_2 - \cos\varepsilon_1 \cos\varepsilon_2 \sin\alpha_2 \cos\alpha_1)}{r_2 \cos\varepsilon_2 \sin\alpha_2 + r_1 \cos\varepsilon_1 \sin\alpha_1} \quad ,$$

$$y = \frac{r_1 r_2 \cos \varepsilon_1 \cos \varepsilon_2 \sin(\alpha_1 - \alpha_2)}{r_2 \cos \varepsilon_2 \sin \alpha_2 + r_1 \cos \varepsilon_1 \sin \alpha_1} ;$$

and $$z = \frac{r_1 \cos \varepsilon_1 \sin \alpha_1 (r_2 \sin \varepsilon_2 + r_1 \sin \varepsilon_1)}{r_2 \cos \varepsilon_2 \sin \alpha_2 + r_1 \cos \varepsilon_1 \sin \alpha_1} - r_1 \sin \varepsilon_1 ,$$

$$= \frac{r_1 r_2 (\cos \varepsilon_1 \sin \alpha_1 \sin \varepsilon_2 - \cos \varepsilon_2 \sin \alpha_2 \sin \varepsilon_1)}{r_2 \cos \varepsilon_2 \sin \alpha_2 + r_1 \cos \varepsilon_1 \sin \alpha_1} .$$

Since b is fixed $\overrightarrow{OP_1}$ will not in general be equal to the distance from the bomber to the fighter. It is consequently necessary to correct the length of $\overrightarrow{OP_2}$ so that the triangle P_1OP_2 will be similar to the actual space triangle. The following relation is derived from the fact that if two triangles are similar their corresponding sides have equal ratios.

In the following relations

δ = actual length of vector from bomber to ghost,

d = range from bomber to ghost,

α_s' = azimuth of center of chart,

ε_s' = elevation of center of chart,

$$\frac{\delta}{d} = \frac{r_2}{r_1} , \quad \text{or} \quad r_2 = r_1 \frac{\delta}{d} ,$$

whence $$r_1 = \frac{b}{\cos(\alpha - \alpha_s) \cos(\varepsilon - \varepsilon_s)} ,$$

or $$r_2 = \frac{b \frac{\delta}{d}}{\cos(\alpha - \alpha_s) \cos(\varepsilon - \varepsilon_s)} .$$

Substituting these relations in the expressions for y and z one obtains

$$y = \frac{r_2 \cos \varepsilon_1 \cos \varepsilon_2 \sin(\alpha_1 - \alpha_2)}{\frac{r_2}{r_1} \cos \varepsilon_2 \sin \alpha_2 + \cos \varepsilon_1 \sin \alpha_1} ,$$

$$y = \frac{\dfrac{b\frac{\delta}{d}}{\cos(\alpha - \alpha_s)\cos(\varepsilon - \varepsilon_s)} \cos\varepsilon_1 \cos\varepsilon_2 \sin(\alpha_1 - \alpha_2)}{\frac{\delta}{d}\cos\varepsilon_2 \sin\alpha_2 + \cos\varepsilon_1 \sin\alpha_1}, \text{ and}$$

$$z = \frac{r_2 (\cos\varepsilon_1 \sin\alpha_1 \sin\varepsilon_2 - \cos\varepsilon_2 \sin\alpha_2 \sin\varepsilon_1)}{\frac{r_2}{r_1}\cos\varepsilon_2 \sin\alpha_2 + \cos\varepsilon_1 \sin\alpha_1},$$

$$z = \frac{\dfrac{b\frac{\delta}{d}}{\cos(\alpha - \alpha_s)\cos(\varepsilon - \varepsilon_s')} (\cos\varepsilon_1 \sin\alpha_1 \sin\varepsilon_2 - \cos\varepsilon_2 \sin\alpha_2 \sin\varepsilon_1)}{\frac{\delta}{d}\cos\varepsilon_2 \sin\alpha_2 + \cos\varepsilon_1 \sin\alpha_1}$$

If the x'y'z'-system, and with it the chart is rotated through $-\alpha_2$, then the new α_2, α_2', is zero. The above expressions then become

$$y = \frac{b\frac{\delta}{d}}{\cos(\alpha_1' - \alpha_s)\cos(\varepsilon_1 - \varepsilon_s)} \cos\varepsilon_2$$

$$z = \frac{b\frac{\delta}{d}}{\cos(\alpha_1' - \alpha_s)\cos(\varepsilon_1 - \varepsilon_s)} \sin\varepsilon_2$$

(α_1' is the new value of α_1 after the rotation through $-\alpha_2$).

Now pitch through $-\varepsilon_2$ so that ε_2', the new value of ε_2, is zero. This gives

$$y = \frac{b\frac{\delta}{d}}{\cos(\alpha_1' - \alpha_s)\cos(\varepsilon_1' - \varepsilon_s)}, \text{ and}$$

$$z = 0$$

(ε_1' is the new value of ε_1 after the above rotation has been made).

To calculate the azimuth and elevation of the ghost with respect to the bomber: first locate the target point, α_1 , ε_1 , on the chart, then yaw through $-\alpha_2$ on the chart if $\alpha_2 \leqq 90^\circ$, or $(180^\circ - \alpha_2)$ if $\alpha_1 \geqq 90^\circ$; second, pitch through $-\varepsilon_2$ on the chart and mark the resulting point α' , ε' . Then measure a length Y as given above through α' , ε' , and parallel to the line $\varepsilon = 0^\circ$ of the chart. Pitch and yaw both end points through the negative of the original rotation angles. The initial point, α_1' , ε_1' , will then go into α , ε , the original target point, and the terminal point will go into the projection of $\overrightarrow{OP_2}$ onto the chart.

In some cases the yaw mentioned above may take the target point off the chart, in which case the chart must be shifted to one of the positions $\varepsilon = 90^\circ$ or $\varepsilon = -90^\circ$, depending upon the direction in which the point went off the chart. A proof analagous to the one already given will show that with the chart in this position a yaw followed by a pitch suffices to make $\overrightarrow{OP_2}$ lie in the plane of the chart. If the pitch takes the target off the chart in one of the positions $\varepsilon = \pm 90^\circ$ the following mathematical procedure should be used:

Consider the equation of the lines of constant azimuth

$$y = b \tan (\alpha_1' - \alpha_s)$$

Differentiating, one has

$$y = b \sec^2 (\alpha_1' - \alpha_s)\, d\alpha \quad , \text{or}$$

$$\frac{y \cos^2 (\alpha_1' - \alpha_s)}{b} = d\alpha$$

Note: y as used in the sense of Fig. 1.11 is the same as dy .

This says that a small change in y , $dy = Y$, will cause another small change in dy , which can be calculated, if

$$Y = \frac{b\, \delta/d \cos \varepsilon_2}{\cos (\alpha_1' - \alpha_s) \cos (\varepsilon_1 - \varepsilon_s)} \quad ,$$

then $$d\alpha = \frac{\delta/d \cos(\alpha_1' - \alpha_s) \cos \varepsilon_2}{\cos \varepsilon_1}, \text{ radians.}$$

In a similar way for the elevation hyperbolas

$$z = \tan\varepsilon \sqrt{b^2 + y^2} = b \tan \varepsilon \sec \alpha ,$$

$$dz = b \sec^2 (\varepsilon_1 - \varepsilon_s) \cos (\alpha_1' - \alpha_s) ,$$

$$d\varepsilon = \frac{z \cos^2 (\varepsilon_1 - \varepsilon_s) \cos (\alpha_1' - \alpha_s)}{a} .$$

Since $$z = \frac{b \ \delta/d \sin \varepsilon_2'}{\cos (\alpha_1' - \alpha_s) \cos (\varepsilon_1 - \varepsilon_s)} ,$$

$$d\varepsilon = \delta/d \cos (\varepsilon_1' - \varepsilon_s) \sin \varepsilon_2 , \text{ radians.}$$

The azimuth of the ghost with respect to the bomber equals $\alpha + d\alpha$.

The elevation of the ghost with respect to the bomber equals $\varepsilon + d\varepsilon$.

FIGHTER VS BOMBER

CHAPTER C-1

THE THEORY - A BRIEF TREATMENT

C-1.01. Content and Assumptions. The purpose of the experiment is to measure the effectiveness of the fixed guns in a fighter plane which is attacking a bomber. The method here described tests the overall performance of the gun-sight and pilot. If the camera in the fighter is installed in such a manner that it takes a picture through the sight, then the pilot's tracking error can be found and his gunnery performance as distinct from that of the sight can be analyzed.

The theory was devised to measure experimentally the gunnery performance of a fighter attacking a bomber. The only fundamental restrictions are that the bomber fly at a constant speed on a straight horizontal course and that the fighter's guns fire straight ahead. If the bullet time-of-flight is less than one second*, the fighter may have any elevation relative to the bomber. For times-of-flight greater than one second see Art. C-2.03, Error Estimates, for permissible elevations of the fighter.

These are the only theoretical limitations and essentially the same theory could be used in a similar experiment to measure the gunnery performance of a plane attacking a ship, train, or any other object which is stationary or traveling in a straight line at constant speed.

A theory for an experiment which would assess a fighter with offset guns probably could be devised along lines similar to the present ones. The computations would be more complicated, however.

The theory as given in the Theory Manual is mathematically sound. No important factor has been neglected or glossed over and approximations occur only in the part dealing

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* The time-of-flight will be less than one second if the fighter uses API M8 or AP M2 ammunition and is within 900 yards of the bomber at firing time.

with ballistics. The only real experimental difficulty arises in trying to locate on the fighter film the direction of the bomber's flight path. It is proposed to do this by estimating where the image of the longitudinal-axis of the bomber lies, and assuming the flight path to lie along this line. Some better method should be devised.

C-1.02. Theory. A brief description of the assessment method is presented. A complete and detailed account of the theory together with all mathematical formulas used and their derivation will be found in the Theory Manual. Ballistic questions are discussed by Dr. George Piranian in his two papers: "Simple Formulas to Fit the Values Tabulated in the Firing Tables FT 0.50 AC-M-1", AMP Memo No. 104.1, April 6, 1944 (Restricted); and "Computation of Kinematic Leads for Fire From Fighter Aircraft", AMG-N No. 24, February 1, 1945 (Confidential).

It is assumed that the bomber is flying a straight line horizontal course at constant speed. The computing is considerably simplified if the fighter speed (magnitude of its velocity relative to air-mass coordinates) is also constant, but this is not essential to the theory.

The position of the fighter F as given by its coordinates α_0' , ε_0' , and r_0 relative to the bomber is determined from data recorded by cameras in the bomber (see Fig. 1.1). (This is identical with and can be taken from the corresponding part in Section A, Bomber vs Fighter Problem).

The first part of the analysis is concerned with the determination of the direction of the fighter's gun bore-point relative to a system of axes x, y, z located at the fighter and parallel to the stabilized bomber axes X, Y, Z. Since the position of the fighter relative to the bomber is known, and the orientation of the bomber and the direction of the bore-point may be established from the fighter camera film, both relative to the fighter's system $x_1y_1z_1$, we can by four planar rotations determine the coordinates α_B' , ε_B' of the bore-point relative to axes x', y', z', located at the fighter and parallel to the bomber axes X', Y', Z' (see Figs. 1.1 and 1.2). By applying to this system the same roll, yaw, and pitch correction used to stabilize the bomber axes (from X'Y'Z' to XYZ) we can find the coordinates α_B , ε_B of the bore-point relative to the axes x, y, z.

Once we know the bore-point direction a_1 it is easy, knowing the velocity of the fighter, to compute the direction b_1 of the bullet as it leaves the gun. A ballistic correction $\overline{G}$ which takes account of gravity then modifies b_1 to get the actual path c_1 of the bullet (see Fig. 1.3).

Next, from the velocity of the bomber and the position of the fighter relative to the bomber we compute the direction c_2 the bullet should have gone in order to have scored a hit. The angle ρ between c_1 and c_2 is a measure of the radial error (see Fig. 1.4).

CHAPTER C-2

EXPERIMENTAL REQUIREMENTS

C-2.01. Measurements and Data. Listed below are the experimental data which must be obtained, each with its source and required accuracy.

1. Bomber Speed (yards per second, $\pm \frac{1}{2}$ yd/sec).

   The true air speed of the bomber is a constant which can be computed from the indicated air speed, temperature and altitude records. The IAS meter reading, temperature and altitude will be recorded in the Bomber Flight Log.

2. Roll, Yaw and Pitch Corrections on the Bomber (degrees and minutes, $\pm \frac{1}{2}$ min).

   These corrections, computed from the gyro readings, will already have been calculated for the Bomber vs Fighter Problem (Section A) and can be taken from there. See also Computer's Manual.

3. Azimuth, Elevation and Range of the Fighter with Respect to Unstabilized Bomber Axes, (for the first two, degrees and minutes, $\pm \frac{1}{2}$ min; for range, yards, $\pm \frac{1}{2}$ yd).

   These quantities, determined from the bomber RAZEL and gun cameras, will already have been made for the Bomber vs Fighter Problem (Section A) and can be taken from there. See also Computer's Manual.

   Note: The vulnerable point Q on the bomber must be located at the turret from which these readings are taken or else a parallax correction must be made on these data to find the azimuth, elevation and range of the fighter at the vulnerable point.

4. Fighter Speed relative to Air-Mass Coordinates (yards per second, $\pm \frac{1}{2}$ yd/sec).

   If, as is hoped, the pilot is able to fly the plane so that the speed is constant, it can be computed from the indicated air speed, temperature and altitude. The IAS meter reading, temperature and altitude will be recorded in the Fighter Flight Log. If the speed is not constant it can be computed from the azimuth, elevation and range of the fighter relative to the stabilized bomber axes (see Detailed Assessment Procedure for details).

5. Bomber Attitude with respect to Fighter.

   This is not found explicitly. It is determined by the bomber's vulnerable point and line of flight as estimated on the fighter camera film.

6. Bullet Muzzle Velocity (yards per second, ± 1 yd/sec).

For API M8 ammunition $V_M = 956.7$ yd/sec.
For AP M2 ammunition $V_M = 900$ yd/sec.
See ballistic tables for further information

7. c_5 , a Ballistic Constant.

For API M8 ammunition $c_5 = 0.436$.
For AP M2 ammunition $c_5 = 0.471$.

8. δ , Relative Air Density.

At 7,000 ft altitude, $\delta = 0.81$.

9. Synch Unit and FLINK-BLINK Lags (seconds, ± 0.005 sec).

The amount of these lags will be found in the Equipment Manual, Airborne Installations.

10. Camera and Projector Lens Calibration (inches, ± 0.01 in.).

See Section A, this Manual, and also the Equipment Manual, Airborne Installations, for details of lens calibration. The manufacturer's nominal rating is not exact enough for our purpose.

C-2.02. Film Synchronization. Data are gathered from several different sources: gyro-, RAZEL-,gun- and fighter-camera films which run at nearly the same speeds. These films are correlated by means of timing marks on their edges which show the second at which a given frame was exposed. The present arrangement is not entirely satisfactory, since for this Problem it is desirable that the films be matched to within 1/8 of a frame (0.005 sec); however, synchronizing methods of satisfactory characteristics are under development.

Due to necessary relays in the synch and FLINK-BLINK units a time lag exists between the timing marks of the various films. This lag is a known constant which can be allowed for when matching the films.

C-2.03. Error Estimates. The bullet time-of-flight u , a function of θ and λ , is much more sensitive to changes in θ than in the Bomber vs Fighter Problem of Section A. Because of this θ should be determined to the nearest minute in this Problem. The tables in AMG-N No. 24 give values of the kinematic lead λ to the nearest 0.00005 radian. With such an accuracy in θ and λ we can find u from the formula given in Art. C-3.02.

Computations, to the nearest 0.01 second provided $30^\circ \leqq \theta \leqq 150^\circ$. For nose and tail attacks, however, the value of u so computed can be considerably in error.

If trigonometric tables, accurate to minutes, and the tables in AMG-N No. 24 are to be used in the computing, it is recommended that this method of assessment be employed only when the fighter has an angle off the bomber's nose between 30° and 150°. Since most of the possible error in u comes from a possible error in λ a recomputation of the tables for λ in AMG-N No. 24 to a greater degree of accuracy would permit attacks nearer the nose or tail to be assessed.

Another possible source of error in u comes from the fact that the tables for λ in AMG-N No. 24 and the formula of Step 8 of Art. C-3.02 for u hold only for fire in an approximately horizontal direction. The value of u as computed from the formula of Step 8 and the tables will be correct to the nearest 0.01 second provided $|u^2 \sin \varepsilon| \leqq 1$, where ε is the angle of elevation relative to the xyz-system of the air track. This implies that for $u \leqq 1$ sec the fighter can have any angle of elevation relative to the bomber. For $u > 1$ sec, ε must satisfy the above relation or a correction must be made to the value of u as computed from the formula of Step 8 and the tables to get the true time-of-flight. For details see AMG-N No. 24.

As in the Angle of Attack and Skid Problem (this Manual, Section D, following), an important step in the analysis is the determination of the direction relative to the bomber of the fighter's flight-path. The method is the same as that in the Attack and Skid Problem: the position of the fighter relative to the bomber is located at 0.1 second intervals and the tangent to the path is assumed to be approximated by the line joining two successive points. A small error in locating the position of the fighter may result in a large error in the determination of the direction of the tangent which in turn will produce a sizeable error in the coordinates α_c, ε_c of the effective bore-line. This error can be as large as ± 5 minutes.

The maximum errors likely to be introduced in the various stages of the computation have been estimated and are listed in the following:

Instrument Installation		Reading of Bomber RAZEL Film	
Azimuth	± 3 min	Azimuth	± 3 min
Elevation	± 3 min	Elevation	± 3 min

Reading of Bomber Gun Film by CRADLE

r_0	± 5 yards
α_0'	± 2 min
ε_0'	± 2 min

Reading of Gyro Films

R	± 1 min
Y	± 1 min
P	± 1 min

Plotting, Smoothing and Reading of Data

	Plotting and Smoothing	Reading
θ_0'	± 3 min	± 1 min
φ_0'	± 3 min	± 1 min

Reading of Fighter Film* by GLOOK

α_B'	± 2 min
ε_B'	± 2 min

Plotting, Smoothing and Reading of Data

	Plotting and Smoothing	First Reading	Second Reading
R	± 3 min	± 1 min	± 1 min
Y	± 3 min	± 1 min	± 1 min
P	± 3 min	± 1 min	± 1 min

Stabilization of Coordinates by GLOOK

α_B	± 2 min
ε_B	± 2 min
α_0	± 2 min
ε_0	± 2 min

Plotting, Smoothing and Reading of Data

	Plotting and Smoothing	Reading
r_0	± 6 yards	± 2 yards
α_0	± 3 yards	± 1 yard
ε_0	± 3 yards	± 1 yard
α_B	± 3 yards	± 1 yard
ε_B	± 3 yards	± 1 yard

Error in the Coordinates of the Actual Bullet Line Due to a Possible Error of 30' in the Tangent to the Flight Path

α_C	± 5 min
$\varepsilon_C - \bar{G}$	± 5 min

Error in the Gravity Drop Correction $\bar{G}$ and in the Coordinates of the True Bullet Line due to a Possible Error of 0.005 sec in u

$\bar{G}$	± 0 min
α	± 4 min
ε	± 4 min

Error Introduced by GLOOK (if used) in the Computation of the Radial Bullet Line Error

ρ	± 2 min

CHAPTER C-3

COMPUTING PROCEDURE

C-3.01. Scope. The detailed procedure for processing the data is given in the following: first, the outline of the computational steps together with formulas; then, the procedure for synchronizing the data from the various films; and, finally, the Flow Chart IX (see left part of Manual) and Form Sheets Nos. 41-50.

Much of the data required has already been gathered for the Bomber vs Fighter Problem of Section A. Our only new source is the fighter-camera film, the data from which must be correlated with that from the other films.

C-3.02. Computations.

Step 1. Compute the unstabilized angle-off θ_0' and the unstabilized tilt angle φ_0' from the formulas

$$\cos\theta_0' = \cos\alpha_0' \cos\varepsilon_0' \quad , \quad \text{and}$$
$$\cot\varphi_0' = \sin\alpha_0' \cot\varepsilon_0' \quad .$$

(Do not use the Angle-Off Table to find θ_0', It is not sufficiently accurate for this part of the problem).

The fighter-camera film shows the bomber, its line-of-flight and the fighter gun-bore point, thereby determining these quantities relative to the fighter axes $x_1 y_1 z_1$.

Step 2. Using the GLOOK and fighter-camera film and knowing θ_0' and φ_0' find α_B' and ε_B' , the coordinates of the fighter gun bore-point B in the x'y'z'-system. (The details of this problem are given in the Computer's Manual and the theory in Art. C-3.03).

Step 3. (a) Make a roll, yaw, pitch correction on α_0' , ε_0' , the unstabilized coordinates of the fighter, to find the fighter's coordinates α_0 ,

ε_0 in the stabilized XYZ-system.

(b) Make the same roll, yaw, pitch correction on α_B' , ε_B' to get α_B , ε_B , the coordinates of the bore-point B in the xyz-system. (See the Computer's Manual for the details of these two problems).

Step 4. Compute the Cartesian coordinates of the fighter in the XYZ-system by

$$X = r_0 \cos \varepsilon_0 \sin \alpha_0 \quad ,$$
$$Y = r_0 \cos \varepsilon_0 \cos \alpha_0 \quad ,$$
$$Z = r_0 \sin \varepsilon_0 \quad .$$

Step 5. The coordinates α_c , ε_c of the effective bore-line (initial bullet direction) in the xyz-system are, then, given by

$$\tan \alpha_c = \frac{\sin \alpha_B \cos \varepsilon_B + \dfrac{V_F (X_{i+1} - X_{i-1})}{V_M \sqrt{(X_{i+1} - X_{i-1})^2 + (Y_{i+1} - Y_{i-1})^2 + (Z_{i+1} - Z_{i-1})^2}}}{\cos \alpha_B \cos \varepsilon_B + \dfrac{V_F (Y_{i+1} - Y_{i-1})}{V_M \sqrt{(X_{i+1} - X_{i-1})^2 + (Y_{i+1} - Y_{i-1})^2 + (Z_{i+1} - Z_{i-1})^2}}} ,$$

$$\sin \varepsilon_c = \frac{V_M}{V_M + V_F} \left[\sin \varepsilon_B + \frac{V_F (Z_{i+1} - Z_{i-1})}{V_M \sqrt{(X_{i+1} - X_{i-1})^2 + (Y_{i+1} - Y_{i-1})^2 + (Z_{i+1} - Z_{i-1})^2}} \right] ,$$

where $X_{i+1} - X_{i-1}$ is the value of X at t - 0.1 seconds subtracted from its value at t + 0.1 seconds.

Step 6. Compute the stabilized angle-off θ_0 from the formula

$$\cos \theta_0 = \cos \alpha_0 \cos \varepsilon_0$$

(Do not use the Angle-Off Table to find θ_0).

Step 7. Using the tables in AMG-N No. 24 find the kinematic lead angle λ , which is a function of r_0 and θ_0 .

Step 8. Compute the quantity uV_B , where u is the time-of-flight, from the formula

$$uV_B = \frac{r_0 \sin}{\sin(\lambda + \theta_0)} \quad .$$

Step 9. Compute the gravity drop correction $\bar{G}$ (in minutes) by

$$\bar{G} = \left[\frac{6246.671\ h}{(V_M + V_F)\ V_B^2} \quad uV_B + \frac{18,427.680}{(V_M + V_F)\ V_B} \right] uV_B \cos \varepsilon_c \quad ,$$

where $h \doteq 0.00059 \ \frac{\delta}{c_5} \sqrt{30\ (V_M + V_F)}$.

Step 10. α_c and $(\varepsilon_c - \bar{G})$ are the coordinates in the xyz-system of the actual bullet-line c_1 .

Step 11. The coordinates α , ε in the xyz-system of the true bullet-line c_2 , the line the bullet should have traveled to score a hit, are given by

$$\cot \alpha = \frac{Y - uV_B}{X} \quad ,$$

$$\sin \varepsilon = - \frac{\sin \varepsilon_0 \sin(\lambda + \theta_0)}{\sin \theta_0}$$

Step 12. The angle ρ between c_1 and c_2 gives the radial bullet-line error. The angle ρ can be found exactly by means of the GLOOK (see Computer's Manual), or approximately from the formula,

$$\rho \doteq 0.2909 \sqrt{(\alpha_c - \alpha)^2 \cos(\varepsilon_c - \bar{G}) \cos \varepsilon + (\varepsilon_c - \bar{G} - \varepsilon)^2} \quad ,$$

where $(\alpha_c - \alpha)$ and $(\varepsilon_c - \bar{G} - \varepsilon)$ are measured in minutes. The formula gives the value of ρ in milliradians.

If V_F is not constant, it can be found from the formula

$$V_F = 5\sqrt{(\xi_{i+1} - \xi_{i-1})^2 + (\eta_{i+1} - \eta_{i-1})^2 + (\zeta_{i+1} - \zeta_{i+1})^2} \quad ,$$

where $\xi_{i+1} - \xi_{i-1} = X_{i+1} - X_{i-1}$,

$\eta_{i+1} - \eta_{i-1} = Y_{i+1} - Y_{i-1} + 0.2\, V_B$, and

$\zeta_{i+1} - \zeta_{i-1} = Z_{i+1} - Z_{i-1}$.

C-3.03. Determination of the Bore-Point Coordinates in the x'y'z' System. (This article relates to Step 5 of the preceding Article C-3.02). The fighter-camera, which points along the positive x_1-axis for a left side attack (negative x_1-axis for a right side attack), takes a picture of the bomber. From this film the orientation of the fighter's axes $x_1y_1z_1$ with respect to the x'y'z'-system can be determined by means of four planar rotations: a roll, a pitch, a yaw and a pitch

The projector head must be positioned so that the camera bore-point is at the center of the flat screen and rotated through the same angle as the camera.

Project the fighter film on the flat screen and mark on the screen the image Q of the vulnerable point of the bomber, the bomber's line-of-flight L and the bore-point B .

1. Zero all GLOOK and transit scales and using the lower azimuth adjustment point the telescope at the center of the screen. The saddle is now parallel and the rocker and telescope perpendicular to the screen. Throughout this problem the ring and turntable are not moved from their initial positions. Let the telescope represent the x_1-axis of the fighter, positive in the direction of sight for a left side attack (negative in the direction of sight for a right side attack), and the center of the telescope the point F . It is desired to determine the position of the x'y'z'-system relative to the fighter's system $x_1y_1z_1$.
2. Roll the saddle and pitch the rocker until the horizontal cross-hair of the telescope lies on the line L . This operation positions the telescope so

that it represents the x_3-axis and thus determines the position of the fighter's axes after the first two planar rotations, a roll R followed by a pitch P . The x_3y_3-plane now contains the Y'-axis.

3. Using the lower azimuth adjustment, sight on Q . Then using the upper azimuth adjustment turn the telescope through the angle $\theta_0' - 90^\circ$ for a left side attack ($90^\circ - \theta'$ for a right side attack). This is the third planar rotation, a yaw Y , and the x_4y_4-plane now not only contains the Y'-axis, but the x_4-axis as represented by the telescope is perpendicular to the Y'-axis.

4. The fourth planar rotation, a pitch P' , is accomplished by turning the telescope (transit elevation adjustment) through the angle $180^\circ - \varphi_0'$ for a left side attack (φ_0' for a right side attack). The telescope now represents the x'-axis, positive for a left side attack and negative for a right side attack, and the GLOOK base the original fighter axes $x_1y_1z_1$.

5. Mark on the screen the point A at which the telescope is pointed. Also mark the four points A_1 , A_2 , A_3 , A_4 on and near the ends of both cross-hairs. This determines the orientation of the telescope. To provide a check point on this in the next operation, move the telescope in elevation up or down and mark another point A_5 on the screen one or two feet from A .

6. Zero the transit azimuth and elevation scales. Using simultaneously the saddle, rocker and lower azimuth adjustment point the telescope at A such that the cross-hairs pass through A_1 , A_2 , A_3 , A_4 . The telescope is now oriented as in the previous operation, and when the telescope is moved in elevation, the check point A_5 should lie on the vertical cross-hair.

7. Using the transit upper azimuth and elevation adjustments sight on B . The transit azimuth and elevation scales give $\alpha_B' - 90^\circ$ and ε_B' , respectively, for a left side attack ($\alpha_B' - 270^\circ$ and ε_B' for a right side attack). The

coordinates α_B' and ε_B' represent the fighter gun bore-point in the x'y'z'-system.

C-3.04. Film Synchronization. The Fighter vs Bomber Problem when solved by the use of the CRADLE and GLOOK instead of the Gnomonic Charts demands particularly careful film synchronization. Some suggestions follow.

The roll, yaw, pitch corrections must be computed at points corresponding to the bomber film-frames as well as the fighter film-frames to be read. The angle-off θ_0' and tilt-angle φ_0' must be computed at fighter frame-intervals.

This synchronization is most easily accomplished by plotting the data as read from each film. A time value is assigned to each frame. The data can now be plotted as a function of the time and a smooth curve drawn joining the plotted points to give a graph of the function. The value of the function at any required instant can now be read from the graph and thus the values of several functions at any given instant can be determined.

The same procedure can be used to find the values of α_B , ε_B and X , Y , Z for every 0.1 second. Plot these curves as functions of time and read from the resulting graphs their values at every 0.1 second.

C-3.05. Flow Chart No. IX. The Flow Chart, though seemingly complicated, is the simplest way of presenting an overall picture of the analysis. It is an outline of the various steps in the analysis with a brief description of each, showing their order and interdependence. Though intended primarily for the supervisor, it serves also as a guide for the computer. It will be an aid to the supervisor in scheduling the computing and furnishing time estimates.

Though the constancy of V_F , the fighter speed, is not essential to the theory, it does simplify the computing. The Flow Chart gives the steps required under the assumption that V_F is constant. If V_F is not constant, its value will have been computed at each instant, per directions given in Art. C-3.02, Computations, and the Flow Chart modified accordingly.

C-3.06. Form Sheets. Ten Form Sheets (Nos. 41-50) are included for use in the computing. They provide for an orderly arrangement of the data and the various steps in the computation. They are to be used in conjunction with Flow Chart No. IX which provides, in effect, an abbreviated set of directions for their use. Each step on the flow chart tells where on the form sheets the quantity there discussed is to be computed and entered. These Sheets have been made with the assumption that the fighter speed is constant.

The first form, Form 41, lists various constants to be computed and recorded on the sheet. Most of these have no physical significance, being merely an aid in the computing to follow. On Forms 42 and 43 are computed the stabilized coordinates α_0, ε_0 of the fighter and on Form 44 the stabilized fighter gun-bore coordinates α_B, ε_B. On Form 45 are found the Cartesian coordinates X, Y, Z of the fighter leading to the direction components $X_{i+1} - X_{i-1}$, etc., of the tangent to the flight path (Form 46). In Form 47 are found $\tan \alpha_c$ and $\sin \varepsilon_c$ which gives the direction α_c, ε_c of the effective bore-line, and in Form 48 the time-of-flight u. In Form 49 are computed the gravity drop correction $\overline{G}$, and the actual α_c, $\varepsilon_c - \overline{G}$ and (with Form 48) the true α, ε bullet line directions. From Form 50 the angle ρ between them is found, which gives the radial error.

The supervisor must understand thoroughly the Flow Chart and Form Sheets. The constants on Form 41 are constant over the entire attack and probably will not change even from flight to flight. However, it is the supervisor's responsibility to check each attack and make changes in the constants if necessary. Throughout the computing the units in which quantities are measured must be carefully observed. The proper units are listed on the Form Sheets. All angles, unless otherwise stated, are to be measured in degrees and minutes.

The supervisor must keep a close watch over the data and computing to ensure its accuracy, and check it frequently for this. Any sudden jump in the values which cannot be accounted for is very likely to be due to an error.

The two simplest rough checks on data are to plot it or compute the differences of successive values. Either of these will generally show up any gross error. When the data are plotted, the curve should be smooth with a nearly constant slope. In the second method the differences should be constant or changing slowly.

Spot checking should also be applied. Pick a computation at random and repeat it, checking the final results. This should be done several times, the oftener the better. Places where the data change signs should be carefully watched and checked.

It is particularly important that the supervisor look over the work, viewing it as a whole, and check the final results for reasonableness.

ANGLE OF ATTACK AND SKID PROBLEM

CHAPTER D-1

THE THEORY - A BRIEF TREATMENT

D-1.01. Content and Assumptions. The purpose of the experiment is to measure the angles of attack and skid in a fighter plane diving at a fixed target as in a rocket attack. The assessment method described here also gives the angles of bank and dive of the plane.

The experiment is very general in its scope and could also be used to measure the angles of attack and skid in other types of planes, as bombers. There are no restrictions on the path of the fighter other than that it fly so as to keep the target circle on the ground within the field of view of the fighter camera, and itself in the field of view of the fixed target camera. With modifications, this experiment could be used to measure the attack and skid angles of a plane diving at a target such as a bomber, ship, or tank traveling in a straight line. (See Section C, Fighter vs Bomber Theory).

The theory as given in the Theory Manual is mathematically sound. Wind drift is the only important factor which has been neglected. This should be taken into account, and an obvious way of doing this would be to make the runs in pairs, one upwind and the other downwind, averaging the results. An alternative is to measure the wind velocity at the time the run is made and take this into account when computing the attack and skid angles.

D-1.02. Theory. A brief description of the assessment method is presented. A complete and detailed account of the theory together with all mathematical formulas used and their derivations will be found in the Theory Manual.

A plane whose angle of skid ν and angle of attack μ are to be measured dives at a fixed target in the form of a large circle on the ground. Data is obtained from pictures taken by two fixed motion picture cameras. One, located at the center of the target takes a picture of the fighter, and the other, located in the fighter, takes a picture of the target.

The fundamental coordinate system XYZ is located on the ground with the origin T at the target center and the Z-axis directed upward. The fighter F, starting at some point approximately above the negative Y-axis, dives at T. There are two coordinate systems in the fighter. One, $x_1y_1z_1$, is the fighter's own system (y_1-axis along the nose of the plane) and the other, xyz, is parallel to the XYZ-system (Fig. 1.1).

The direction of the fighter, as given by its coordinates α_0, ε_0 relative to the XYZ-system, is determined from data recorded by the target camera. The first part of the analysis is concerned with the determination of the orientation of the xyz-system relative to the fighter's system $x_1y_1z_1$. Knowing the direction of the fighter relative to the ground system XYZ and, from the fighter camera film, the orientation of the XYZ-system relative to the fighter's system $x_1y_1z_1$, we are able by four planar rotations to determine the orientation of the xyz-system relative to the $x_1y_1z_1$-system. The range of the fighter is found by measuring the length of the major axis of the elliptical image of the target circle on the fighter film. The direction of the tangent FF' to the flight path (Fig. 1.2) and relative to the xyz-system, is given by the angles , ; it can be computed from successive values of the coordinates α_0, ε_0 and r_0 of the fighter, and hence so can its direction $\alpha_{F'}$, $\varepsilon_{F'}$ relative to the $x_1y_1z_1$-system. The angles μ and ν may be computed from $\alpha_{F'}$ and $\varepsilon_{F'}$ (Fig. 1.3). The four planar rotations mentioned above are a roll R, a pitch P, a yaw Y, and another pitch P', and in that order. If the product of these is expressed as a product of a roll R*, a pitch P* and a yaw Y* in that order, then R* and P* are the bank and dive angles of the fighter.

CHAPTER D-2

EXPERIMENTAL REQUIREMENTS

D-2.01. Measurements and Data. Below are the experimental data which must be obtained, each with its source and required accuracy.

1. Azimuth, Elevation and Range of the Fighter with Respect to the Ground XYZ-System (for the first two, degrees and minutes, $\pm \frac{1}{2}$ min; for range, $\pm \frac{1}{2}$ yd).

   The first two quantities are determined from the camera film located at the center of the target, and the range from the fighter camera film by measuring on the screen the length of the elliptical image of the target circle.

2. Orientation of the Ground XYZ-System relative to the Fighter.

   This is not found explicitly, but is determined by the images of the target center and X-axis on the fighter-camera film.

3. FLINK-BLINK Lag (seconds, $\pm$ 0.005 sec).

   The amount of this lag will be found in the Equipment Manual, Airborne Installations.

4. Camera and Projector Lens Calibration (inches, $\pm$ 0.01 inch).

   See Bomber vs Fighter (Section A) for details of lens calibration. The manufacturer's nominal rating is not exact enough for our purposes.

D-2.02. Film Synchronization. Data are gathered from two sources, the target- and the fighter-cameras which run at nearly the same speed. At present the films are correlated by means of timing marks on their edges which show the second at which a given frame was exposed. It is desirable that the films be matched to within 1/8 of a frame (0.005 sec); synchronizing methods of satisfactory characteristics are under development.

A further difficulty is introduced by the lag in the FLINK-BLINK unit. However, this lag is a known constant which can be allowed for when matching the films.

D-2.03. Error Estimates. It is hoped to be able to measure the angles of attack, skid, bank and pitch to within an accuracy of one mil. There is a good possibility of attaining this accuracy for the last two, but it is unlikely that the present equipment will do as well for the attack and skid angles.

The critical step in the experiment is the determination of the direction of the tangent to the flight path. This is done by locating from the ground the position of the fighter at 0.1-second intervals and taking the tangent to the path as the line joining two successive points. It is easily seen that a small error in locating the position of the fighter may result in a large error in the determination of the direction of the tangent which, in turn, will produce a comparable error in the measurement of the attack and skid angles. The angles of bank and dive do not depend on the flight path and hence are not subject to this possible error.

The estimated maximum errors likely to be introduced in the various stages of the computation are listed below:

Instrument Installation

Azimuth	± 3 min
Elevation	± 3 min

Reading of Target Film by CRADLE

β_0'	± 2 min
ψ_0'	± 2 min

Plotting, Smoothing and Reading of Data

	Plotting and Smoothing	Reading
r_0	± 6 yards	± 2 yards
β_0'	± 3 yards	± 1 yard
ψ_0'	± 3 yards	± 1 yard
α_T	± 3 yards	± 1 yard
ε_T	± 3 yards	± 1 yard
α_Q	± 3 yards	± 1 yard
ε_Q	± 3 yards	± 1 yard

Reading of Fighter Film by CRADLE

r_0	± 3 yards
α_T	± 2 yards
ε_T	± 2 yards
α_Q	± 2 yards
ε_Q	± 2 yards

Computation of Angles of Attack, Skid, Bank and Dive by the GLOOK

μ	± 2 min
ν	± 2 min
R*	± 2 min
P*	± 2 min

Possible Maximum Errors in the Computation of the Direction of the Flight Path

(Fighter Speed: 300 mph)

	Straight Course, i.e. $\lvert \beta'_{i+1} - \beta'_{i-1} \rvert \leqq 5$ min, $\lvert \psi'_{i+1} - \psi'_{i-1} \rvert \leqq 12$ min		Weaving Course, i.e. $\lvert \beta'_{i+1} - \beta'_{i-1} \rvert \leqq 30$ min, $\lvert \psi'_{i+1} - \psi'_{i-1} \rvert \leqq 30$ min	
Total Possible Maximum Error of ± 2 minutes in and ψ'_0.	α_F ± 37 min	ε_F ± 30 min	α_F ± 2° 44'	ε_F ± 2° 27'
Total Possible Maximum Error of ± 6 minutes in and ψ'_0.	α_F ± 47 min	ε_F ± 2° 32'	α_F ± 3° 00'	ε_F ± 1° 29'

It is emphasized that these figures represent greatest possible errors. In practice, the errors will often be much less, and will tend to cancel each other. However, in view of the possible size of those in α_F and ε_F an accuracy of better than ± 40 min cannot be expected in the measurement of μ and ν, even under the most favorable conditions.

In view of the above table it is recommended that this experiment be tried for only straight courses if an accuracy of ± 50 min is desired. If an accuracy of only ± 3 degrees is sufficient, then weaving courses also may be assessed.

The table below shows the percentage of the time the error will be numerically less than a given angle. (The percentages for μ and ν were computed for a straight course, a fighter speed of 300 mph, and a possible total maximum error of ± 2 min in β'_0 and ψ'_0)

Percentage of Time the Error can be expected to be Less than a Given Angle

Angle	R* or P*	μ or ν
1 min	15 %	2 %
2	30	3
3	44	5
4	56	7
5	67	9
10	95	17
15	99	26
20		35
25		44
30		52
35		61
40		70
45		79
50		87
55		96

CHAPTER D-3

COMPUTING PROCEDURE

D-3.01. Scope. The detailed procedure for processing the data is given in the following: first, the outline of the computational steps together with formulas; then, the procedure for synchronizing the data from the various films; and, finally, the Flow Chart X (see left part of Manual) and Form Sheets Nos. 61-64.

D-3.02. Computations.

Step 1. Using the CRADLE and target film find β_0' and ψ_0', where $\beta_0 = \beta_0' + 90^\circ$ and $\psi_0 = \psi_0' + 270^\circ$ are the traverse and inclination angles, respectively. (If the Gnomonic Charts instead of the GLOOK are to be used to solve the four planar rotations, find α_0 and ε_0 rather than β_0' and ψ_0'). See Computer's Manual for details and P-14 Memo No. 37 for theory.

Step 2. Using the CRADLE and fighter film, compute the range r_0, and the coordinates α_T, ε_T of the target center T and the coordinates α_0, ε_0 of the point of intersection Q of the positive X-axis and the target circle, both relative to the $x_1y_1z_1$-system. See Computer's Manual for details. ($r_0 = \frac{dmf}{s}$, where d is the diameter of the target in yards, s the length in inches of the major axis of its elliptical screen image, m the magnification, and f the focal length of the camera lens in inches. With these units the above formula gives r_0 in yards).

Step 3. Compute the Cartesian coordinates of the fighter in the XYZ-system by the formulas:

$$X = -r_0 \sin \beta_0' = r_0 \sin \alpha_0 \cos \varepsilon_0 ,$$

$$Y = -r_0 \cos \beta_0' \cos \psi_0' = r_0 \cos \alpha_0 \cos \varepsilon_0 ,$$

$$Z = r_0 \cos \beta_0' \sin \psi_0' = r_0 \sin \varepsilon_0 .$$

Step 4. Compute the direction α_F , ε_F of the tangent to the flight path relative to the xyz-system from:

$$\tan \alpha_F = \frac{X_{i+1} - X_{i-1}}{Y_{i+1} - Y_{i-1}} ,$$

$$\tan \varepsilon_F = \frac{Z_{i+1} - Z_{i-1}}{Y_{i+1} - Y_{i-1}} \cos \alpha_F ,$$

where $X_{i+1} - X_{i-1}$ is the value of X at t - 0.1 seconds subtracted from its value at t + 0.1 seconds.

Step 5. Using the GLOOK, find the attack and skid angles μ and ν , and, if desired, the bank and dive angles R^* and P^* . See Computer's Manual for details and P-14 Memo No. 37 for theory.

D-3.03. Film Synchronization. The synchronization of the two films is most easily accomplished by plotting. A time value is assigned to each frame (see procedure in the Computer's Manual). The data can now be plotted as a function of the time and a smooth curve drawn joining the plotted points to give a graph of the function. The value of the function at any required instant can now be read from the graph and thus the values of both functions at any given instant determined.

The same procedure can be used to find the values of X, Y, and Z for every 0.1-second: plot these curves as functions of time and read from the resulting graphs their values at every 0.1 second.

D-3.04. Flow Chart X. The Flow Chart, though seemingly complicated, is the simplest way of presenting an overall picture of the analysis. It is an outline of the various steps in the analysis with a brief description of each, showing their order and interdependence. Though intended primarily for the supervisor, it serves also as a guide for the computer. It will be an aid to the supervisor in scheduling the computing and furnishing time estimates.

D-3.05. Form Sheets. Four Form Sheets, Nos. 61, 62, 63 and 64, are given for use in computing. They provide for an orderly arrangement of the data and the various steps in the computation. They are to be used in conjunction with Flow Chart No. X which provides, in effect, an abbreviated set of directions for their use. Each step on the flow chart tells where on the form sheets the quantity there discussed is to be computed and entered.

On Form Sheet No. 61 are computed the spherical coordinates β_0' , ψ_0' , r_0 of the fighter and the coordinates α_T , ϵ_T , α_Q , ϵ_Q of the target relative to the fighter. On the second, No. 62, are computed the cartesian coordinates X, Y, Z of the fighter, and on the third the direction α_F , ϵ_F of the flight-path relative to the xyz-system. The last, No. 64, is for computing μ and ν , the angles of attack and skid, and R^* and P^* , the bank and dive angles.

The supervisor must understand thoroughly the flow chart and form sheets. Throughout the computing the units in which quantities are measured must be carefully observed. The proper units are listed on the form sheets. All angles, unless otherwise stated, are to be measured in degrees and minutes.

The supervisor must keep a close watch over the data and computing to ensure its accuracy and check it frequently for this. Any sudden jump in the values which cannot be accounted for is very likely to be due to an error.

The two simplest rough checks on data are to plot it or compute the differences of successive values. Either of these will generally show up any gross error. If the data is plotted, the curve should be smooth with a nearly constant slope. In the second method the differences should be constant or changing slowly.

Spot checking should also be applied. Pick a computation at random and repeat it, checking the final result. This should be done several times, the oftener the better. Places where the data change signs should be carefully watched and checked.

It is particularly important that the supervisor look over the work, viewing it as a whole, and check the final results for reasonableness.

FLIGHT PATH PROBLEM

CHAPTER E-1

THEORY AND METHOD

E-1.01. Objective of the Experiment*. During the summer of 1945, a project designated as F. C. No. 36 was carried out at A. T., U. S. N. A. T. C., Patuxent River, to determine the actual flight path of an Army RP-63 fighter when making specified pursuit-curve attacks on a bomber flying straight and level at constant speed. This path was desired relative to the bomber and also to the air mass. One reason for this experiment was to determine how closely the fighter stayed in the plane of action, defined as the plane** of the bomber's path and the fighter's position at the beginning of the attack.

E-1.02. Experimental Requirements. Since the target range, azimuth, and elevation, found in the course of the assessment for F. C. No. 14, are essentially the spherical coordinates of the fighter relative to the turret axes at the Martin forward crown-turret, the first part of the Flight Path Problem amounts to a partial assessment of the type discussed in Section A of this Manual, using the PB4Y-2, A. T. No. 14, for the bomber. To obtain the path relative to the air mass it is only necessary to convert the spherical coordinates to a set of rectangular coordinates, one of whose axes coincides with the path of the bomber, and add to the corresponding coordinate the distance the bomber traveled from an arbitrarily chosen starting point. Since the turret axes must be stabilized in the sense that they only translate along the bomber's path and do not rotate, corrections for bomber roll, yaw, and pitch are required.

In view of the fact that the RP-63 possessed neither winglights nor wingmarks, the range scaling procedure would not have been sufficiently accurate on gun-camera film taken

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* For further details see "Final Report on Photographic Assessment of RP-63 Aircraft Pursuit Attacks", (Restricted), Project No. PTR 32261, 24 Sep 1945, Armament Test, U. S. Naval Air Test Center, Patuxent River, Maryland.

** This should really be called the initial plane of action.

with a 2-inch lens because of the difficulty in seeing the wingtips. This problem was solved by installing a special 10-inch lens in the Martin rear crown-turret gun-camera, thus obtaining an image about five times the size of that given by a 2-inch lens. It was not considered advisable to use the 10-inch lens on the Martin forward crown-turret gun-camera because of the restricted field of view and because the CRADLE was set up for the 2-inch lens.

Gun, target, and gyro data were gathered in the same fashion as in F. C. No. 14 (Chapter A-2). Sight-cameras were not used, since no question of gunners' performance was involved. They merely had to track well enough to keep the fighter in the field of view of the gun-cameras.

E-1.03. Method of Analysis. The RAZEL- and forward crown-turret gun-camera films are processed in the same manner as in F. C. No. 14, except that the wing distances are not scaled. The rear crown-turret gun-camera film is projected separately and the wingspan scaled from it. Careful alignment of the frames is not required for the latter.

The reading of data from gyro film is carried out as before, but it is to be interpreted differently. There being no firing nor impact times in this problem, local stabilization (Section A-3.04) has no meaning. Here the stabilized fighter position means its azimuth and elevation with respect to stabilized axes (XYZ) where the origin is at the center of the Martin forward crown-turret, XY-plane is horizontal, and the bomber's path is directed along the Y-axis. In this connection it must be emphasized that Gyro Set No. 2, used in this experiment, was installed differently from Set No. 1 (Section A-2.07) in that the axes of the former were parallel to the turret axes instead of being rotated through the expected flight angle from that position. Hence the pitch readings will include the flight angle. Since this is correct when the GLOOK is to be used in the order YRP (see the Theory Manual, Chapter A-4), the pitch readings should not be corrected for initial pitch. There is of course an uncertainty due to the fact that it is impossible to tell how much of the initial reading is flight angle and how much is misalignment of the

Z-rotor when erected. However, the fact that the pitch readings turned out to be in the neighborhood of 2 or 3 degrees (actually -2 or -3 degrees, but the signs must be reversed) indicates that flight angle is the principal contribution and therefore justifies neglecting the initial pitch.

A further difficulty results from the fact that the gyro rotor-axes will fail to be aligned perpendicular to each other by the amount of the initial pitch even if the erection mechanism works perfectly, owing to the gravity erection on the Z-rotor. This much misalignment and the previously mentioned uncertainty together may cause the stabilized azimuth and elevation to be in error by several minutes, but will generally produce errors of less than $\pm$ 3 yards in the rectangular coordinates of the fighter and so are considered tolerable.

E-1.04. Form of Results. As far as the path relative to the bomber is concerned, the spherical coordinates (r = range, α = stabilized azimuth, and ε = stabilized elevation) constitute a sufficient answer and are tabulated vs time (see Fig. 1.01). However, to provide a convenient visual representation, as well as to obtain the path relative to the air mass as mentioned in Section E-1.02, it is necessary to convert them to rectangular coordinates. This may be accomplished by means of the formulas:

$$\begin{aligned} x &= r \cos\varepsilon \sin\alpha \\ y &= r \cos\varepsilon \cos\alpha \\ z &= r \sin\varepsilon \end{aligned} \qquad \text{Equation (1)}$$

the derivation of which may be seen by reference to Fig. 1.02. Then (x, y) is a point on the projection of the fighter's path on the XY-plane, (x, z) on the XZ-plane, and (y, z) on the YZ-plane. These three plane projections are plotted to give the "relative" curves, a sample of which is shown in Fig. 1.03.

Since the bomber's path is along the Y-axis, a point on the path relative to the air mass has the coordinates (x, y', z) where x and z are the same as in Equ. (1) and $y' = y + v_b t$, v_b being the bomber's TAS (constant) and t the time since the start of the attack, taken as the instant when the range is about 800 yards. The projections of this path are also plotted on the same graphs, giving the "actual" curves of Fig. 1.03. Note that the projection on the XZ-plane is the same for both relative and actual paths.

Also plotted is the projection of the plane of action, as defined in Section E-1.01, on the XZ-plane. This projection is a straight line through 0 and the initial point of the XZ-projection of the paths. A comparison of these projections indicates how well the fighter stayed in the plane of action.

In addition to the scales along the X, Y, and Z axes on the graphs, the XZ-plane carries scales of range and time corresponding to x . These provide a ready means of determining the range and time at any given point on the relative or actual path.

CHAPTER E-2

DETAILED PROCEDURES (F. C. NO. 36)

E-2.01. Form 10. This sheet is used as before (see Section A-5.03), except that Cols 10-B and 10-E are omitted. The data were read from the RAZEL film at every third frame as in F. C. No. 14, but it turned out later that every sixth frame would have been sufficient, since these attacks all originated aft of the beam and hence the position of the fighter changed relatively slowly.

E-2.02. Form 11. This sheet is also used in general as before (see Section A-5.04), but it is advisable to employ two separate sheets, one for the ranging from the rear crown-turret gun-camera and the other for the target position from the forward crown-turret gun-camera. On the former only Cols 11-A, 11-H, 11-B, and 11-C are used, and on the latter only Cols 11-A, 11-H, 11-F, and 11-G except that two unused columns may be employed to record the gun azimuth and elevation read from P10-F and P10-G at the times of Col 11-H.

The plotting of the target azimuth (P11-F) and elevation (P11-G) vs Col 11-H is required only as a check for accuracy, since no interpolation is required in these data. This graphical step should be carried out as the values are read from the CRADLE, in order to check doubtful points with a minimum of inconvenience. Smoothing is unnecessary except as required to tell whether points are out of line. The supervisor should examine and approve these data before the analysis proceeds further.

E-2.03. Form 21. The only changes from the previous procedure for this sheet (see Section A-5.09) are that Col 21-J is omitted and Col 21-G is merely the negative of Col 21-D, the initial pitch reading being ignored for the reasons stated in Section E-1.03.

E-2.04. Form 24. This sheet is used with the GLOOK problem to find the stabilized azimuth and elevation, the details of which are stated in the Computer's Manual, Section I, GLOOK Problem Solution No. 3.

Cols 24-A and 24-B are for the frame numbers to be assessed on the Martin forward crown-turret gun-camera film and their corresponding times obtained from the proper conversion table.

Cols 24-C and 24-D are the same as Cols 11-F and 11-G, respectively, or may be read from P11-F and P11-G, respectively. Be sure that Cols 11-F and 11-G have been checked before using them here.

Cols 24-E, 24-F, and 24-G are read from P21-G, P21-H, and P21-F, respectively, at the times of Col 24-B. The data needed for the GLOOK problem have now been assembled.

Cols 24-H and 24-J are used to tabulate the results of the GLOOK problem. Rough checks of the type employed in Section A-5.11 are harder to develop here, because the pitch, which is equivalent to the pitch difference, is of the order of 2 or 3 degrees. Hence it will in general have a noticeable effect on both azimuth and elevation.

P24-H and P24-J. The stabilized azimuth and elevation are plotted vs Col 24-B as a check on accuracy and to permit smoothing for interpolation. To avoid confusion, a separate working sheet from that used for gun and unstabilized target data is usually required. Again this graphing should be done as the values are obtained, to simplify repeating the GLOOK problem for doubtful points.

S24-H and S24-J. Smoothing of P24-H and P24-J must be performed with care and should be checked by the supervisor before the next step is carried out.

E-2.05. Form 25. This sheet is used to transform from spherical to rectangular coordinates in accordance with the method explained in Section E-1.04.

Col 25-A. To simplify the time scale for purposes of tabulating and plotting final data, Col 25-A is listed every 0.2 second.

Cols 25-C and 25-D are for tabulating the smoothed, stabilized fighter azimuth and elevation read from S24-H and S24-J, respectively, at the times of Col 25-A.

Col 25-B. The smoothed range available on S11-C is measured from the Martin rear crown-turret. To correct it for parallax to the Martin forward crown-turret, it is read at the times of Col 25-A, θ is found as in Section A-5.05 from Cols 25-C and 25-D, and the range correction given in the proper table in Chapter A-8 of the Theory Manual applied. These steps can all be performed mentally and the results recorded in Col 25-B. However, the supervisor should check it before further calculations are carried out.

Cols 25-E, 25-F, 25-G, and 25-H provide spaces for tabulating the sines and cosines of Cols 25-C and 25-D, which are needed for the calculations of x, y, and z by Equ. (1) of Section E-1.04. Convenient tables of sines and cosines are to be found, for example, in the "Mathematical Tables from the Handbook of Chemistry and Physics", 7th edition, p. 86 et Seq. Care must be exercised to take data from the proper columns of these tables and especially to attach the correct algebraic sign, which is not given in the table.

Cols 25-J, 25-K, and 25-L are for recording the computed values of z, y, and x, respectively. These calculations can be readily performed on a modern computing machine. Again care must be taken to carry the proper sign to each result.

The value of y' is easily calculated by adding the product of v_b, which should be listed at the bottom of Form 25, and Col 25-A algebraically to Col 25-K, an operation also well suited to a computing machine. No column was provided for Y', but it may be listed in the right margin of Form 25, or Col 25-K can be divided in half vertically and one part of it used for y'.

E-2.06. Form 26. This sheet was originally intended for use with calculations designed to give a quantitative estimate of the fighter's performance with regard to staying in the plane of action. The plan was to determine ε', the value which the stabilized elevation would have had if the fighter had stayed in the plane of action. Then $(\varepsilon - \varepsilon')$ was a measure of the deviation from the plane of action. Since it was decided later that the graphical measure (Fig. 1.03) was sufficient, the details of Form 26 will be omitted.

BIBLIOGRAPHY

(see also Section A)

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Section A: Bomber vs Fighter. Elliott L. Buell and Marjorie J. R. Wiley

Section B: Evasive Action. George M. Brown and Nye F. Morehouse, Jr.

Section C: Fighter vs Bomber. William E. Durfee

Section D: Angle of Attack and Skid Problem. William E. Durfee

Section E: Flight Path Problem. Elliott L. Buell and Marjorie J. R. Wiley

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PROJECT 14 PERSONNEL

The following is a complete list of those associated with the active life of Project 14. The listing includes not only the permanent staff, but also those whose employment was temporary, or part-time, as necessitated by the shifting burdens in the different stages of the work. Of the 105 members listed, a peak employment of about seventy was reached during the summer of 1945.

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N O T I C E

This Volume is subject to revision because of development work now in progress on improved instrumentation.

The revision sheets will be sent, as they appear, to the same source from which this Volume was obtained.

EXHIBITS

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GLOSSARY

The following terms are encountered in aerial gunnery-assessment operations. The list contains only those terms not in common scientific use, or those employed in a special or limited sense.

ACTUAL: as applied to this assessment, an adjective describing a situation as it really existed, as distinguished from what it should have been (see also TRUE).

ACTUAL BORE-LINE: the direction of the centerline of a gun barrel.

ACTUAL BORE-POINT: any convenient point on the actual bore-line.

ACTUAL LEAD: the angular displacement of the actual bore-line from the line-of-sight.

AIMING PIP: (see Mk 18 SIGHT).

AIR MASS: the stationary body of air in the vicinity of an aerial assessment test, assumed to have uniform temperature, pressure and velocity.

AIR MASS COORDINATES: a set of reference axes which are fixed with respect to the air mass.

ANALOGUE TYPE OF COMPUTING MACHINE: a computing machine which solves a problem by setting up a similar geometrical or physical configuration.

ANGLE-OFF, θ: the angle between the forward direction of motion of the gun platform and the gun bore-line (see Section A-1.04 and Fig. 1.01).

ANGLE-SHOTS: pictures for each gun- or sight-camera and lens, showing part or all of the photo target range, for which the angular displacements of the various targets are known.

APPARENT WINGSPAN: (see WINGSPAN).

ASPECT: in general, the attitude of the target as seen by the gunner; specifically, the foreshortening of the wingspan when not viewed perpendicularly.

ASPECT ANGLE: the angle between the line of sight and a plane perpendicular to the wing line from tip to tip.

ATTACK: one pass by a fighter against a bomber.

ATTITUDE OF BOMBER: the direction of the bomber-axes at any instant with respect to the gyro-axes (see Section A-2.07).

AUXILIARY TRANSIT: a transit used in conjunction with a GLOOK, PLAXIE, or other computing instrument, but not an integral part of it, for the purpose of "marking" a desired direction and sometimes also to read a given or desired elevation.

AXIS: (1) a line about which rotation takes place.

ROTATION-AXES OF A TRANSIT: the two axes about which the telescope can be rotated, called the azimuth axis and the elevation axis.

ROTATION-AXES OF A TURRET: the two axes about which the guns can be rotated, called the azimuth and elevation axes on the Martin crown-turret and the inclination and traverse axes on the Erco waist-turret (see Fig. 1.02).

(2) a reference line of a coordinate system.

BOMBER-AXES, (X, Y, Z): any coordinate system with axes parallel to the turret axes at the Martin forward crown-turret (X, Y, Z). The origin is located wherever convenient for the purpose at hand (see Section A-2.03).

GUN-AXES AT THE ERCO PORT WAIST-TURRET, (X_g, Y_g, Z_g): a coordinate system whose origin is at the turret center, whose X_g-axis is always parallel to the gun bore-line and whose Y_g-axis is parallel to the traverse plane (see Section A-2.03 and Fig. 2.06).

GYRO-AXES, (X_G, Y_G, Z_G): a coordinate system which translates with the bomber but does not rotate, and which coincides initially (when the gyros are aligned) with (X_r, Y_r, Z_r) (see Section A-3.04).

GYRO-COORDINATE AXES, (X_r, Y_r, Z_r): a coordinate system specified by the rigid mounting of the gyro box; the X_rY_r-plane is parallel to the plane of the yaw dial, the Y_rZ_r-plane to that of the pitch dial, and the Z_rX_r-plane to that of the roll dial (see Section A-2.07 and Fig. 2.13).

TURRET-AXES AT THE ERCO PORT WAIST-TURRET, (X_t, Y_t, Z_t): a coordinate system whose origin is at the turret center and which differs from the bomber-axes at that turret only by a rotation of the XY-plane through the offset angle in the negative azimuth direction (see Section A-2.03 and Figs. 2.04 and 2.05).

TURRET-AXES AT THE MARTIN FORWARD CROWN-TURRET, (X, Y, Z): a coordinate system whose origin is at the turret center, whose Z-axis coincides with the turret's axis of rotation, and whose Y-axis is parallel to the bomber's plane of symmetry (see Section A-2.03 and Fig. 2.02).

AZEL: an instrument which indicates gun azimuth and elevation directly on appropriate scales (see also RAZEL).

AZIMUTH (α): with respect to bomber-axes (X, Y, Z), the angle between the positive Y-axis and the projection of a given direction from the origin onto the XY-plane (see Section A-2.03 and Fig. 2.03).

AZIMUTH ERROR: the azimuth component of an error.

GUN AZIMUTH (α_G): the azimuth of the gun bore-line.

PLAXIE AZIMUTH SETTING (α_1): in parallax correction between 0 and 0' , the azimuth of the direction 00' (see Section A-3.05 and Fig. 3.11).

TARGET AZIMUTH (α_T): the azimuth of the direction from the origin of the bomber-axes to the target point.

BI-CAMERA: (see TARGET-CAMERAS).

BOMBER-AXES: (see AXES).

BORE-LINE (or GUN BORE-LINE): the direction of the centerline of a gun barrel, i.e., the direction in which the gun is pointed.

BORE-POINT: any convenient point on the bore-line.

BORESIGHTING: the process of aligning a camera's or sight's optical-axis parallel to a given bore-line.

BULLET DISPERSION: the phenomenon that projectiles fired from a fixed gun do not all strike the same point, but tend to be grouped in a regular pattern about a mean point of impact.

CATALOGING MARKS: a set of dots or streaks placed on a film by a special lamp, generally toward the end of each attack, for the purpose of identifying the attack to which the film belongs.

CENTER OF A PICTURE ON A SCREEN: the intersection of the diagonals (assuming a rectangular frame).

CENTER OF A TURRET: the chosen origin of the turret axes (see Section A-1.04 and A-2.03).

CIRCULAR MIL: 1/1600 of a right angle (6400 circular mils = 360°).

CRADLE: a computing instrument designed for use in reading data from projected film and performing certain rotations of axes at the same time (see Section A-3.03 and Figs. 3.01, 3.02, and 3.03).

CRADLE AXIS: the fixed horizontal axis about which the CRADLE transit rotates (see Section A-3.03 and Fig. 3.01).

CUTTING BARREL (or FILM CATCHALL): a lined fiber receptacle for unwound film to prevent damage to it.

DEFLECTOMETER: a device built for the AAF for turret installation, using flexible cables to move dials which indicate gun azimuth and elevation for recording directly on the gun-camera film (see Section A-2.04 and Fig. 2.08).

DEFLECTOMETER-CAMERA: a gun-camera whose pictures show also deflectometer dial readings on the edges (see Fig. 2.08).

DEPENDENT ERRORS: (see ERRORS).

…CTIONAL STABILIZER: (see GYROS).

…PERSION: (see BULLET DISPERSION).

DOFOGRAPH: a graphical representation of ballistic deflections (gravity drop and trail), giving specifically the rate of azimuth and elevation component deflections in minutes of arc per second of time-of-flight (see Sections A-1.04 and A-5.12 and Fig. 5.06).

DRY RUN: an attack in which no actual firing occurs.

ELEVATION, (ε): with respect to bomber-axes (X, Y, Z), the angle between the projection of a given direction from the origin onto the XY-plane and the direction itself (see Section A-2.03 and Fig. 2.03).

ELEVATION ERROR: the elevation component of an error.

GUN ELEVATION, (ε_G): the elevation of the gun bore-line.

PLAXIE ELEVATION SETTING, (ε_1): in parallax correction between 0 and 0' , the elevation of the direction 00' (see Section A-3.05 and Fig. 3.11).

TARGET ELEVATION, (ε_T): the elevation of the direction from the origin of the bomber-axes to the target point.

ERCO WAIST-TURRET: a turret manufactured by the Engineering Research Corporation and installed in the PB4Y-2, A. T. No. 14 (see Fig. 2.01 (b)).

ERECTING MECHANISM: a device for aligning the axes of the gyros initially parallel to specified directions.

ERROR: a failure or shortcoming of a device or method as distinguished from a mistake (see Section A-7.06).

DEPENDENT ERRORS: two or more related errors, where the size of one affects the others.

INDEPENDENT ERRORS: two or more unrelated errors, where the size of any one is not affected by that of any other.

EVASIVE ACTION: any intentional deviation of an aircraft from a straight path or constant speed.

FIDUCIAL MARKS: on a film, the triangular indentations on the middle of the edges of each frame, useful in aligning the image on the screen (see Section A-3.06 and Fig. 2.08).

FILM CATCHALL: (see CUTTING BARREL).

FILM TEST-STRIPS: (see LENS CALIBRATION-SHOTS).

FIRING TIME (or PRESENT TIME): the instant when a projectile is assumed to be fired from a gun.

FIXED RETICLE: (see Mk 18 SIGHT).

FLIGHT: one sortie. In aerial assessment several attacks are usually executed in the course of each flight.

FLIGHT ANGLE, (P_o): the angle between Z_r and Z ; approximately the aerodynamic angle of attack of the wings (see Section A-2.07 and Fig. 2.13).

FLIGHT SHEETS: a record of the conditions, equipment, and personnel involved in each flight (see Section A-2.09 and Figs. 2.15 and 2.19).

FORM SHEETS: data sheets for use in carrying out the assessment systematically (see Chapter A-5 and A-6). For the method of denoting columns and the operations of plotting and smoothing, see Section A-5.03.

FRAME: one picture on a motion picture film.

FRAMING-MARKS: boundary lines placed on the screen to designate the proper position of a projected image (see Sectiona A-3.03 and A-3.06, also Figs. 3.02 and 3.03).

FUTURE TIME: (see IMPACT TIME).

GLOOK: a computing instrument designed to [illegible] e more general rotations of axes than the CRADLE; for example, in corrections [illegible] nges in bomber attitude (see Section A-3.04 and Figs. 3.04 and 3.05).

GRAVITY DROP: the deflection of a projectile from a straight path due to gravity.

GRAVITY DROP ANGLE: the angular deflection of a projectile due to gravity drop, the vertex being at the origin of the turret axes.

GUN-AXES: (see AXES).

GUN BORE-LINE: (see BORE-LINE).

GUN-CAMERA: a motion picture camera aligned parallel to the gun bore (often attached to a gun) for the purpose of photographing the location of the target with respect to the bore-line, i.e., to record the actual lead (see Section A-2.05 and Fig. 2.09).

BORESIGHTED GUN-CAMERA: a gun-camera whose optical-axis is parallel to the bore-line. (See also GUN-CAMERA).

OFFSET GUN-CAMERA: a gun-camera whose optical-axis makes a fixed, non-zero angle with the bore-line. (See also GUN-CAMERA).

GUN-LEAD: the angle at the gun between the line-of-sight and the bore-line.

GUN-LEAD ERRORS: errors in the gun-lead, usually consisting of the radial error and its components in elevation and either azimuth or traverse.

GUNNER'S RANGE ERROR: the range-input minus the range.

GUNNER'S TRACKING ERRORS: measures of the gunner's failure to keep the aiming pip on the target, usually consisting of the radial error and its components in elevation and either azimuth or traverse.

GUN-SIGHT: (see SIGHT).

GYRO: gyroscope, a device which, when free, maintains a fixed direction in space (see Section A-2.07).

DIRECTIONAL STABILIZER GYRO (Y-ROTOR): a particular type of gyroscope whose axis of rotation is designed to be parallel to Y_G (or X_G); measures yaw.

VERTICAL FLIGHT GYRO (Z-ROTOR): a particular type of gyroscope whose axis of rotation is designed to be parallel to Z_G ; measures roll and pitch.

GYRO-AXES: (see AXES).

GYRO-CAMERA: a motion picture camera which photographs the gyro scales (see Fig. 2.11

GYRO-COORDINATE AXES: (see AXES).

IMPACT TIME (or FUTURE TIME): the instant when a projectile fired at firing time is assumed to strike the target.

INCLINATION: on the Erco port waist-turret, (1) the motion of the guns about the turret's axis of rotation (see Fig. 1.02); (2) the dihedral angle between the X_tY_t-plane and the traverse plane (see Fig. 2.06).

INDEPENDENT ERRORS: (see ERRORS).

INDICATED AIR SPEED, (IAS): the speed shown on an aircraft's indicated airspeed meter.

INITIAL READINGS: the roll, yaw, and pitch indicated on the gyro dials at the instant the gyros were freed (see Section A-2.07). If the erecting mechanism works perfectly, the initial readings will agree with the zero dial readings.

JUMP CARD TESTS: an experimental procedure for determining bullet dispersion.

LEAD: (see GUN LEAD).

LENS CALIBRATION-SHOTS (or FILM TEST-STRIPS): films used to align or check the location of the film-reading equipment; e.g., angle-shots, level-shots, and position-shots.

LEVEL-SHOTS: pictures for each installed gun- and sight-camera and lens showing a line parallel to the XY-plane (see Sections A-2.10 and A-3.06 and Fig. 3.13).

LINE-OF-SIGHT: the direction from the gun or sight to the target.

LOCAL STABILIZATION: the process of calculating the target direction with respect to gyro-axes from its direction with respect to turret-axes and the roll, yaw, pitch data.

Mk 18 SIGHT: a gyroscopic fire control device designed to compute the true lead when the gunner tracks and ranges correctly.

AIMING PIP: the center pip of the moving reticle, to be kept in line with the target while tracking.

FIXED RETICLE: the lighted pip which always shows the bore-line (unless it is superelevated), if the sight is properly installed.

MOVING RETICLE: the lighted pips which move from the fixed reticle direction in order to allow for the required lead.

RANGING PIPS: the set of six pips arranged in a circle around the center pip, the diameter of this circle being controlled by the gunner during ranging.

MARTIN CROWN-TURRET: a turret manufactured by the Glenn L. Martin Company and installed in the PB4Y-2, A. T. No. 14 (see Fig. 2.01 (a)).

MIL: a small unit of angular measure; may refer to circular mil, milliradian, or Navy mil (see Section A-5.13).

MILLIRADIAN: 0.001 radian.

MISTAKE: a failure of some person to perform an operation or calculation correctly (see Section A-7.06).

MOVING RETICLE: (see Mk 18 SIGHT).

NAVY MIL: arc tan 0.001; 1 milliradian = 1.0000003 Navy mils.

OFFSET ANGLE, (δ): the angle in the XY-plane between the Erco waist-turret's axis of rotation, Y_t , and the Y-axis (see Section A-2.03 and Figs. 2.04, 2.05 and 2.06).

OPTICAL RANGING: (see STADIAMETRIC RANGING).

OVERRANGING: describes the situation where the gunner is feeding too large a range into a Mk 18 sight by having the reticle diameter smaller than the apparent wingspan.

PARALLAX CORRECTION: the process of calculating the target position at one location from a knowledge of it at another location and their relative positions (see Section A-3.05).

PHOTO TARGET RANGE: a row of targets used in getting angle-shots, where the angular positions of the targets as seen from the optical center of the camera lens are known.

PITCH, (P): the angle through which an aircraft has turned from an initial position when rotating about an axis parallel to X , positive if the nose is up (see Section A-2.07).

PLANE OF ACTION: the plane of the gun bore-line and the direction of motion of the gun platform.

PLANE OF SYMMETRY OF AN AIRCRAFT: the plane which is perpendicular to the line connecting the wingtips and which divides the aircraft into symmetrical halves.

PLAXIE: a computing instrument designed to handle certain translations of axes, especially those involved in parallax correction (see Section A-3.05 and Figs. 3.06 and 3.07).

POSITION-SHOTS: pictures showing the location of a reference point on gun- or sight-camera film, usually taken just prior to each flight by aiming the sight at a designated target (see Sectiona A-2.10 and A-3.06 and Fig. 3.14).

PRESENT TIME: (see FIRING TIME).

PURSUIT CURVE: the path of a fighter attacking a bomber.

RADIAL ERROR: the angular difference between an actual and corresponding true direction (see Section A-5.13).

RANGE, (r): the distance from a turret center to the target point at any instant.

RANGE-INPUT: the range fed into a Mk 18 sight by the gunner by setting the wingspan of the target and adjusting the ranging pips (see Section A-2.08).

RAZEL-RANGE: range-input as recorded by the RAZEL range scale.

REMOTE-RANGE: range-input as recorded by a selsyn device activated by the sight's range circuit.

SIGHT-RANGE: range-input as calculated from the reticle diameter on the sight-camera film.

RANGING: the process by which a gunner using a Mk 18 sight attempts to keep the reticle diameter equal to the apparent wingspan of the approaching target.

RANGING PIPS: (see Mk 18 SIGHT).

RANGING-SHOT: a set of pictures designed to provide the constant which converts reticle diameter into sight-range, usually taken just before each flight with the sight set for minimum range and maximum wingspan (see Section A-5.15).

RAZEL: an instrument which indicates range-input, gun azimuth and elevation directly on appropriate scales (see Section A-2.04).

RAZEL-CAMERA: the camera photographing the RAZEL scales (see Fig. 2.07).

RELATIVE AIR DENSITY, (ρ): the ratio of the actual air density to that at sea level under standard atmospheric conditions of temperature and pressure.

RETICLE: a system of lines, circles, or points in a sight, by means of which the gunner aims and sometimes also ranges.

RETICLE DIAMETER: on a Mk 18 SIGHT, the inside diameter of the circle of ranging pips.

ROLL, (R): the angle through which an aircraft has turned from an initial position when rotating about an axis parallel to Y , positive if the starboard wing is up (see Section A-2.07).

SCREEN CENTER: the intersection of the projector's optical-axis and the screen.

SEMI-GLOOK: a CRADLE mounted on a turntable to provide motion about a vertical axis; equivalent in motions to a GLOOK lacking either its rocker or saddle (see Section A-3.03).

SIGHT (or GUN-SIGHT): a device used in observing a target for purposes of aiming a gun.

SIGHT-CAMERA: the camera photographing what the gunner sees through the sight (see Fig. 2.14).

SIGHT-POINT: the center of the aiming pip on the sight.

SINGLE-SHOT HIT PROBABILITY: the probability that a projectile fired at some instant will score a hit at some later instant.

SLOW-DOWN: the decrease in the speed of a projectile due to air resistance.

STABILIZATION: the process of correcting the target direction for changes in the aircraft's attitude over the time-of-flight, as recorded in the form of roll, yaw, pitch data.

STADIAMETRIC RANGING (or OPTICAL RANGING): the process of calculating range by measurements of the apparent size of the target.

SUPER-ELEVATION: an intentional raising of a bore-line to compensate for bullet gravity drop.

SYNCHRONIZATION: the process of controlling the speed and relative phase of all cameras and recording a regularly spaced time signal on the film.

SYNCH SYSTEM (or UNIT, SU): an electrical device for attaining desired synchronization and providing suitable control of all cameras and other recording equipment.

TARGET-CAMERAS: one or more cameras mounted in a fixed but sometimes (ground) adjustable position on an aircraft for the purpose of photographing a target (see Section A-2.05).

BI-CAMERA: a group of two target-cameras.

TRI-CAMERA: a group of three target-cameras (see Fig. 2.01 (a)).

TARGET-POINT: the point on the target which a gunner attempts to hit, taken as the center of the propeller hub on a single-engine fighter like the F6F (see Section A-1.04).

TEST-STRIPS: (see LENS-CALIBRATION SHOTS).

TIME-OF-FLIGHT (or TRANSIT-TIME, T): impact time minus firing time, i.e., the interval of time between the instant the gun is fired and the instant the projectile strikes the target, assuming that a hit is scored (see Section A-1.03).

TIME-OF-FLIGHT METHOD: (see TRANSIT-TIME METHOD).

TIMING MARKS: a set of dots or streaks placed on a film at regular time intervals by a special lamp for the purpose of determining the speed of the film.

TOTAL-ATTACK AVERAGING METHOD: a method of computing the time corresponding to any desired frame (see Section A-4.03).

TRACKING: the process by which a gunner using a computing sight attempts to keep the aiming pip on the target.

TRAIL: the apparent deflection of a projectile from a straight path with respect to the (moving) turret axes caused by its slow-down.

TRAIL-ANGLE: the apparent angular deflection of a projectile due to trail, the vertex being at the origin of the turret-axes.

TRANSIT: (1) a surveying instrument for measuring azimuth and elevation (see Fig. 3.08).
(2) the passage of the projectile from gun to target, as in transit-time.

TRANSIT CENTER: the intersection of the axes of rotation of a transit's telescope.

TRANSIT-TIME: (see TIME-OF-FLIGHT).

TRANSIT-TIME METHOD (or TIME-OF-FLIGHT METHOD): the method of determining the true bore-line by working back from impact time to firing time (see Chapter A-1).

TRAVERSE: on the Erco waist-turret, (1) the motion of the guns about their axis of rotation (see Fig. 1.02); (2) the angle between the projection of the X_t-axis on the traverse plane and the gun bore-line (see Fig. 2.06).

TRAVERSE ERROR: the azimuth error multiplied by the cosine of the gun or target elevation (see Sections A-5.13, A-5.16, and A-6.05).

TRAVERSE PLANE: the X_gY_t-plane, i.e., the plane in which the guns move when rotated about their axis of rotation (see Section A-2.03 and Figs. 1.02 and 2.06).

TRI-CAMERA: (see TARGET-CAMERAS).

TRUE: as applied to this assessment, an adjective describing a situation as it should have existed, as opposed to the actual situation.

TRUE BORE-LINE: the direction in which the gun should have been aimed when a projectile was fired in order to score a hit at some later instant (see Section A-1.03).

TRUE BORE-POINT: any convenient point on the true bore-line (see Section A-1.03).

TRUE LEAD: the angular difference between the true bore-line and the line-of-sight.

TRUE AIR SPEED, (TAS): the speed of an aircraft relative to the air mass, usually obtained by correcting IAS for altitude and temperature, assuming standard atmospheric conditions.

TRUE-ANGLE POINT: the point on the projector's optical-axis from which angles as viewed on the (flat) screen are identical with the corresponding angles as photographed (see Section A-2.10).

TURRET-AXES: (see AXES).

TURRET CENTER: (see CENTER OF A TURRET).

UNDERRANGING: describes the situation where the gunner is feeding too small a range into a Mk 18 sight by having the reticle diameter larger than the apparent wingspan.

VECTOR METHOD: an alternative way of determining the true bore-line, generally less satisfactory than the transit-time method (see Section A-1.01).

VERTICAL-FLIGHT GYRO: (see GYROS).

WING-LIGHTS: special lights mounted on the wings to define clearly a known wing distance and thus facilitate stadiametric ranging.

WING-MARKS: strips painted on each wing in a color contrasting with that of the wing, for the same purpose as wing-lights.

WINGSPAN: the distance on an aircraft from the tip of one wing to the tip of the other.

APPARENT WINGSPAN: the image of the wingspan in a sight or camera or on a screen.

YAW, (Y): the angle through which an aircraft has turned from an initial position when rotating about an axis parallel to Z, positive if the nose has turned to the left (see Section A-2.07).

Y-ROTOR: (see GYRO).

ZENITH ANGLE, (z): the angle between the vertical with respect to the earth and a given direction.

ZERO DIAL READINGS: the roll, yaw, and pitch indicated on the gyro dials when the rotors are in alignment (see Section A-2.07).

Z-ROTOR: (see GYRO).

NOTATION AND ABBREVIATIONS

(Unusual terms used below are explained in the GLOSSARY)

a, b, c: in parallax correction between O and O', the rectangular coordinates of O' with respect to bomber axes centered at O (see Section A-3.05 and Fig. 3.11 (a)).

α: azimuth.

α_I: PLAXIE azimuth setting.

α_G: gun azimuth

α_T: target azimuth

AMG-C: Applied Mathematics Group at Columbia University.

AMG-N: Applied Mathematics Group at Northwestern University.

AMP: Applied Mathematics Panel.

API M-8: armor piercing and incendiary 0.50 caliber projectile, type M-8.

A. T.: Armament Test, a Test Unit of U. S. N. A. T. C., Patuxent River, Maryland.

d: distance PLAXIE transit is moved during parallax correction (see Section A-3.05 and Fig. 3.11 (b)).

δ: offset angle.

ε: elevation.

ε_I: PLAXIE elevation setting

ε_G: gun elevation

ε_T: target elevation

F. C.: fire control.

F. C. No.: fire control project number, at A. T.

F6F: a Navy fighter, the Hellcat, manufactured by Grumman Aircraft Engineering Corporation.

GSAP: gun sight aim point, used to describe a type of 16 mm motion picture camera.

h: in parallax correction, the distance between O and O' on the aircraft (see Section A-3.05 and Fig. 3.11 (a)).

i: the time interval between frames on a film (see Section A-4.03).

IAS: indicated air speed.

$K = h\ell$: in parallax correction, the constant which converts range into distance d see Section A-3.05).

K_1, K_2, K_3, K_5: proportionality constants which convert screen measurements into range or sight range (see Forms 11 and 15).

ℓ: in parallax correction, the radius of the circular PLAXIE screen (see Section A-3.05 and Fig. 3.11 (b)).

N. U. P14E: Research Project No. 14, Northwestern University, Evanston, Illinois. The E denotes work done at Evanston rather than elsewhere. P14 was active until 31 October 1944, after which it was designated P22.

P: pitch.

P_o: flight angle.

PB4Y-2: a Navy patrol bomber, the Privateer, manufactured by Consolidated Vultee Aircraft Company.

ρ: relative air density.

r: range.

r_o: the range setting on a Mk 18 sight during the ranging shot (see Section A-5.15).

R: roll.

s_o: the wingspan measured on the screen from the projected image of the ranging shot (see Section A-5.15).

SRG-C: Statistical Research Group at Columbia University.

SU: sync

t: the t[illegible]sponding to a given frame (see Section A-4.03).

T: time-of-[illegible].

T_F: time-of-flight (final) (see Section A-5.07 and Form 13).

T_I: time-of-flight (initial) (see Section A-5.05 and Form 12).

TAS: true air speed.

θ: angle-off.

U. S. N. A. T. C.: United States Naval Air Test Center.

w_o: the wingspan setting on a Mk 18 sight during the ranging shot (see Section A-5.15).

X, Y, Z: turret axes at the Martin forward crown-turret, or bomber axes.

X_g, Y_g, Z_g: gun axes at the Erco port waist-turret.

X_G, Y_G, Z_G: gyro axes.

X_r, Y_r, Z_r: gyro-coordinate axes.

X_t, Y_t, Z_t: turret axes at the Erco port waist-turret.

Y: yaw.

z: zenith angle.

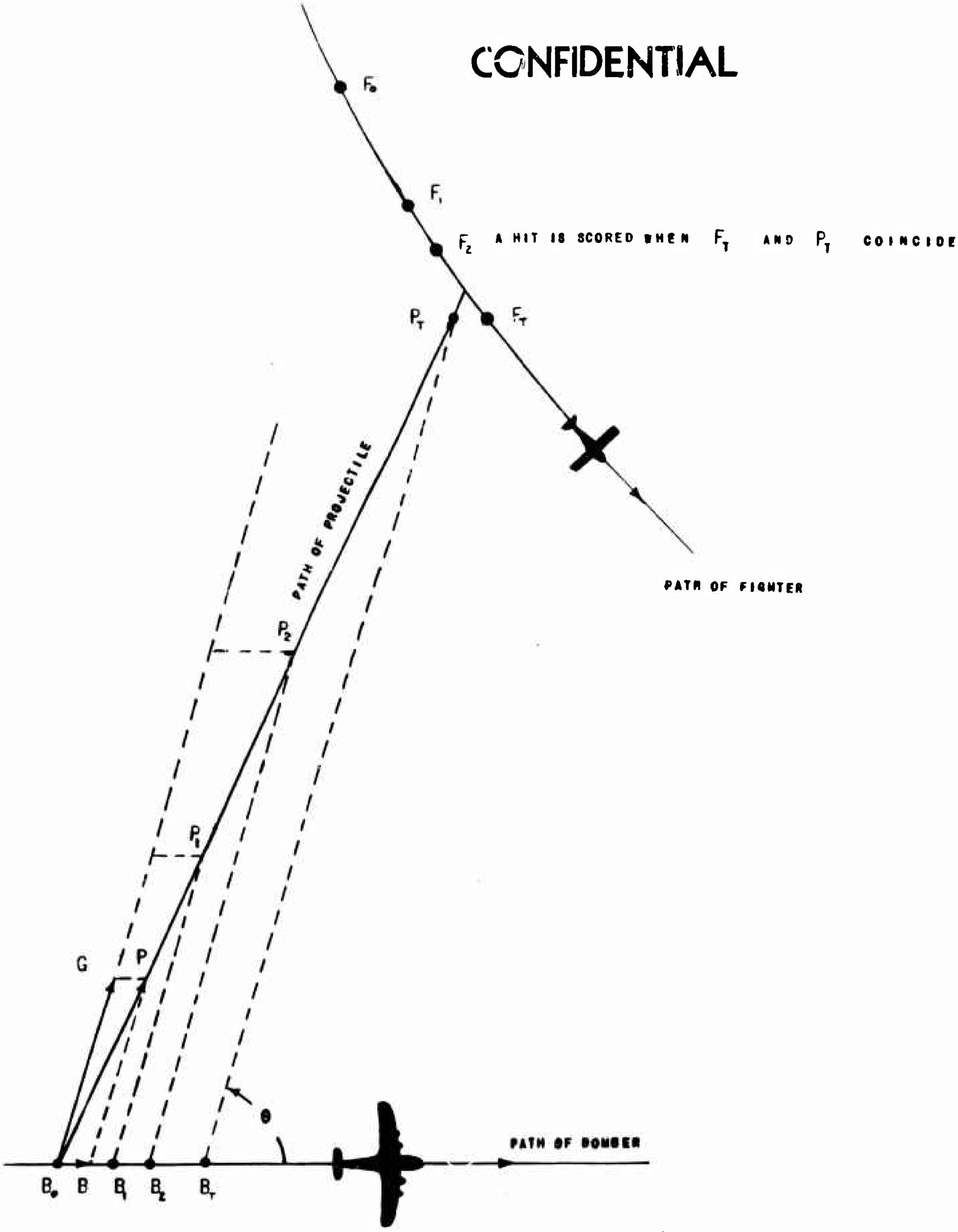

Fig. 1.1. Bomber defense.

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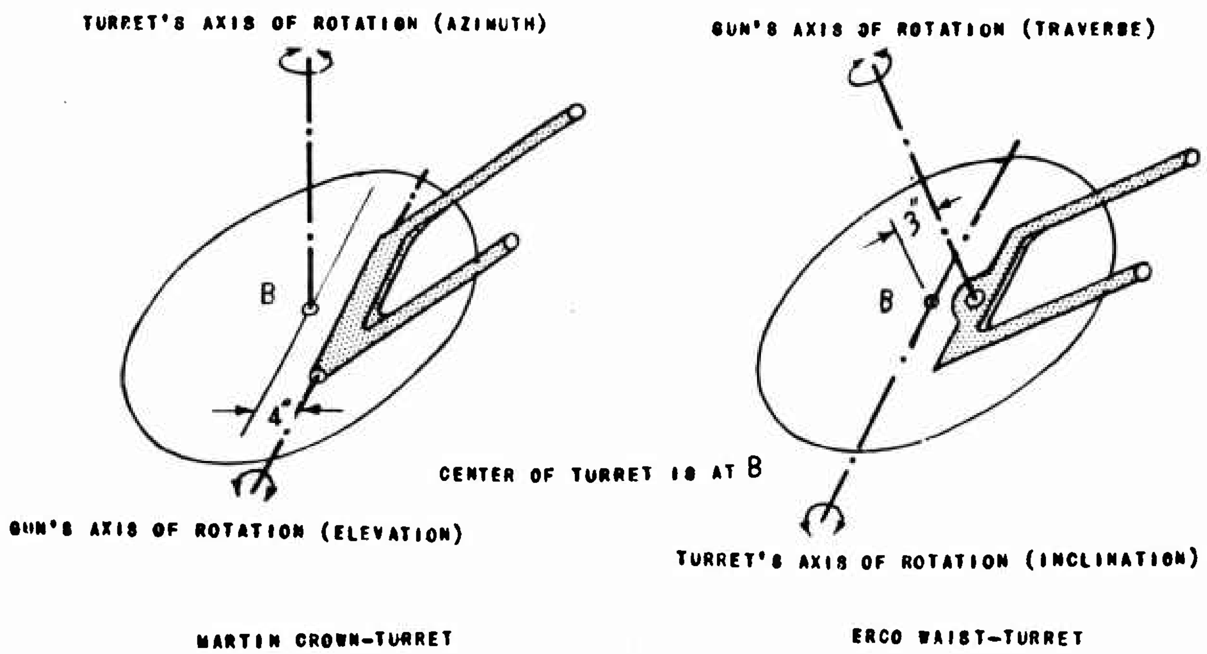

Fig. 1.2. Diagrams of turret and gun motions.

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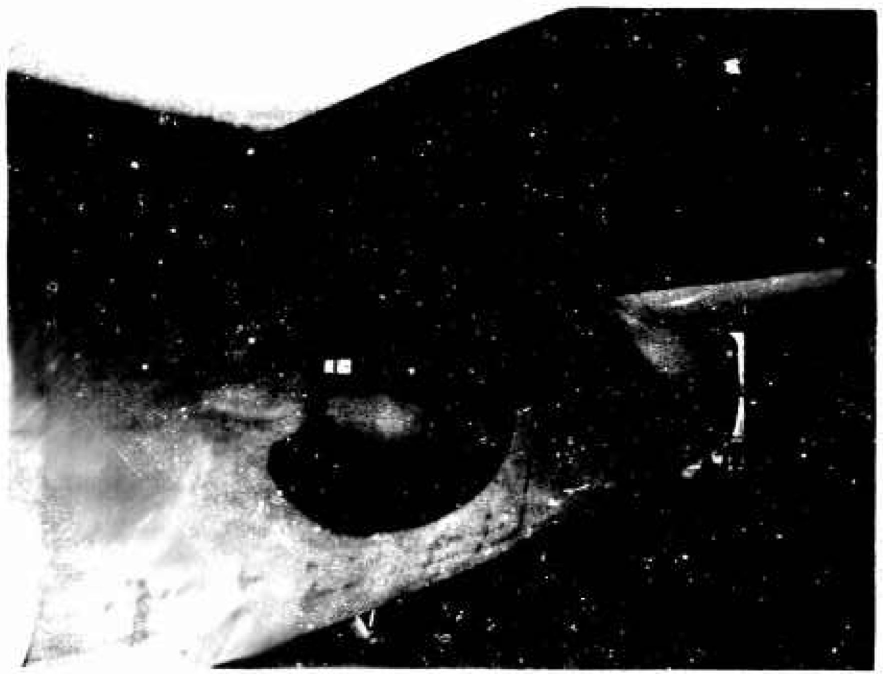
Fig. 2.01(a). PB4Y-2, A.T. No. 14, showing (from l. to r.) Martin forward crown-turret with 16 mm camera on right gun, tri-camera, and Martin rear crown-turret with 35 mm camera on right gun and APG-5 antenna on left gun. A



Note: The points marked A are identical.

Fig. 2.01(b). PB4Y-2, A.T. No. 14, showing Erco port waist-turret with camera on gun.

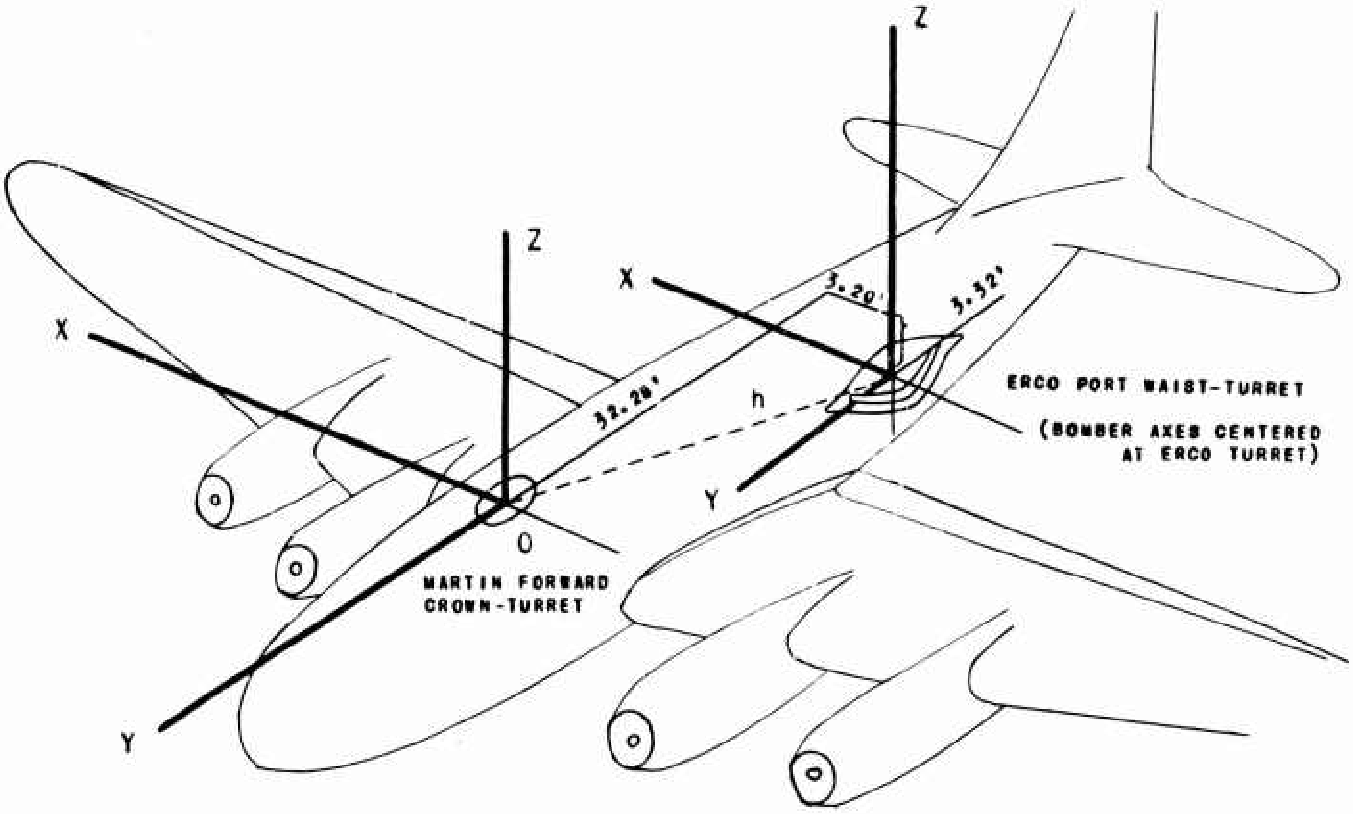


Fig. 2.02. Turret axes at Martin forward crown-turret and bomber axes at Erco port waist-turret.

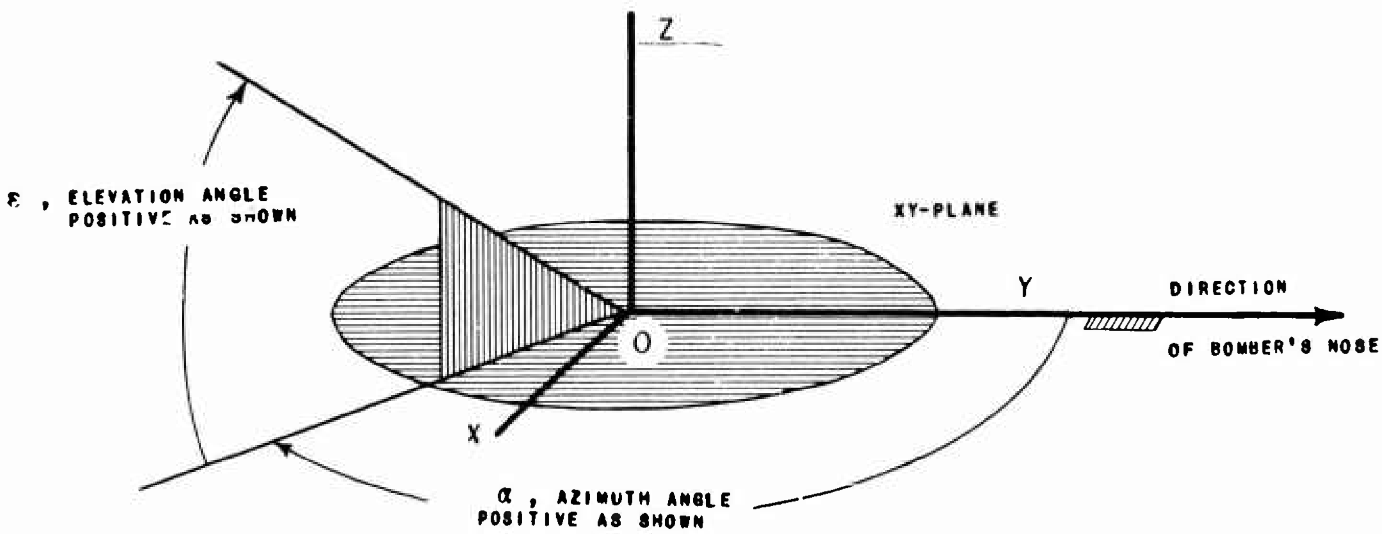


Fig. 2.03. Azimuth and elevation angles.

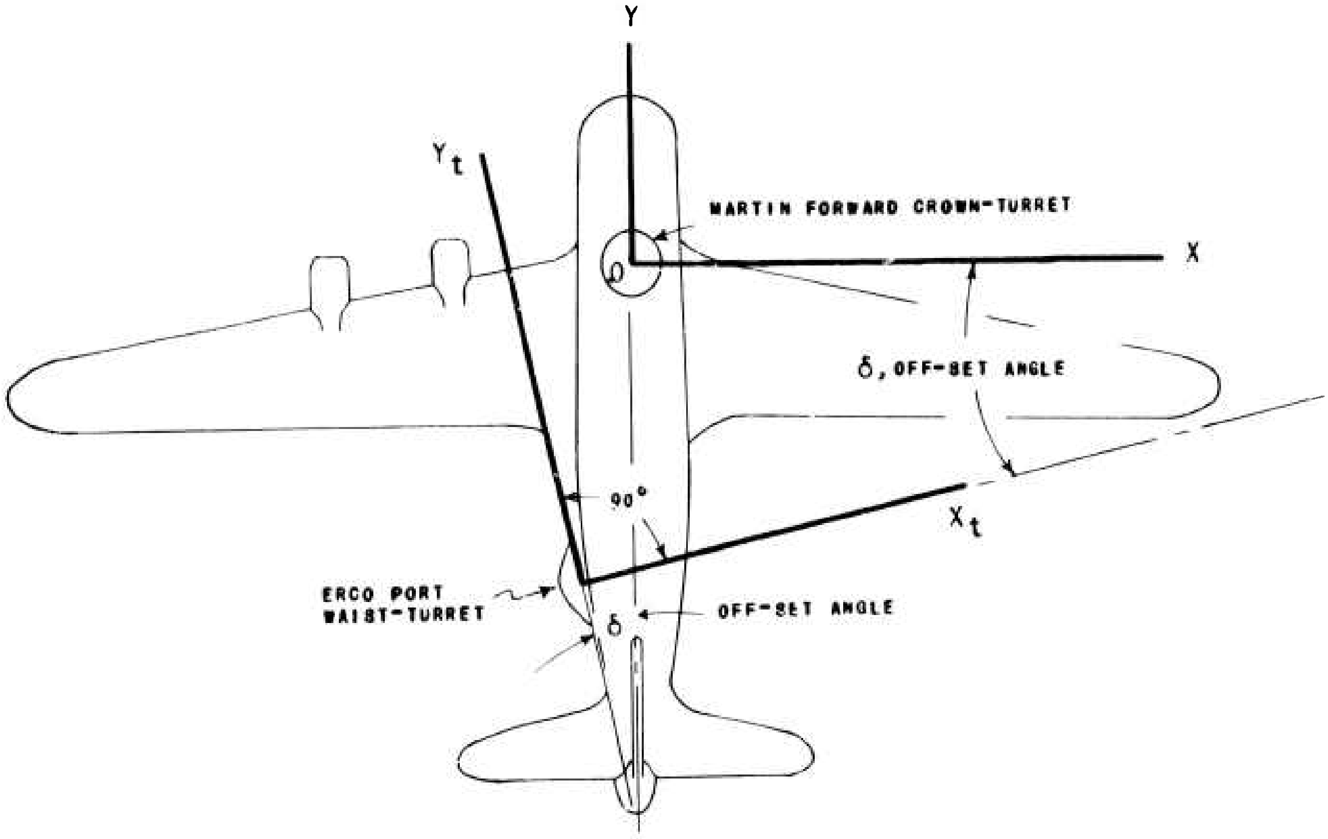


Fig. 2.04. Off-set angle of Erco port waist-turret.

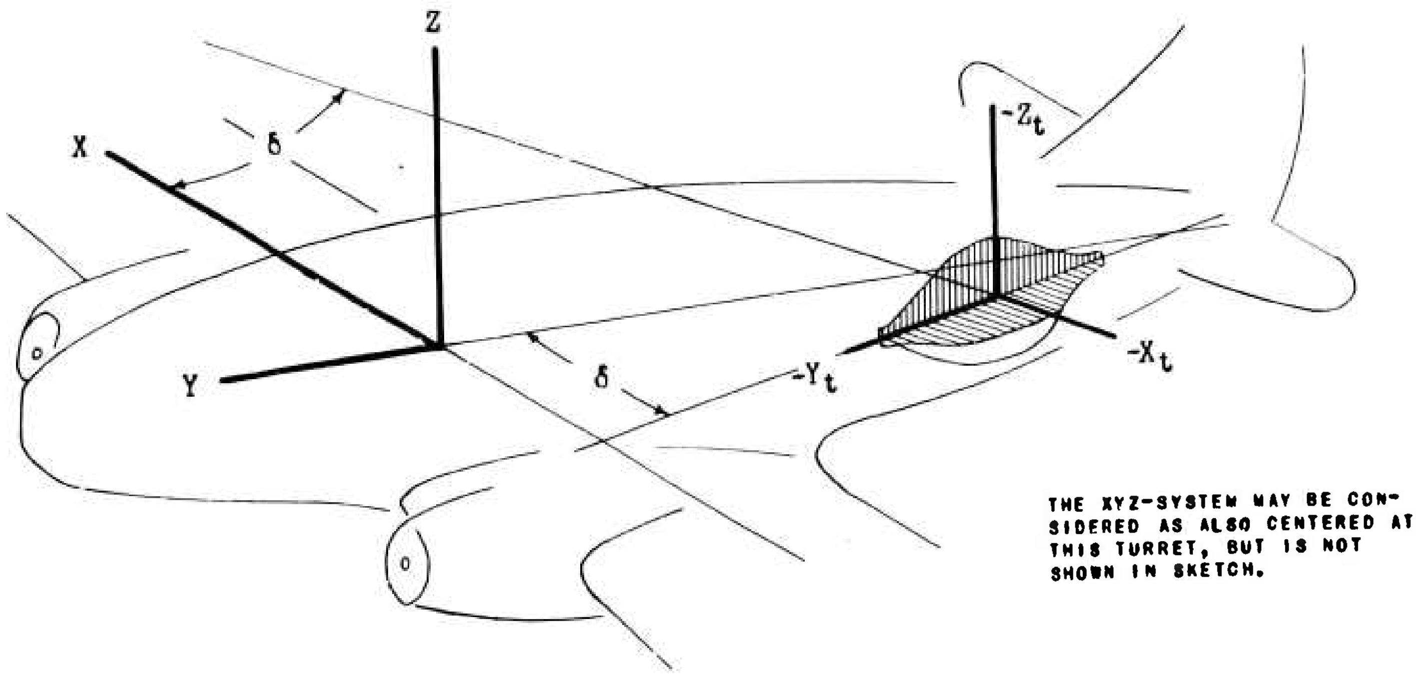


Fig. 2.05. Turret axes at Martin forward crown- and Erco port waist-turrets.

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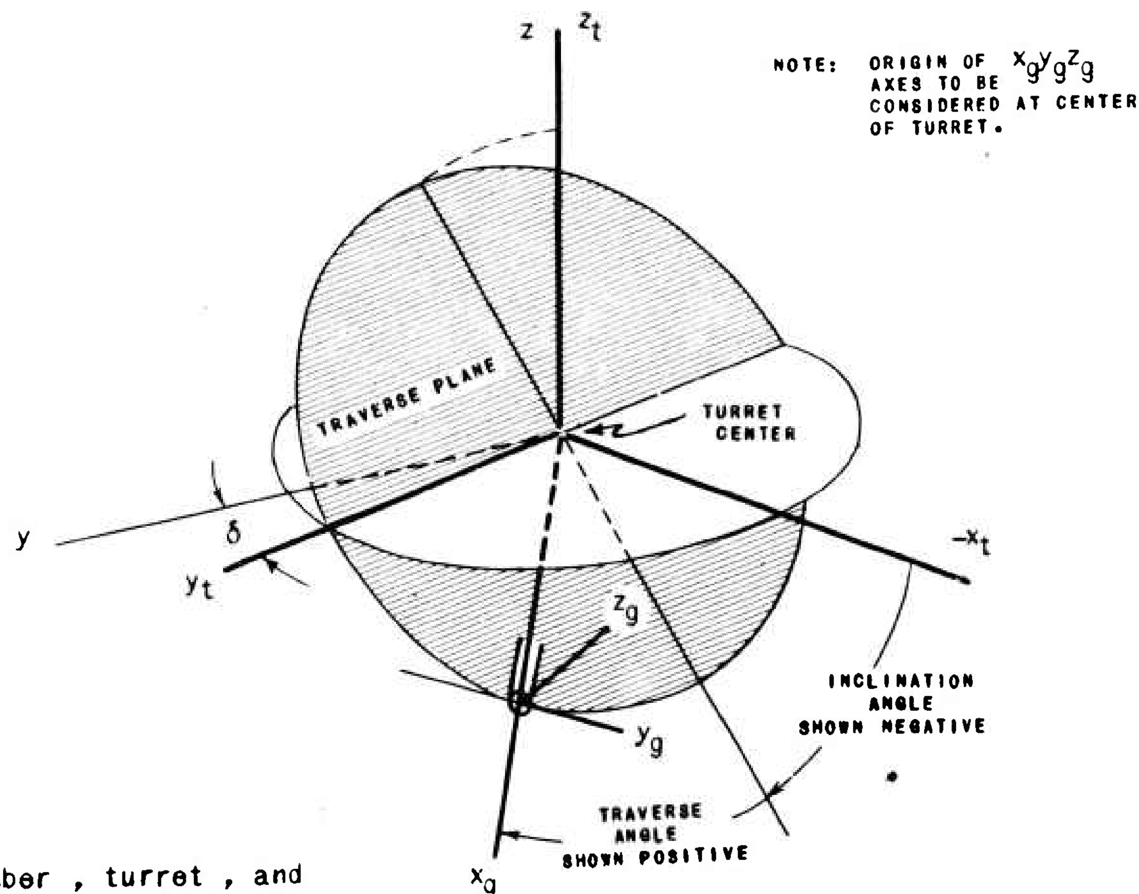

Fig. 2.06. Bomber, turret, and gun axes at Erco port waist-turret.

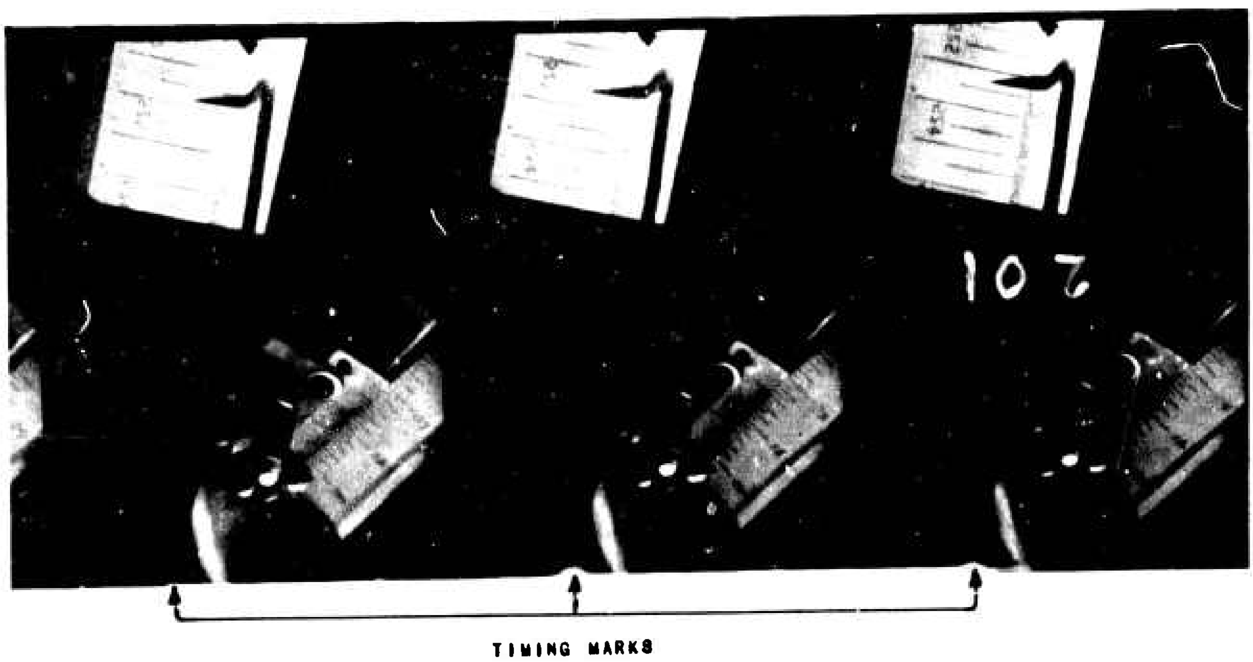

Fig. 2.07. Sample RAZEL film.

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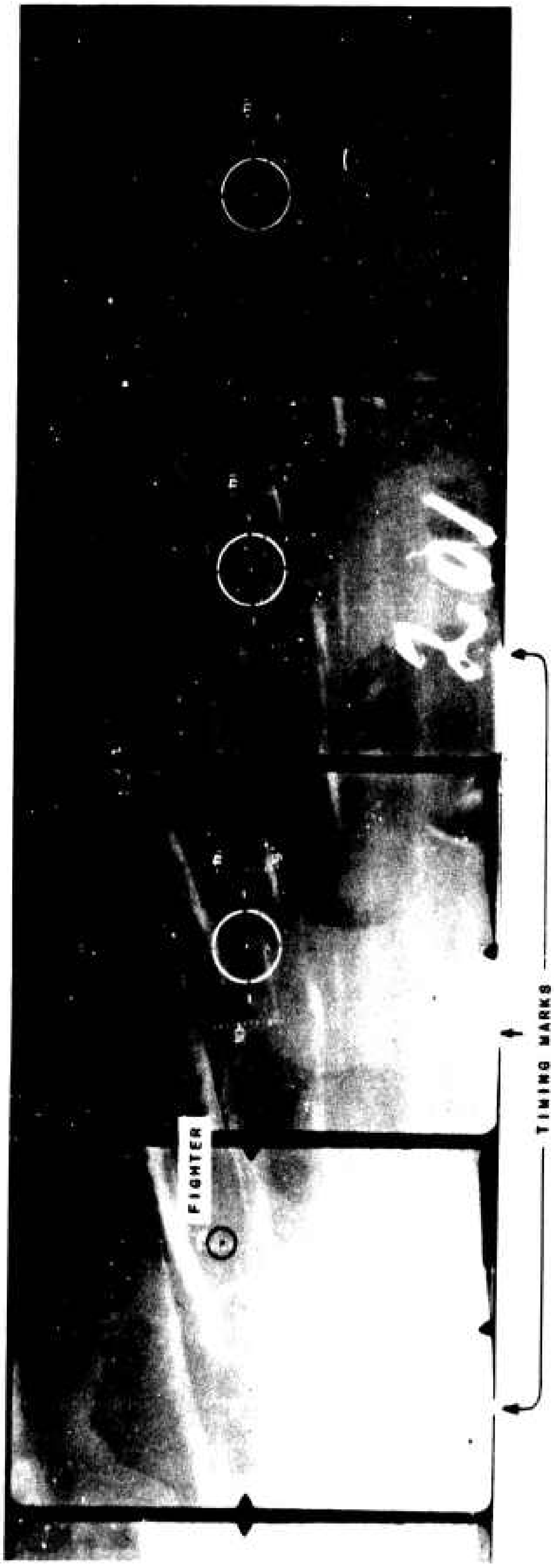

Fig. 2.08. Sample deflsctometer film.

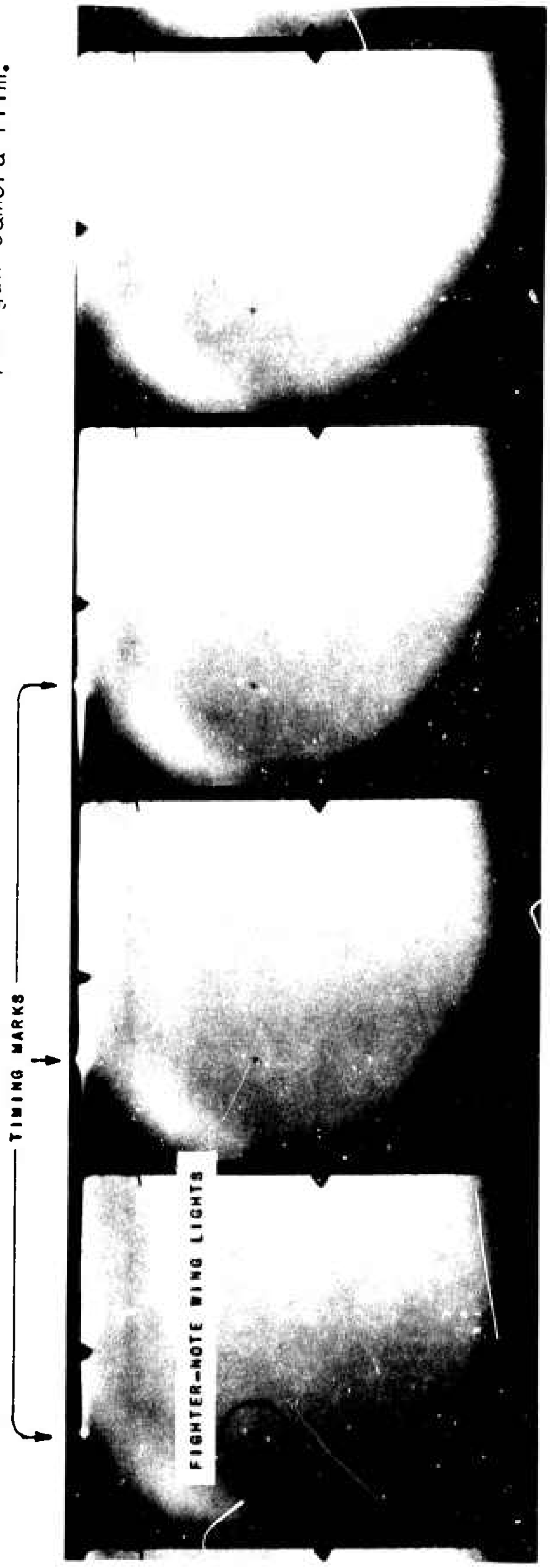

Fig. 2.09. Sample gun-camera film.

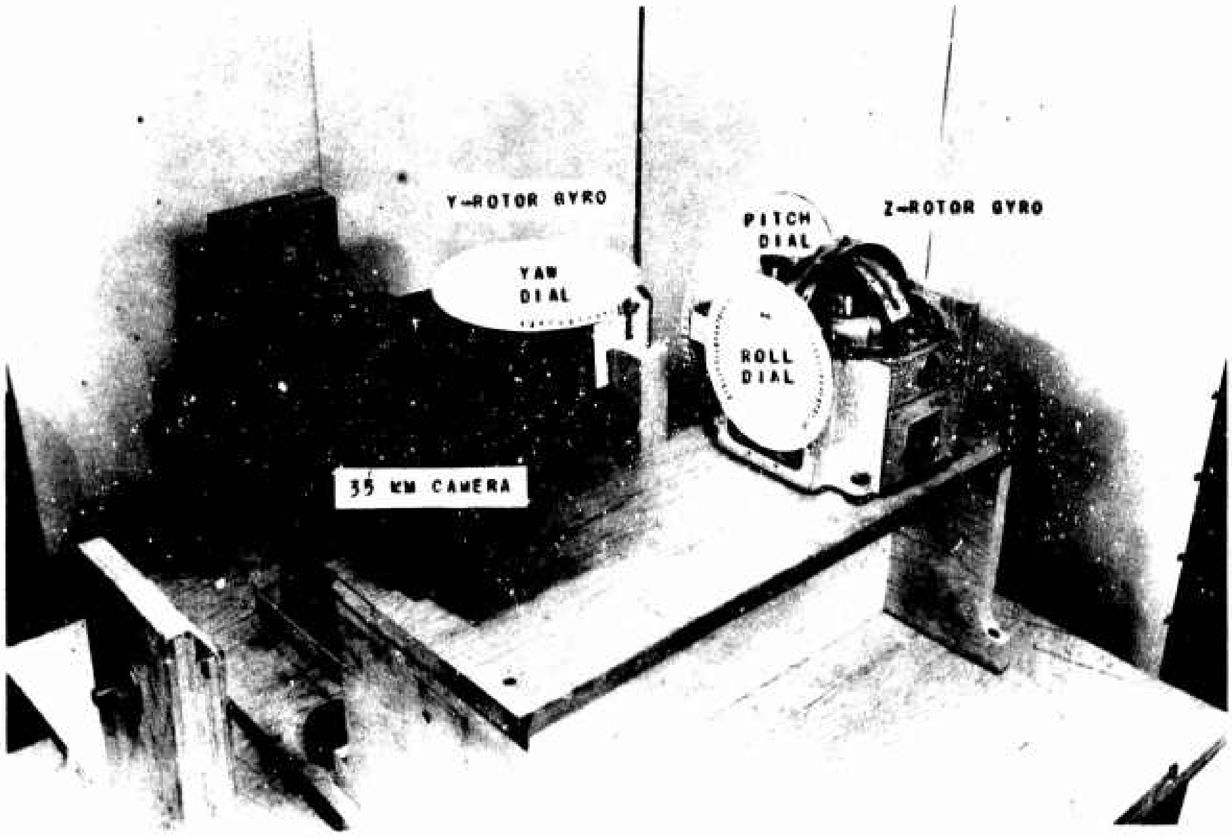

Fig. 2.10(a). Gyro mockup in laboratory.

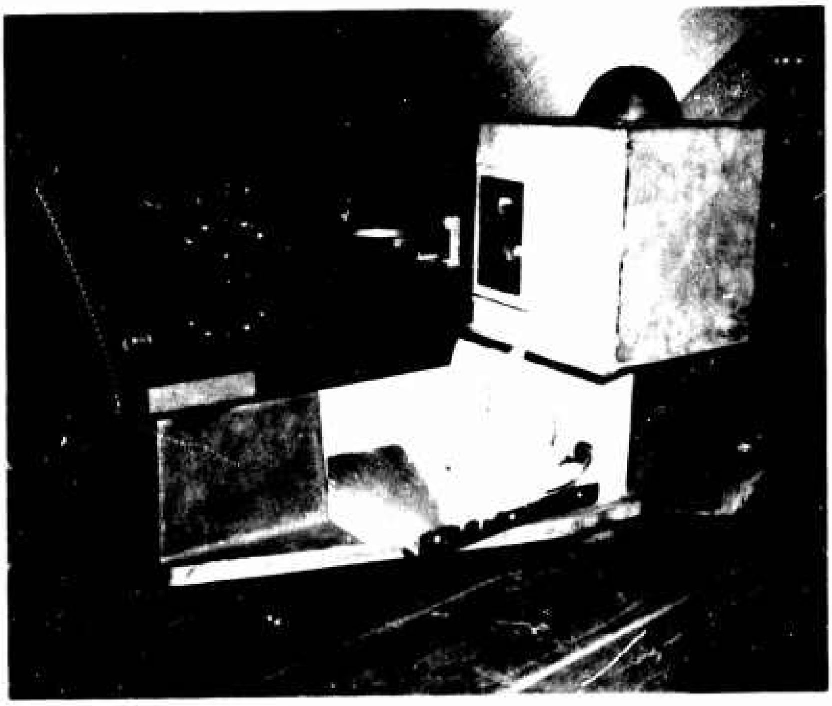

Fig. 2.10(b). Gyros ready for installation in airplane.

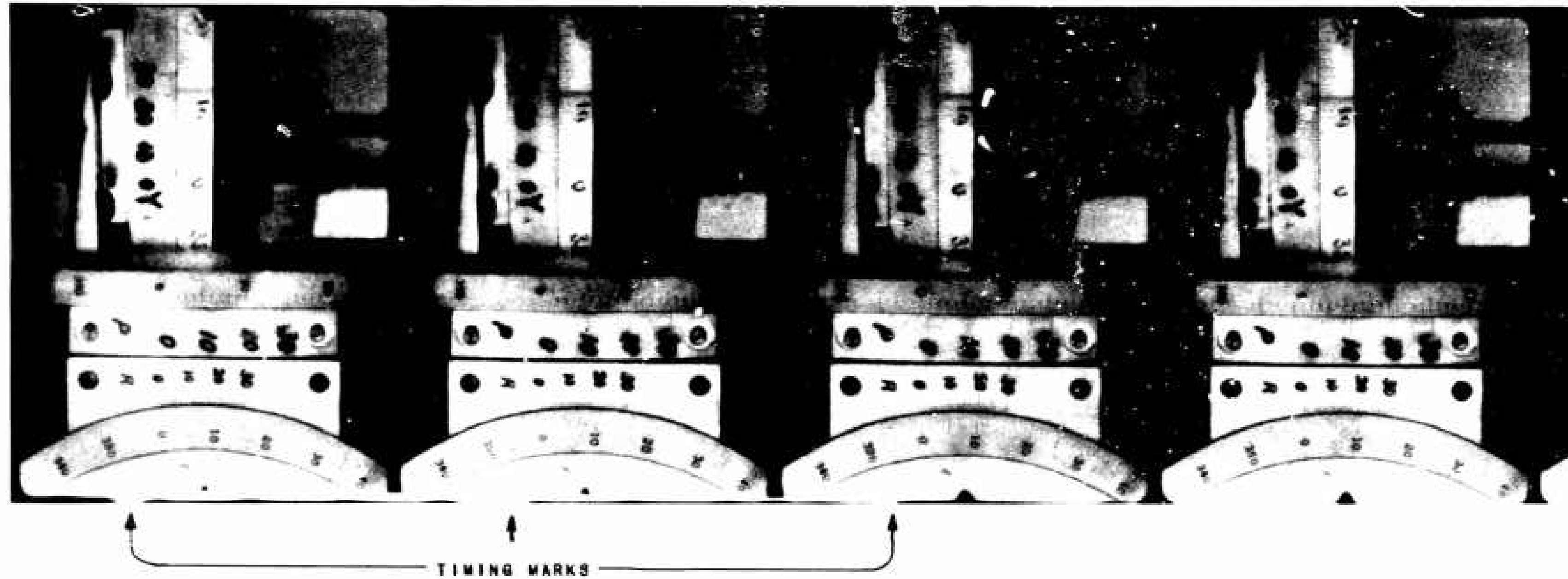

Fig. 2.11. Sample gyro film.

Fig. 2.14. Sample sight-camera film.

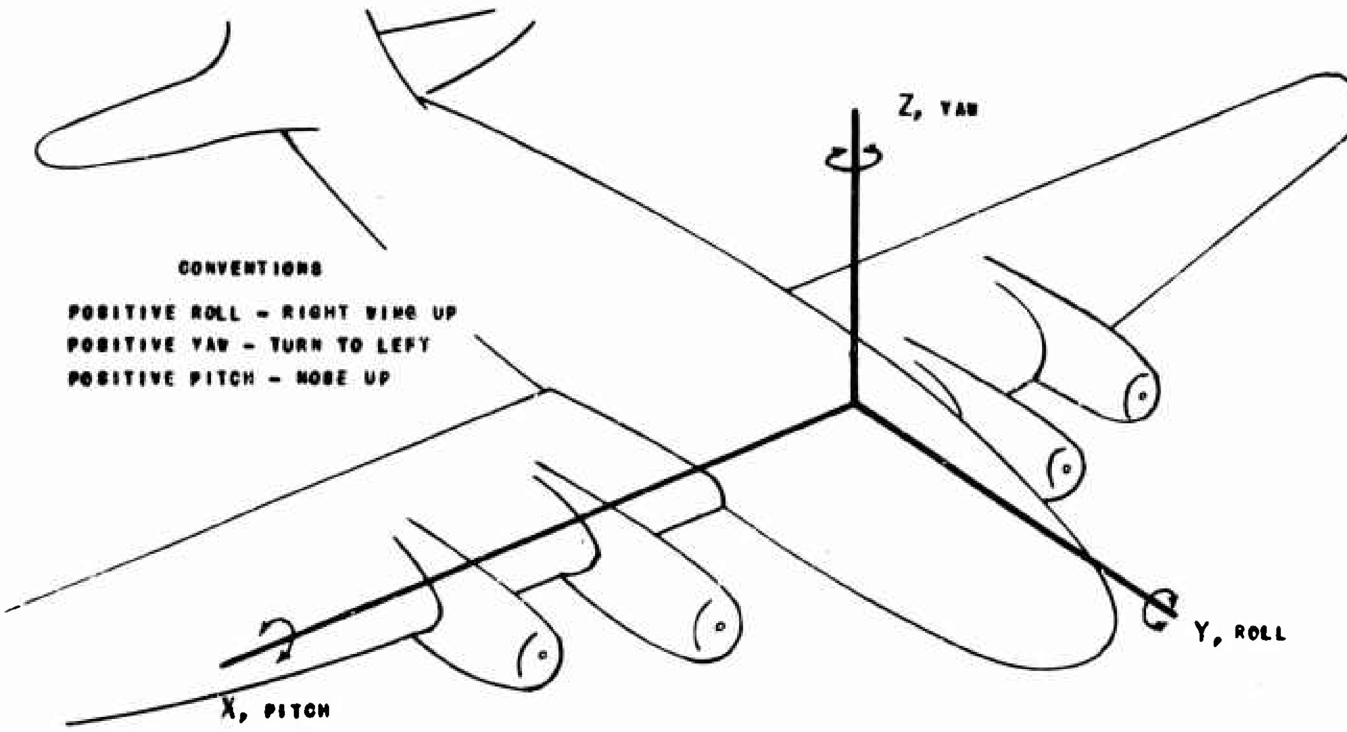

Fig. 2.12. Roll, yaw and pitch angles.

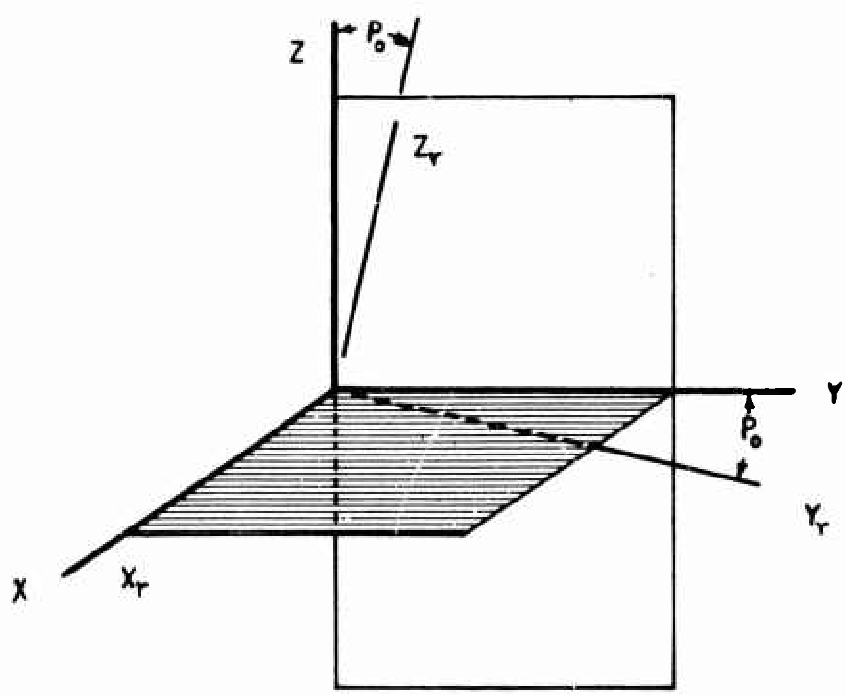

Fig. 2.13. Relation of gyro coordinate axes X_r Y_r Z_r to bomber axes X Y Z for Gyro Set No. 1.

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Sec.

Form G

Flight Plan Details

F. C. Nos. 9
14
15

Date 26 March 1945 Time Take-off ______ Time Land ______

Bomber TAS 140 A. T. No. 14

Flight No. 6 Fighter IAS ______ A. T. No. 5

Altitude 6000

Attack		Turret Gunner		
Number	Type	Upper fwd.	Upper rear	Port waist
Practice	Flat-side	Campbell	Stavis	McKenna
1	" "	"	"	"
2	" "	"	"	"
Practice	" "	"	~~Nichols~~ *	"
3	" "	"	"	"
4	" "	"	"	"
Practice	" "	Harp	Stavis	Gallagher
5	" "	"	"	"
6	" "	"	"	"

Fig. 2.15 Flight Plan Details

* In upper rear turret
Nichols was not available

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Sec.

Photographic Flight Data
Bomber Pilot's Report

F. C. No. 9 / 14 / 15

Pilot Humphrey Date 26 March 1945 Flight No. 6

Plane A.T. # 14 .Fighter Plane A.T. # 5 and — .

Take off time 1010 . Landing time 1113 .

Assigned Altitude 6000 . TAS 140 . Evasive Action none .

1. Before Take-off
   Gyros running ✓ . Range calibration filmed ✓ .
   Borepoint and Boresight checked by film ✓ .

2. Before attacks give sight settings to gunners
   Altitude 6000 . Wing span 43' . IAS 127 .

3. Attack Record. Temp. +10°C .

Attack No.	Type & Direction	Attacking Plane	Wing Lights on	Actual Alt.	IAS	Remarks
Practice	Flat side Port	# 5				Gyro camera on few seconds accidentally
1	"	"	Yes	6000	127	OK
2	"	"	"	6000	127	OK
Practice	"	"				
3	"	"	Yes	6000	127	OK
4	"	"	"	6000	129	OK
Practice	"	"				
5	"	"	Yes	5900	126	Fighter too low and too close on nose
6	"	"	"	6000	127	OK

Fig. 2.16 Bomber Pilot's Report

4. Before Landing. Gyro Running ✓

Recorder Humphrey

Sec.

Photographic Flight Data
Observer's Report

F. C. No. 9
14
15

Date 26 March 1945

Air: Smooth, rough, bumpy. Flight No. 6.

Weather: clear, cloudy, hazy. Ceiling ———.

1. RYP gyros on 1010 off 1114 total 1 hr. 4 min.

2. Attack Record.

Attack No.	Synch Unit Seconds Reading After Attack	RYP Gyros Uncaged Before Attack	Remarks
Practice			Leveling shot camera accidentally on.
1	12	✓	
2	20	✓	
Practice			
3	29	✓	Counter not working
4	38	✓	
Practice			
5	48	✓	Fighter too low for F.C. & P.W.
6	56	✓	

Fig. 2.17 Observer's Report

3. Change in Phase Reports (if any):

Recorder D Goldschmidt

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Sec.

Photographic Flight Data
Fighter Pilot's Report

F. C. No. 9/14/15

Pilot Rees . Flight No. 6 .

Plane # 5 . Date 26 March 1945 .

Film Nos. (sight) 102 . 103 . (Others) —— . —— .

1. Boresight burst before take off (sight-camera) ✓ .

2. Sight gyros running on Take Off ✓ Landing ✓ .

3. Sight settings: Wing span 74' 9" Alt. —— IAS —— .

4. Attack Data.

Attack No.	Alt. before Attack	Actual IAS	Remarks
Practice	8000	260	
1	8000	260	OK
2	7800	250	OK
Practice	8000	250	
3	8000	250	OK
4	8000	255	OK
Practice	8500	275	
5	7500	250	too low - too close
6	8000	265	OK

Fig. 2.18 Fighter Pilot's Report

CONFIDENTIAL

Sec.

Film Details

Flight No. 6

F. C. No. 9 - 14 / 15

Date 26 March 1945

Cam.	Roll No.	F Stop	Cam. Opr.	Film Dens	Frames Sec	Cat. Lights	No. Good Attacks	Remarks
F. Tri.								
M. Tri.								
R. Tri.								
RAZ	129	11			24			
Ft. Gun	131	8			24			
Gyro	130	8			24			
R. Gun	132	5.6			24			
Frt. St.	99	8			16			
Erc. Gun	100	16			16			
Erc. St.	101	3.5			16			
Str. Hor.								
Frt. Hor								
Prt. Hor.								

Fig. 2.19 Film Details

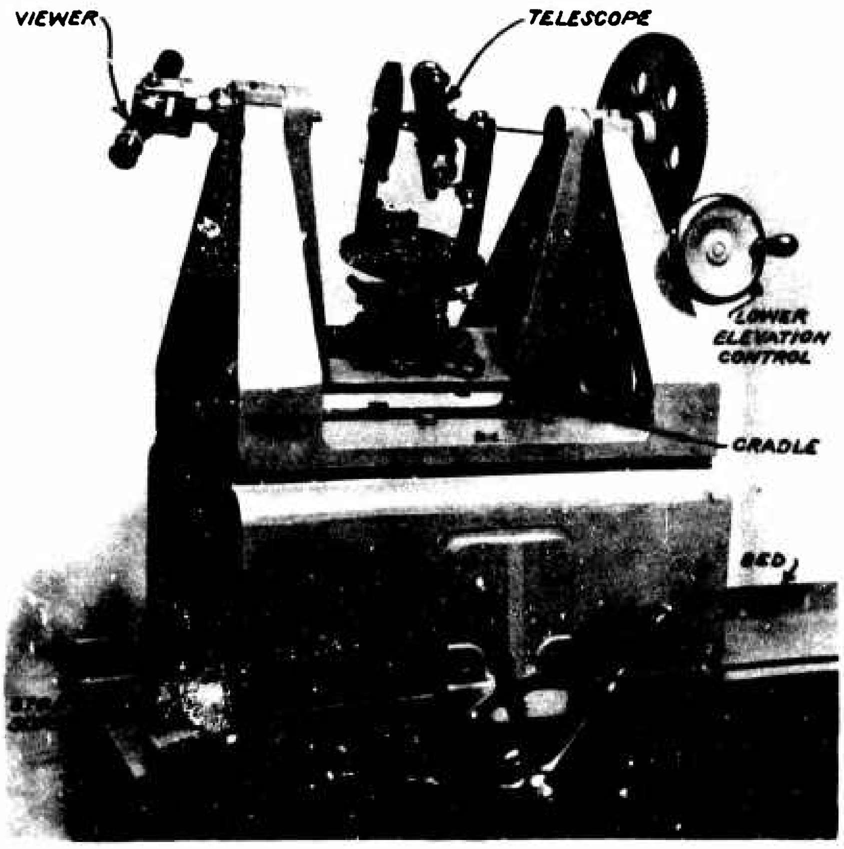


Fig. 3.01. The CRADLE.

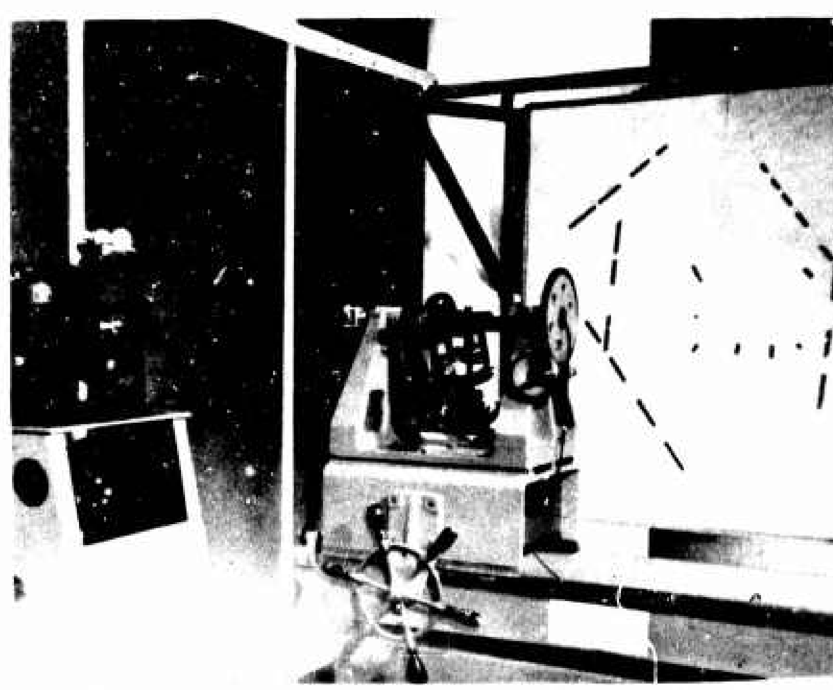


Fig. 3.02. CRADLE in operating position.

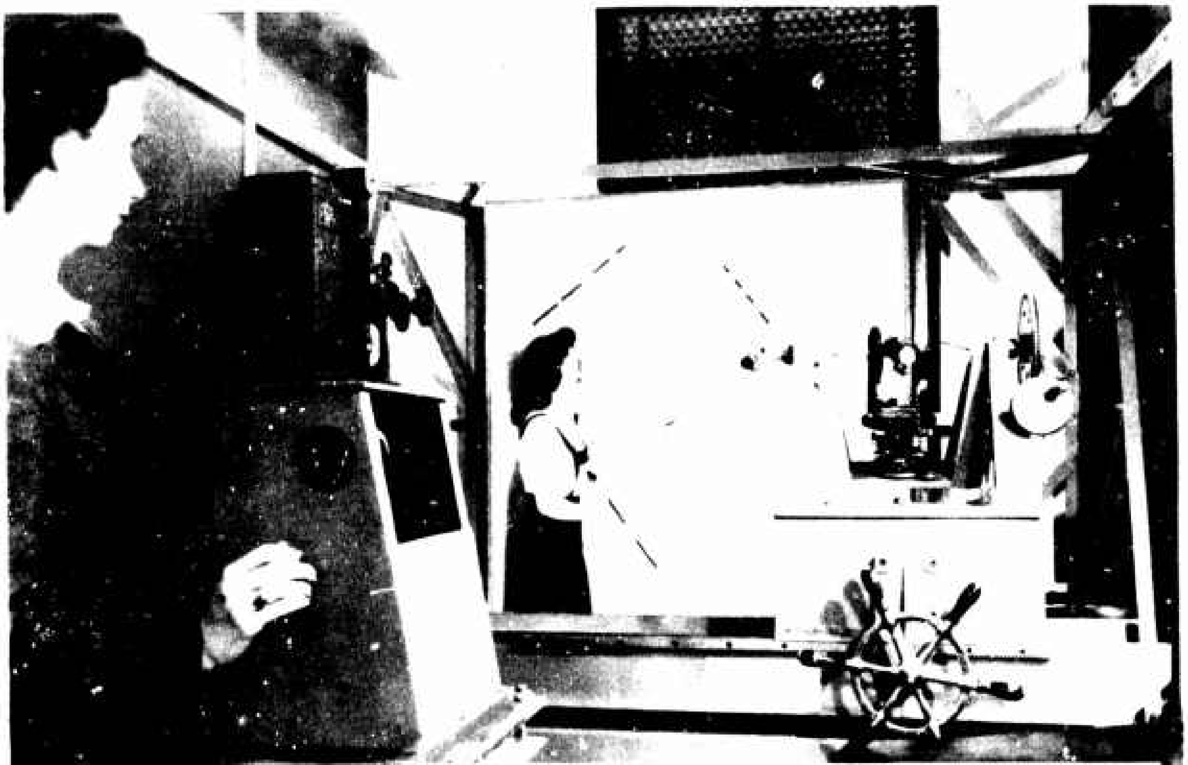


Fig. 3.03. CRADLE slid out of way to permit projection of film.

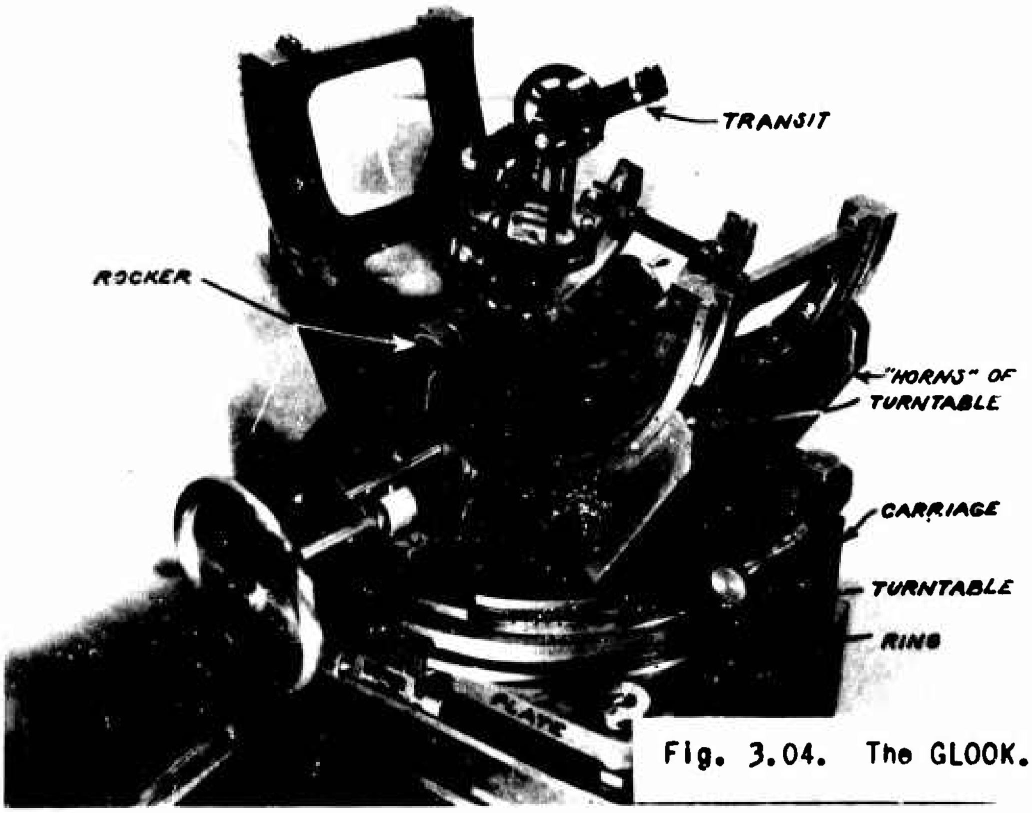


Fig. 3.04. The GLOOK.

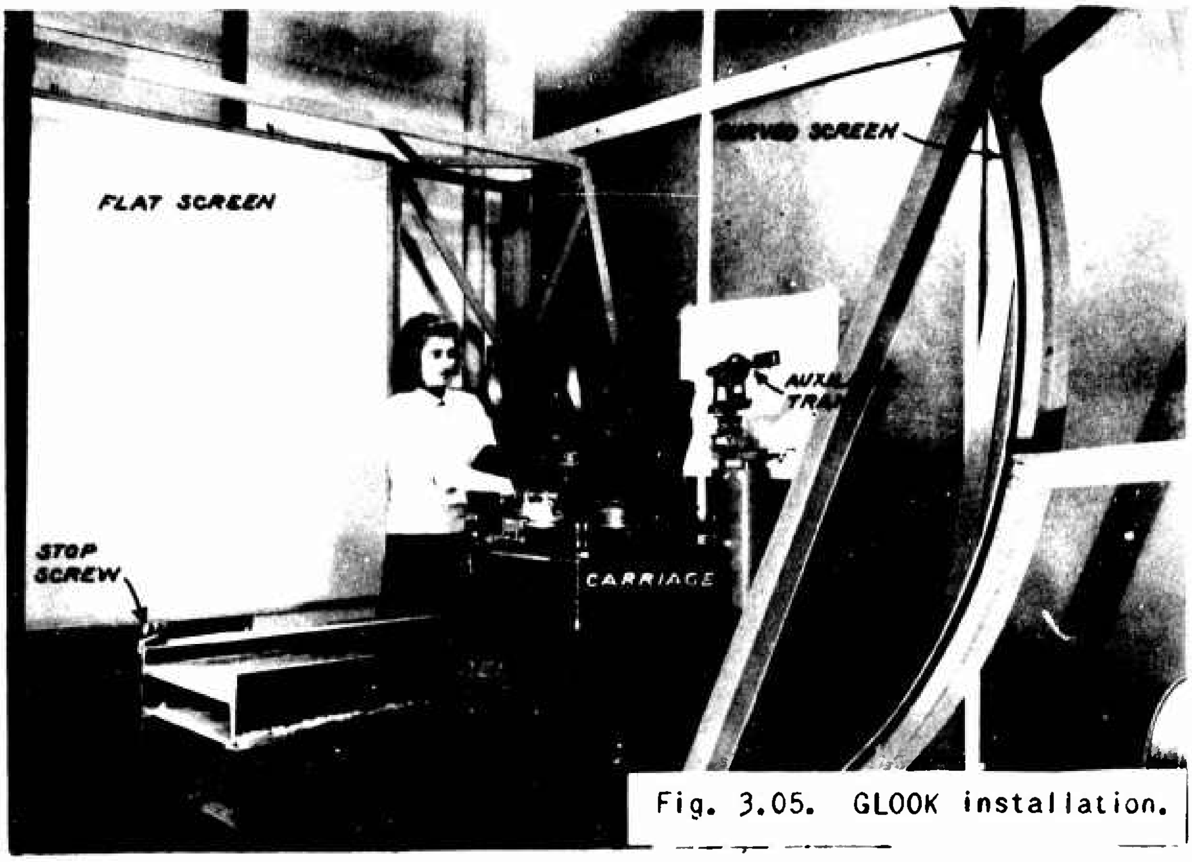


Fig. 3.05. GLOOK installation.

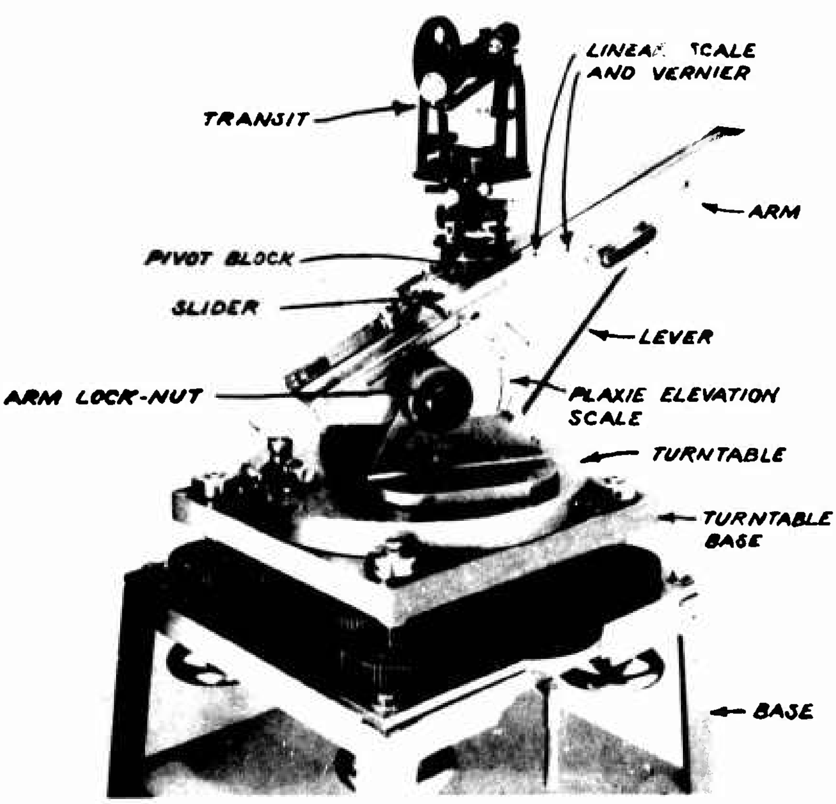


Fig 3.06. The PLAXIE.

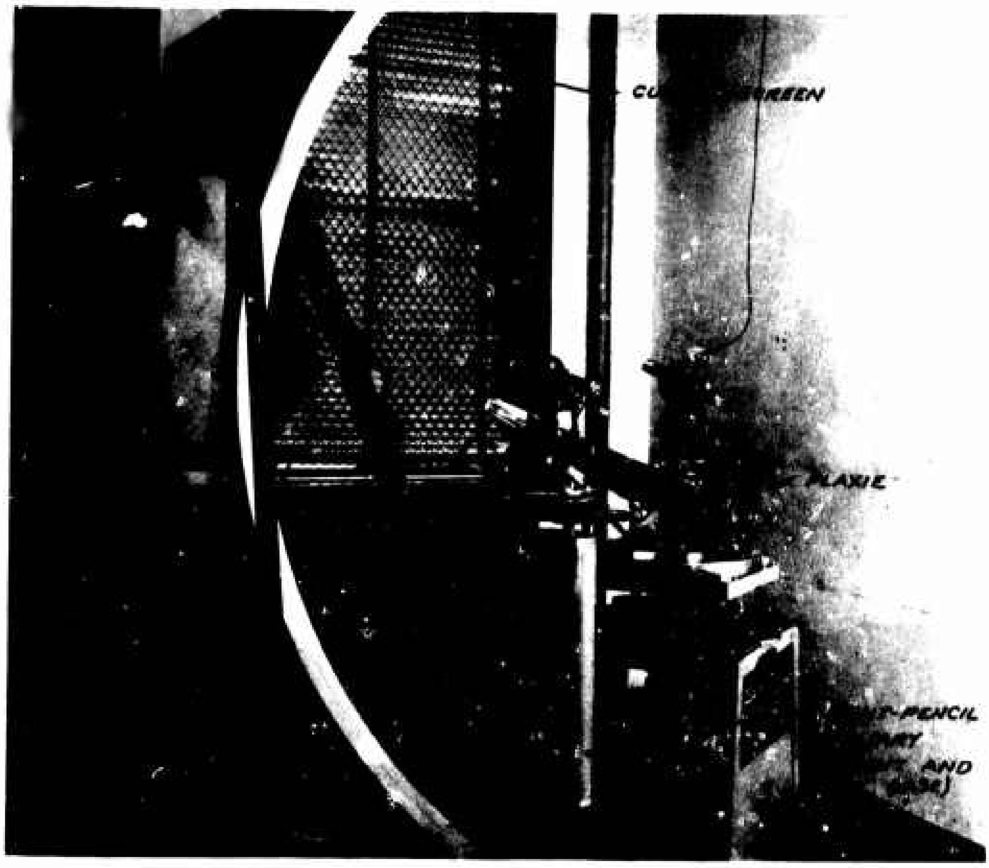


Fig. 3.07. PLAXIE installation.

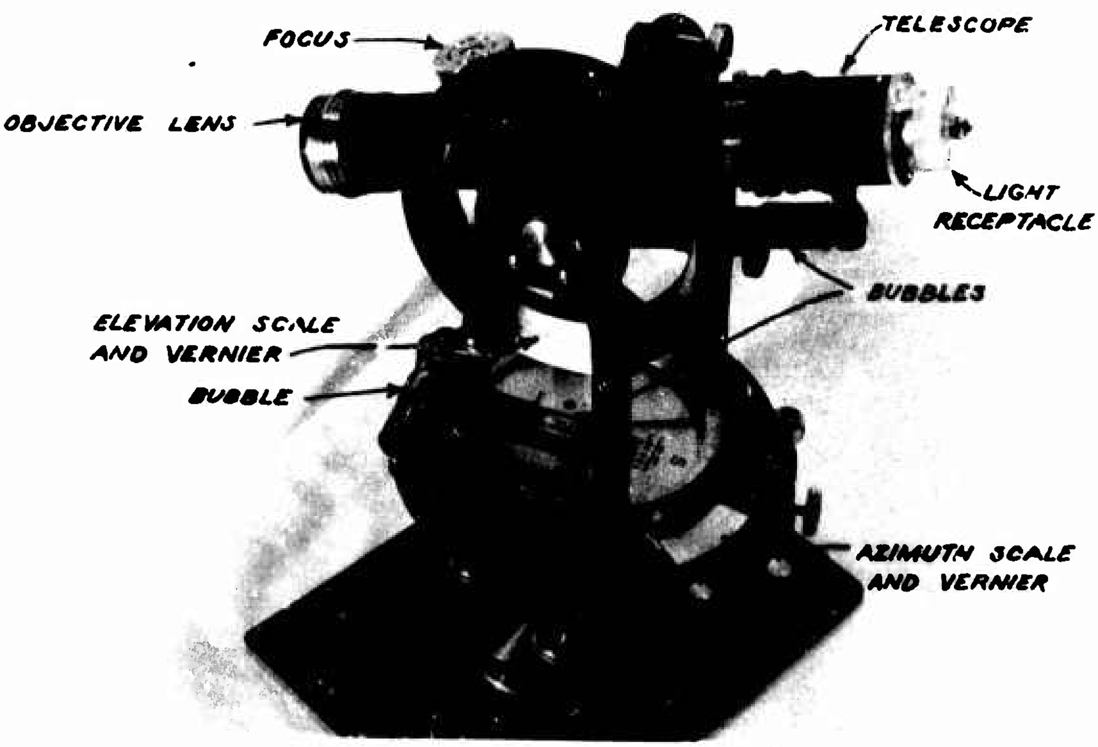


Fig. 3.08. The transit.

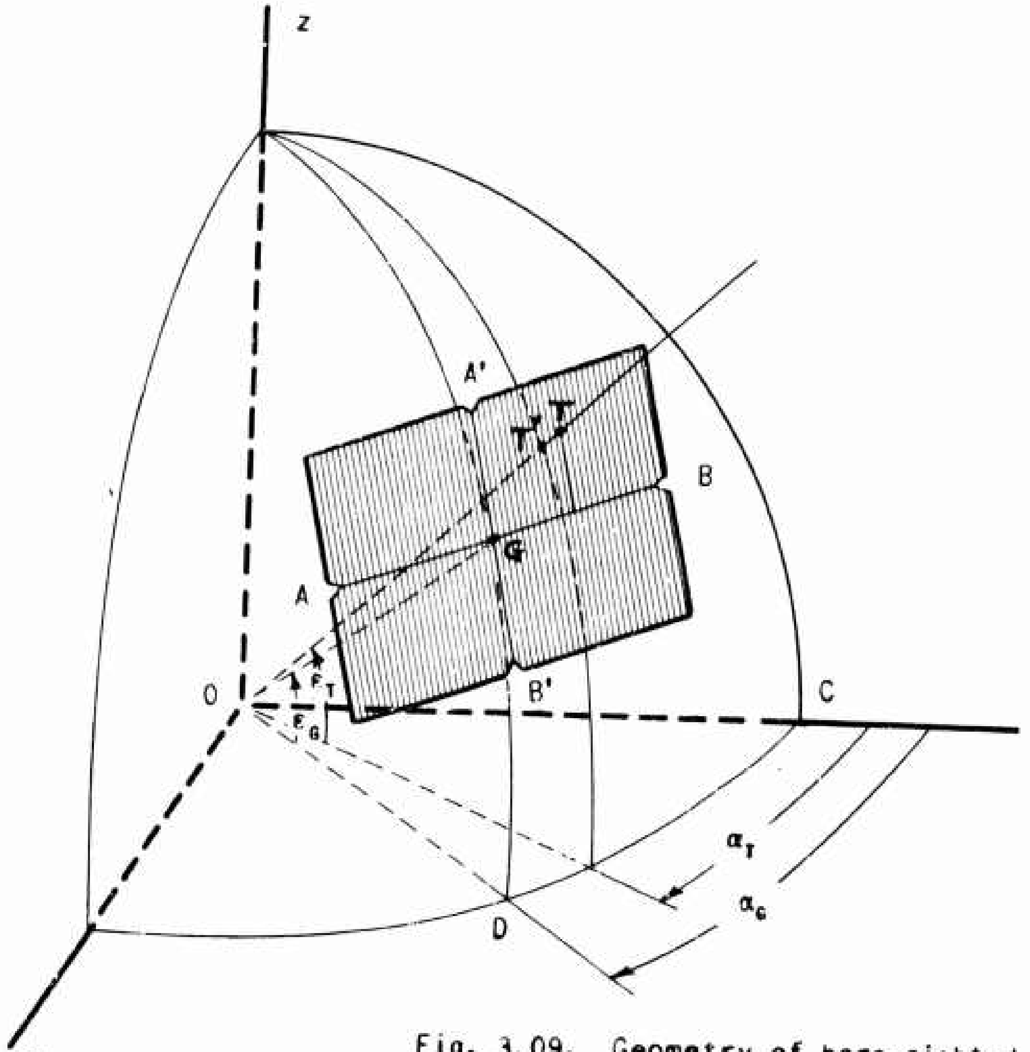


Fig. 3.09. Geometry of bore-sighted gun-camera.

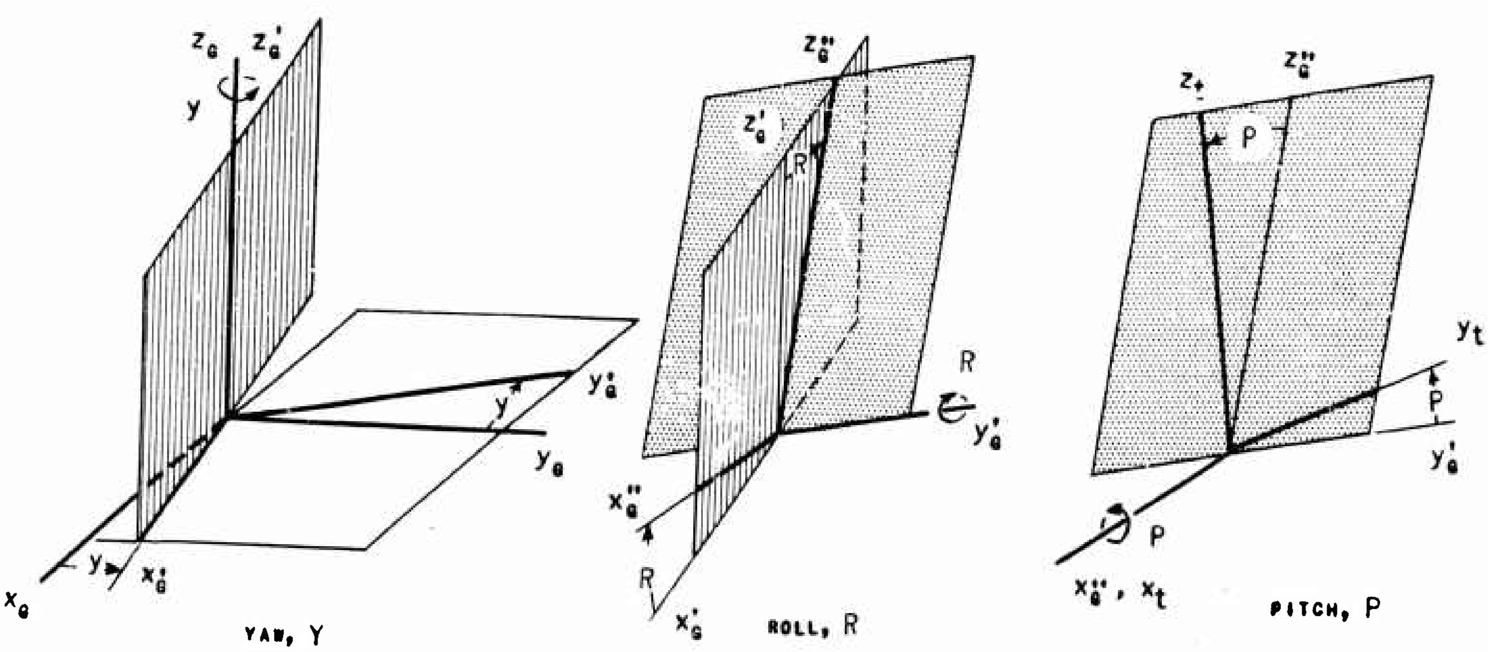
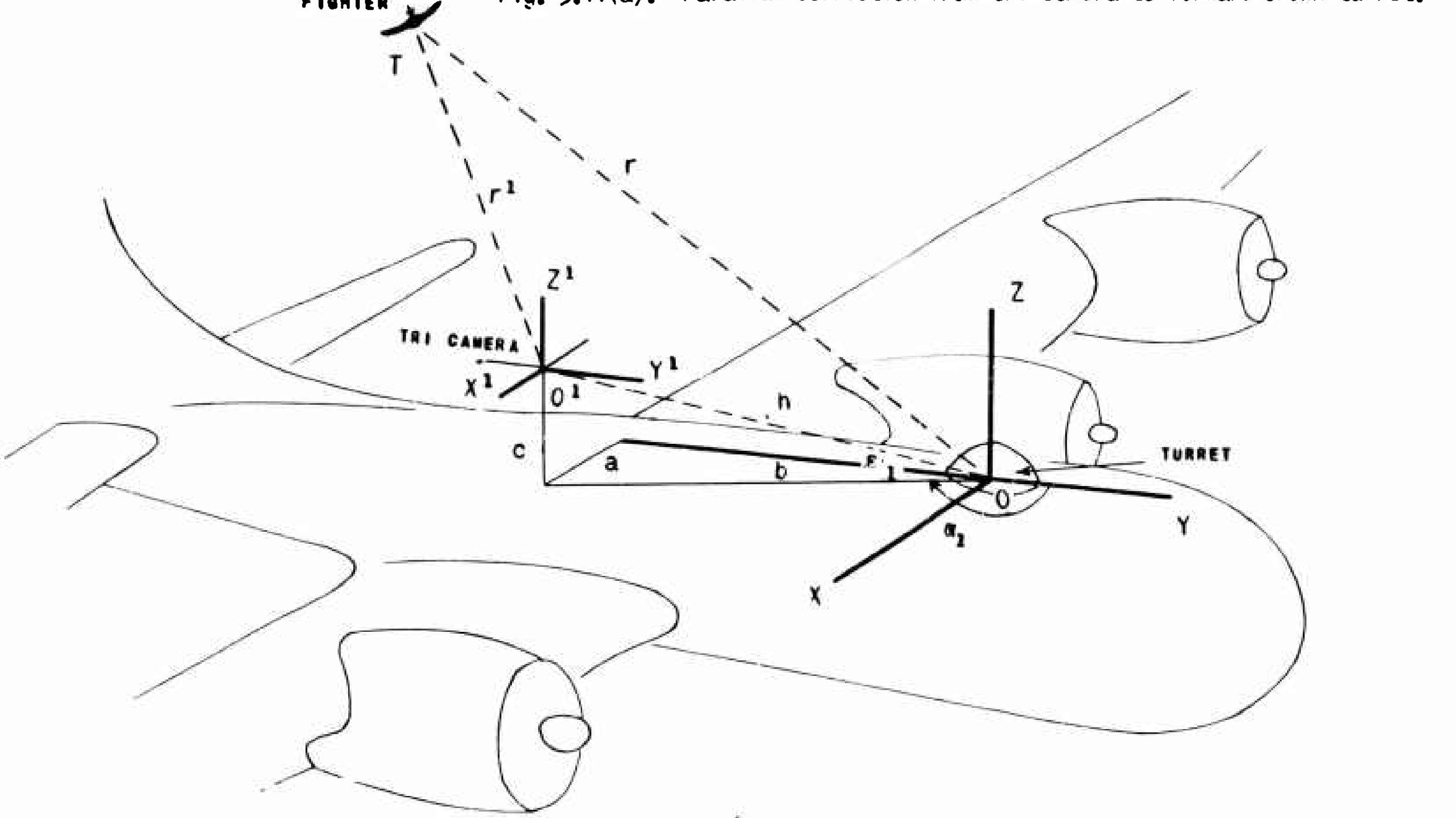


Fig. 3.10. Rotations in the order YRP, carrying gyro-axes $X_GY_GZ_G$ into turret axes $X_tY_tZ_t$.

Fig. 3.11(a). Parallax correction from tri-camera to forward crown-turret.



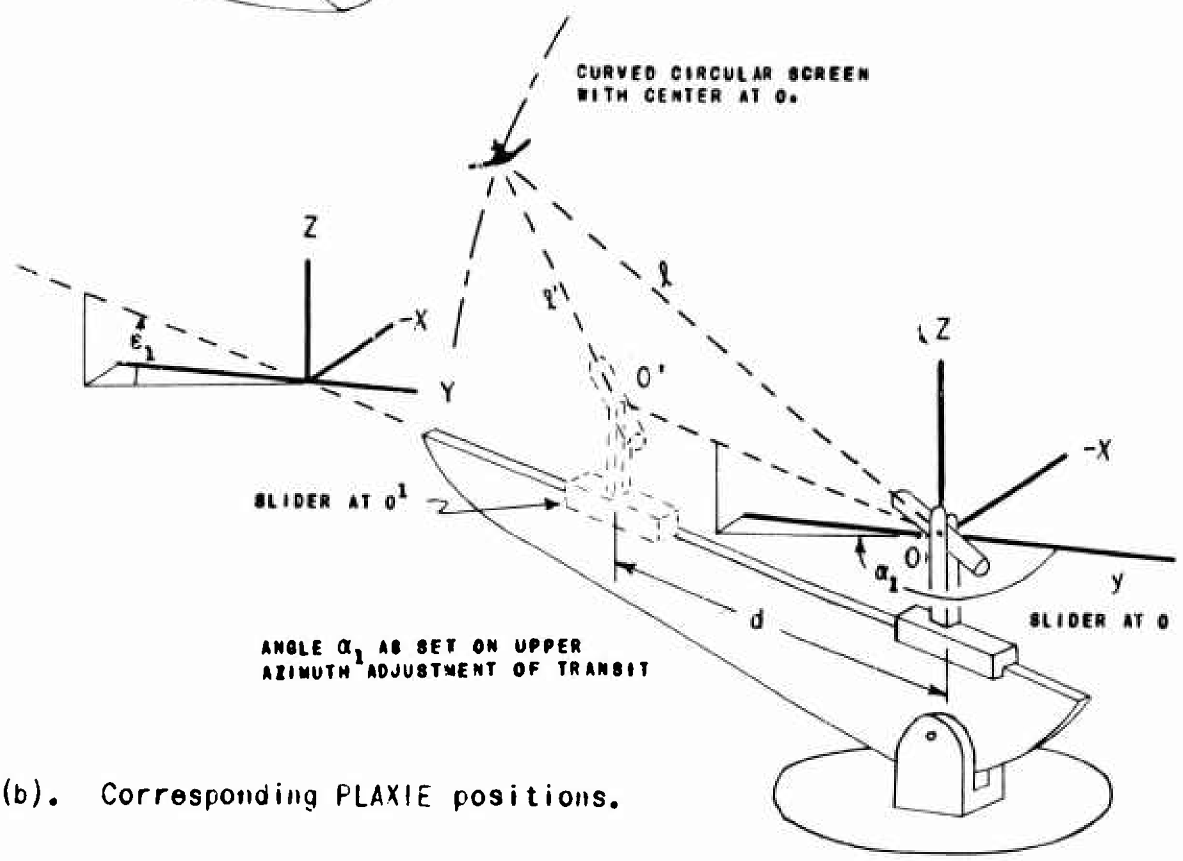


Fig. 3.11(b). Corresponding PLAXIE positions.

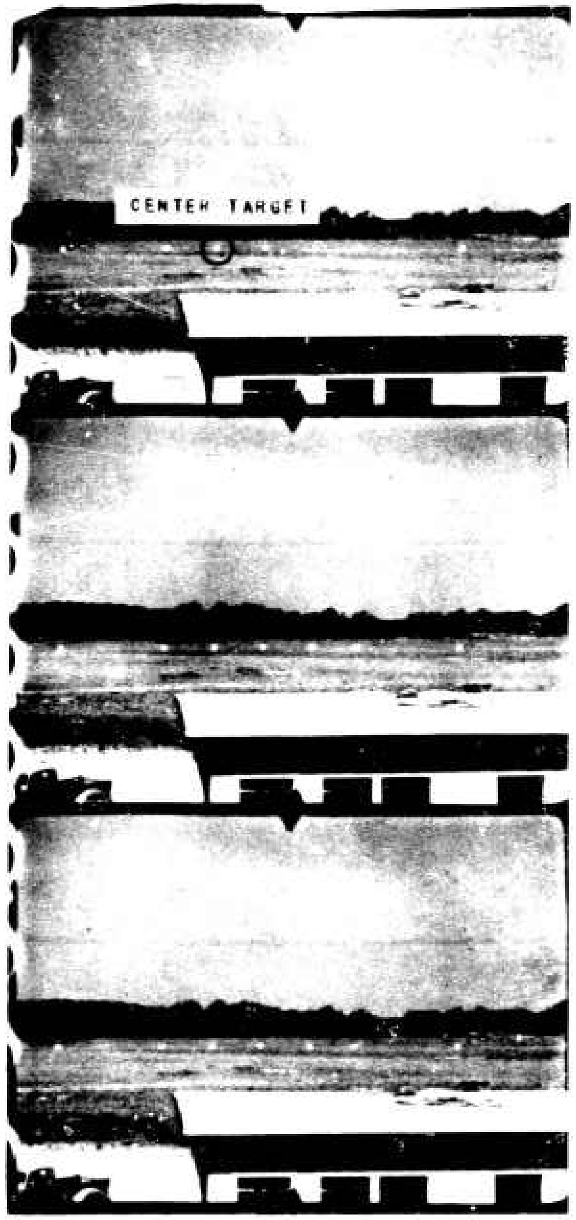


Fig. 3.12. Sample Angle-Shot.

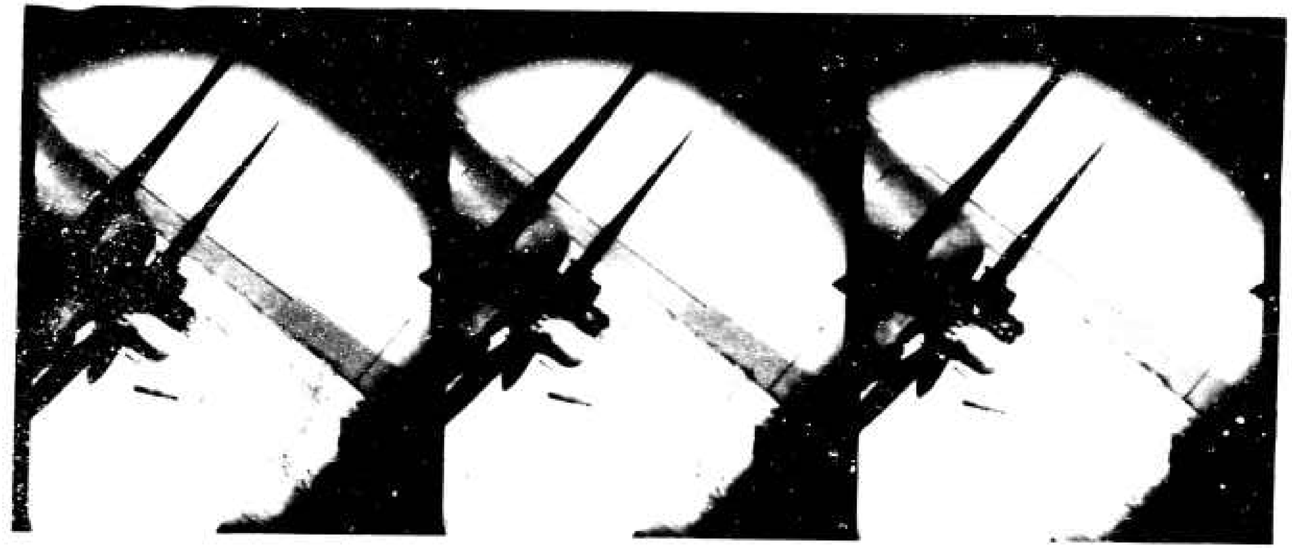


Fig. 3.13. Sample Level-Shot.

Fig. 3.14. Sample Position-Shot.

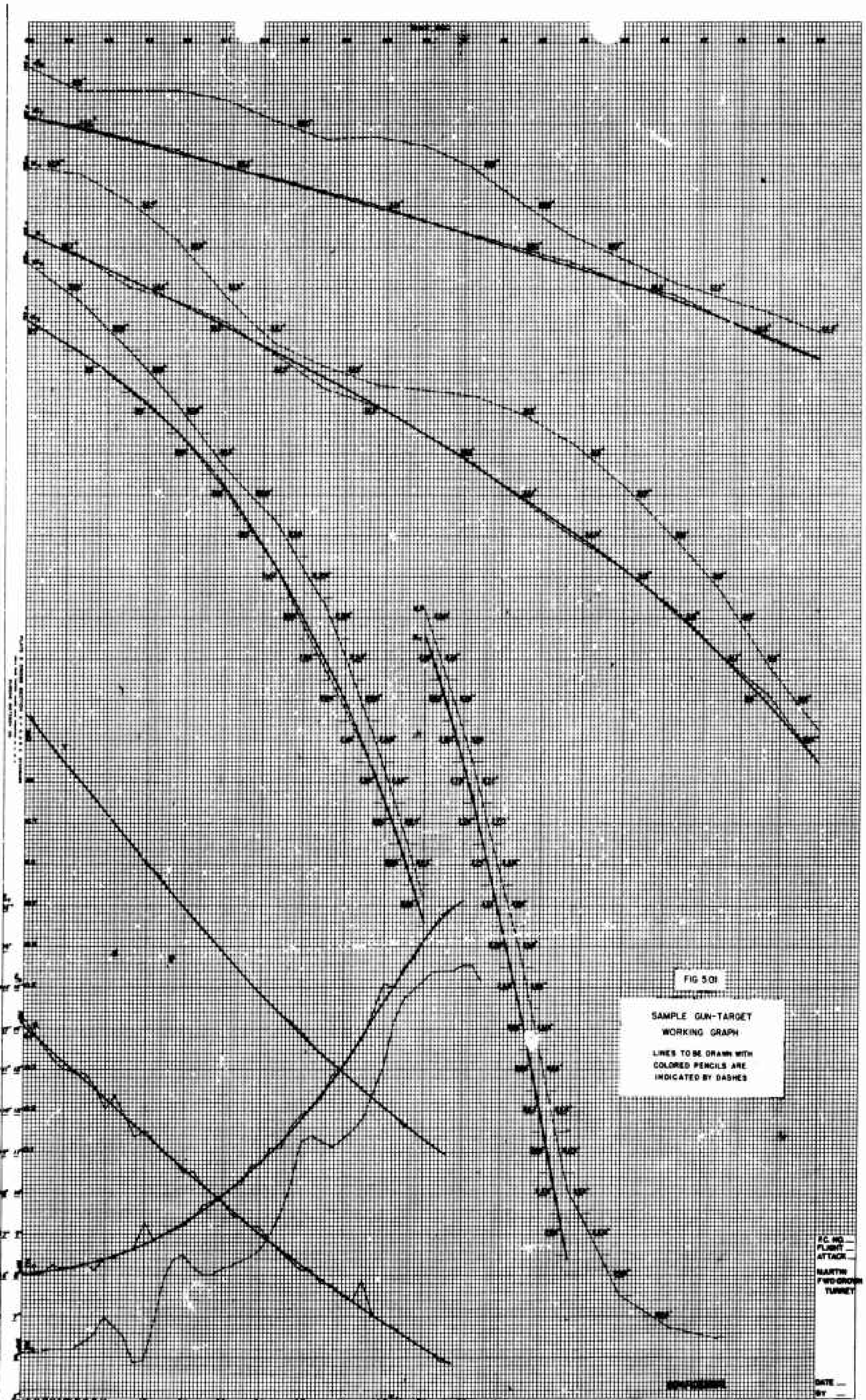


FIG 5.01

SAMPLE GUN-TARGET WORKING GRAPH

LINES TO BE DRAWN WITH COLORED PENCILS ARE INDICATED BY DASHES

VALUES OF FUTURE RANGE r_f IN YARDS AS FUNCTION OF TIME-OF-FLIGHT T AND ANGLE-OFF θ

Ammunition: Caliber 0.50 API M8 (muzzle velocity 2870 ft per sec)
Altitude: 8000 ft (relative air density 0.786)
TAS of Aircraft: 155 knots

AMG-N
June 1945

T	θ = 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°	160°	170°	180°
.05	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	48
.10	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94
.15	139	139	139	139	139	140	140	140	140	140	140	140	140	140	140	140	140	140	140
.20	184	184	184	184	184	184	184	184	185	185	185	185	185	185	185	185	186	186	186
.25	228	228	228	228	228	228	228	229	229	229	229	229	230	230	230	230	230	230	230
.30	270	270	271	271	271	271	271	272	272	272	273	273	273	274	274	274	274	274	274
.35	312	312	313	313	313	313	314	314	315	315	316	316	316	317	317	317	318	318	318
.40	354	354	354	354	354	355	355	356	357	357	358	358	358	359	360	360	360	360	360
.45	394	394	394	395	395	396	396	397	398	398	399	400	401	401	402	402	402	403	403
.50	434	434	434	434	435	436	436	436	438	439	440	441	442	442	443	444	444	444	444
.55	473	473	473	473	475	475	476	477	478	479	480	481	482	483	484	484	485	485	485
.60	511	511	511	512	513	513	515	516	517	518	519	521	522	523	524	525	525	525	525
.65	548	548	549	549	550	551	553	554	555	557	558	560	561	562	563	564	565	565	565
.70	586	586	587	587	588	589	591	592	593	595	596	598	599	600	601	602	603	603	604
.75	621	621	622	623	624	625	627	629	630	632	634	636	638	640	641	642	643	643	644
.80	657	657	657	658	660	661	663	665	667	669	671	674	676	677	679	680	681	682	682
.85	691	692	692	693	695	696	698	701	703	706	708	710	713	715	716	718	719	719	720
.90	726	726	726	728	729	731	733	736	738	741	744	747	749	751	753	755	756	757	757
.95	759	759	760	761	763	765	768	770	773	776	779	782	785	788	790	791	793	793	794
1.00	792	792	793	795	797	799	802	805	808	811	814	817	820	823	825	82[illegible]	829	830	830
1.05	824	825	826	827	829	832	835	838	842	845	849	852	855	858	861	861	862	863	864
1.10	856	857	858	859	862	864	868	871	875	879	883	886	890	893	896	898	900	901	901
1.15	888	888	889	891	893	896	900	904	908	912	916	920	924	927	930	933	935	936	936
1.20	918	919	920	922	924	928	931	935	940	944	949	953	957	961	964	967	969	970	970
1.25	948	949	950	952	955	959	962	967	972	976	981	986	990	994	998	1000	1003	1004	1004

Fig. 5.02. Sample Time-of-Flight Table.

V A L U E S O F F U T U R E R A N G E r_f I N Y A R D S

A S F U N C T I O N O F

T I M E - O F - F L I G H T T A N D A N G L E - O F F Θ

Ammunition: Caliber 0.50 API M8 (muzzle velocity 2870 ft per sec)
Altitude: 6000 ft (relative air density 0.786)
TAS of Aircraft: 170 knots

T \ Θ	0°	10°	20°	30°	40°	50°	60°	[illegible]	[illegible]	110°	120°	130°	140°	150°	160°	170°	180°
.00	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
.01	9	9	9	9	9	9	9	9		9	9	9	9	9	9	9	9
.02	19	19	19	19	19	19	19	19		19	19	19	19	[illegible]	19	19	19
.03	28	28	28	28	28	28	28	28		28	28	28	28	8	28	28	28
.04	38	38	38	38	38	38	38	38		38	38	38	38	38	38	38	38
.05	47	47	47	47	47	47	47	47		7	47	47	47	47	47	47	47
.06	56	56	56	56	56	56	56	56		6	56	56	56	56	56	56	56
.07	66	66	66	66	66	66	66	66		6	66	66	66	66	66	66	66
.08	75	75	75	75	75	75	75	75		5	75	75	75	75	75	75	75
.09	85	85	85	85	85	85	85	85		5	85	85	85	85	85	85	85
.10	94	94	94	94	94	94	94	94		4	94	94	94	94	94	94	94
.11	103	103	103	103	103	103	103	103		03	103	103	103	103	103	103	103
.12	112															112	12
.13	121															122	122
.14	130															131	131
.15	139															140	14[illegible]
																149	14[illegible]
.93	[illegible]																
.94	742																
.95	749																
.96	755	755	756	758	760	763	766		9	783	786	789	791	793	795	796	796
.97	762	762	763	765	767	769	772		6	790	793	796	798	800	802	803	803
.98	768	768	769	771	773	776	779		93	796	800	803	805	808	809	810	811
.99	775	775	776	778	780	782	785		00	803	807	810	812	815	816	817	818
1.00	781	781	782	784	786	789	79[illegible]		807	810	814	817	819	822	823	824	825
1.01	787	787	788	790	792	795	79		814	817	821	824	826	829	830	831	832
1.02	793	794	795	797	799	802	80		820	824	828	831	833	836	837	838	839
1.03	800	800	801	803	805	808	81		827	830	834	838	841	843	845	846	846
1.04	806	807	808	810	812	815	818		33	837	841	845	848	850	852	853	853
1.05	812	813	814	816	818	821	824		40	844	848	852	855	857	859	860	860
1.06	818	819	820	822	824	827	830		7	851	854	858	861	863	865	867	867
1.07	824	825	826	828	830	834	837		4	858	862	866	869	871	873	874	874
1.08	831	832	833	835	837	840	843			864	868	872	875	877	879	881	881
1.09	837	838	839	841	843	847	850			871	875	879	882	884	886	888	888
1.10	843	844	845	847	849	853	856			878	882	886	889	891	893	895	895
1.11	849	850	851	853	855	859	862			885	889	893	896	898	900	902	902
1.12	855	856	857	859	861	865	869			891	895	899	903	905	907	909	909
1.13	862	862	863	865	868	872	875			898	902	906	909	912	914	915	915
1.14	868	868	869	871	874	878	882			904	908	912	916	919	921	922	922
1.15	874	874	875	877	880	884	888		5	911	915	919	923	926	928	929	929
1.16	880	880	881	883	886	890	894		3	918	922	926	930	933	935	936	936
1.17	886	886	887	889	892	896	900		9	924	928	933	936	939	942	943	943
1.18	891	892	893	895	898	902	906		26	931	935	939	943	946	948	949	950
1.19	897	898	899	901	904	908	91[illegible]		932	937	941	946	949	952	955	956	957
1.20	903	904	905	907	910	914	91		939	944	948	953	956	959	962	963	964

Fig. 5.03. Sample Time-of-Flight Table (extended).

AZIMUTH (DEG)

ELEVATION (DEG)	360		358		356		354		352		3					284		282		280		278		276		274		272		270
	0	1	2	3	4	5	6	7	8	9	10				76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
0	0	1	2	3	4	5	6	7	8	9	1				76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	1	1	2	3	4	5	6	7	8	9					76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
2	2	2	3	4	4	5	6	7	8	9				5	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
3	3	3	4	4	5	6	7	8	9	9				5	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
4	4	4	4	5	6	6	7	8	9	10				5	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
5	5	5	5	6	6	7	8	9	9	10				75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
6	6	6	6	7	7	8	8	9	10	11	1			5	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
7	7	7	7	8	8	9	9	10	11	11	1				76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
8	8	8	8	9	9	9	10	11	11	12	1				76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
9	9	9	9	9	10	10	11	11	12	13	13				76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
10	10	10	10	10	11	11	12	12	13	13	14					77	78	79	80	81	82	83	84	85	86	87	88	89	90
11	11	11	11	11	12	12	13	13	14	14	15	1				77	78	79	80	81	82	83	84	85	86	87	88	89	90
12	12	12																									88	89	90
13	13	13																									88	89	90
14	14	14																									88	89	90
15	15	15																									88	89	90
16	16	16																									88	89	90
17	17	17																									88	89	90
		18																										89	90
30	30	30																									8		
31	31	31																									88	89	
32	32	32	32	32	32	32	32	33	33	33	33	34					80	81	82	82	83	84	85	86	87	87	88	89	90
33	33	33	33	33	33	33	33	34	34	34	34	35					80	81	82	82	83	84	85	86	87	87	88	89	90
34	34	34	34	34	34	34	34	35	35	35	35	36					0	81	82	83	83	84	85	86	87	88	88	89	90
35	35	35	35	35	35	35	35	36	36	36	36	36	3					81	82	83	83	84	85	86	87	88	88	89	90
36	36	36	36	36	36	36	36	37	37	37	37	37	3					81	82	83	84	84	85	86	87	88	88	89	90
37	37	37	37	37	37	37	37	38	38	38	38	38						81	82	83	84	84	85	86	87	88	88	89	90
38	38	38	38	38	38	38	38	39	39	39	39	39					1	81	82	83	84	84	85	86	87	88	88	89	90
39	39	39	39	39	39	39	39	40	40	40	40	40					1	81	82	83	84	85	85	86	87	88	88	89	90
40	40	40	40	40	40	40	40	41	41	41	41	4					81	82	82	83	84	85	85	86	87	88	88	89	90
41	41	41	41	41	41	41	41	41	42	42	42	4					81	82	82	83	84	85	85	86	87	88	88	89	90
42	42	42	42	42	42	42	42	42	43	43	43	4					81	82	83	83	84	85	85	86	87	88	89	89	90
43	43	43	43	43	43	43	43	43	44	44	44	4				1	81	82	83	83	84	85	86	86	87	88	89	89	90
44	44	44	44	44	44	44	44	44	45	45	45	4					81	82	83	84	84	85	86	86	87	88	89	89	90
45	45	45	45	45	45	45	45	45	46	46	46	4					82	82	83	84	84	85	86	86	87	88	89	89	90
46	46	46	46	46	46	46	46	46	47	47	47	4					82	82	83	84	84	85	86	87	87	88	89	89	90
47	47	47	47	47	47	47	47	47	48	48	48	48					82	83	83	84	85	85	86	87	87	88	89	89	90
48	48	48	48	48	48	48	48	48	49	49	49	49					82	83	83	84	85	85	86	87	87	88	89	89	90
49	49	49	49	49	49	49	49	49	49	50	50	50					82	83	83	84	85	85	86	87	87	88	89	89	90

ANGLE-OFF, θ, IN TERMS OF AZIMUTH α AND ELEVATION ε

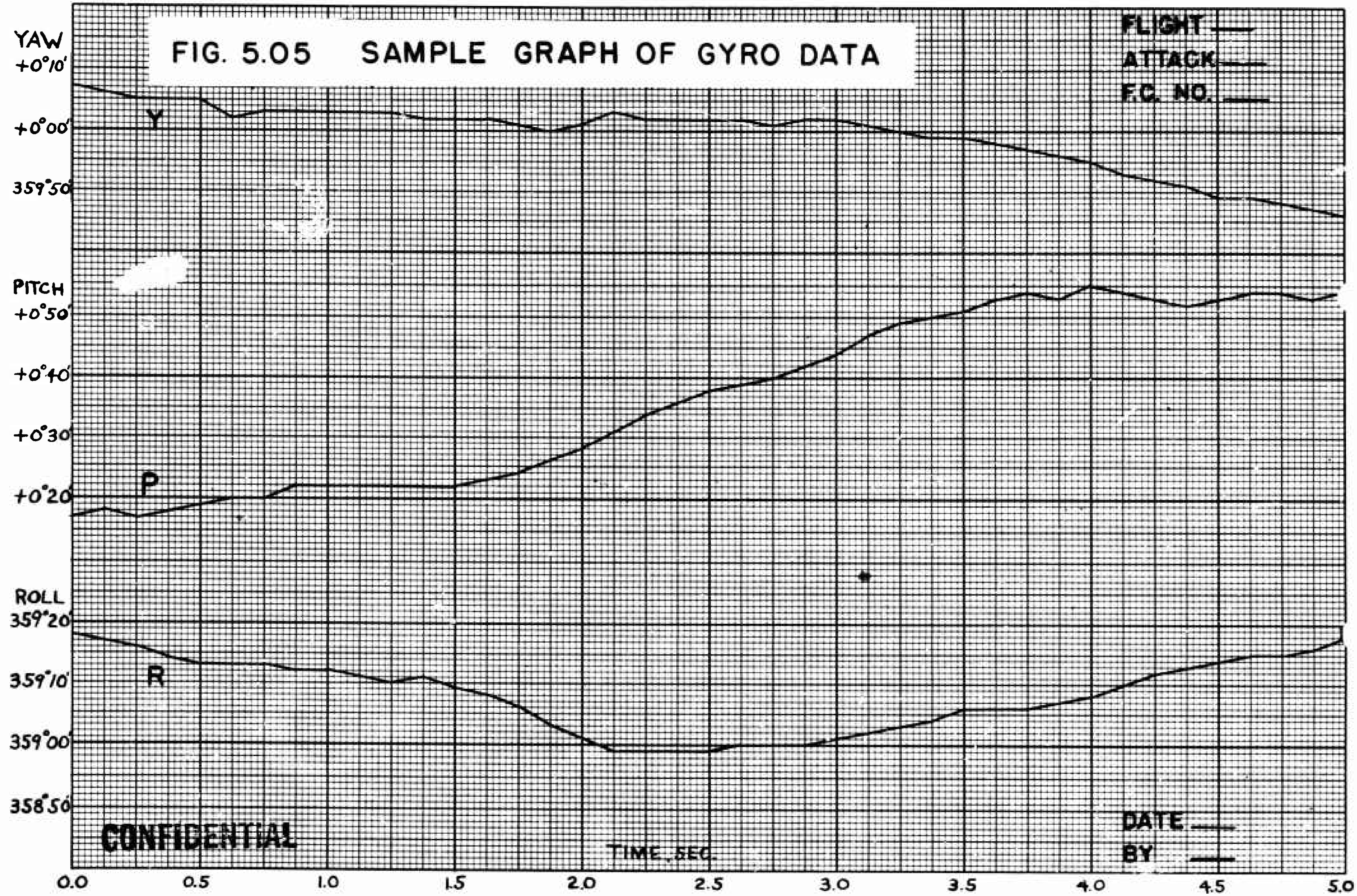
$$\cos\theta = \cos\alpha \cos\varepsilon$$

For $0^\circ \leq \alpha \leq 90^\circ$
and $270^\circ \leq \alpha \leq 360^\circ$
$0^\circ \leq \varepsilon \leq 49^\circ$

P14-E 6-15-45 H. F. H.

Fig. 5.04.

FIG. 5.05 SAMPLE GRAPH OF GYRO DATA



CONFIDENTIAL

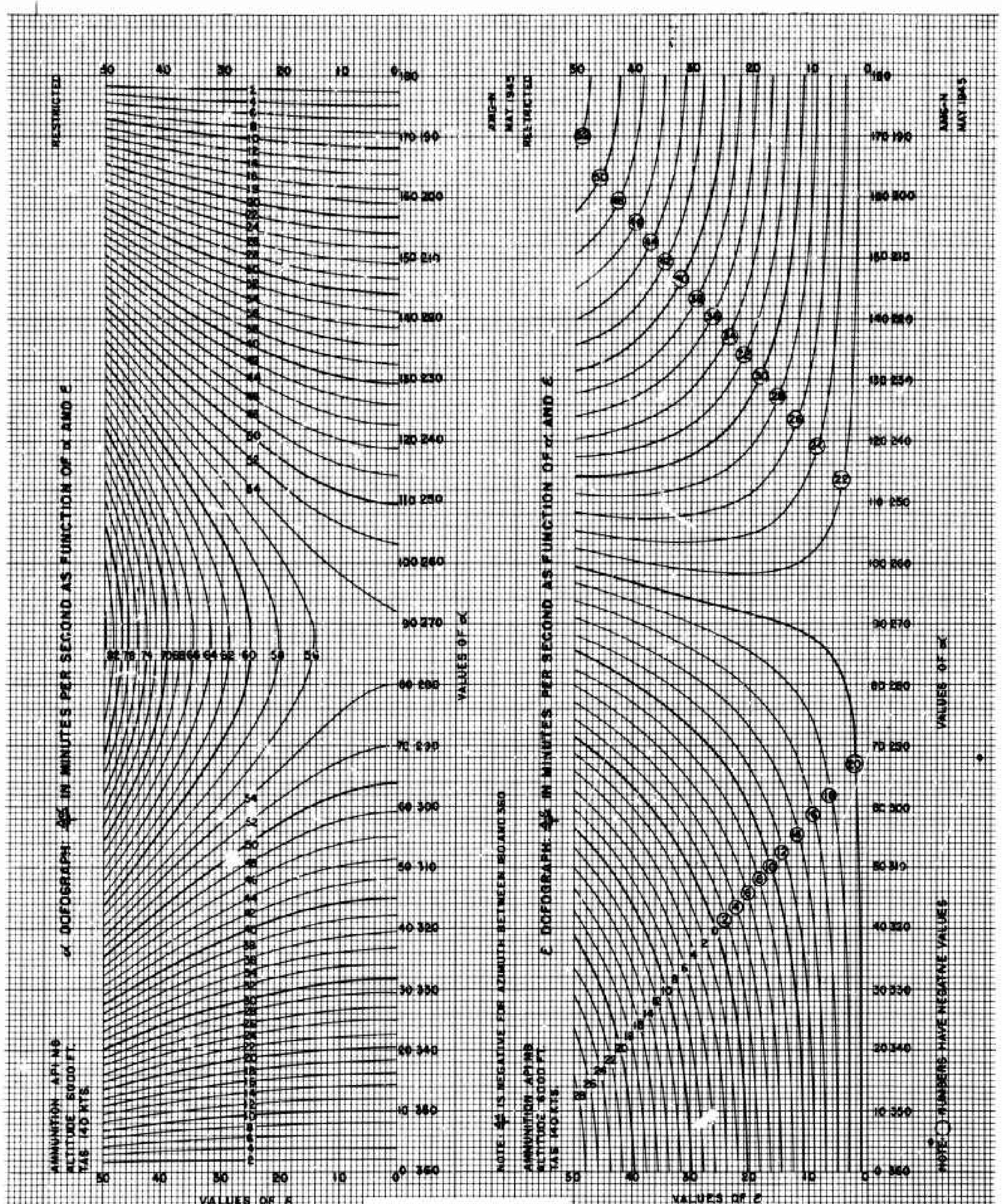


FIG. 5.06. DOFOGRAPHS

RESTRICTED

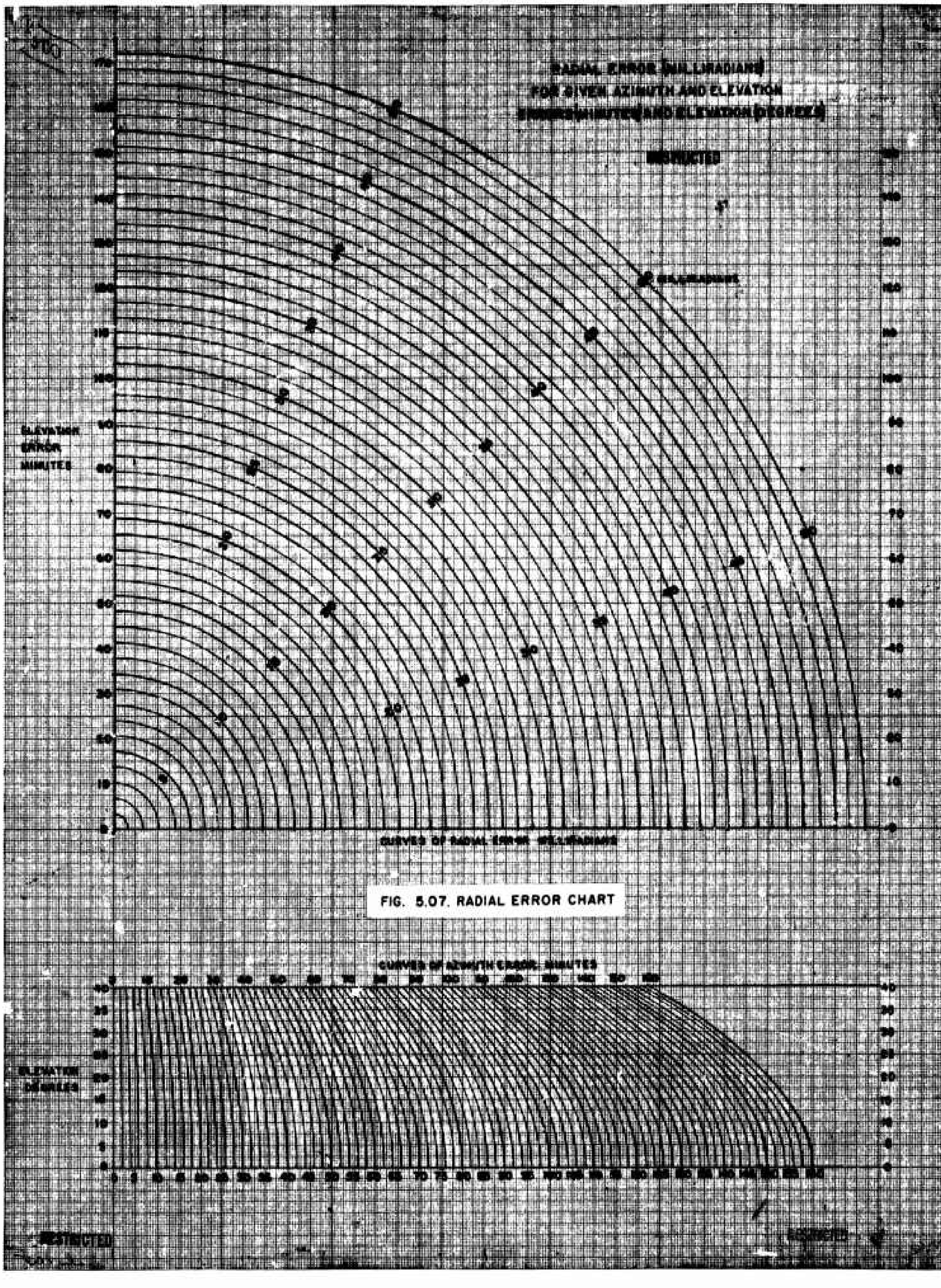


FIG. 5.07. RADIAL ERROR CHART

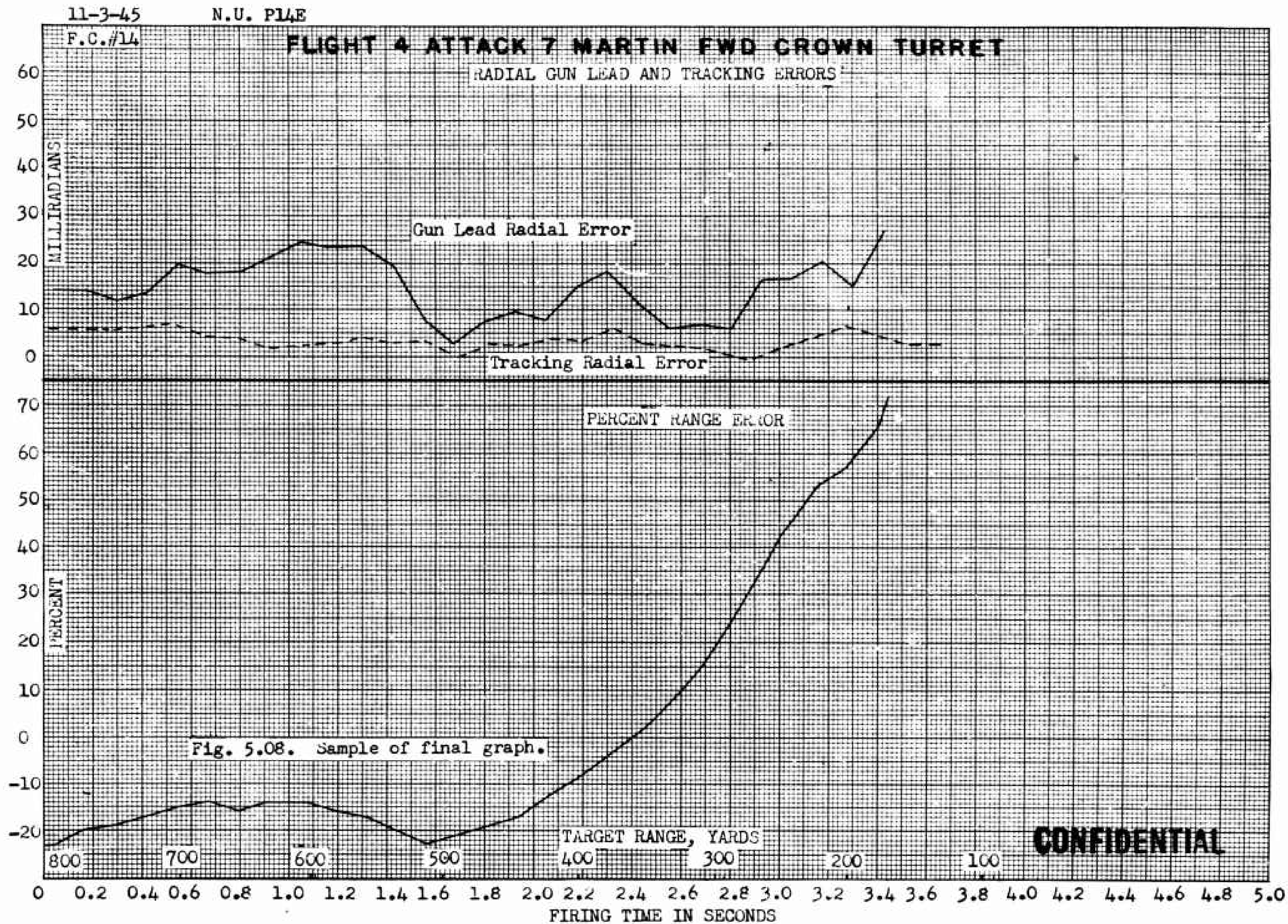


Fig. 5.08. Sample of final graph.

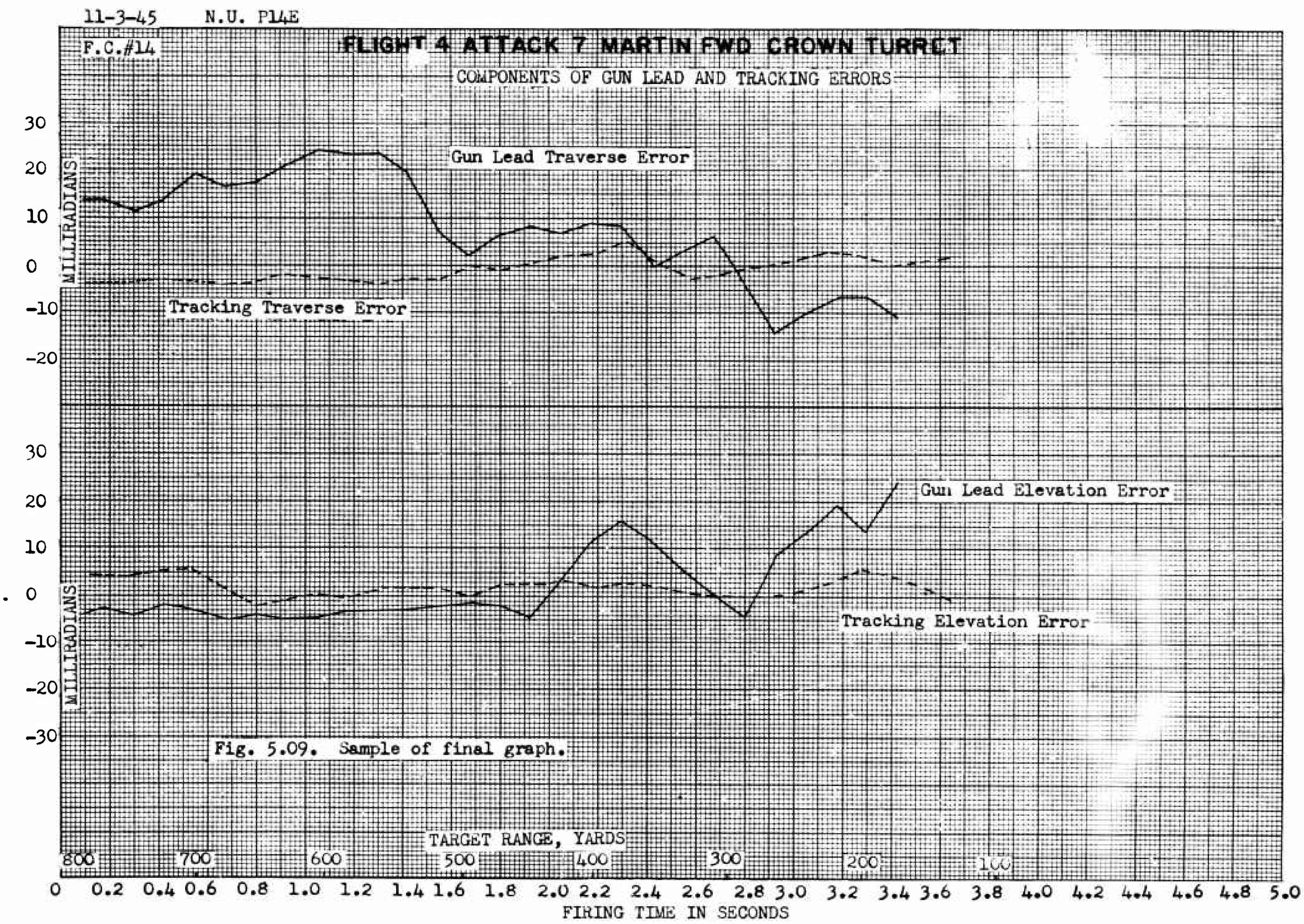


Fig. 5.09. Sample of final graph.

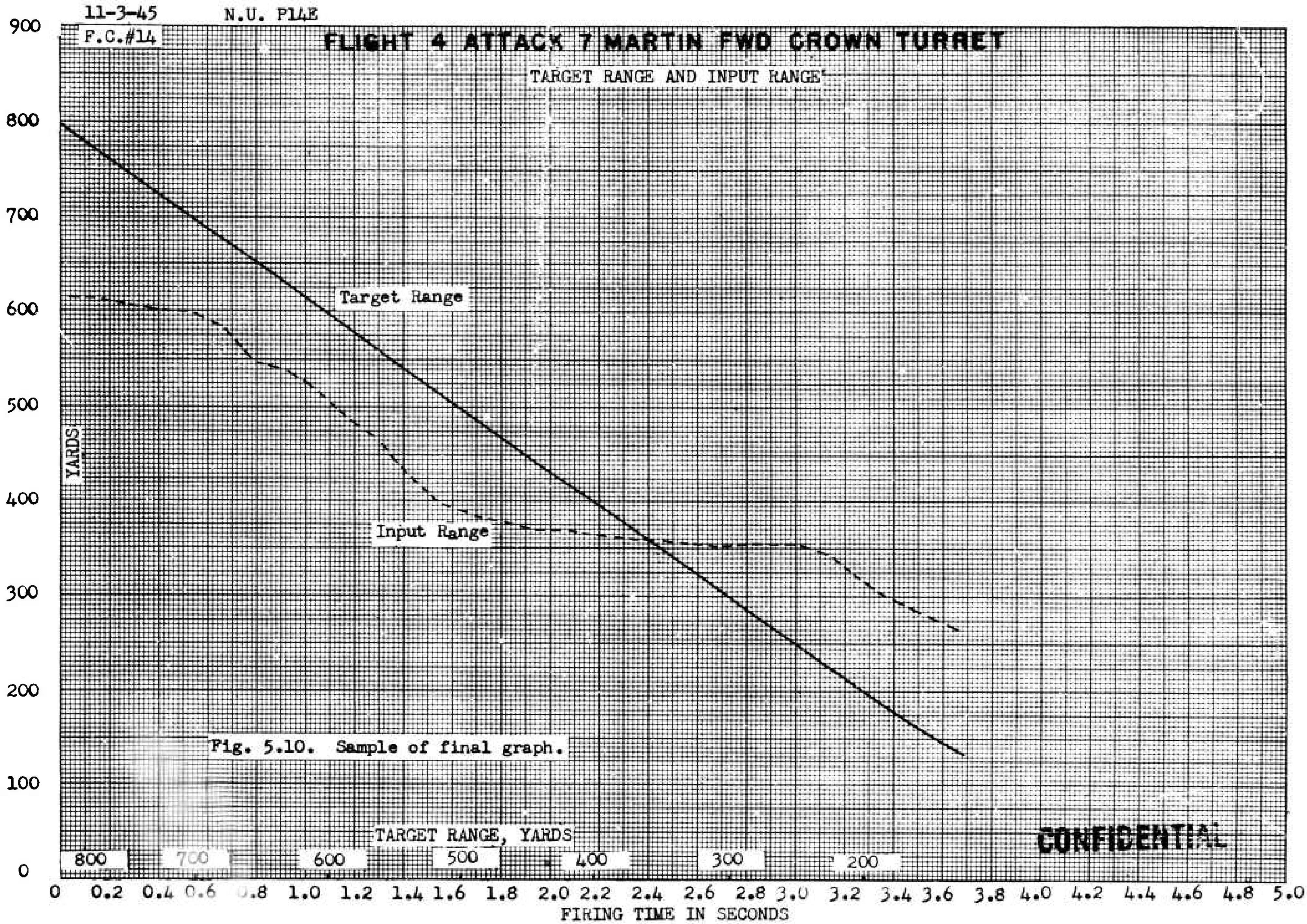


Fig. 5.10. Sample of final graph.

CONFIDENTIAL

CONFIDENTIAL

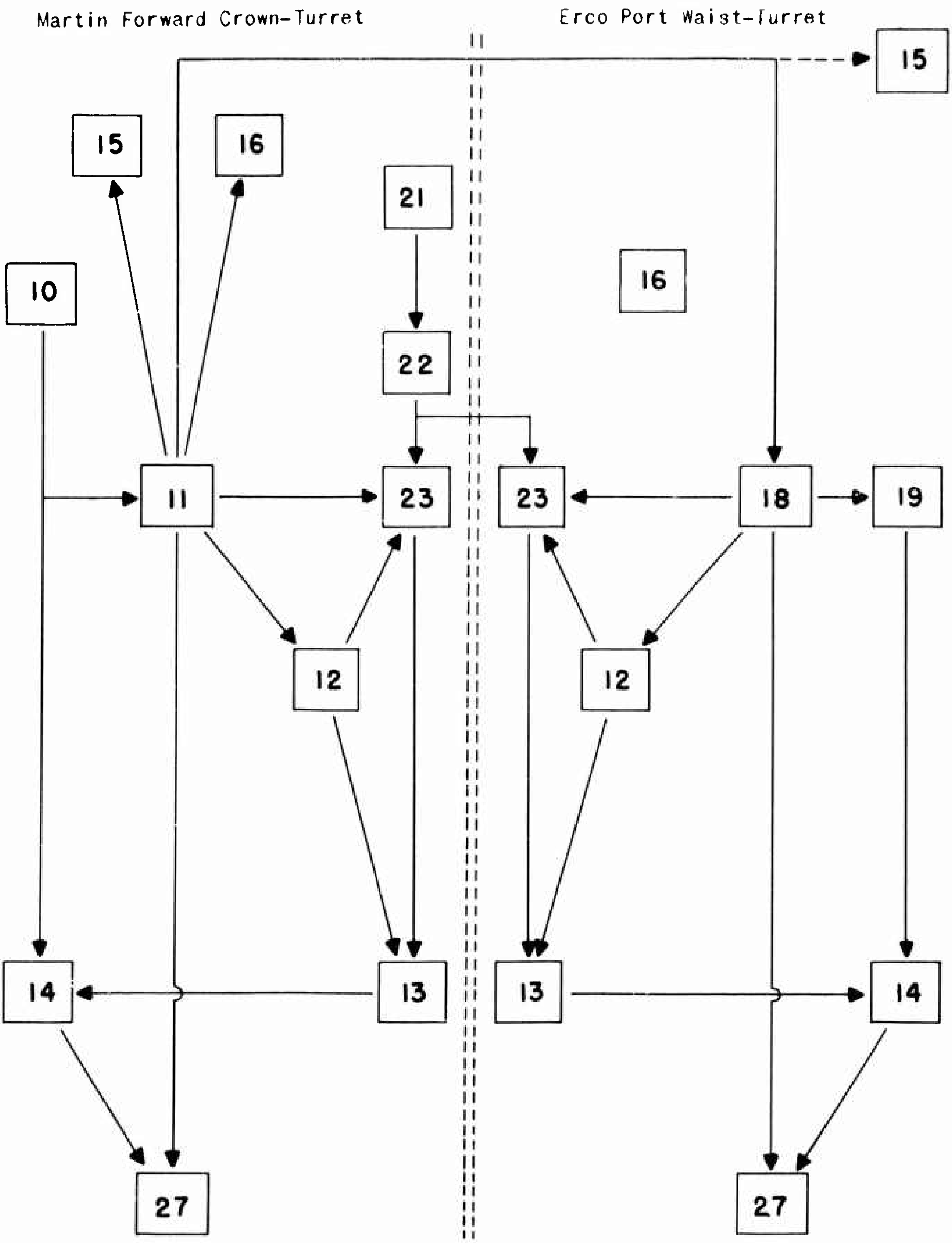


Fig. 5.11. Simplified Flow Chart for F.C. Nos. 9 and 14.
(The numbers refer to Form Sheets)

CONFIDENTIAL

RAZEL FILM

A. Read scale at selected frame intervals, and record Range Input in Col 10-B (convert feet to yards and enter values in Col 10-E).

B. Compare with range-appraisal obtained by scaling sight-reticle and using calculated range data (see FLOW CHART II).

1. Read scales at selected frame intervals, and record gun Az. and El. w.r.t.* turret axes in Cols 10-C and 10-D.**

2. Correct Cols 10-C and 10-D, recording in Cols 10-F and 10-G.

3. Plot these gun Az. and El. readings against frame numbers and corresponding time scale. Record in Cols 14-B and 14-C.

1. Using projector points on scree

2. Using CRADLE No w.r.t.* turret 11-G.

3. Plot and smooth readings agains ponding time sc at impact-time$_I$ in Cols 12-G an

5. Read graph (ite in Cols 13-B an and El. at impa

6. Obtain from pro (i.e., ballisti per unit time-o Cols 13-D and 1

7. Multiply by T_F effects (Δ α Cols 13-G and 1

8. Compute true bo (subtract balli operation 5 abo

9. Compute gun-lea Subtract true gun bore-point Record in Cols

10. Convert gun-le 14-G). Comput radians (Cols

11. Calculate Sing and bullet dis

---

* w.r.t. = with respect to

** These instructions assume that all films correspond frame by frame. If they do not, interpolation of the graphs will be required to "synchronize" data.

*** I = Initial; F = Final

**** Supervisor will supply values of K_1 or K_2 depending on use of wing-lights or wing-marks.

1

GUN-CAMERA FILM

ing projector and screen, plot target-
ints on screen.

ing CRADLE No. 2, obtain target Az. and El.
-.t.* turret axes. Record in Cols 11-F and
-G.

ot and smooth these target Az. and El.
adings against frame numbers and corres-
nding time scale. Record smoothed data
impact-time$_I$*** (intervals of 0.1 sec)
Cols 12-G and 12-H.

4. Compute Θ, the "angle off", from table provided. Record in Col. 12-C.

d graph (item 3 above) and record
Cols 13-B and 13-C the target Az.
El. at impact-time$_F$.***

ain from proper DOFOGRAPH $\frac{\Delta\alpha}{T}$ and $\frac{\Delta\epsilon}{T}$
e., ballistic effects on α and ϵ
unit time-of-flight). Record in
s 13-D and 13-E.

tiply by T_F to obtain the ballistic
ects ($\Delta\alpha$ and $\Delta\epsilon$). Record in
s 13-G and 13-H.

pute true bore-point Az. and El. at firing-time$_F$
btract ballistic effects from values obtained in
ration 5 above). Record in Cols 13-J and 13-K.

pute gun-lead errors in Az. and El. at firing-time$_F$.
btract true bore-point Az. and El. from the actual
n bore-point (i.e., corrected RAZEL data)..
cord in Cols 14-D and 14-E.

nvert gun-lead errors to milliradians (Cols 14-F and
-G). Compute traverse and radial errors in milli-
dians (Cols 14-H and 14-J).

lculate Single Shot Probability for known target size
d bullet dispersion (see AMG-C Report 302).

A. Using projector and screen, scale wing-lights and/or wing-marks, and record in Cols 11-B and 11-D.

B. Calculate range data from the formula:****

$$r = \frac{K_1}{s} \text{ or } \frac{K_2}{m}$$

Record in Cols 11-C and 11-E.

C. Plot and smooth range data against frame numbers and corresponding time scale. Record smoothed range data in Col 12-D.

D. Obtain bullet flight-times, T_I***, to the nearest 0.005 second from proper AMG-N Table II. Record in Col 12-E.

E. Calculate firing-time$_I$ (subtract time-of-flight, T_I, from impact-time$_I$). Record in Col 12-F.

F. Plot time-of-flight$_I$ against firing-time$_I$.

G. Choose firing time$_F$*** at RAZEL frame numbers**. Record in Col 14-A. Read the corresponding time-of-flight$_F$***, and record in Col 13-F.

H. Calculate impact-time$_F$ (corresponding to firing-time$_F$) by adding time-of-flight, T_F, to firing-time$_F$. Record in Col 13-A.

FLOW CHART I

HIT PROBABILITY

FROM MARTIN FORWARD CROWN-TURRET

Using RAZEL in place of Tri-Camera Film, but

Neglecting: (1) Range Correction for Fighter Aspect and Amount Fighter is off Gun-Camera's Optical Axis;
(2) Roll, Yaw, and Pitch.

CONFIDENTIAL
8 May 1945

2

GUN-CAMERA FILM

1. Referring to Flow Chart I, Gun-Camera Operation 3, read graph of smoothed target data. In Columns 16-C and 16-D record target Az. and El. at the time intervals corresponding to sight-film frame numbers.

SIGHT FILM

1. Using 16 mm projector and screen (Bay 1), mark target and sight-points on the screen.

2. Using CRADLE No. 1 in target-to-sight-point solution, determine Az. and El. of sight-point w.r.t.* turret axes. Record in Columns 16-F and 16-G.

3. Compute TRACKING ERRORS in Az. and El. by subtracting target data from sight data. Record in Columns 16-H and 16-J.

4. Use "Radial Error" chart to compute RADIAL TRACKING ERROR in milliradians. Record in Column 16-M. (The Az. and El. components of tracking errors -- Columns 16-H and 16-J -- may be converted to milliradians by using conversion table, the milliradian values being entered in Columns 16-K and 16-L.)

5. Compute traverse error in milliradians. Record in Col 16-N.

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B. A
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C. C
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R

D. C
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E. C
i

FLOW CHART II

RANGING AND TRACKING ERRORS
FORWARD CROWN-TURR

(Supplements FLOW CHARTS

* w.r.t. = with respect to
**Obtain "sight-range" constant from supervisor.

1

SIGHT FILM

A. Using 16 mm. projector and screen, mark visible reticle-points, and measure as many of the three diameters as determinable. Record in Columns 15-C, 15-D and 15-E.

B. Average the reticle diameters and record in Column 15-F.

C. Compute "sight-range" from the average reticle dimater, using the formula:

$$r = \frac{\text{constant**}}{\text{average reticle diameter}}$$

Record sight-range in Column 15-G.

D. Compute RANGING ERROR (from Reticle) by subtracting "smoothed range" (Column 15-J) from "sight-range" (Column 15-G); record difference in Column 15-K. (This is the gunner's error in manipulating the reticle range-control.)

E. Compute percent range error. Record in Col. 15-M.

GUN-CAMERA FILM

A'. Referring to Flow Chart I, Gun-Camera Operation C, read graph of smoothed range data. In Column 15-J, record range values at time intervals corresponding to sight-film frame numbers.

B'. On the graph of smoothed range, also plot RAZEL range-input. (Column 10-E)

C'. In Column 15-H record range input values at time intervals corresponding to sight-film frame numbers.

D'. Compute RANGING ERROR (from RAZEL) by subtracting "smoothed range" (Column 15-J) from "RAZEL range-input" (Column 15-H); record difference in Column 15-L. (If sight mechanism was functioning properly and if plotting- and calculating-errors are negligible, the RANGING ERRORS obtained by these two methods, D and D', should be the same.)

-

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J.

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L.)

s.

OW CHART II

ACKING ERRORS IN MARTIN
D CROWN-TURRET

FLOW CHARTS I & III)

CONFIDENTIAL

16 May 1945

RAZEL FILM

GUN

A. Read scale at selected frame intervals, and record Range Input in Col 10-B. (Convert feet to yards and enter values in Col 10-E).

B. Compare with range-appraisal obtained by scaling sight-reticle and using calculated range data (see FLOW CHART II) .

1. Read scales at selected frame intervals, and record gun Az. and El. w.r.t.* turret axes in Cols 10-C and 10-D.**

2. Correct Cols 10-C and 10-D, recording in Cols 10-F and 10-G.

3. Plot these gun Az. and El. readings against frame numbers and corresponding time scale. Record in Cols 14-B and 14-C.

1. Using projector and screen, plot target-points on screen.

2. Using CRADLE No. 2, obtain target Az. and El. w.r.t.* turret axes. Record in Cols 11-F and 11-G.

3. Plot and smooth these target Az. and El. readings against frame numbers and corresponding time scale. Record smoothed data at impact-time$_I$*** in Cols 12-G and 12-H, at intervals of 0.1 sec.

4. Compute Θ, the "angle-off", from table provided. Record in Col 12-C.

5. Read graph (item 3 above) and record in Cols 23-B and 23-C the target Az. and El. at impact-time$_F$.***

6. Use GLOOK to compute target Az. firing-time$_F$. Record in Cols 1

7. Obtain from proper DOFOGRAPH ε per unit time-of-flight).

8. Multiply by T_F to obtain the ba Cols 13-G and 13-H.

9. Compute true bore-point Az. and from values obtained in operati

10. Compute gun lead errors in Az. Az. and El. from the actual gun in Cols 14-D and 14-E.

11. Convert gun lead errors to mill and radial errors in milliradia

12. Calculate Single Shot Probabili (see AMG-C Report 302).

---

* w.r.t. = with respect to

** These instructions assume that all films correspond frame by frame. If they do not, interpolation of the graphs will be required to "synchronize" data.

*** I = Initial; F = Final

**** Supervisor will supply values of K_1 or K_2 depending on use of wing-lights or wing-marks.

GUN-CAMERA FILM

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***

A. Using projector and screen, scale wing-lights and/or wing-marks, and record in Cols 11-B and 11-D.

B. Calculate range data from the formula:****
Record in Cols 11-C and 11-E.

$r = \frac{K_1}{s}$ or $\frac{K_2}{m}$.

C. Plot and smooth range data against frame numbers and corresponding time scale. Record smoothed range data in Col 12-D.

D. Obtain bullet flight-time, T_I***, to the nearest 0.005 sec from proper AMG-N Table II. Record in Col 12-E.

E. Calculate firing-time$_I$ (subtract time-of-flight, T_I, from impact-time$_I$). Record in Col 12-F.

F. Plot time-of-flight$_I$ against firing-time$_I$.

G. Choose firing-time$_F$*** at RAZEL frame numbers.** Record in Col 14-A and 23-G. Read the corresponding time-of-flight$_F$*** and record in Col 13-F.

H. Calculate impact-time$_F$ (corresponding to firing-time$_F$) by adding time-of-flight, T_F, to firing-time$_F$. Record in Col 13-A and 23-A.

GYRO FILM

1. Read dials at selected frame intervals and record yaw, pitch, and roll angles in Cols 21-C, 21-D and 21-E.

2. Correct yaw, pitch, and roll for initial gyro reading (see supervisor). Record in Cols 21-F, 21-G and 21-H. Add "flight angle", P_o, to pitch. Record in Col 21-J.

3. If necessary (see supervisor) correct roll and yaw readings for use in GLOOK (using AMG-N Table I).

4. Plot pitch, roll and yaw against frame numbers and corresponding time scale.

5. Read graph (item 4 above) and record on Form 23 the pitch, roll and yaw of the turret axes at impact-time$_F$ and at firing-time$_F$.

ute target Az. and El. at impact-time$_F$ w.r.t.* turret axes at
cord in Cols 13-B and 13-C.

r DOFOGRAPH $\frac{\Delta\alpha}{T}$ and $\frac{\Delta\varepsilon}{T}$ (i.e., ballistic effects on α and
e-of-flight). Record in Cols 13-D and 13-E.

obtain the ballistic effects ($\Delta\alpha$ and $\Delta\varepsilon$). Record in
-H.

-point Az. and El. at firing-time$_F$ (subtract ballistic effects
ined in operation 6 above). Record in Cols 13-J and 13-K.

errors in Az. and El. at firing-time$_F$. [Subtract true bore-point
the actual gun bore-point (i.e., corrected RAZEL data)]. Record
14-E.

errors to milliradians (Cols 14-F and 14-G). Compute traverse
in milliradians. Record in Col 14-H and 14-J.

Shot Probability for known target size and bullet dispersion
302).

FLOW CHART III

HIT PROBABILITY FROM

MARTIN FORWARD CROWN-TURRET

Using the GLOOK for Roll, Yaw and Pitch Corrections, but

Neglecting: (1) Range-Correction of the Fighter Aspect;
(2) Amount Fighter is off Gun-Camera's Optical-Axis.

CONFIDENTIAL

25 May 1945

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Frame Number	Film Dial Readings			Corrected Values			
	Range Input (Feet)	Azimuth-2° (Deg-Min)	Elevation (Deg-Min)	Range Input (Yards)	Gun Az. (Deg-Min)	Gun El. (Deg-Min)	Time (Sec)
A	B	C	D	E	F	G	H
RAZEL frame numbers	RAZEL input range read from RAZEL film (see Sect. E on Film Reading) nearest 10 feet	Gun Az. -2° read from RAZEL film (see Sect. E on Film Reading) nearest min	Gun El. read from RAZEL film (see Sect. E on Film Reading) nearest min	$\frac{\text{Col 10-B}}{3}$ P10-E: plot Col 10-E vs Col 10-H on Martin graph nearest yard	Same as (Col 10-C) + 2° unless corrected (consult supervisor) P10-F: plot Col 10-F vs Col 10-H nearest min	Same as Col 10-D unless corrected (consult supervisor) P10-G: plot Col 10-G vs Col 10-H nearest min	Col 10-A converted to seconds nearest .001 sec

Flight No. ____________
Attack No. ____________
F. C. No. ____________

RAZEL DATA
Martin forward crown-turret

By ____________
Started ____________
Completed ____________

Form 10

Sheet _____ of _____

CONFIDENTIAL

Frame Number	Wing Tip Lights K_1 = ______		Wing Marks K_2 = ______		Target Position		Time (Sec)
	Screen Length (Inches)	Range (Yards) $r = K_1/B$	Screen Length (Inches)	Range (Yards) $r = K_2/B$	Azimuth (Deg-Min)	Elevation (Deg-Min)	
A	B	C	D	E	F	G	H
Martin gun-camera frame numbers	Measure target from wing-light to wing-light on screen (Range-Scaling Procedure, see Sect. F) nearest .01 inch	Range = $\frac{K_1}{\text{Col 11-B}}$ Use Martin range conversion table or consult supervisor for value of K_1 P11-C: plot Col 11-C vs Col 11-H S11-C: draw in smooth curve nearest yard	Measure target from wing-mark to wing-mark on screen (Range-Scaling Procedure, see Sect. F) nearest .01 inch	Range = $\frac{K_2}{\text{Col 11-D}}$ Compute and plot range from this column only if so directed by supervisor nearest yard	Obtain target Az. using CRADLE Problem Solution No. 2 P11-F: plot Col 11-F vs Col 11-H S11-F: draw in smooth curve nearest min	Obtain target El. using CRADLE Problem Solution No. 2 P11-G: plot Col 11-G vs Col 11-H S11-G: draw in smooth curve nearest min	Col 11-A converted to seconds nearest .001 sec

Flight No. ______
Attack No. ______
F. C. No. ______

RANGE AND TARGET POSITION
via CRADLE in Booth No. ___
Martin Turret

By ______
Started ______
Completed ______
Sheet ____ of ____

Form 11

N. U. P14E 25 May '45

Frame Number	Impact Time (Initial) (Sec)	Angle-off θ (Deg)	Smoothed Range (Yards)	Bullet Time of Flight (Initial), T_I (Sec)	Firing Time (Initial) (Sec)	Smoothed Target Position at Impact Time (Initial)	
						Azimuth (Deg-Min)	Elevation (Deg-Min)
A	B	C	D	E	F	G	H
Do not use if a Form 18 has been done (Alternative: List Martin gun-camera frame numbers)	List time in 0.1's second (Alternative: Col 12-A converted to nearest .001 sec)	Use θ table with Cols 18-G and 18-H (Taking φ and ε to the nearest degree) to find θ (Alternative: Use Cols 12-G, 12-H, or 11-F, 11-G to find θ) nearest degree	Same as Col 18-E (Alternative: Read from S11-C at times in Col 12-B) nearest yard	Use time-of-flight table for proper altitude, ammunition and true air speed (consult supervisor) with Cols 12-C and 12-D to obtain T_I nearest .005 sec P12-E: plot Col 12-E vs 12-F on Martin graph S12-E: draw in smooth curve	(Col 12-B) - (Col 12-E) nearest .001 sec	Same as Cols 18-C and 18-D; so can be omitted (Alternative: Read from S11-F and S11-G at times in Col 12-B) nearest min	nearest min

Flight No. ________
Attack No. ________
F. C. No. ________

BULLET TIME OF FLIGHT

Alt. ________
T.A.S. ________
Amm. ________ Martin Turret

By ________
Started ________
Completed ________
Sheet ____ of ________

Form 12

N. U. P14E 25 May '45

Imp. Time Final (Sec)	Target Position at Impact Time (Final) Corrected for RYP		From Dofograph		Bullet Time of Flight (Final) T_F (Sec)	Ballistic Effects		True Bore-Point at Firing Time		
	Az. (Deg-Min)	El. (Deg-Min)	$\frac{\Delta\alpha}{T}$	$\frac{\Delta\varepsilon}{T}$		$\Delta\alpha$ (Min)	$\Delta\varepsilon$ (Min)	Az. (Deg-Min)	El. (Deg-Min)	
A	B	C	D	E	F	G	H	J	K	
nearest .001 sec	nearest min	nearest min	nearest min/sec	nearest min/sec	nearest .001 sec	nearest min	nearest min	nearest min	nearest min	
(Col 14-A) + (Col 13-F)	Obtained by GLOOK Problem Solution No. 1 from Cols 23-B and 23-C		Use DOFOGRAPH for proper altitude, ammunition and true air speed (consult supervisor) to obtain $\frac{\Delta\alpha}{T}$, $\frac{\Delta\varepsilon}{T}$		Read from S12-E at times in Col 14-A	(Col 13-D) x (Col 13-F)	(Col 13-E) x (Col 13-F)	(Col 13-B) - (Col 13-G)	(Col 13-C) - (Col 13-H)	

Flight No. ____________
Attack No. ____________
F. C. No. ____________

TRUE BORE POINT
CORRECTED FOR RYP

By ____________
Started ____________
Completed ____________

Alt. ' ______
T.A.S. ______ Amm. ______ Turret Martin

Form 13

Sheet ______ of ______

Firing Time (Final) (Sec)	Gun Position at Firing Time		Gun Lead Errors at Firing Time (Actual Position Minus True Position)					
	Azimuth (Deg-Min)	Elevation (Deg-Min)	Azimuth (Deg-Min)	Elevation (Deg-Min)	Azimuth (Millirad)	Elevation (Millirad)	Traverse (Milli-rad)	Radial (Milli-rad)
A	B	C	D	E	F	G	H	J
List time in sec corresponding to RAZEL frame numbers,(Col 10-H) starting with the earliest time for which a value can be read from the T curve (S12-E). nearest .001 sec	Same as Cols 10-F and 10-G at times in Col 14-A nearest min	nearest min	(Col 14-B) - (Col 13-J) nearest min	(Col 14-C) - (Col 13-K) nearest min	Col 14-D converted to milliradians nearest .1 millirad	Col 14-E converted to milliradians nearest .1 millirad	Traverse error = (cos Col 13-C) x (Col 14-F) nearest .1 millirad	Use radial error chart with Col 14-D, Col 14-E and Col 13-C to find radial error, or compute $\sqrt{(\text{Col 14-H})^2 + (\text{Col 14-G})^2}$ "

Flight No. ________
Attack No. ________
F. C. No. ________

GUN LEAD ERRORS
CORRECTED FOR RYP
Martin Turret

By ________
Started ________
Completed ________

Form 14

Sheet ______ of ______

N. U. P14E 26 May '45

Sight Camera Frame Number	Time (Sec)	Reticle Diameters (Inches)				Sight Range	RAZEL Range	Smooth Range	Range Errors (Yards)		Percent Sight Range Error	
		1	2	3	Average	(Yards)	(Yards)	(Yards)	From Sight Range	From RAZEL Range		
A	B	C	D	E	F	G	H	J	K	L	M	
—	nearest .001 sec	nearest .01 inch	nearest .01 inch	nearest .01 inch	nearest .01 inch	nearest yard	nearest yard	nearest yard	nearest yard	nearest yard	nearest 1%	
Martin sight-camera frame numbers	Col 15-A converted to seconds		(Inside) reticle diamters measured from Martin sight-film		$\frac{(\text{Col 15-C}) + (\text{Col 15-D}) + (\text{Col 15-E})}{3}$	$\frac{K_3}{\text{Col 15-F}}$ Use Martin sight-range conversion table and Col 15-F (or consult supervisor for value of K_3)	Read from P10-E at times in Col 15-A	Read from S11-C at times in Col 15-A	(Col 15-G) - (Col 15-J)	(Col 15-H) - (Col 15-J)	$100 \frac{\text{Col 15-K}}{\text{Col 15-J}}$	

Flight No. ____________
Attack No. ____________
F. C. No. ____________

GUNNER'S RANGE ERROR
Martin Turret

By ____________
Started ____________
Completed ____________

Form 15

Sheet of

Sight Camera Frame Number	Time (Sec)	Smoothed Target Position Az. (Deg-Min)	Smoothed Target Position El.	cos D	SIGHT POINT Az. (Deg-Min)	SIGHT POINT El.	TRACKING ERRORS Az. (Deg-Min)	TRACKING ERRORS El.	TRACKING ERRORS Az. (Milliradians)	TRACKING ERRORS El.	TRACKING ERRORS Radial	Traverse Error (Milli-rad)
A	B	C	D	E	F	G	H	J	K	L	M	N
	nearest .001 sec	nearest min	nearest min	nearest .001	nearest min	nearest min	nearest min	nearest min	nearest .1 milliradian	nearest .1 milliradian	nearest .1 milliradian	nearest .1 milliradian
Martin sight-camera frame numbers (same as Col 15-A)	Col 16-A converted to seconds (same as Col 15-B)	Read from S11-F and S11-G at times in Col 16-B		Cosine Col 16-D (can be used directly from table or entered here)	Obtained in Bay No. 1 by CRADLE Problem Solution No. 5		(Col 16-F) - (Col 16-C)	(Col 16-G) - (Col 16-D)	Col 16-H converted to milliradians	Col 16-J converted to milliradians	$\sqrt{(\text{Col 16-N})^2 - (\text{Col 16-L})^2}$ or radial error chart using Cols 16-H, 16-J and 16-D	(cosine Col 16-D) x (Col 16-K)

Flight No. ____________
Attack No. ____________
F. C. No. ____________

GUNNER'S TRACKING ERROR
Via CRADLE in Booth No. ____
Martin ________ Turret

By ____________
Started ____________
Completed ____________
Sheet ______ of ______

Form 16

CONFIDENTIAL

N. U. P14E 26 May '45

Frame Number	Time (Sec)	Smoothed Target Relative to Bomber Axes at Martin Turret		Smoothed Range at Martin Turret	d	Target Relative to Bomber Axes at Erco Turret	
		Azimuth (Deg-Min)	Elevation (Deg-Min)	(Yards)	(Inches)	Azimuth (Deg-Min)	Elevation (Deg-Min)
A	B	C	D	E	F	G	H
	Time in 0.1's second	Target Azimuth read from S11-F (Martin) at times in Col 18-B nearest min	Target Elevation read from S11-G (Martin) at times in Col 18-B nearest min	Range read from S11-C (Martin) at times in Col 18-B nearest yard	d = 654/Col 18-E nearest .001 inch	Target Azimuth at Erco turret obtained by PLAXIE Problem Solution No. 2 P18-G: plot Col 18-G vs Col 18-B S18-G: draw in smooth curve nearest min	Target Elevation at Erco turret obtained by PLAXIE Problem Solution No. 2 P18-H: plot Col 18-H vs Col 18-B S18-H: draw in smooth curve nearest min

Flight No. ____________
Attack No. ____________
F. C. No. ____________

PARALLAX CORRECTION
From Martin Forward Crown-Turret
To Erco Port Waist-Turret

By ____________
Started ____________
Completed ____________

Form 18

$h = 10.9$ yds; $\alpha_1 = 185^{\circ}39'$; $\varepsilon_1 = -5^{\circ}48'$; $d = 654/r$

Sheet ____ of ____

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N. U. P14E 25 May '45

Gyro Camera Frame Number	Time (Sec)	Film Dial Readings — Initial Readings: Yaw, Y'y (Deg-Min)	Pitch, P'z (Deg-Min)	Roll, R'z (Deg-Min)	Corrected Values: Yaw, Yy (Deg-Min)	Pitch, Pz-P (Deg-Min)	Roll, Rz (Deg-Min)	GLOOK Pitch, $P + P_o$ (Deg-Min)
A	B	C	D	E	F	G	H	J
	nearest .001 sec	nearest min	nearest min	nearest min	nearest min	nearest min	nearest min	nearest min
Gyro camera frame numbers	Col 21-A converted to seconds		Readings from gyro film (see Sect. E on Film Reading)		(Col 21-G) - (initial yaw reading) P21-F: plot Col 21-F vs Col 21-B	(initial pitch reading) - (Col 21-D)	(initial roll reading) - (Col 21-E) P21-H: plot Col 21-H vs Col 21-B	(Col 21-G) + P_o. For P_o see bottom of this Form Sheet. P21-J: plot Col 21-J vs Col 21-B

Flight No. ______
Attack No. ______
F. C. No. ______
Form 21

GYRO FILM DATA
Gyro Set No. 1
Flight Angle, P_o = ____

By ______
Started ______
Completed ______
Sheet ____ of ____

CONFIDENTIAL

Impact Time (final) (Sec)	Smoothed target at impact time		Attitude at impact time			Firing Time (final) (Sec)	Attitude at firing time			
	Elevation (Deg-Min)	Azimuth (Deg-Min)	Pitch, $P + P_o$ (Deg-Min)	Roll, R (Deg-Min)	Yaw, Y (Deg-Min)		Pitch, $P + P_o$ (Deg-Min)	Roll, R (Deg-Min)	Yaw, Y (Deg-Min)	
A	B	C	D	E	F	G	H	J	K	
Same as Col 13-A nearest .001 sec	Read from S11-G at times in Col 23-A nearest min	Read from S11-F at times in Col 23-A nearest min	Read from P21-J at times in Col 23-A nearest min	Read from P21-H at times in Col 23-A nearest min	Read from P21-F at times in Col 23-A nearest min	Same as Col 14-A nearest .001 sec	Read from P21-J at times in Col 23-G nearest min	Read from P21-H at times in Col 23-G nearest min	Read from P21-F at times in Col 23-G nearest min	

Flight No. ________
Attack No. ________
F. C. No. ________

Form 23

CORRECTION FOR
ROLL, YAW, PITCH
Martin Turret

By ________
Started ________
Completed ________
Sheet ____ of ____

I.T. Impact Time (final) (Sec)	r, Range at I.T. (Yards)	F.T., Firing Time (final) (Sec)	δ, Radial Gun Lead Error at F.T. (Milliradians)	R = Q/r where Q=1000a/σ Q = ____	X = δ/σ	q = q(R,X) from prob.table or graph	p = 1-q, Single Shot Prob. at F.T.	Range at F. T. (Yards)
A	B	C	D	E = Q/B	F = D/σ	G	H = 1-G	J
nearest .001 sec	nearest yard	nearest .001 sec	nearest .1 millirad	nearest .01	nearest .01	nearest .001	nearest .001	nearest yard
Same as Col 13-A	Read from S11-C at times in Col 27-A	Same as Col 14-A	Same as Col 14-J	Q/Col 27-B (Supervisor will supply value of Q)	Col 27-D / σ (Supervisor will supply value of σ)	Use AMG-C Report 302 (Germond-Hastings Tables) with Cols 27-E, 27-F to find q(R,X)	1 - (Col 27-G)	Read from S11-C at times in Col 27-C

Flight No. ________
Attack No. ________
F. C. No. ________

SINGLE SHOT PROBABILITY
Martin Turret
Dispersion: σ = ____ milliradians
Target radius: a = ________ yards

By ________
Started ________
Completed ________
Sheet ____ of ____

Form 27

RAZEL FILM
(Forward crown-turret)

1. Read sc les at selected frame interv , and record gun Az. and El. w.r.t.* turret axes in Cols 10-C and 10-D**.

2. Correct Cols 10-C and 10-D, recording in Cols 10-F and 10-G.

3. Plot these gun Az. and El. readings against frame numbers and corresponding time scale.

GUN-CAMERA F
(Forward crown-t

1. Using 35 mm projector and screen in Booth No. 2 plot target-points on screen.

2. Using CRADLE, obtain target Az. and El. readings w.r.t.* bomber axes centered at forward crown-turret**. Record in Cols 11-F and 11-G.

3. Plot and smooth these target Az. and El. readings against frame numbers and corresponding time scale.

4. Read these smoothed target data (Az. and El. w.r.t.* bomber axes at forward crown-turret), at intervals of 0.1 sec. Record in Cols 18-C and 18-D.

5. Using PLAXIE, adjusted for prope target Az. and El. w.r.t.* bombe waist-turret. Record in Cols 18-

6. Plot and smooth these parallax-corrected target Az. and El. data.

7. Obtain from pr per unit time-

8. Multiply by T_F Record in Cols

9. Compute true b ballistic effe Record in Cols

10.

11.

12.

* w.r.t. = with respect to

** These instructions assume that all films correspond frame by frame. If they do not, interpolation of the graphs will be required to "synchronize" data.

*** I = Initial; F = Final

**** Supervisor will supply values of K_1 and K_2 depending on use of wing-lights or wing-marks.

GUN-CAMERA FILM
(Forward crown-turret)

een in Booth No. 2

z. and El. readings
at forward crown-
F and 11-G.

Az. and El. readings
rresponding time scale.

ata (Az. and El. w.r.t.*
-turret), at intervals of
and 18-D.

A. Using 35 mm projector and screen in Booth No. 2, scale wing-lights and/or -marks, and record in Cols 11-B and 11-D.

B. Calculate range data from the formula: $r = \frac{K1}{s}$ or $\frac{K2}{m}$ **** Record in Cols 11-C and 11-E.

C. Plot and smooth range data against frame numbers and corresponding time scale.

D. Read these smoothed range data (w.r.t.* bomber axes at forward crown-turret) at times of step 4. Record in Col 18-E.

A. Correct these for the waist Record in Col of 0.1 sec).

E. Calculate "d", the distance PLAXIE slider is to move; record in Col 18-F.

PLAXIE, adjusted for proper α_1 and ε_1, find
t Az. and El. w.r.t.* bomber axes centered at port
-turret. Record in Cols 18-G and 18-H.

Compute Θ, the "angle off", from table provided. Record in Col 12-C.

B. Obtain bullet 0.005 sec fro Col 12-E.

C. Calculate fir from impact-t

D. Plot T_I again

and smooth these
llax-corrected
t Az. and El. data.

(a) From graph read these target data at times corresponding to port waist gun-camera frame numbers. Record in Cols 19-G and 19-H.

(b) From graph read these target data at impact-time$_F$. Record in Cols 13-B and 13-C.

7. Obtain from proper LOFOGRAPH $\frac{\Delta\alpha}{T}$ and $\frac{\Delta\varepsilon}{T}$ (ballistic effects on α and ε per unit time-of-flight). Record in Cols 13-D and 13-E.

8. Multiply by T_F to obtain the ballistic effects ($\Delta\alpha$ and $\Delta\varepsilon$). Record in Cols 13-G and 13-H.

E. Choose firing waist-turret 14-. Read t record in Col

9. Compute true bore-point Az. and El. at firing-time$_F$ (subtract ballistic effect from values obtained from graph 6(b). Record in Cols 13-J and 13-K.

F. Calculate imp by adding T_F

10. Compute gun lead errors in Az. and El. at firing-times$_F$ (subtract true bore-point from actual bore-point). Record in Cols 14-D and 14-E.

11. Convert gun lead errors to milliradians; record in Cols 14-F and 14-G. Compute traverse and radial errors in milliradians; record in Cols 14-H and 14-J.

12. Calculate Single Shot Probability for known target size and bullet dispersion. (See AMG-C Report 302)

2

GUN-CAMERA FILM
(Erco port waist-turret)

1. Using 16 mm projector and screen in Booth No. 1, plot target-points on screen.

2. Using CRADLE transit, read target Az. and El. w.r.t.* port waist gun axes; record in Cols 19-C and 19-D.

A. Correct these forward range data (Col 18-E) for the waist-turret from table provided. Record in Col 12-D at impact-time$_I$ (intervals of 0.1 sec).

B. Obtain bullet flight-times, T_I*** to the nearest 0.005 sec from proper AMG-N Table II. Record in Col 12-E.

C. Calculate firing-time$_I$ (subtract time-of-flight, T_I, from impact-time$_I$). Record in Col 12-F.

D. Plot T_I against firing-time$_I$.

3. Using GLOOK (Booth No. 3) set for proper "offset angle", find port waist gun Az. and El. w.r.t.* bomber axes centered at the Erco waist-turret. Record in Cols 19-E and 19-F and Cols 14-B and 14-C. This is the actual gun bore-point.

E. Choose firing-time$_F$*** at times corresponding to waist-turret gun-camera frame numbers; record in Col 14-A. Read the corresponding time-of-flight, T_F; and record in Col 13-F.

F. Calculate impact-time$_F$ (corresponding to firing-time$_F$) by adding T_F to firing-time$_F$. Record in Col 13-A.

t true bore-point

d 14-G. Compute
and 14-J.

let dispersion.

FLOW CHART IV

HIT PROBABILITY FROM ERCO PORT WAIST-TURRET

Using Forward crown-turret to obtain Target Azimuth, Elevation and Range; but
Neglecting: Roll, Yaw and Pitch Corrections

31 May 1945

3

CONFIDENTIAL

SIGHT FILM
(Port Waist)

1. Using 16 mm projector and screen in Booth No. 1, mark target-and sight-points on screen.

2. Using CRADLE in target-point to sight-point solution, determine Az. and El. of target- and sight-point w.r.t.* port waist <u>gun</u> axes. Record in Cols. 16-F and 16-G (on form sheet labeled for Erco port waist-turret).

3. Compute <u>tracking</u> <u>errors</u> in Az. and El. by subtracting target data from sight data. Record in Cols. 16-H and 16-J.

4. Convert <u>tracking</u> <u>errors</u> in Az. and El. to milliradians. Record in Cols. 16-K and 16-L. Compute <u>radial</u> <u>tracking</u> <u>error</u> in milliradians. Record in Col. 16-M.

A. Using 16 mm projector and screen in Booth No. 1, mark visible reticle-points, and measure as many of the three diameters as determinable. Record in Cols. 15-C, 15-D, and 15-E (on form sheet labeled for Erco port waist-turret).

B. Average the reticle diameters, and record in Col. 15-F.

C. Compute "sight-range" from the average reticle diameter using the formula:

$$r = \frac{\text{constant **}}{\text{average reticle diameter}}$$

Record sight-range in Col. 15-G.

D. Compute <u>ranging</u> <u>error</u> by subtracting "smoothed range" (Col. 15-J) from "sight-range" (Col. 15-G); record difference in Col. 15-K.

E. Compute % range error; record in Col. 15-L.

---

* w.r.t. = with respect to

** Obtain "sight-range" constant from supervisor.

1

.L

FILM
ist)

GUN CAMERA FILM
(Forward Crown)

A. Using 16 mm projector and screen in Booth No. 1, mark visible reticle-points, and measure as many of the three diameters as determinable. Record in Cols. 15-C, 15-D, and 15-E (on form sheet labeled for Erco port waist-turret).

B. Average the reticle diameters, and record in Col. 15-F.

C. Compute "sight-range" from the average reticle diameter using the formula:

$$r = \frac{\text{constant} \quad **}{\text{average reticle diameter}}$$

Record sight-range in Col. 15-G.

-L.
ns.

D. Compute ranging error by subtracting "smoothed range" (Col. 15-J) from "sight-range" (Col. 15-G); record difference in Col. 15-K.

E. Compute % range error; record in Col. 15-L.

A. Referring to FLOW CHART I Forward Crown Gun-Camera Operation C, read graph of smoothed range data. In Col. 15-H record range values at time-intervals corresponding to port waist sight-camera frame numbers.

B. Correct these data for port waist-turret from table provided. Record in Col. 15-J.

FLOW CHART V

RANGING AND TRACKING ERRORS IN ERCO
PORT WAIST-TURRET

(Supplementing FLOW CHART IV)

2

CONFIDENTIAL

1 May 1945

RAZEL FILM
(Forward crown-turret)

1. Read scales at selected frame intervals, and record gun Az. and El. w.r.t.* turret axes in Cols 10-C and 10-D.**

2. Correct Cols 10-C and 10-D, recording in Cols 10-F and 10-G.

3. Plot these gun Az. and El. readings against frame numbers and corresponding time scale.

GYRO FILM

1. Read dials at selected frame intervals and record yaw, pitch and roll angles in Cols 21-C, 21-D and 21-E.

2. Correct yaw, pitch and roll for initial gyro readings (see supervisor). Record in Cols 21-F, 21-G and 21-H. Add "flight angle", P_o, to pitch. Record in Col 21-J.

3. If necessary (see supervisor) correct roll and yaw readings for use in GLOOK (using AMG-N Table I).

4. Plot pitch, roll and yaw against frame numbers and corresponding time scale.

5. Read graph (Item 4 above) and record on Form 23 the pitch, roll and yaw of the turret axes at impact-time$_F$ and at firing-time$_F$.

G
(For

1. Using 35 mm projector and screen in Booth 2
plot target-points on screen.

2. Using CRADLE, obtain target Az. and El. rea
w.r.t.* bomber axes centered at forward cro
turret**. Record in Cols 11-F and 11-G.

3. Plot and smooth these target Az. and El. re
against frame numbers and corresponding tim

4. Read these smoothed target data (Az. and E
bomber axes at forward crown-turret), at in
0.1 sec. Record in Cols 18-C and 18-D.

5. Using PLAXIE, adjusted for pa
bomber axes cent red at port

6. Plot and smooth these parall
corrected target Az. and El.

7. Use GLOOK to c
turret axes a

8. Obtain from p
per unit time-

9. Multiply by T
in Cols 13-G a

10. Compute true
effect from v

11

12

13

* w.r.t. = with respect to

** These instructions assume that all films correspond frame by frame. If they do not, interpolation of the graphs will be required to "synchronize" data.

*** I = Initial; F = Final

**** Supervisor will supply values of K_1 or K_2 depending on use of wing-lights or wing-marks.

1

GUN-CAMERA FILM
(Forward crown-turret)

r and screen in Booth 2
a screen.

target Az. and El. readings
centered at forward crown-
Cols 11-F and 11-G.

s target Az. and El. readings
s and corresponding time scale.

target data (Az. and El. w.r.t.*
rd crown-turret), at intervals of
Cols 18-C and 18-D.

PLAXIE, adjusted for proper α, and
axes centered at port waist-turret.

and smooth these parallax-
sted target Az. and El. data.

A. Using 35 mm projector and screen in Booth No. 2, scale wing-lights and/or -marks, and record in Cols 11-B and 11-D.

B. Calculate range data from the formula: $r = \frac{K1}{s}$ or $\frac{K2}{m}$ ****
Record in Cols 11-C and 11-E.

C. Plot and smooth range data against frame numbers and corresponding time scale.

D. Read these smoothed range data (w.r.t.* bomber axes at forward crown-turret) at times of Step 4. Record in Col 18-E.

E. Calculate "d", the distance PLAXIE slider is to move; record in Col 18-F.

ε, , find target Az. and El. w.r.t.* Record in Cols 18-G and 18-H.

Compute θ, the "angle-off", from table provided. Record in Col 12-C.

(a) From graph read these target data at times corresponding to port waist gun-camera frame numbers. Record in Cols 19-G and 19-H.

(b) From graph read these target data at impact-time$_F$. Record in Cols 23-B and 23-C.

7. Use GLOOK to compute target Az. and El. at impact-time$_F$ w.r.t.* turret axes at firing-time$_F$. Record in Cols 13-B and 13-C.

8. Obtain from proper DOFOGRAPH $\frac{\Delta\alpha}{T}$ and $\frac{\Delta\varepsilon}{T}$ (ballistic effects on α and ε per unit time-of-flight). Record in Cols 13-D and 13-E.

9. Multiply by T_F to obtain the ballistic effects ($\Delta\alpha$ and $\Delta\varepsilon$). Record in Cols 13-G and 13-H.

10. Compute true bore-point Az. and El. at firing-time$_F$ (subtract ballistic effect from values obtained in Step No. 7. Record in Cols 13-J and 13-K.

11. Compute gun lead errors in Az. and El. at firing-times$_F$ (subtract true bore-point from actual bore-point). Record in Cols 14-D and 14-E.

12. Convert gun lead errors to milliradians; record in Cols 14-F and 14-G. Compute traverse and radial errors in milliradians; record in Cols 14-H and 14-J.

13. Calculate Single Shot Probability for known target size and bullet dispersion. (See AMG-C Report 302.)

A.

B.

C.

D.

E.

F.

2

GUN-CAMERA FILM
(Erco port waist-turret)

1. Using 16 mm projector and screen in Booth No. 1, plot target-points on screen.

2. Using CRADLE transit, read target Az. and El. w.r.t.* port waist gun axes; record in Cols 19-C and 19-D.

! ****

ıd

A. Correct these forward range data (Col 18-E) for the waist-turret from table provided. Record in Col 12-D at impact-time$_I$ (intervals of 0.1 sec).

ı at

ın

B. Obtain bullet flight-times, T_I*** to the nearest 0.005 sec from proper AMG-N Table II. Record in Col 12-E.

re;

C. Calculate firing-time$_I$ (subtract time-of-flight, T_I, from impact-time$_I$). Record in Col 12-F.

the

', from

ıded.

Col 12-C.

D. Plot T_I against firing-time$_I$.

3. Using GLOOK (Booth No. 3) set for proper "offset-angle", find port waist gun Az. and El. w.r.t.* bomber axes centered at the Erco waist-turret. Record in Cols 19-E and 19-F and Cols 14-B and 14-C. This is the actual gun bore-point.

E. Choose firing-time$_F$*** at times corresponding to waist-turret gun-camera frame numbers; record in Cols 14-A, 23-G. Read the corresponding time-of-flight, T_F; and record in Col 13-F.

F. Calculate impact-time$_F$ (corresponding to firing-time$_F$) by adding T_F to firing-time$_F$. Record in Cols 13-A, and 23-A.

rue bore-point

-G. Compute
14-J.

dispersion.

FLOW CHART VI

HIT PROBABILITY FROM ERCO PORT WAIST-TURRET

Using Forward crown-turret to obtain Target Azimuth, Elevation and Range.

31 May 1945

CONFIDENTIAL

N. U. P14E 25 May '4[illegible]

Frame Number	Impact Time (Initial) (Sec)	Angle-off θ (Deg)	Smoothed Range (Yards)	Bullet Time of Flight Initial, T_I (Sec)	Firing Time (Initial) (Sec)	Smoothed Target Position at Impact Time (Initial)	
						Azimuth (Deg-Min)	Elevation (Deg-Min)
A	B	C	D	E	F	G	H
	Time in 0.1's second	Use Col 18-G and Col 18-H (to nearest deg) and θ table to find θ; nearest degree	Col 18-E corrected (using Col 12-C) to the Erco turret; nearest yard	Use Cols 12-C and 12-D with time-of-flight table (for proper air speed, altitude and ammunition) [illegible] T_I; P12-E: plot Col 12-[illegible] Col 12-F; S12-E: draw in smooth curve; nearest .005 sec	(Col 12-B) - (Col 12-E); nearest .001 sec		

Flight No. ________
Attack No. ________
F. C. No. ________

BULLET TIME OF FLIGHT

Alt. ________
T.A.S. ________
Amm. ________ ________ Erco Turret

By ________
Started ________
Completed ________

Form 12

Sheet ________ of ________

N. U. P14E 25 May '45

Imp. Time Final (Sec)	Target Position at Impact Time (Final) Corrected for RYP		From Dofograph		Bullet Time of Flight (Final) T_F (Sec)	Ballistic Effects		True Bore-Point at Firing Time		
	Az. (Deg-Min)	El. (Deg-Min)	$\frac{\Delta\alpha}{T}$	$\frac{\Delta\varepsilon}{T}$		$\Delta\alpha$ (Min)	$\Delta\varepsilon$ (Min)	Az. (Deg-Min)	El. (Deg-Min)	
A	B	C	D	E	F	G	H	J	K	
nearest .001 sec	nearest min	nearest min	nearest min/sec	nearest min/sec	nearest .001 sec	nearest min	nearest min	nearest min	nearest min	
(Col 14-A) + (Col 13-F)	Obtained from Col 23-C by GLOOK Problem Solution No. 1	Obtained from Col 23-B by GLOOK Problem Solution No. 1	Use α DOFOGRAPH for proper altitude, ammunition and true air speed with Cols 13-B and 13-C to find $\frac{\Delta\alpha}{T}$	Use ε DOFOGRAPH for proper altitude, ammunition, and true air speed with Cols 13-B and 13-C to find $\frac{\Delta\varepsilon}{T}$	Read from S12-E at times in Col 14-A	(Col 13-D) x (Col 13-F)	(Col 13-E) x (Col 13-F)	(Col 13-B) - (Col 13-G)	(Col 13-C) - (Col 13-H)	

Flight No. ____________
Attack No. ____________
F. C. No. ____________

TRUE BORE POINT
CORRECTED FOR RYP

Alt. ________
T.A.S.______ Amm.______ Turret Erco

By ____________
Started ____________
Completed ____________
Sheet ________ of ________

Form 13

CONFIDENTIAL

N. U. P14E 25 May '45

Firing Time (Final) (Sec)	Gun Position at Firing Time: Azimuth (Deg-Min)	Gun Position at Firing Time: Elevation (Deg-Min)	Gun Lead Errors at Firing Time (Actual Position Minus True Position): Azimuth (Deg-Min)	Elevation (Deg-Min)	Azimuth (Millirad)	Elevation (Millirad)	Traverse (Milli-rad)	Radial (Milli-rad)
A	B	C	D	E	F	G	H	J
List Erco gun-camera times from Col 19-B for which there are data in Cols 19-E and 19-F nearest .001 sec	Same as Col 19-E nearest min	Same as Col 19-F nearest min	(Col 14-B) - (Col 13-J) nearest min	(Col 14-C) - (Col 13-K) nearest min	Use conversion table to change Col 14-D to milliradians nearest 0.1 millirad	Use conversion table to change Col 14-E to milliradians nearest 0.1 millirad	Traverse error = (Cosine Col 13-C) x (Col 14-F) nearest 0.1 millirad	Use radial error chart with Cols 14-D, 14-E and 13-C to find radial error, or compute $\sqrt{(\text{Col 14-H})^2 + (\text{Col 14-G})^2}$ nearest 0.1 millirad

Flight No. ______
Attack No. ______
F. C. No. ______

GUN LEAD ERRORS
CORRECTED FOR RYP
Erco Turret

By ______
Started ______
Completed ______

Form 14

Sheet ____ of ____

CONFIDENTIAL

N. U. P14E 26 May '45

Sight Camera Frame Number	Time (Sec)	Reticle Diameters (Inches) 1	2	3	Average	Sight Range (Yards)	Smooth Range (Martin) (Yards)	Smooth Range (Erco) (Yards)	Range Errors From Sight Range (Yards)	Percent Sight Range Error
A	B	C	D	E	F	G	H	J	K	L
Erco sight-camera frame numbers	Col 15-A converted to seconds; nearest .001 sec	nearest .01 inch	(Inside) reticle diameters measured from Erco sight film (see CRADLE Problem Solution No. 5; nearest .01 inch	nearest .01 inch	$\frac{(\text{Col 15-C}) + (\text{Col 15-D}) + (\text{Col 15-E})}{3}$; nearest .01 inch	$\frac{K_5}{\text{Col 15-F}}$ Use Erco sight range conversion table and Col 15-F (or consult supervisor for value of K_5); nearest yard	Read from S11-C (Fwd) at times in Col 15-B; nearest yard	Use Martin to Erco range correction table with Col 12-C. Add correction to Col 15-H; nearest yard	(Col 15-G) - (Col 15-J); nearest yard	$100\frac{(\text{Col 15-K})}{(\text{Col 15-J})}$; nearest 1%

Flight No. ________
Attack No. ________
F. C. No. ________

GUNNER'S RANGE ERROR

Erco Turret

By ________
Started ________
Completed ________

Form 15

Sheet ____ of ____

N. U. F14E 26 May '45

Sight Camera Frame Number	Time (Sec)	Smoothed Target Position		cos D	SIGHT POINT		TRACKING ERRORS					Traverse Error (Milli-rad)
		Az. (Deg-Min)	El. (Deg-Min)		Az. (Deg-Min)	El. (Deg-Min)	Az. (Deg-Min)	El. (Deg-Min)	Az. (Milliradians)	El. (Milliradians)	Radial (Milliradians)	
A	B	C	D	E	F	G	H	J	K	L	M	N
Erco sight-camera frame numbers (same as Col 15-A)	Col 16-A converted to seconds (same as Col 15-B) nearest .001 sec	Target point (Az.) read from Erco sight-camera film (CRADLE Problem Solution No. 5 nearest min	Target point (El.) read from Erco sight-camera film (CRADLE Problem Solution No. 5 nearest min		Sight-point (Az.) read from Erco sight-camera film (CRADLE Problem Solution No. 5 nearest min	Sight-point (El.) read from Erco sight-camera film (CRADLE Problem Solution No. 5 nearest min	(Col 16-F) - (Col 16-C) nearest min	(Col 16-G) - (Col 16-D) nearest min	Col 16-H converted to milliradians equals traverse error nearest 0.1 milliradian	Col 16-J converted to milliradians nearest 0.1 milliradian	$\sqrt{(\text{Col 16-L})^2 + (\text{Col 16-K})^2}$ or use radial error chart for elevation = 0° nearest 0.1 milliradian	Same as Col 16-K

Flight No. ________
Attack No. ________
F. C. No. ________

GUNNER'S TRACKING ERROR
Via CRADLE in Booth No. ____
Erco Turret

By ________
Started ________
Completed ________
Sheet ____ of

Form 16

CONFIDENTIAL

N.U. P14E 24 May '45

Erco Gun Camera Frame Number	Time (Sec)	Target Relative to Gun Axes (Via CRADLE in Booth No. ________)		Gun Relative to Bomber Axes at Erco Turret		Smoothed Target Relative to Bomber Axes at Erco Turret	
		Azimuth (Deg-Min)	Elevation (Deg-Min)	Azimuth (Deg-Min)	Elevation (Deg-Min)	Azimuth (Deg-Min)	Elevation (Deg-Min)
A	B	C	D	E	F	G	H
Erco gun camera frame numbers	Col 19-A converted to seconds nearest .001 sec	Actual Azimuth gun lead read with CRADLE from Erco gun camera film. Use GLOOK Problem Solution No. 2 (part I) nearest min	Actual Elevation gun lead: read with CRADLE from Erco gun-camera film. Use GLOOK Problem Solution No. 2 (part I) nearest min	Erco gun Azimuth read with GLOOK. Use GLOOK Problem Solution No. 2 (part III) nearest min	Erco gun Elevation read with GLOOK. Use GLOOK Problem Solution No. 2 (part III) nearest min	Erco target Azimuth read from S18-G at times in Col 19-B nearest min	Erco target Elevation read from S18-H at times in Col 19-B nearest min

Flight No. ________
Attack No. ________
F. C. No. ________

ACTUAL GUN LEAD
Erco Port Waist-Turret
GLOOK Ring Settings = ____

By ________
Started ________
Completed ________

Form 19

Sheet ______ of ______

CONFIDENTIAL

N.U. P14E 26 June '45

Impact Time (final) (Sec)	Smoothed target at impact time Elevation (Deg-Min)	Azimuth (Deg-Min)	Attitude at impact time Pitch, $P + P_o$ (Deg-Min)	Roll, R (Deg-Min)	Yaw, Y (Deg-Min)	Firing Time (final) (Sec)	Attitude at firing time Pitch, $P + P_o$ (Deg-Min)	Roll, R (Deg-Min)	Yaw, Y (Deg-Min)	
A	B	C	D	E	F	G	H	J	K	
(Col 14-A) + (Col 13-F)(same as Col 13-A) nearest .001 sec	Read from S18-H at times in Col 23-A nearest min	Read from S18-G at times in Col 23-A nearest min	Read from P21-J at times in Col 23-A nearest min	Read from P21-H at times in Col 23-A nearest min	Read from P21-F at times in Col 23-A nearest min	Erco gun-camera times (same as Col 14-A) nearest .001 sec	Read from P21-J at times in Col 23-G nearest min	Read from P21-H at times in Col 23-G nearest min	Read from P21-F at times in Col 23-G nearest min	

Flight No. ______
Attack No. ______
F. C. No. ______

CORRECTION FOR
Roll, Yaw, Pitch
Erco Turret

By ______
Started ______
Completed ______

Form 23

Sheet ______ of ______

N.U. P14E 8 Aug. '45

I. T. Impact Time (final) (Sec)	r Range at I. T. (Yards)	F. T. Firing Time (final) (Sec)	δ Radial Gun Lead Error at F. T. (Milliradians)	R = Q/r where Q=1000a/σ Q = ____	X = δ/σ	q = q(R,X) from prob.table or graph	p = 1-q, Single Shot Prob. at F. T.	Range at F. T. (Yards)
A	B	C	D	E = Q/B	F = D/σ	G	H = 1-G	J
Same as Col 13-A nearest .001 sec	Read from S11-C at times in Col 27-A Correct for Erco turret using Martin to Erco Table (Use Cols 13-B, 13-C to find Θ) nearest yard	Same as Col 14-A nearest .001 sec	Same as Col 14-J nearest .1 millirad	Q/Col 27-B (Supervisor will supply value of Q) nearest .01	$\frac{\text{Col 27-D}}{\sigma}$ (Supervisor will supply value of σ) nearest .01	Use AMG-C Report 302 (Germond-Hastings Tables) with Cols 27-E, 27-F to find q(R,X) nearest .001	1 - (Col 27-G) nearest .001	Read from S11-C (Martin) at times in Col 27-C. Correct for Erco turret using Martin to Erco table (Use Cols 19-G, 19-H to find Θ) nearest yard

Flight No. ____________
Attack No. ____________
F. C. No. ____________

Form 27

SINGLE SHOT PROBABILITY
Erco Turret
Dispersion: = ____ milliradians
Target Radius: a = ________ yards

By ________________
Started ________________
Completed ________________
Sheet ______ of ______

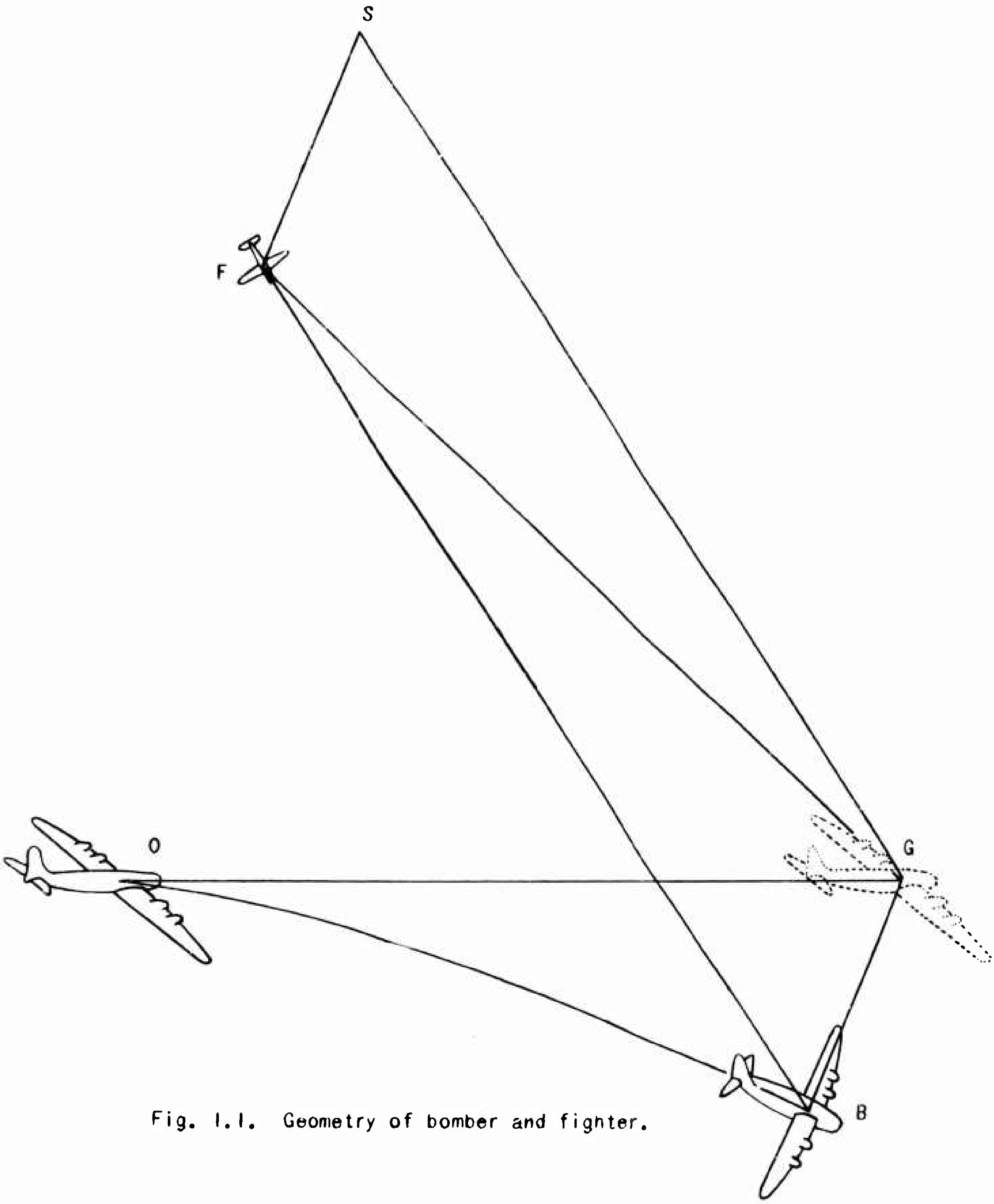

Fig. 1.1. Geometry of bomber and fighter.

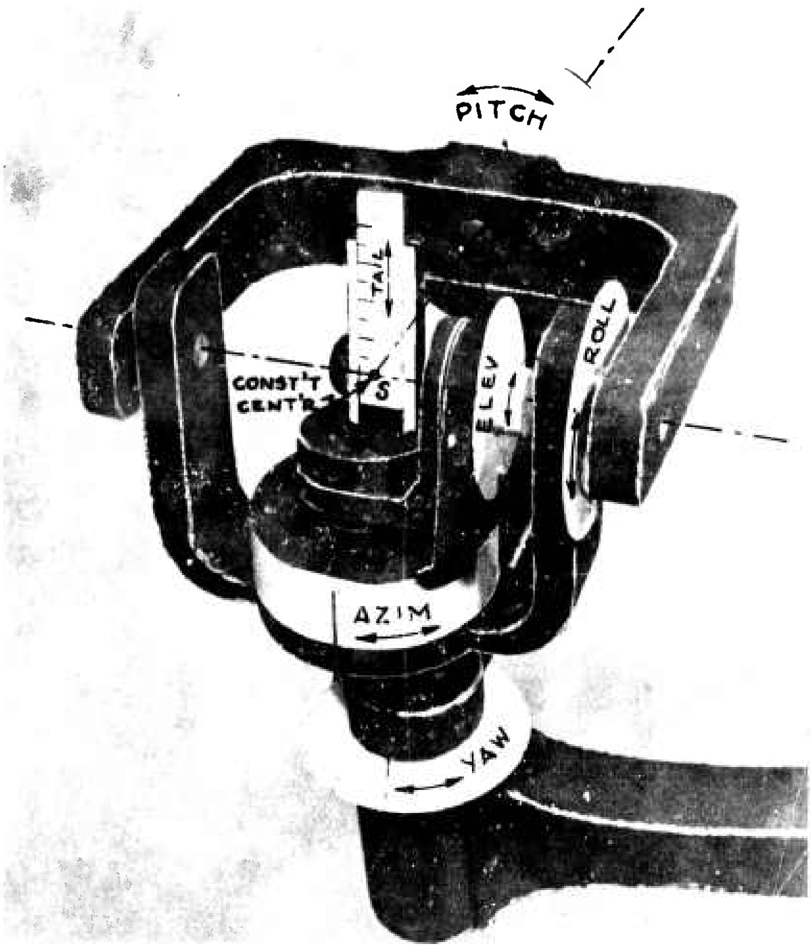

Fig. 1.2(a). The MONKEY(mockup).

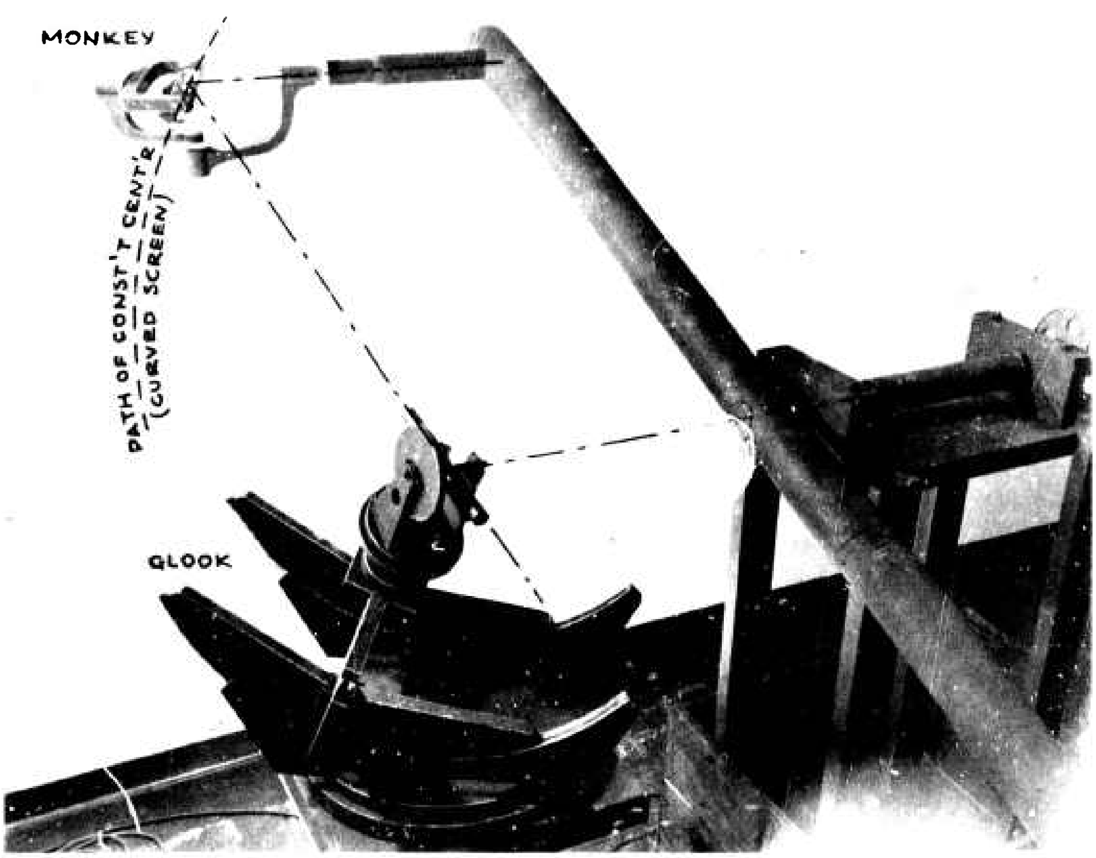

Fig. 1.2(b). Relation of MONKEY and GLOOK(mockup).

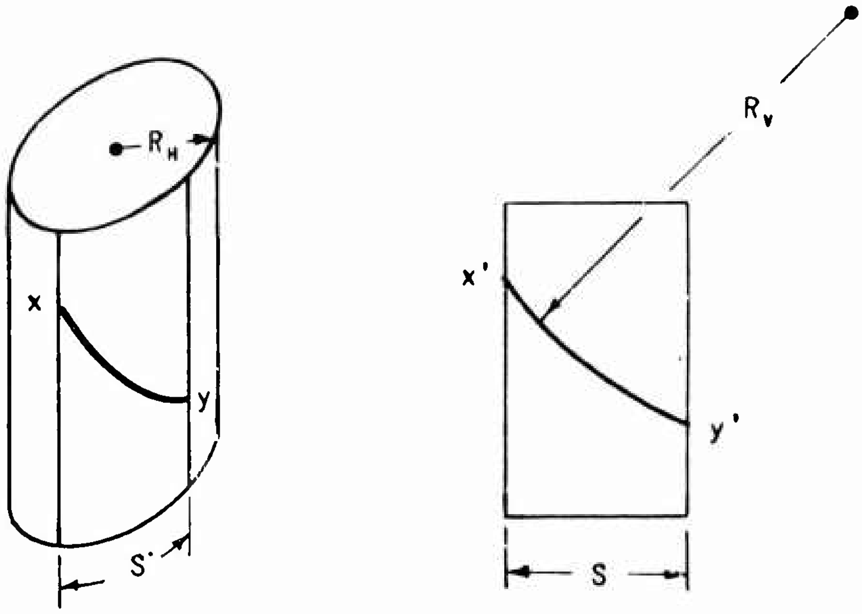

Fig. 1.3. General curve, METHOD A.

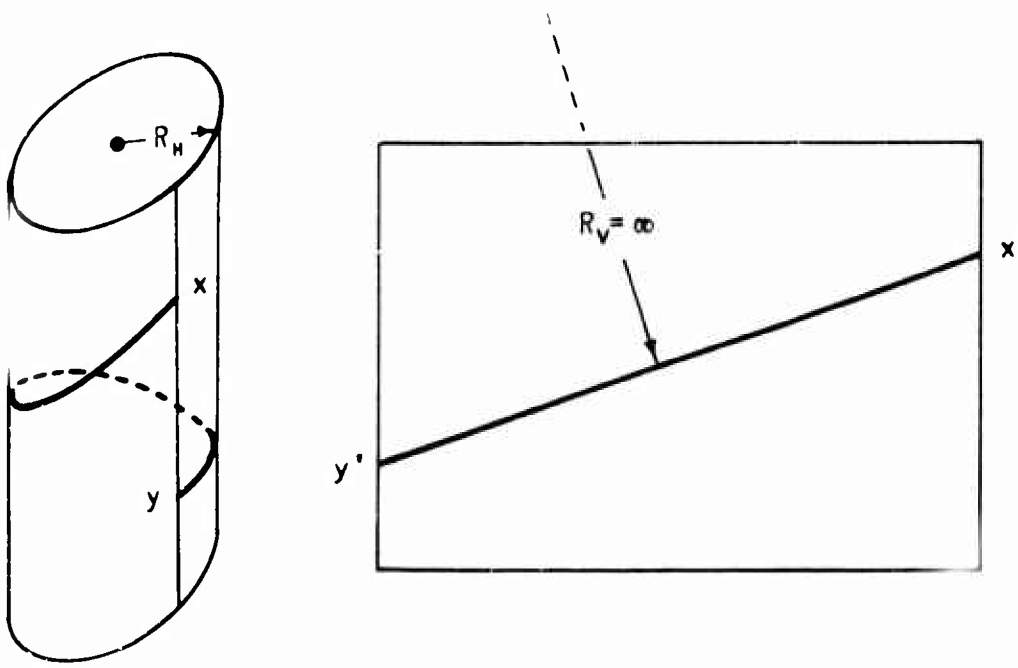

Fig. 1.4. Spiral dive, METHOD A.

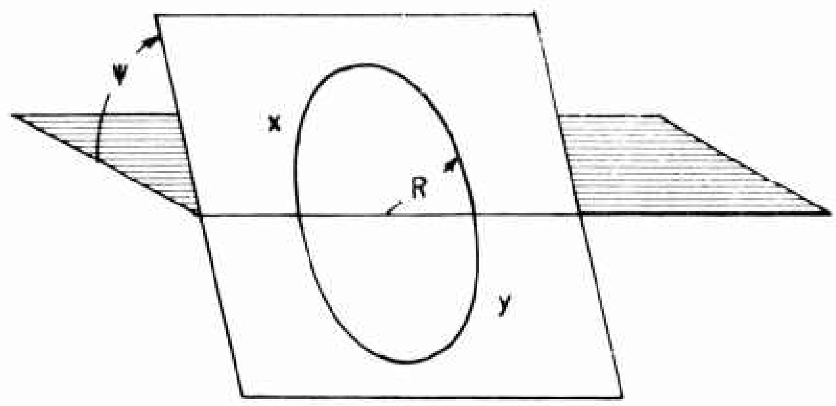

Fig. 1.5. General curve, METHOD B.

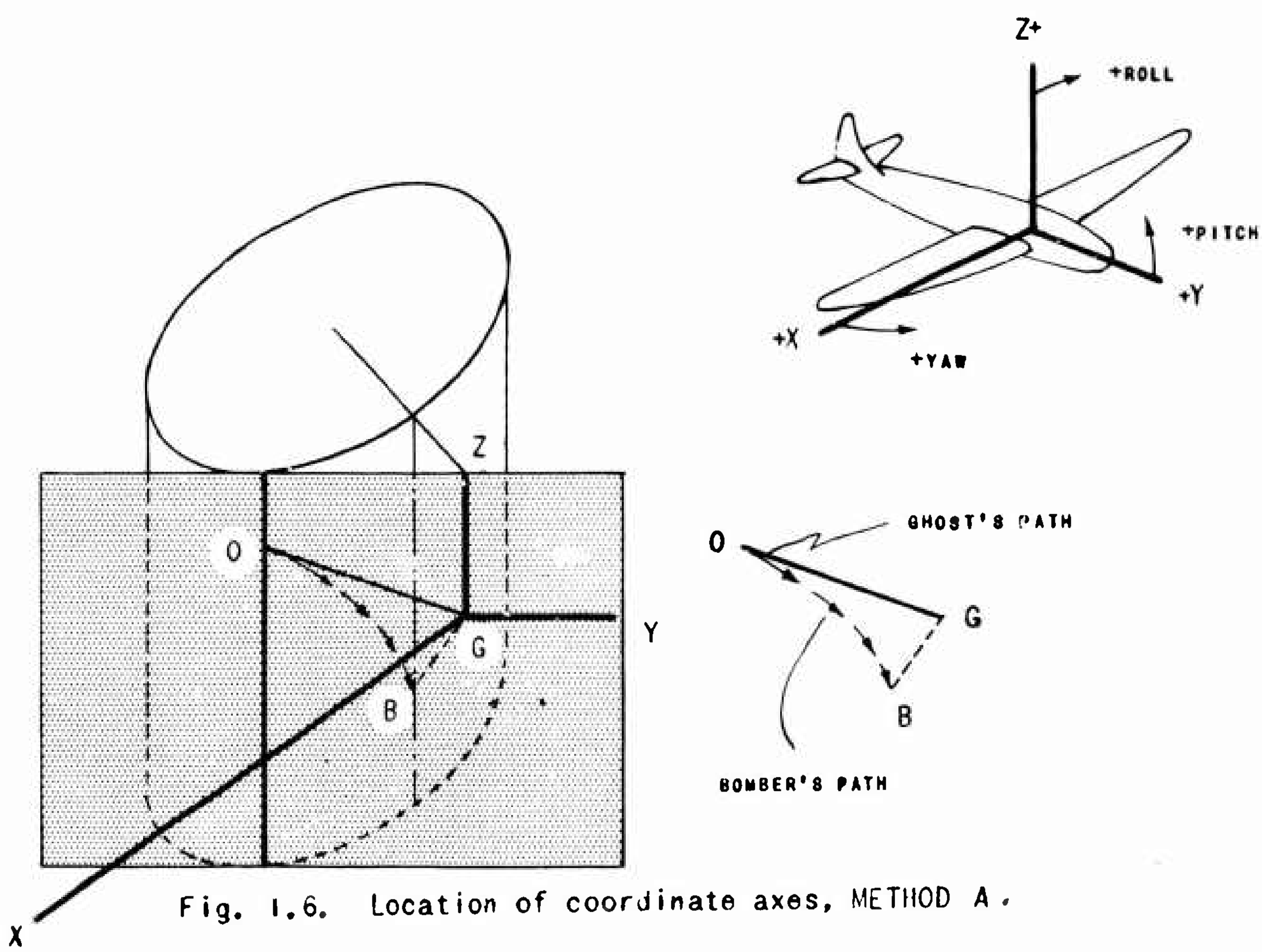

Fig. 1.6. Location of coordinate axes, METHOD A.

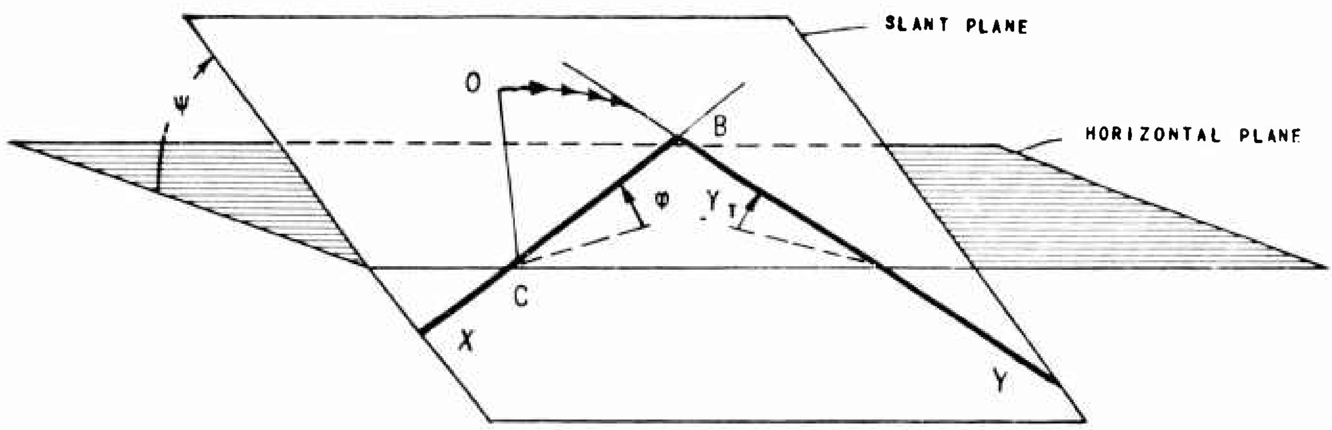

Fig. 1.7. Location of coordinate axes, METHOD B.

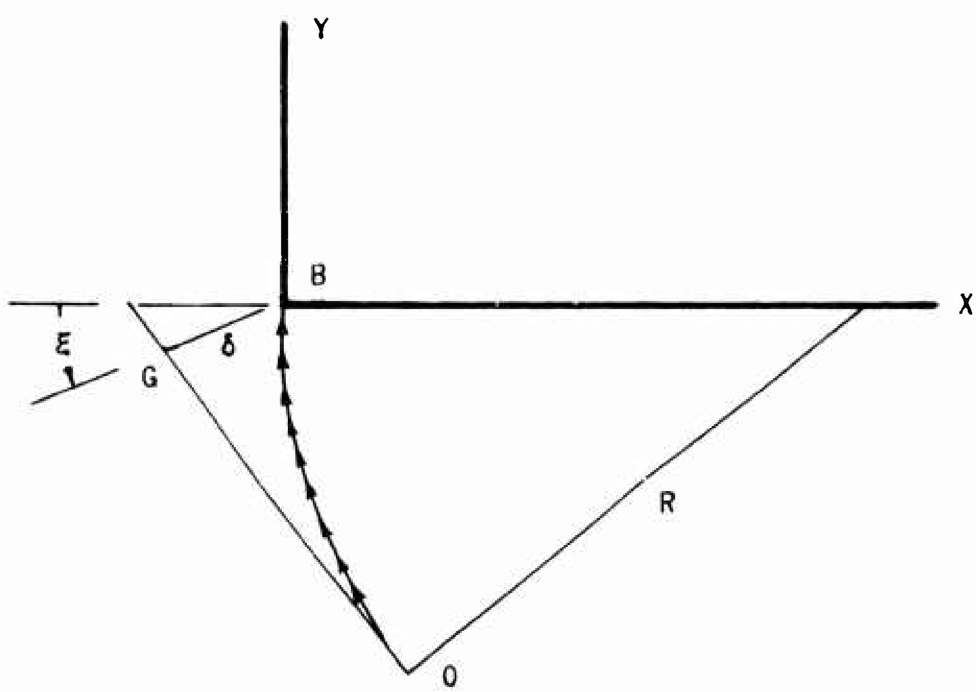

Fig. 1.8. Location of δ and ξ, METHOD B.

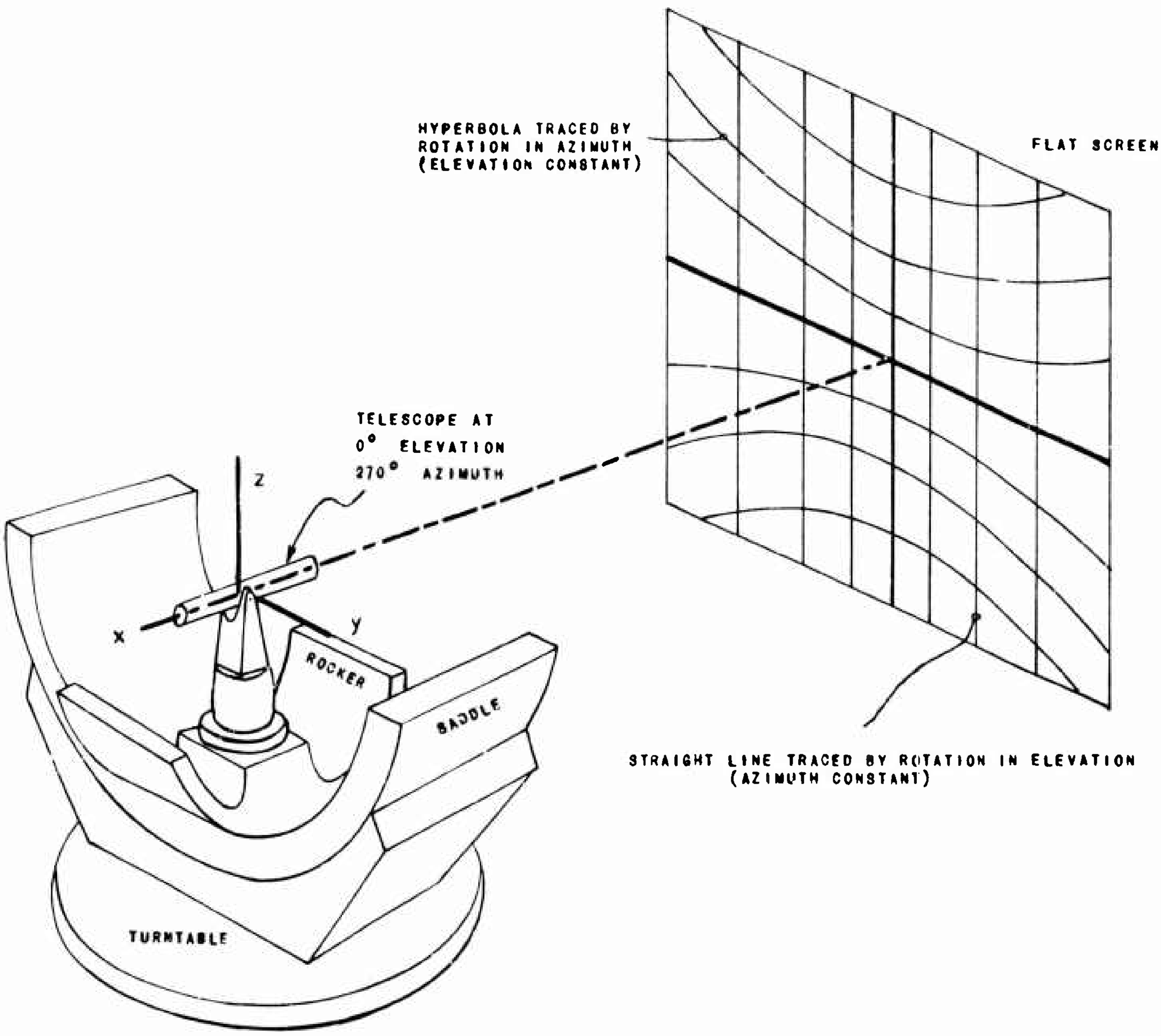

Fig. I.9. Schematic of GLOOK and FLAT SCREEN.
(Roll, Pitch, and Yaw all ZERO).

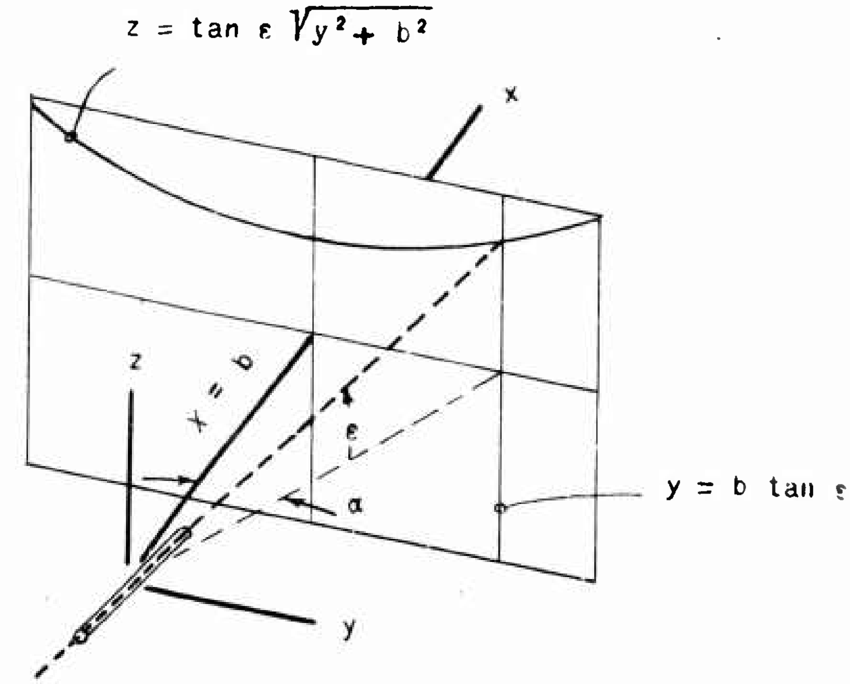

Fig. 1.10. Curves of the gnomonic chart.

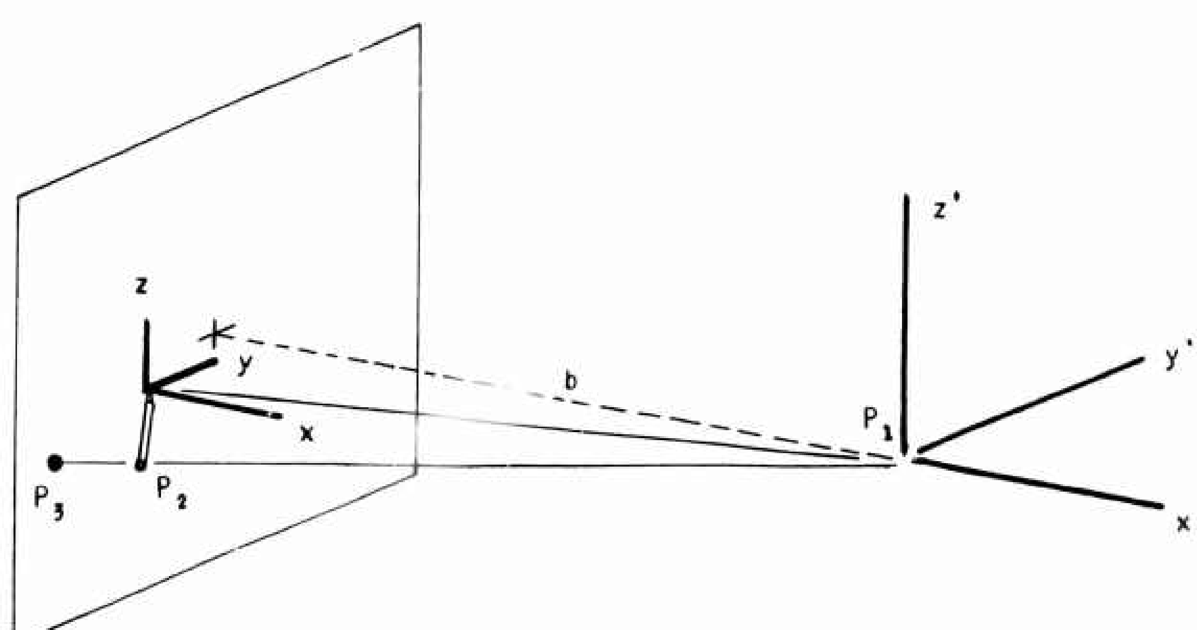

Fig. 1.11. Coordinates of the evasive action problem.

RAZEL FILM

A. Read scale at selected frame intervals, and record Range Input in Col 10-B. (Convert feet to yards and enter values in Col 10-E).

B. [Compare with range-appraisal obtained by scaling sight-reticle and using calculated range data (see FLOW CHART II)].

1. Read scales at selected frame intervals, and record gun Az. and El. w.r.t.* turret axes in Cols 10-C and 10-D.**

2. Correct Cols 10-C and 10-D, recording in Cols 10-F and 10-G.

3. Plot these gun Az. and El. readings against frame numbers and corresponding time scale. Record in Cols 14-B and 14-C.

GUN-CAMER

1. Using projector and screen plot target-points on screen.

2. Using CRADLE No. 2, obtain target Az. and El. w.r.t.* turret axes. Record in Cols 11-F and 11-G.

3. Plot and smooth these target Az. and El. readings against frame numbers and corresponding time scale. Record smoothed data at impact-time$_I$*** in Cols 12-G and 12-H, at intervals of 0.1 sec.

4. Compute θ, the "angle-off", from table provided. Record in Col 12-C.

5. Read graph (Item 3 above) and record in Cols 23-B and 23-C the target Az. and El. at impact-time$_F$***

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15 and 16. Use GLOOK and MONKEY to co
turret axes at firing-time

17. Obtain from DOFOGRAPH and
effects on α and ε per u

18. Multiply by T_F to obtain the
13-G and 13-H.

19. Compute true bore-point Az.
effects from values obtain

20. Compute gun lead errors in
the actual gun bore-point (

21. Convert gun lead errors to
in milliradians. Record i

22. Calculate Single Shot Prob

* w.r.t. = with respect to

** These instructions assume that all films correspond frame by frame. If they do not, interpolation of the graphs will be required to "synchronize" data.

*** I = Initial: F = Final

**** Supervisor will supply values of K_1 or K_2 depending on use of wing-lights or wing-marks.

GUN-CAMERA FILM

GYRO FILM

ɔr and screen
ɔints on screen.

Io. 2, obtain
l El. w.r.t.*
Record in
11-G.

ıh these target
ıadings against
and correspond-
ı. Record
at impact-
ls 12-G and
vals of 0.1

Compute Θ, the "angle-off", from table provided. Record in Col 12-C.

ɜm 3 above)
Cols 23-B
ırget Az. and
ɪimeF***

A. Using projector and screen, scale wing-lights and/or wing-marks, and record in Cols 11-B and 11-D.

B. Calculate range data from the formula:**** Record in Cols 11-C and 11-E.

$$r = \frac{K_1}{s} \text{ or } \frac{K_2}{m}$$

C. Plot and smooth range data against frame numbers and corresponding time scale. Record smoothed range data in Col 12-D.

D. Obtain bullet flight-time, T_I***, to the nearest 0.005 sec from proper AMG-N Table II. Record in Col 12-E.

E. Calculate firing-time$_I$ (subtract time-of-flight, T_I, from impact-time$_I$). Record in Col 12-F.

F. Plot time-of-flight$_I$ against firing-time$_I$.

G. Choose firing-time$_F$*** at Gun-Camera frame numbers** Record in Cols 14-A and 34A-B. Read the corresponding time-of-flight$_F$,*** and record in Cols 13-F and 34A-J.

H. Calculate impact-time$_F$ (corresponding to firing-time$_F$) by adding time-of-flight, T_F, to firing-time$_F$. Record in Cols 13-A and 34A-A.

1. Read dials at selected frame intervals and record yaw, pitch, and roll angle in Cols 21-C, 21-D and 21-I

2. Correct yaw, pitch, and ro: for initial gyro reading (see supervisor). Record in Cols 21-F, 21-G and 21-I

3. If necessary (see supervisc correct pitch and yaw readi for use in GLOOK (using AMG Table I).

4. Plot pitch, roll and yaw against frame numbers and corresponding time scale.

5. Read graph (Item 4 above) a: record on Form 23 the pitch, roll and yaw of the turret axes at impact-time$_F$ and at firing-time$_F$. Also reco: roll and pitch at impact-ti: in Cols 32A-E and 32A-F.

6. Compute for impact-times γ = P - angle-of-attack fı Col 32A-F and record in Col 34A-I. Compute SinR, CosR, CosP to 0.01 and record in C 32A-G, 32A-H, 33A-B and 33A-

GLOOK and MONKEY to compute target Az. and El. at impact-time$_F$ w.r.t.* ɛt axes at firing-time$_F$. Record in Cols 13-B and 13-C.

ɪin from DOFOGRAPH and correction tables $\frac{\Delta\alpha}{T}$ and $\frac{\Delta\varepsilon}{T}$ (i.e., ballistic cts on α and ε per unit time-of-flight). Record in Cols 13-D and 13-E.

ɪply by T_F to obtain the ballistic effects ($\Delta\alpha$ and $\Delta\varepsilon$). Record in Cols and 13-H.

ute true bore-point Az. and El. at firing-time$_F$ (subtract ballistic cts from values obtained in Operation 6 above). Record in Cols 13-J and 13-K.

ute gun lead errors in Az. and El. at firing-time$_F$. [Subtract true bore-point Az. and El. from actual gun bore-point (i.e., corrected RAZEL data)]. Record in Cols 14-D and 14-E.

ɜrt gun lead errors to milliradians (Cols 14-F and 14-G). Compute traverse and radial errors ɪlliradians. Record in Cols 14-H and 14-J.

ılate Single Shot Probability for known target size and bullet dispersion (see AMG-C Report 302).

FLOW CHART VIII
EVASIVE ACTION

Method A

2

1 December 1945

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Record
G and 21-H.

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scale.

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$_F$ and
Also record
impact-time$_F$
32A-F.

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d in Col
R, CosR, SinP
cord in Cols
and 33A-C.

ACCELEROMETER FILM

1. Read dials at selected frame intervals and record velocity and X, Y, Z accelerations in Cols 31A-C, 31A-D, 31A-E and 31A-F.

2. Correct velocity and acceleration readings (if necessary****). Record in Cols 31A-G, 31A-H, 31A-I and 31A-J.

3. Plot velocity and acceleration readings against frame numbers and corresponding time scale.

4. Read graph (Item 3 above) and record accelerations to 0.01 at impact-time$_F$ in Cols 32A-B, 32A-C and 32A-D. Record velocity in Col 33A-K.

5. Compute N_XCosR, N_ZSinR, N_XSinR, and N_ZCosR to 0.01 and record in Cols 33A-D, 33A-E, 33A-F and 33A-G.

6. Compute A_H, A_F, A_V and record in Cols 33A-H, 33A-I, and 33A-J.

7. Compute average values of A_H, A_F, A_V, V, P over the time-of-flight and record in Cols 34A-C, 34A-D, 34A-E, 34A-F and 34A-G.

8. Compute average values of $\delta_{AV} = P_{AV}$ - angle-of-attack and record in Col 34A-H.

9. Compute $m = \dfrac{A_H \Delta T}{V \cos^2 \delta_{AV}}$

and $n = \dfrac{A_V \Delta T}{V}$

from Cols 34A-C, 34A-E, 34A-F, 34A-H, and 34A-J with aid of Chart IV and record to 0.001 in Cols 35A-E and 35A-F. Note m, n have same signs as A_H, A_V respectively.

10. Compute Q to 0.01 from Cols 34A-C, 34A-D, 34A-E, 34A-I, 35A-E and 35A-F with aid of Chart V and record in Col 35A-G.

11. Compute W to 0.01 from Cols 34A-D, 34A-E and 34A-I with aid of Chart VII and record in Col 36A-B.

13. Compute tan ϵ_3 from W/S and compute ϵ_3 to $\frac{1}{2}^\circ$ and record in Cols 36A-D and 36A-G.

12. Compute $S = (A_H^2 + Q^2)^{\frac{1}{2}}$ to 0.01 from Cols 34A-C and 35A-G with aid of Chart II and record in Col 36A-C. Note S is always positive.

14. Compute tan α_3 from A_H/Q and compute α_3 to $\frac{1}{2}^\circ$ and record in Cols 35A-H, 35A-I and 36A-H.

A. Compute $A = (A_H^2 + A_V^2)^{\frac{1}{2}}$ to 0.01g from Cols 34A-C and 34A-E with aid of Chart II and record in Col 35A-B. Note A has same sign as A_H.

B. Compute $A_\delta = (A^2 + A_F^2)^{\frac{1}{2}}$ to 0.01g from Cols 35A-B and 34A-D with aid of Chart II and record in Col 35A-C. Note A_δ is always positive.

C. Compute δ to 0.1 ft from Cols 35A-C and 34A-J with aid of Table III and record in Col 35A-D.

D. Read plot of smoothed range data at values of impact-time$_F$ and record in Col 36A-D.

E. Compute $L = \frac{\delta}{D}$ to 0.005" from Cols 35A-D, 36A-E and record in Col 36A-F.

15 and 16. Operate GLOOK and MONKEY. (See Under GUN-CAMERA FILM.)

CONFIDENTIAL

3

RAZEL FILM

A. Read scale at selected frame intervals, and record Range Input in Col 10-B. (Convert feet to yards and enter values in Col 10-E.

B. [Compare with range-appraisal obtained by scaling sight-reticle and using calculated range data (see FLOW CHART II)].

1. Read scales at selected frame intervals, and record gun Az. and El. w.r.t.* turret axes in Cols 10-C and 10-D.**

2. Correct Cols 10-C and 10-D, recording in Cols 10-F and 10-G.

3. Plot these gun Az. and El. readings against frame numbers and corresponding time scale. Record in Cols 14-B and 14-C.

GUN-CAM…

1. Using projector and screen plot target-points on screen.

2. Using CRADLE No. 2, obtain target Az. and El. w.r.t.* turret axes. Record in Cols 11-F and 11-G.

3. Plot and smooth these target Az. and El. readings against frame numbers and corresponding time scale. Record smoothed data at impact-time$_I$*** in Cols 12-G and 12-H, at intervals of 0.1 sec.

4. Compute θ, the "angle-off", from table provided. Record in Col 12-C.

5. Read graph (Item 3 above) and record in Cols 23-B and 23-C the target Az. and El. at impact-time$_F$.***

12-16. Use GLOOK and MONKEY to compute … at firing-time$_F$. Record in Col…

17. Obtain from proper DOFOGRAPH an… on α and ε per unit time-of-fl…

18. Multiply by T_F to obtain the ba…

19. Compute true bore-point Az. and … obtained in Operation 16 above)…

20. Compute gun lead errors in Az. … El. from the actual gun bore-poi…

21. Convert gun lead errors to mill… errors in milliradians. Record…

22. Calculate Single Shot Probabili…

---

* w.r.t. = with respect to

** These instructions assume that all films correspond frame by frame. If they do not, interpolation of the graphs will be required to "synchronize" data.

*** I = Initial; F = Final

**** Supervisor will supply values of K_1 or K_2 depending on use of wing-lights or wing-marks.

GUN-CAMERA FILM

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Az. and
***

A. Using projector and screen, scale wing-lights and/or wing-marks, and record in Cols 11-B and 11-D.

B. Calculate range data from the formula:**** Record in Cols 11-C and 11-E.

$$r = \frac{K_1}{s} \text{ or } \frac{K_2}{m}$$

C. Plot and smooth range data against frame numbers and corresponding time scale. Record smoothed range data in Col 12-D.

D. Obtain bullet flight-time, T_I***, to the nearest 0.005 sec from proper AMG-N Table II. Record in Col 12-E.

E. Calculate firing-time$_I$ (subtract time-of-flight, T_I, from impact-time$_I$). Record in Col 12-F.

F. Plot time-of-flight$_I$ against firing-time$_I$.

G. Choose firing-time$_F$*** at Gun-Camera frame numbers** Record in Cols 14-A and 34B-B. Read the corresponding time-of-flight$_F$,*** and record in Cols 13-F and 34B-J.

H. Calculate impact-time$_F$ (corresponding to firing-time$_F$) by adding time-of-flight, T_F, to firing-time$_F$. Record in Cols 13-A and 34B-A.

GYRO FILM

1. Read dials at selected frame intervals and record yaw, pitch, and roll angle in Cols 21-C, 21-D and 21-

2. Correct yaw, pitch, and roll for initial gyro reading (see supervisor). Record in Cols 21-F, 21-G, and 21-H.

3. If necessary (see supervisor) correct pitch and yaw readings for use in GLOOK (using AMG-N Table I

4. Plot pitch, roll and yaw against frame numbers and corresponding time scale.

5. Read graph (Item 4 above) and record on Form 23 the pitch, roll and yaw of the turret axes at impact-time$_F$. Also record roll and pitch at impact-time$_F$ in Cols 32B-E, 32B-F and 34B-C.

6. Compute for impact-times γ = P - angle-of-attack from Col 32B-F and record in Col 34B-I. Compute SinR, CosR, SinP, CosP to 0.01 and record in Cols 32B-G, 32B-H, 33B-B and 33B-C.

MONKEY to compute target Az. and El. at impact-time$_F$ w.r.t.* turret axes
F. Record in Cols 13-B and 13-C.

oper DOFOGRAPH and correction tables $\frac{\Delta\alpha}{T}$ and $\frac{\Delta\varepsilon}{T}$ (i.e., ballistic effects
er unit time-of-flight). Record in Cols 13-D and 13-E.

to obtain the ballistic effects ($\Delta\alpha$ and $\Delta\varepsilon$). Record in Cols 13-G and 13-H.

ore-point Az. and El. at firing-time$_F$ (subtract ballistic effects from values
eration 16 above). Record in Cols 13-J and 13-K.

d errors in Az. and El. at firing-time$_F$. [Subtract true bore-point Az. and
tual gun bore-point (i.e., corrected RAZEL data)]. Record in Cols 14-D and 14-E.

d errors to milliradians (Cols 14-F and 14-G). Compute traverse and radial
radians. Record in Cols 14-H and 14-J.

le Shot Probability for known target size and bullet dispersion (see AMG-C Report 302).

FLOW CHART VIII

EVASIVE ACTION

Method B

1 December 1945

2

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ACCELEROMETER FILM

1. Read dials at selected frame intervals and record velocity and X, Y, Z accelerations in Cols 31B-C, 31B-D, 31B-E and 31B-F.

2. Correct velocity and acceleration readings (if necessary****). Record in Cols 31B-G, 31B-H, 31B-I and 31B-J.

3. Plot velocity and acceleration readings against frame numbers and corresponding time scale.

4. Read graph (Item 3 above) and record accelerations to 0.01 at impact-time$_F$ in Cols 32B-B, 32B-C and 32B-D. Record velocity in Col 33B-K.

5. Compute $N_X \cos R$, $N_Z \sin R$, $N_X \sin R$, and $N_Z \cos R$ to 0.01 and record in Cols 33B-D, 33B-E, 33B-F and 33B-G.

6. Compute A_H, A_F, A_V and record in Cols 33B-H, 33B-I and 33B-J.

7. Compute average values of A_H, A_F, A_V, V over the time-of-flight and record in Cols 34B-C, 34B-D, 34B-E and 34B-F.

8. Compute impact-time$_F$ values of $\alpha_T = P_T$ - angle-of-attack and record in Col 34B-H.

9. Compute $x = \frac{A \Delta T}{V}$ and $p = \frac{A_F \Delta T}{V}$ from Cols 35B-B, 34B-J and 34B-F with aid of Chart IV and record to 0.001 in Cols 35B-E, 35B-F. Note x, p have same signs as A, A_F, respectively.

A. Compute $A = (A_H^2 + A_V^2)^{\frac{1}{2}}$ to 0.01 g from Cols 34B-C and 34B-E with aid of Chart II and record in Col 35B-B. Note A has same sign as A_H.

B. Compute $A_\delta = (A^2 + A_F^2)^{\frac{1}{2}}$ to 0.01 g from Cols 35B-B and 34B-D with aid of Chart II and record in Col 35B-C. Note A_δ is always positive.

C. Compute δ to 0.1 ft from Cols 35B-C and 34B-J with aid of Table III and record in Col 35B-D.

D. Read plot of smoothed range data at values of impact-time$_F$ and record in Col 35B-J.

E. Compute $L = \frac{K\delta}{3D}$ to 0.005" from Cols 35B-D and 35B-J and record in Col 35B-K.

10. Compute ξ to $\frac{1}{2}°$ from x, p in Cols 35B-E and 35B-F, with aid of chart and record in Col 35B-G.

11. Compute tan ϕ and ϕ to $\frac{1}{2}°$ from A_V/A_H in Cols 33B-H, 33B-J, and record in Cols 35B-H and 35B-I.

12-16. Operate GLOOK and MONKEY.

N. U. P22E 15 Dec '45

Acc Film Frame No.	Time (Sec)	Observed Readings				Corrected Readings				
		IAS Bomber Speed (Mph)	Accelerations (g)			TAS Bomber Speed (Mph)	Accelerations (g)			
			N_x	N_y	N_z		N_x	N_y	N_z	
A	B	C	D	E	F	G	H	I	J	

Flight No. ________
Attack No. ________
F. C. No. ________

EVASIVE ACTION DATA

By ________
Started ________
Completed ________

Form 31

Sheet ______ of ______

N. U. P22E 1 Dec '45

Impact Time (Sec)	Smoothed Readings						
	Accelerations, g's			Roll Angle R (Deg-Min)	Pitch Angle P (Deg-Min)		
	N_x	N_y	N_z			SinR	CosR
A	B	C	D	E	F	G	H

Flight No. ________
Attack No. ________
F. C. No. ________

EVASIVE ACTION DATA

By ________
Started ________
Completed ________

Sheet ______ of ______

Form 32

N. U. P22E 15 Dec '45

Impact Time (Sec)	SinP	CosP	N_XCosR	N_ZSinR	N_XSinR	N_ZCosR	Stabilized Accelerations D + E A_H	Stabilized Accelerations 32C–B A_F	Stabilized Accelerations F+G–C A_V	TAS Bomber Speed (Mph) V
A	B	C	D	E	F	G	H	I	J	K

Flight No. ____________
Attack No. ____________
F. C. No. ____________

EVASIVE ACTION DATA

By ____________
Started ____________
Completed ____________

Form 33

Sheet ______ of ______

P22E 15 Dec '45

Impact Time (Sec)	Firing Time (Sec)	Average Values of							Initial Value of Climb (Deg)	Transit Time (Sec)	
		Accelerations (g)			Speed (Mph)	Pitch (Deg)	Climb (Deg)			
		A_H	A_F	A_V	V	P	γ_{AV}	γ_o	ΔT	
A	B	C	D	E	F	G	H	I	J	

Flight No. ________
Attack No. ________
F. C. No. ________

EVASIVE ACTION DATA
Method A

By ________
Started ________
Completed ________

Form 34A

Sheet   of

Impact Time (Sec)	Firing Time (Sec)	Average Values of Accelerations (g)			Average Values of Speed (Mph)	Impact Time Values of Pitch (Deg)	Impact Time Values of Climb (Deg)	Transit Time (Sec)
		A_H	A_F	A_V	V	P_T	γ_T	ΔT
A	B	C	D	E	F	G	H	J

Flight No. ________
Attack No. ________
F. C. No. ________

EVASIVE ACTION DATA
Method B

By ________
Started ________
Completed ________

Sheet ______ of ______

Form 34B

CONFIDENTIAL

Impact Time (Sec)	Average Accelerations (g)		Deviation From Straight Line (Ft)	Dimensionless Ratios Based On			MONKEY Azimuth	
				A_H	A_V		34A-C / 35A-C	(Deg)
	A	A_δ	δ	m	n	Q	tan α	α
A	B	C	D	E	F	G	H	I

Flight No. ______
Attack No. ______
F. C. No. ______

EVASIVE ACTION DATA
Method A

By ______
Started ______
Completed ______

Sheet ______ of ______

Form 35A

CONFIDENTIAL

CONFIDENTIAL

P22E 15 Dec '45

Impact Time (Sec)	Average Accelerations g		Deviation from Straight Line (Ft)	Dimensionless Ratios Based on		MONKEY Azimuth (Deg)	MONKEY Roll (Deg)		Target Range (Yd)	MONKEY Tail (In)	Ring Angle (Deg)	MONKEY Yaw (Deg)
				A	A_F							
	A	A_f	σ	x	p	ξ	tan ϕ	ϕ	D	L	Ring	Y_T-Ring
A	B	C	D	E	F	G	H	I	J	K	L	M

Flight No. ________
Attack No. ________
F. C. No. ________

Form 35B

EVASIVE ACTION DATA
Method B

By ________
Started ________
Completed ________

Sheet ______ of ______

CONFIDENTIAL

CONFIDENTIAL

N. U. P22E 15 Dec '45

Impact Time (Sec)	Calculation of MONKEY Elevation (g)		B/C	Target Range (Yd)	MONKEY Tail (In)	MONKEY Elevation (Deg)	MONKEY Azimuth (Deg)			
	W	S	tan ε_s	D	L	E_m	α_3	Ring	α_m	
A	B	C	D	E	F	G	H	I	J	

Flight No. ____________
Attack No. ____________
F. C. No. ____________

EVASIVE ACTION DATA
Method A

By ____________
Started ____________
Completed ____________

Form 36A

Sheet ______ of ______

CONFIDENTIAL

TABLE III

CONFIDENTIAL

Values of A in multiples of g.

		0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00	
16.086 A		0.804	1.609	2.413	3.217	4.022	4.826	5.630	6.434	7.239	8.043	8.847	9.652	10.456	11.260	12.065	12.869	13.673	14.477	15.282	16.086	
ΔTsec	$(\Delta T)^2$																					ΔTsec
0.05	0.0025	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.05
0.10	0.0100	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.10
0.15	0.0225	0.02	0.04	0.05	0.07	0.09	0.11	0.13	0.14	0.16	0.18	0.20	0.22	0.24	0.25	0.27	0.29	0.31	0.33	0.34	0.36	0.15
0.20	0.0400	0.03	0.06	0.10	0.13	0.16	0.19	0.23	0.26	0.29	0.32	0.35	0.39	0.42	0.45	0.48	0.51	0.55	0.58	0.61	0.64	0.20
0.25	0.0625	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.96	1.01	0.25
0.30	0.0900	0.07	0.15	0.22	0.29	0.36	0.43	0.51	0.58	0.65	0.72	0.80	0.87	0.94	1.01	1.09	1.16	1.23	1.30	1.38	1.45	0.30
0.35	0.1225	0.10	0.20	0.30	0.39	0.49	0.59	0.69	0.79	0.89	0.99	1.08	1.18	1.28	1.38	1.48	1.58	1.67	1.77	1.87	1.97	0.35
0.40	0.1600	0.13	0.26	0.39	0.51	0.64	0.77	0.90	1.03	1.16	1.29	1.42	1.54	1.67	1.80	1.93	2.06	2.19	2.32	2.45	2.57	0.40
0.45	0.2025	0.16	0.33	0.49	0.65	0.81	0.98	1.14	1.30	1.47	1.63	1.79	1.95	2.12	2.28	2.44	2.61	2.77	2.93	3.09	3.26	0.45
0.50	0.2500	0.20	0.40	0.60	0.80	1.01	1.21	1.41	1.61	1.81	2.01	2.21	2.41	2.61	2.82	3.02	3.22	3.42	3.62	3.82	4.02	0.50
0.55	0.3025	0.24	0.49	0.73	0.97	1.22	1.46	1.70	1.95	2.19	2.43	2.68	2.92	3.16	3.41	3.65	3.89	4.14	4.38	4.62	4.87	0.55
0.60	0.3600	0.29	0.58	0.87	1.16	1.45	1.74	2.03	2.32	2.61	2.90	3.18	3.47	3.76	4.05	4.34	4.63	4.92	5.21	5.50	5.79	0.60
0.65	0.4225	0.34	0.68	1.02	1.36	1.70	2.04	2.38	2.72	3.06	3.40	3.74	4.08	4.42	4.76	5.10	5.44	5.78	6.12	6.46	6.80	0.65
0.70	0.4900	0.39	0.79	1.18	1.58	1.97	2.36	2.76	3.15	3.55	3.94	4.34	4.73	5.12	5.52	5.91	6.31	6.70	7.09	7.49	7.88	0.70
0.75	0.5625	0.45	0.91	1.36	1.81	2.26	2.71	3.17	3.62	4.07	4.52	4.98	5.43	5.88	6.33	6.79	7.24	7.69	8.14	8.60	9.05	0.75
0.80	0.6400	0.51	1.03	1.54	2.06	2.57	3.09	3.60	4.12	4.63	5.15	5.66	6.18	6.69	7.21	7.72	8.24	8.75	9.27	9.78	10.30	0.80
0.85	0.7225	0.58	1.16	1.74	2.32	2.91	3.49	4.07	4.65	5.23	5.81	6.39	6.97	7.55	8.14	8.72	9.30	9.88	10.46	11.04	11.62	0.85
0.90	0.8100	0.65	1.30	1.95	2.61	3.26	3.91	4.56	5.21	5.86	6.51	7.17	7.82	8.47	9.12	9.77	10.42	11.08	11.73	12.38	13.03	0.90
0.95	0.9025	0.73	1.45	2.18	2.90	3.63	4.36	5.08	5.81	6.53	7.26	7.98	8.71	9.44	10.16	10.89	11.61	12.34	13.07	13.79	14.52	0.95
1.00	1.0000	0.80	1.61	2.41	3.22	4.02	4.83	5.63	6.43	7.24	8.04	8.85	9.65	10.46	11.26	12.07	12.87	13.67	14.48	15.28	16.09	1.00
1.05	1.1025	0.89	1.77	2.66	3.55	4.43	5.32	6.21	7.09	7.98	8.87	9.75	10.64	11.53	12.41	13.30	14.19	15.07	15.96	16.85	17.73	1.05
1.10	1.2100	0.97	1.95	2.92	3.89	4.87	5.84	6.81	7.79	8.76	9.73	10.70	11.68	12.65	13.62	14.60	15.57	16.54	17.52	18.49	19.46	1.10
1.15	1.3225	1.06	2.13	3.19	4.25	5.32	6.38	7.45	8.51	9.57	10.64	11.70	12.76	13.83	14.89	15.96	17.02	18.08	19.15	20.21	21.27	1.15
1.20	1.4400	1.16	2.32	3.47	4.63	5.79	6.95	8.11	9.26	10.42	11.58	12.74	13.90	15.06	16.21	17.37	18.53	19.69	20.85	22.01	23.16	1.20
1.25	1.5625	1.26	2.51	3.77	5.03	6.28	7.54	8.80	10.05	11.31	12.57	13.82	15.08	16.34	17.59	18.85	20.11	21.36	22.62	23.88	25.13	1.25
1.30	1.6900	1.36	2.72	4.08	5.44	6.80	8.16	9.51	10.87	12.23	13.59	14.95	16.31	17.67	19.03	20.39	21.75	23.11	24.47	25.83	27.19	1.30
1.35	1.8225	1.47	2.93	4.40	5.86	7.33	8.80	10.26	11.73	13.19	14.66	16.12	17.59	19.06	20.52	21.99	23.45	24.92	26.38	27.85	29.32	1.35
1.40	1.9600	1.58	3.15	4.73	6.31	7.88	9.46	11.03	12.61	14.19	15.76	17.34	18.92	20.49	22.07	23.65	25.22	26.80	28.37	29.95	31.53	1.40
1.45	2.1025	1.69	3.38	5.07	6.76	8.46	10.15	11.84	13.53	15.22	16.91	18.60	20.29	21.98	23.67	25.37	27.06	28.75	30.44	32.13	33.82	1.45
1.50	2.2500	1.81	3.62	5.43	7.24	9.05	10.86	12.67	14.48	16.29	18.10	19.91	21.72	23.53	25.34	27.15	28.96	30.76	32.57	34.38	36.19	1.50

Values of A in multiples of g.

$\delta(\text{FT.}) = 16.08A(\Delta T)^2$

		1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00	
16.086 A		16.890	17.695	18.499	19.303	20.108	20.912	21.716	22.520	23.325	24.129	24.933	25.738	26.542	27.346	28.151	28.955	29.759	30.563	31.368	32.172	
ΔTsec	$(\Delta T)^2$																					ΔTsec
0.05	0.0025	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.05
0.10	0.0100	0.17	0.18	0.18	0.19	0.20	0.21	0.22	0.23	0.23	0.24	0.25	0.26	0.27	0.27	0.28	0.29	0.30	0.31	0.31	0.32	0.10
0.15	0.0225	0.38	0.40	0.42	0.43	0.45	0.47	0.49	0.51	0.52	0.54	0.56	0.58	0.60	0.62	0.63	0.65	0.67	0.69	0.71	0.72	0.15
0.20	0.0400	0.68	0.71	0.74	0.77	0.80	0.84	0.87	0.90	0.93	0.97	1.00	1.03	1.06	1.09	1.13	1.16	1.19	1.22	1.25	1.29	0.20
0.25	0.0625	1.06	1.11	1.16	1.21	1.26	1.31	1.36	1.41	1.46	1.51	1.56	1.61	1.66	1.71	1.76	1.81	1.86	1.91	1.96	2.01	0.25
0.30	0.0900	1.52	1.59	1.66	1.74	1.81	1.88	1.95	2.03	2.10	2.17	2.24	2.32	2.39	2.46	2.53	2.61	2.68	2.75	2.82	2.90	0.30
0.35	0.1225	2.07	2.17	2.27	2.36	2.46	2.56	2.66	2.76	2.86	2.96	3.05	3.15	3.25	3.35	3.45	3.55	3.65	3.74	3.84	3.94	0.35
0.40	0.1600	2.70	2.83	2.96	3.09	3.22	3.35	3.47	3.60	3.73	3.86	3.99	4.12	4.25	4.38	4.50	4.63	4.76	4.89	5.02	5.15	0.40
0.45	0.2025	3.42	3.58	3.75	3.91	4.07	4.23	4.40	4.56	4.72	4.89	5.05	5.21	5.37	5.54	5.70	5.86	6.03	6.19	6.35	6.51	0.45
0.50	0.2500	4.22	4.42	4.62	4.83	5.03	5.23	5.43	5.63	5.83	6.03	6.23	6.43	6.64	6.84	7.04	7.24	7.44	7.64	7.84	8.04	0.50
0.55	0.3025	5.11	5.35	5.60	5.84	6.08	6.33	6.57	6.81	7.06	7.30	7.54	7.79	8.03	8.27	8.52	8.76	9.00	9.25	9.49	9.73	0.55
0.60	0.3600	6.08	6.37	6.66	6.95	7.24	7.53	7.82	8.11	8.40	8.69	8.98	9.27	9.56	9.84	10.13	10.42	10.71	11.00	11.29	11.58	0.60
0.65	0.4225	7.14	7.48	7.82	8.16	8.50	8.84	9.18	9.51	9.85	10.19	10.53	10.87	11.21	11.55	11.89	12.23	12.57	12.91	13.25	13.59	0.65
0.70	0.4900	8.28	8.67	9.06	9.46	9.85	10.25	10.64	11.03	11.43	11.82	12.22	12.61	13.01	13.40	13.79	14.19	14.58	14.98	15.37	15.76	0.70
0.75	0.5625	9.50	9.95	10.41	10.86	11.31	11.75	12.22	12.67	13.12	13.57	14.02	14.48	14.93	15.38	15.83	16.29	16.74	17.19	17.64	18.10	0.75
0.80	0.6400	10.81	11.32	11.84	12.35	12.87	13.38	13.90	14.41	14.93	15.44	15.96	16.47	16.99	17.50	18.02	18.53	19.05	19.56	20.08	20.59	0.80
0.85	0.7225	12.20	12.78	13.37	13.95	14.53	15.11	15.69	16.27	16.85	17.43	18.01	18.60	19.18	19.76	20.34	20.92	21.50	22.08	22.66	23.24	0.85
0.90	0.8100	13.68	14.33	14.98	15.64	16.29	16.94	17.59	18.24	18.89	19.54	20.20	20.85	21.50	22.15	22.80	23.45	24.10	24.76	25.41	26.06	0.90
0.95	0.9025	15.24	15.97	16.70	17.42	18.15	18.87	19.60	20.32	21.05	21.78	22.50	23.23	23.95	24.68	25.41	26.13	26.86	27.59	28.31	29.04	0.95
1.00	1.0000	16.89	17.70	18.50	19.30	20.11	20.91	21.72	22.52	23.33	24.13	24.93	25.74	26.54	27.35	28.15	28.96	29.76	30.56	31.37	32.17	1.00
1.05	1.1025	18.62	19.51	20.40	21.28	22.17	23.06	23.94	24.83	25.72	26.60	27.49	28.38	29.26	30.15	31.04	31.92	32.81	33.70	34.58	35.47	1.05
1.10	1.2100	20.44	21.41	22.38	23.36	24.33	25.30	26.28	27.25	28.22	29.20	30.17	31.14	32.12	33.09	34.06	35.04	36.01	36.98	37.96	38.93	1.10
1.15	1.3225	22.34	23.40	24.46	25.53	26.59	27.66	28.72	29.78	30.85	31.91	32.97	34.04	35.10	36.17	37.23	38.29	39.36	40.42	41.48	42.55	1.15
1.20	1.4400	24.32	25.48	26.64	27.80	28.96	30.11	31.27	32.43	33.59	34.75	35.90	37.06	38.22	39.38	40.54	41.70	42.85	44.01	45.17	46.33	1.20
1.25	1.5625	26.39	27.65	28.90	30.16	31.42	32.68	33.93	35.19	36.45	37.70	38.96	40.22	41.47	42.73	43.99	45.24	46.50	47.75	49.01	50.27	1.25
1.30	1.6900	28.54	29.90	31.26	32.62	33.98	35.34	36.70	38.06	39.42	40.78	42.14	43.50	44.86	46.21	47.58	48.93	50.29	51.65	53.01	54.37	1.30
1.35	1.8225	30.78	32.25	33.71	35.18	36.65	38.11	39.58	41.04	42.51	43.98	45.44	46.91	48.37	49.84	51.31	52.77	54.24	55.70	57.17	58.63	1.35
1.40	1.9600	33.10	34.68	36.26	37.83	39.41	40.99	42.56	44.14	45.72	47.29	48.87	50.45	52.02	53.60	55.18	56.75	58.33	59.90	61.48	63.06	1.40
1.45	2.1025	35.51	37.20	38.89	40.58	42.28	43.97	45.66	47.35	49.04	50.73	52.42	54.11	55.80	57.49	59.19	60.88	62.57	64.26	65.95	67.64	1.45
1.50	2.2500	38.00	39.81	41.62	43.43	45.24	47.05	48.86	50.67	52.48	54.29	56.10	57.91	59.72	61.53	63.34	65.15	66.96	68.77	70.58	72.39	1.50

TABLE III

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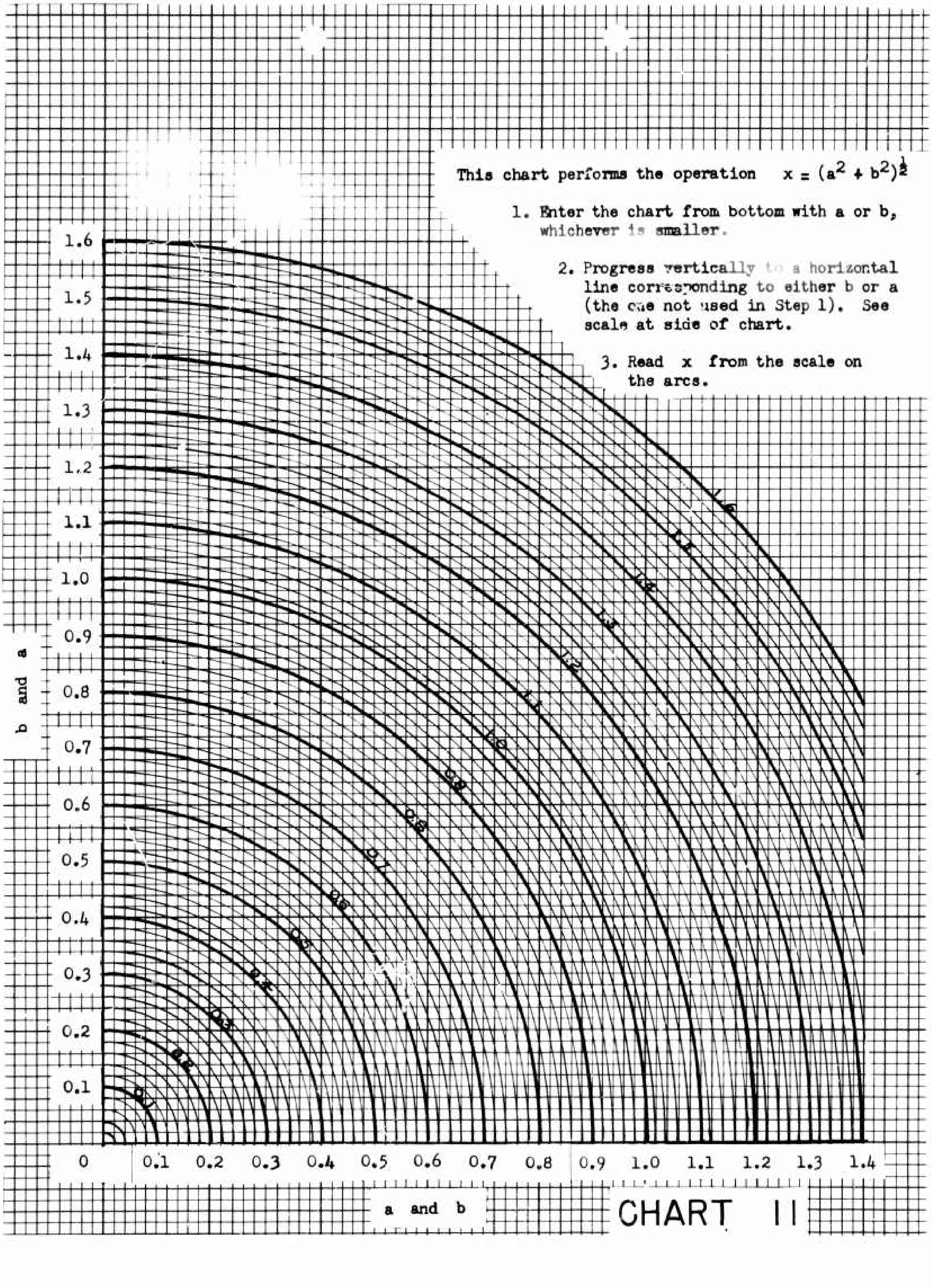
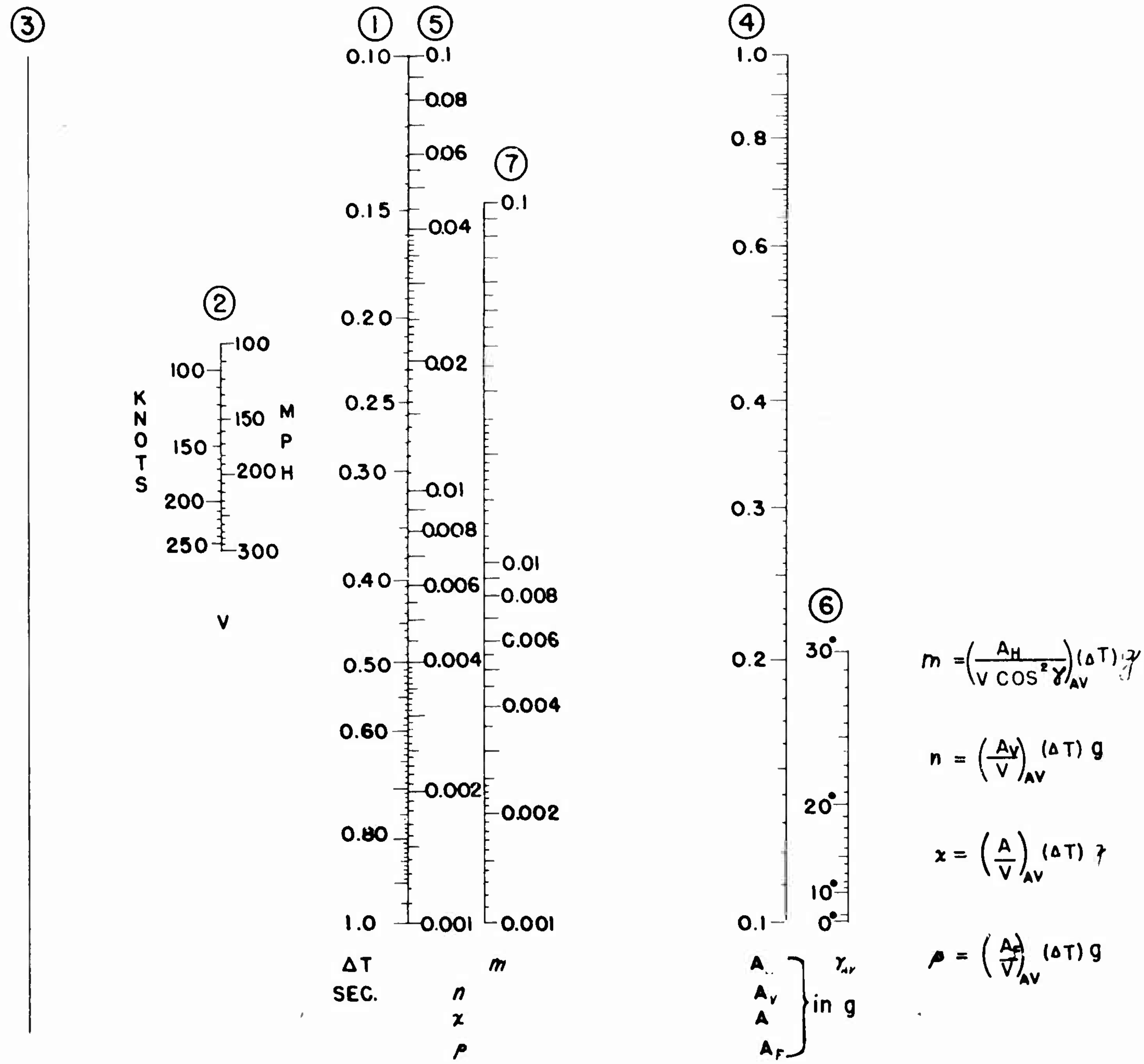

This chart performs the operation $x = (a^2 + b^2)^{\frac{1}{2}}$
1. Enter the chart from bottom with a or b, whichever is smaller.
2. Progress vertically to a horizontal line corresponding to either b or a (the one not used in Step 1). See scale at side of chart.
3. Read x from the scale on the arcs.
b and a
a and b
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6

CHART 11



A. Calculation of *m*

1. Obtain T from Col 34A-J. Enter on Scale 1.
2. Obtain V from Col 34A-F. Enter on Scale 2.
3. Connect ΔT and V with a straight edge. Mark intersection on Scale 3.
4. Obtain A_H from Col 34A-C. Enter on Scale 4.
5. Connect mark on Scale 3 with A_H on Scale 4 with a straight edge. Mark intersection on Scale 5.
6. Obtain γ_{AV} from Col 34A-H. Enter on Scale 6.
7. Connect mark on Scale 5 with γ_{AV} on Scale 6 with a straight edge. Read the desired value of m from Scale 7 and record in Col 35A-E.

B. Calculation of *n, x, p*

1. Obtain ΔT from Col 34A-J. Enter on Scale 1.
2. Obtain V from Col 34A-F. Enter on Scale 2.
3. Connect ΔT with V with a straight edge. Mark intersection on Scale 3.
4. Obtain A_V, A or A_F (depending on whether n, x, or p is desired) from Cols 34A-E, 35B-B or 34B-D. Enter on Scale 4.
5. Connect mark on Scale 3 with A_V, A, or A_F on Scale 4 with a straight edge. Read the desired value of n, x, or p from Scale 5 and record in Cols 35B-E or 35B-F.

Directions for Use

Calculation of

$$Q = -A_H\frac{m}{3} - A_V\left(\gamma_o + \frac{n}{3}\right) + A_F\left(1 - \frac{\gamma_o^2}{2}\right)$$

1. Obtain m from Col 35A-E. Enter this value on Scale 1.
2. Obtain A_H from Col 34A-C. Enter this value on Scale 2.
3. Connect m on Scale 1 and A_H with straight edge and mark the intersection of this line with Scale 3.
4. Obtain n from Col 35A-F. Enter this value on Scale 4.
5. Obtain γ_o from Col 34A-I. Enter this value on Scale 5. Note that if n and γ_o have the same sign use the upper half of the scale, if n and γ_o have opposite signs use the lower half of scale.
6. Connect n and γ_o with a straight edge and mark the intersection of this line with Scale 6.
7. Obtain A_V from Col 34A-E. Enter this value on Scale 7.
8. Connect the mark on Scale 6 and A_V with a straight edge and mark the intersection of this line with Scale 8.
9. Connect the mark on Scale 3 and the mark on Scale 8 with a straight edge and mark the intersection of this line with Scale 9.
10. Obtain A_F from Col 34A-D. Enter this value on Scale 10.
11. Obtain γ_o from Col 34A-I. Enter this value on Scale 11.
12. Connect A_F and γ_o with a straight edge and mark the intersection of this line with Scale 12.
13. Connect the mark on Scale 10 and the mark on Scale 12 with a straight edge and read Q from Scale 13. Record this value in Col 35A-G.

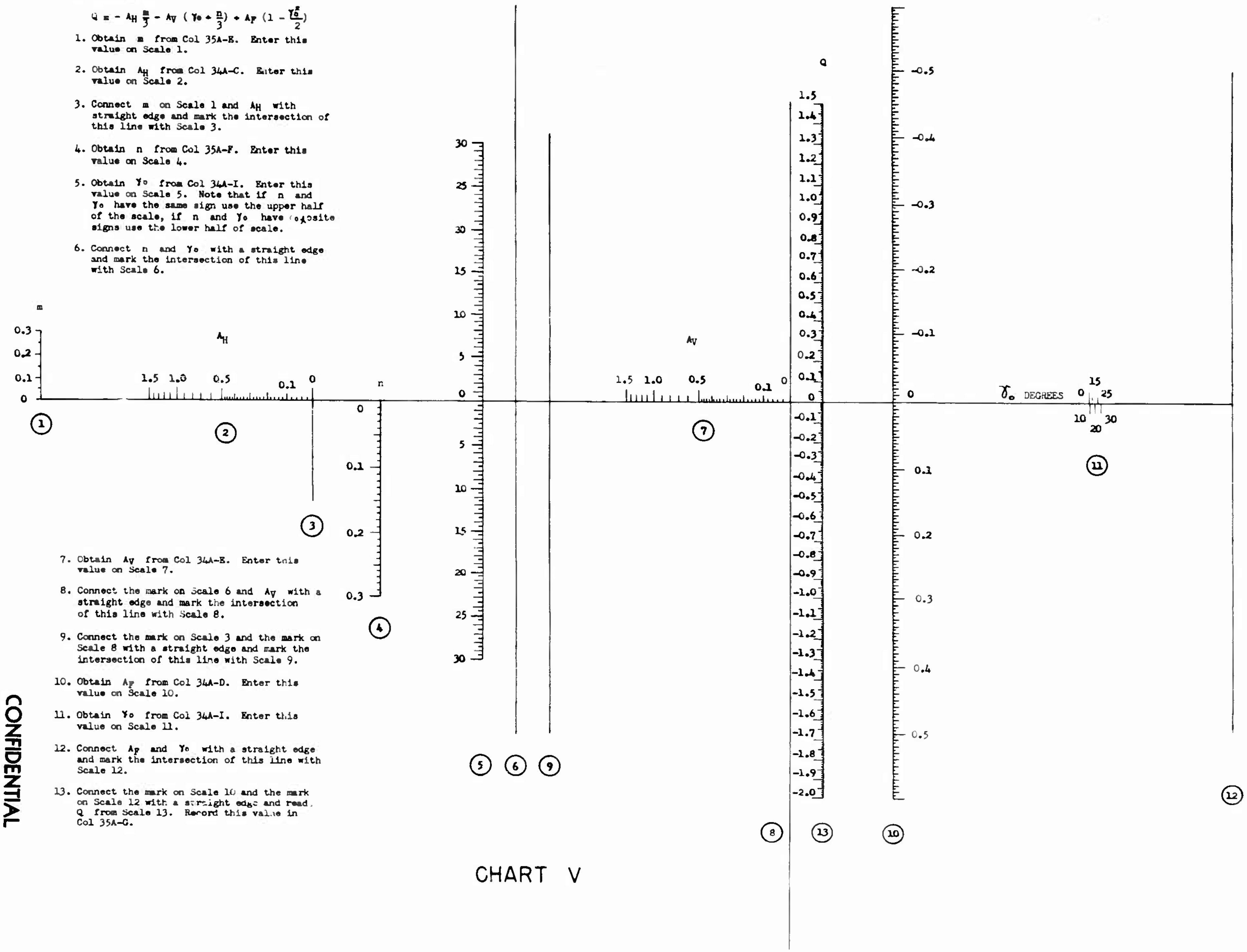


CHART V

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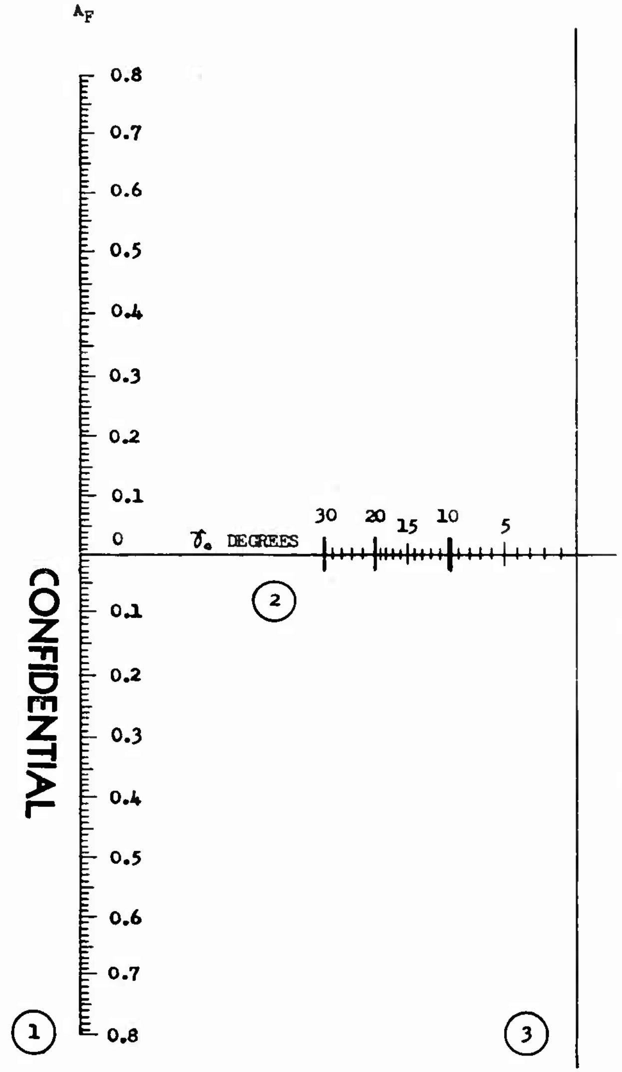

Directions for Use

Calculation of

$$W = A_F \gamma_o + A_V \left(1 - \frac{\gamma_o^2}{2}\right)$$

1. Obtain A_F from Col 34A-D. Enter on Scale 1. Notice that if is positive (Col 34A-I), positive A_F is on the lower half of the chart and negative A_F is on the upper half of the chart. If γ_o is negative, the reverse is true.
2. Obtain γ_o from Col 34A-I. Enter on Scale 2.
3. Connect A_F with γ_o by a straight edge. Mark intersection on Scale 3.
4. Obtain A_V from Col 34A-E. Enter on Scale 4. Notice sign.
5. Enter γ_o on Scale 5.
6. Connect A_V with γ_o ; mark intersection with Scale 6.
7. Connect mark on Scale 3 with mark on Scale 6 and find intersection with Scale 7. Read desired value of W from Scale 7 and record in Col 36A-B.

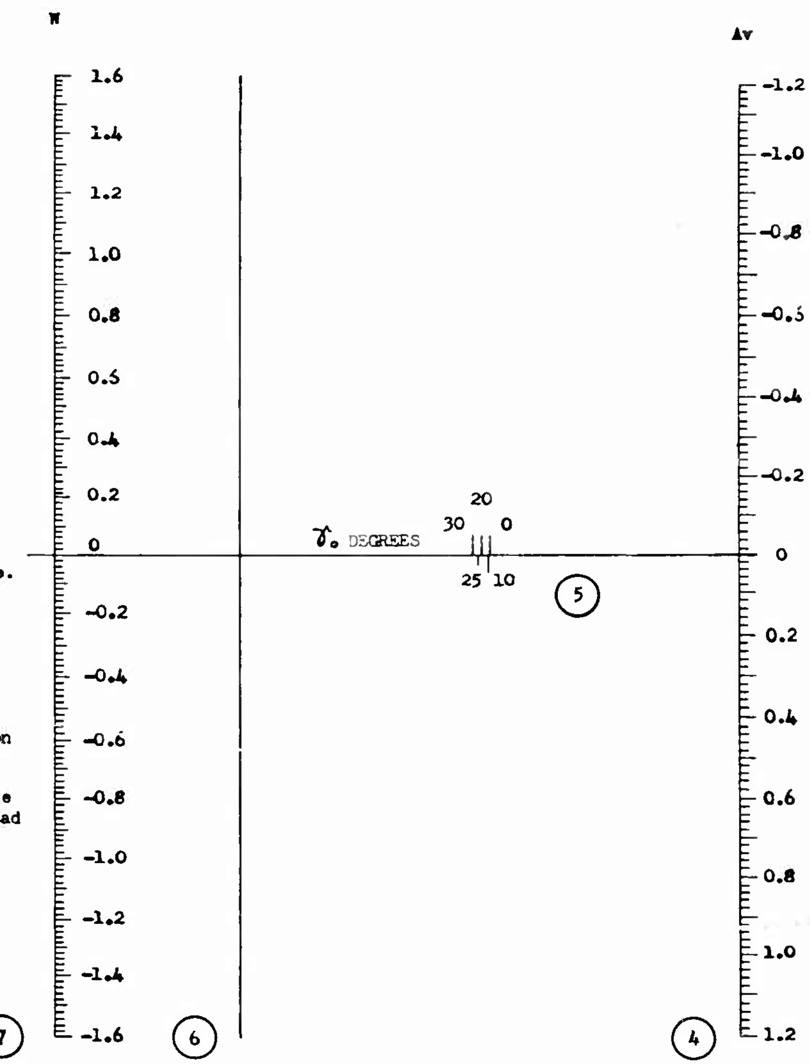

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CHART VII

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CHART VIII

$$\left(\frac{p}{1-p}\right)\frac{1}{x} + \left(\frac{8+5p+6p^2}{12}\right)x + \frac{x^3}{10} = \tan \xi$$

x \ p	-0.50	-0.45	-0.40	-0.35	-0.30	-0.25	-0.20	-0.15	-0.10	-0.05	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
-0.50	[illegible]	[illegible]	15°03'	12°08'	8°51'	5°11'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-24°40'	-30°36'	-36°20'	-41°54'	-47°13'	-52°10'	-56°46'	-60°59'	-64°49'	-68°18'
-0.45	[illegible]	22°45'	20°03'	16°58'	13°29'	9°33'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-23°33'	-29°59'	-36°18'	-42°20'	-48°00'	-53°13'	-57°59'	-62°16'	-66°06'	-69°33'
-0.40	[illegible]	28°15'	25°27'	22°14'	18°34'	14°22'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-22°28'	-29°40'	-36°38'	-43°15'	-49°15'	-54°42'	-59°34'	63°52'	67°40'	-71°01'
-0.35	[illegible]	[illegible]	[illegible]	28°03'	24°18'	19°46'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-21°35'	-29°45'	-37°31'	-44°39'	-51°03'	56°41'	-61°35'	[illegible]	-69°31'	-72°42'
-0.30	[illegible]	[illegible]	37°48'	34°29'	30°34'	25°55'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-21°03'	-30°25'	-39°07'	-46°51'	-53°34'	-59°16'	[illegible]	[illegible]	71°40'	74°37'
-0.25	[illegible]	47°35'	44°54'	41°40'	37°46'	33°01'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-21°01'	-31°59'	41°45'	-50°05'	56°55'	-62°33'	-67°09'	-70°57'	-74°07'	76°46'
-0.20	[illegible]	[illegible]	52°41'	[illegible]	46°00'	41°22'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-21°53'	34°57'	45°53'	-54°33'	-61°19'	-66°36'	70°47'	-74°08'	-76°51'	79°07'
-0.15	[illegible]	[illegible]	[illegible]	[illegible]	55°25'	51°12'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-26°27'	-40°18'	-52°10'	-60°42'	-66°53'	71°28'	-74°57'	77°41'	-79°52'	-81°39'
-0.10	[illegible]	[illegible]	[illegible]	68°28'	66°02'	62°44'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-30°46'	-49°41'	-61°28'	-68°48'	-73°40'	-77°07'	-79°39'	[illegible]	-83°07'	-84°21'
-0.05	[illegible]	[illegible]	80°01'	79°01'	77°42'	75°52'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-41°25'	-66°07'	-74°20'	-78°46'	-81°51'	-83°26'	-84°43'	-85°43'	-86°21'	[illegible]
0.00	[illegible]	[illegible]	90°00'	90°00'	90°00'	90°00'	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]	90°00'	90°00'	90°00'	90°00'	90°00'	90°00'	90°00'	90°00'	90°00'
0.05	[illegible]	[illegible]	-80°01'	-79°01'	-77°42'	-75°53'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41°23'	[illegible]	74°20'	78°46'	81°31'	83°26'	84°43'	85°43'	86°31'	87°09'
0.10	[illegible]	[illegible]	-70°20'	-68°28'	[illegible]	-62°44'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30°46'	49°47'	61°28'	68°48'	73°40'	77°07'	79°39'	81°35'	83°07'	84°21'
0.15	[illegible]	[illegible]	-61°11'	-58°30'	-55°25'	-51°12'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26°27'	40°18'	52°10'	60°42'	66°53'	71°28'	74°57'	77°41'	79°52'	81°39'
0.20	[illegible]	[illegible]	-52°41'	-49°42'	-46°00'	-41°22'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21°53'	34°57'	45°53'	54°33'	61°19'	66°36'	70°47'	74°08'	76°51'	79°07'
0.25	[illegible]	[illegible]	-44°54'	-44°41'	-37°46'	-33°01'	[illegible]	[illegible]	[illegible]	9°33'	21°01'	31°59'	41°45'	50°05'	56°55'	62°33'	67°09'	70°57'	74°07'	76°46'	[illegible]
0.30	[illegible]	[illegible]	-31°48'	-34°29'	-30°34'	-25°55'	[illegible]	[illegible]	[illegible]	11°26'	21°03'	30°25'	39°07'	46°51'	53°34'	59°16'	64°06'	68°11'	71°40'	74°37'	[illegible]
0.35	[illegible]	[illegible]	-31°21'	-28°03'	-24°18'	-19°46'	[illegible]	[illegible]	[illegible]	11°22'	21°39'	29°45'	37°31'	44°39'	51°03'	56°41'	61°35'	65°50'	69°31'	72°42'	[illegible]
0.40	[illegible]	[illegible]	-25°27'	-22°14'	-18°34'	-14°22'	[illegible]	[illegible]	[illegible]	11°16'	22°20'	29°40'	36°38'	43°13'	49°15'	54°42'	59°34'	63°52'	67°40'	71°01'	[illegible]
0.45	[illegible]	22°45'	-20°03'	-16°58'	-13°29'	-9°33'	[illegible]	[illegible]	[illegible]	[illegible]	23°33'	29°59'	36°18'	42°20'	48°00'	53°13'	57°59'	62°16'	66°06'	69°33'	[illegible]
0.50	[illegible]	[illegible]	-15°03'	-12°08'	-8°51'	-5°11'	[illegible]	[illegible]	[illegible]	19°05'	24°48'	30°36'	36°20'	41°54'	47°13'	52°10'	56°46'	60°59'	64°49'	68°18'	[illegible]

MIDDLE OF CHART

x \ p	-0.20	-0.18	-0.16	-0.14	-0.12	-0.10	-0.09	-0.08	-0.07	-0.06	-0.05	-0.04	-0.03	-0.02	-0.01	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.12	0.14	0.16	0.18	0.20
-0.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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NOMENCLATURE

1. Coordinate Systems

$\xi\eta\zeta$ - Fixed Air-Mass Axes: The $\xi\eta$-plane is parallel to the ground and the positive η-axis has the direction of the bomber's line-of-flight.

$X'Y'Z'$ - Bomber Axes: Origin at Q, the vulnerable point.

XYZ - Stabilized Bomber Axes: Origin at Q and parallel to the $\xi\eta\zeta$-system.

$x_1y_1z_1$ - Fighter Axes: For a left side attack the plane points along the positive x_1-axis and the left wing along the positive y_1-axis. For a right side attack the plane points along the negative x_1-axis and the right wing along the positive y_1-axis.

$x'y'z'$ - Origin at the fighter and parallel to the $X'Y'Z'$-system.

xyz - Stabilized Fighter Axes: Origin at the fighter and parallel to the XYZ-system.

$x_iy_iz_i$ $(i = 1, 2, 3, 4)$ - Fighter Axes: Represent the axes of the fighter in the various stages of the four planar rotations.

2. Constants

V_B - Bomber Speed (yd per sec). The bomber velocity vector is constant.

V_F - Fighter Speed (yd per sec) relative to air-mass coordinates $\xi\eta\zeta$.

V_M - Muzzle Speed of Bullet (yd per sec) when fired from a stationary gun.

c_5 - Ballistic Constant (dimensionless)

δ - Relative Air Density (dimensionless).

3. Variables (the ranges of the variables are indicated).

α_0', ε_0', r_0 - Coordinates of the Fighter Relative to the Unstabilized Bomber Axes $X'Y'Z'$.

$0^\circ \leqq \alpha_0' < 360^\circ$		$-90^\circ \leqq \varepsilon_0' \leqq 90^\circ$	
$0^\circ \leqq \alpha_0' \leqq 180^\circ$	for a right side attack	$-90^\circ \leqq \varepsilon_0' \leqq 0^\circ$	when the fighter is below the bomber
$180^\circ \leqq \alpha_0' < 360^\circ$	for a left side attack	$0^\circ \leqq \varepsilon_0' \leqq 90^\circ$	when the fighter is above the bomber

3. Variables (Continued)

θ'_0 , φ'_0 - Unstabilized angle off the bomber's nose, and tilt a , respectively, of the fighter relative to the X'Y'Z'-system.

$0^\circ \leqq \theta'_0 \leqq 180^\circ$ $\quad$ $0^\circ \leqq \varphi'_0 < 360^\circ$

$0^\circ \leqq \varphi'_0 \leqq 180^\circ$ when the fighter is above the bomber

$180^\circ \leqq \varphi'_0 < 360^\circ$ when the fighter is below the bomber

α_0 , ε_0 , r_0 - Coordinates of the Fighter Relative to the Stabilized Bomber Axes XYZ .

$0^\circ \leqq \alpha_0 < 360^\circ$ $\quad$ $-90^\circ \leqq \varepsilon_0 \leqq 90^\circ$

$0^\circ \leqq \alpha_0 = 180^\circ$ for a right side attack $\quad$ $-90^\circ \leqq \varepsilon_0 \leqq 0^\circ$ when the fighter is below the bomber

$180^\circ \leqq \alpha_0 < 360^\circ$ for a left side attack $\quad$ $0^\circ \leqq \varepsilon_0 \leqq 90^\circ$ when the fighter is above the bomber

θ_0 , φ_0 - Stabilized angle off the bomber's nose, and tilt angle, respectively, of the fighter relative to the XYZ-system.

$0^\circ \leqq \theta_0 \leqq 180^\circ$ $\quad$ $0^\circ \leqq \varphi_0 < 360^\circ$

$0^\circ \leqq \varphi_0 \leqq 180^\circ$ when the fighter is above the bomber

$180^\circ \leqq \varphi_0 < 360^\circ$ when the fighter is below the bomber

α'_B , ε'_B - Coordinates of the fighter gun bore-point B in the x'y'z'-system.

α_B , ε_B - Coordinates of the fighter gun bore-point B in the xyz-system.

α_C , ε_C - Coordinates of the effective bore-line in the xyz-system (resultant of V_M and V_F without ballistic correction).

3. Variables (Continued).

α , ε - Coordinates of the true bullet line in the xyz-system (i.e., the line from the fighter at firing time to the target at impact time).

$0^\circ \leqq \alpha < 360^\circ$ $\qquad$ $-90^\circ \leqq \varepsilon \leqq 90^\circ$

$0^\circ \leqq \alpha \leqq 180^\circ$ for a left side attack $\qquad$ $\varepsilon = -\varepsilon_0$

$180^\circ \leqq \alpha < 360^\circ$ for a right side attack

u - Bullet time-of-flight (seconds).

ρ - Radial bullet line error (milliradians). (ρ is the angle between the actual and true bullet lines).

$\overline{G}$ - Gravity drop correction (minutes).

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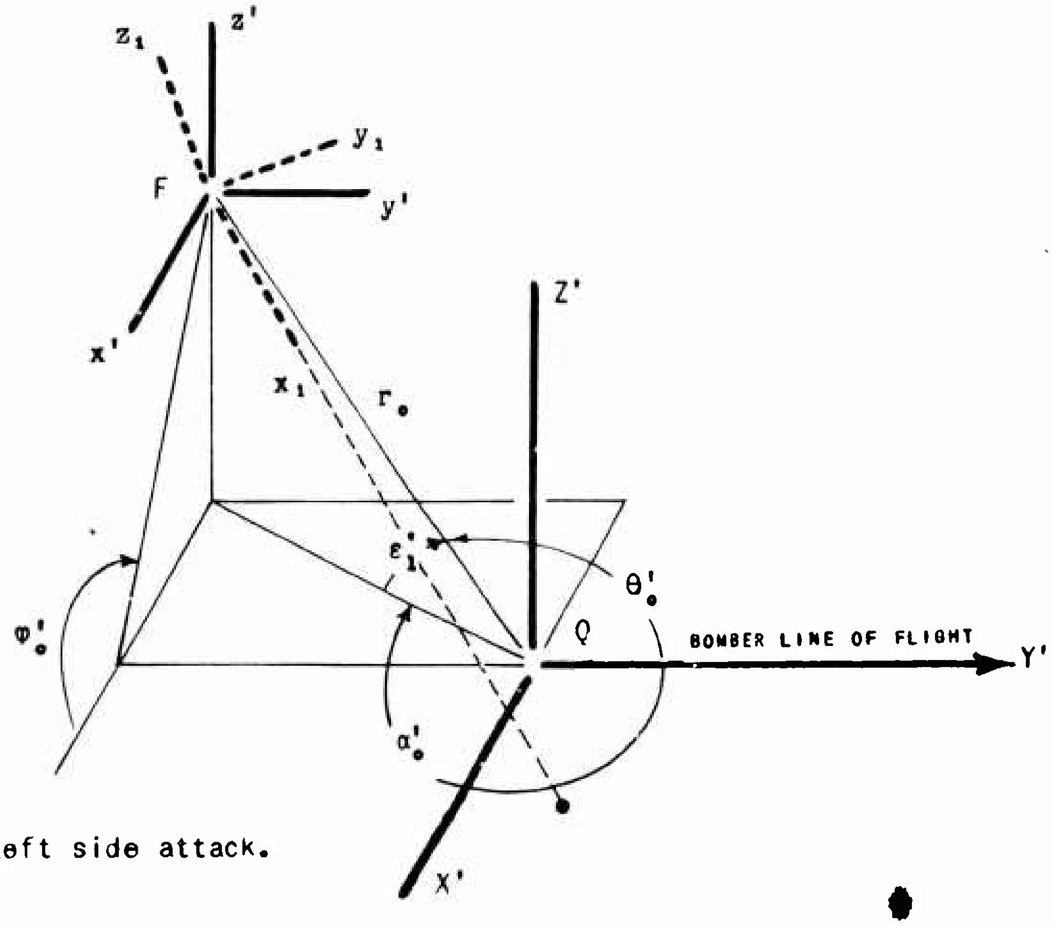

Fig. 1.1. Left side attack.

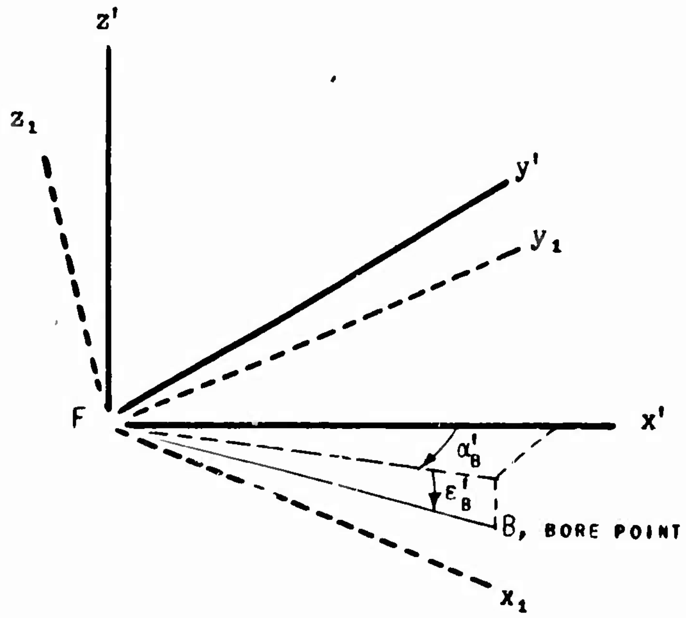

Fig. 1.2

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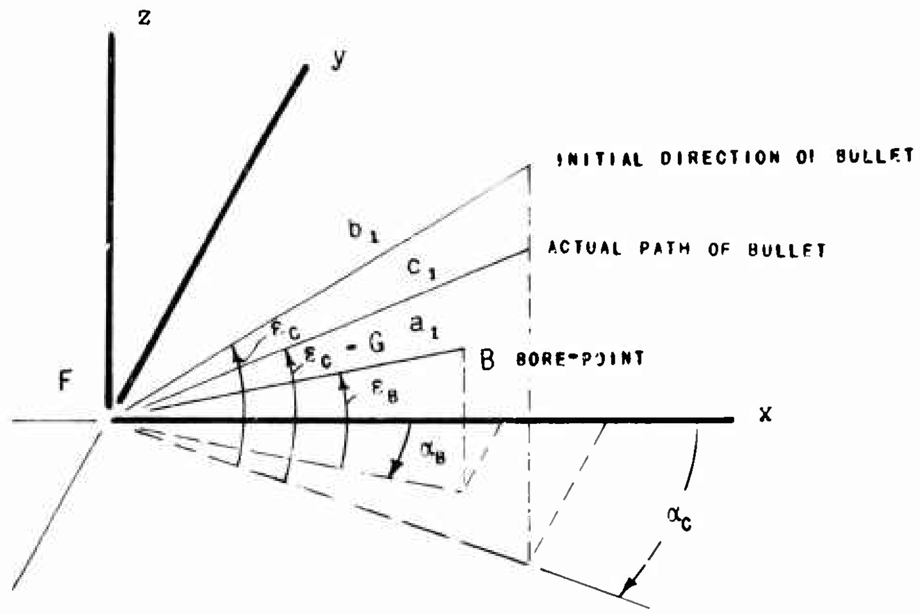
z
y
INITIAL DIRECTION OF BULLET
ACTUAL PATH OF BULLET
b_1
c_1
a_1
ε_c
$\varepsilon_c - G$
B BORE-POINT
ε_B
F
x
α_B
α_c

Fig. 1.3

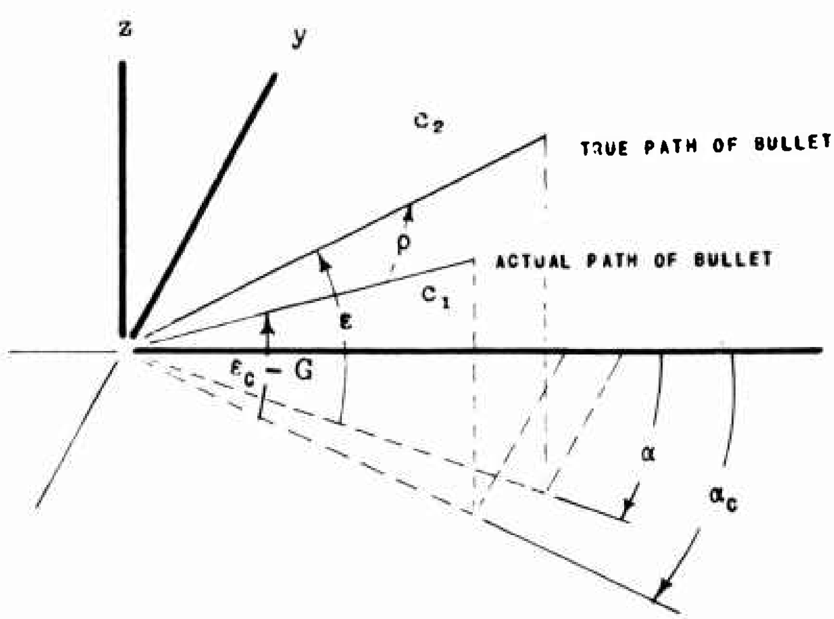
z
y
c_2
TRUE PATH OF BULLET
ρ
ACTUAL PATH OF BULLET
c_1
ε
$\varepsilon_c - G$
α
α_c

Fig. 1.4

1. Compute and record on Form 41 the values of the constants listed there.

2. Obtain the unstabilized coordinates of the fighter r_o, α'_o, ε'_o from bomber vs fighter data and record in Cols 42-B, 42-C and 42-D.

3. Compute Θ'_o, φ'_o from the formulas below and record in Cols 43-C and 43-E.

$$\cos \Theta'_o = \cos \alpha'_o \cos \varepsilon'_o \ ;$$

$$\cot \varphi'_o = \sin \alpha'_o \cot \varepsilon'_o \ .$$

4. Graph Θ'_o and φ'_o, smooth and read their values at points corresponding to the fighter **film frames** to be read. Record in Cols 44-B and 44-C.

5. Using the GLOOK and fighter film determine the coordinates of the bore-point α'_B ε'_B in the x'y'z'-system. Record in Cols 44-D and 44-E.

6. Using the GLOOK make a yaw, roll, pitch correction on α'_B, ε'_B to determine the coordinates α_B, ε_B of the bore-point in the xyz-system. Record in Cols 44-I, and 44-J.

7. Graph α_B and ε_B, smooth and read their values for every 0.1 sec. Record in Cols 47-B and 47-C.

A.

A1.

B.

C.

D.

E.

F.

8. Compute the coordinates α_c and ε_c of th xyz-system from the formulas below and r

$$\tan \alpha_c = \frac{\sin \alpha_B \cos \varepsilon_B + \sigma\,(X_{i+}}{\cos \alpha_B \cos \varepsilon_B + \sigma\,(Y_{i+}}$$

$$\sin \varepsilon_c = \frac{V_M}{V_M + V_F}\Big[\sin \varepsilon_B + \sigma\,(Z$$

9. Compute $\varepsilon_c - \bar{G}$ and record in Col 49-H.

10. Compute $\varepsilon_c - \bar{G} - \varepsilon$ in minutes and rec

11. Compute $\alpha_c - \alpha$ in minutes and record

12. Compute the radial error ρ by the GLOO and record in Col 50-K. The formula giv

$$\rho = 0.2909 \sqrt{\ (\alpha_c - \alpha)^2 \cos (}$$

Ranges of the Variables

$0° \leq \alpha_o < 360°$;	$0° \leq \alpha_o \leq 180°$ for a right side attack, $180° \leq \alpha_o < 360°$ for a left side attack.
$-90° \leq \varepsilon_o \leq 90°$;	$-90° \leq \varepsilon_o \leq 0°$ when fighter is below bomber, $0° \leq \varepsilon_o \leq 90°$ when fighter is above bomber
$0° \leq \Theta \leq 180°$	
$0° \leq \varphi < 360°$;	$0° \leq \varphi_o \leq 180°$ when fighter is above bomber, $180° \leq \varphi_o < 360°$ when fighter is below bomber.
$0° \leq \alpha < 360°$;	$0° \leq \alpha \leq 180°$ for a left side attack, $180° \leq \alpha < 360°$ for a right side attack.
$-90° \leq \varepsilon \leq 90°$;	ε and ε_o have opposite signs.

α'_o, ε'_o, Θ'_o, φ'_o have respectively, the same ranges as α_o, ε_o, Θ_o, φ_o.

1

A. Obtain values of Y, R, P from bomber vs fighter data. Graph and smooth.

A1. Read their values at points corresponding to the fighter film frames to be read and record in Cols 44-F, 44-G and 44-H.

A2. Read their values at points correspo bomber film frames to be read and re 43-F, 43-G and 43-H.

B. Using the GLOOK make a yaw, roll, pitch correction on α'_o, ε'_o to determine the stabilized α_o, ε_o of the fighter in the XYZ-system. Record in Cols 43-I and 43-J.

C. Graph r_o, α_o and ε_o, smooth and read their values for every 0.1 sec. Record in Cols 45-

iter

ε'_B

D. Compute the coordinates X, Y, Z of the fighter by the formulas:

$X = r_o \cos \varepsilon_o \sin \alpha_o$ and record in Col 45-I,
$Y = r_o \cos \varepsilon_o \cos \alpha_o$ and record in Col 45-J,
$Z = r_o \sin \varepsilon_o$ and record in Col 45-K.

E. Compute $X_{i+1} - X_{i-1}$, the values of X at t-0.1 subtracted from the values of X at t+0.1. Si Record in Cols 46-B, 46-C and 46-D.

F. Compute the following formula and record in Col 46-J.

$$\sigma = \frac{V_F/V_M}{\sqrt{(X_{i+1} - X_{i-1})^2 + (Y_{i+1} - Y_{i-1})^2 + (Z_{i+1} - Z_{i-1})^2}}$$

s α_c and ε_c of the effective bore line in the rmulas below and record in Cols 49-K and 49-C.

$$\frac{\text{cos } \varepsilon_B + \sigma (X_{i+1} - X_{i-1})}{\text{cos } \varepsilon_B + \sigma (Y_{i+1} - Y_{i-1})}$$

$$[\sin \varepsilon_B + \sigma (Z_{i+1} - Z_{i-1})]$$

ecord in Col 49-H.

in minutes and record in Col 49-J.

inutes and record in Col 50-C.

or ρ by the GLOOK or by the formula below . The formula gives ρ in milliradians.

$$\ldots_c - \alpha)^2 \cos(\varepsilon_c - \bar{G}) \cos \varepsilon + (\varepsilon_c - \bar{G} - \varepsilon)^2$$

G. Compute the "angle-off" Θ of the fighter relat bomber from the formula $\cos \Theta_o = \cos \alpha_o \cos$ record in Col 48-C.

H. Compute the kinematic lead angle λ from tabl No. 24. In these tables λ is a function of and present angle-off Θ_o. Record in Col 48-D.

I. Compute the quantity uV_B to the nearest yard formula below and record in Col 48-H.

$$uV_B = \frac{r_o \sin \lambda}{\sin(\lambda + \Theta_o)}$$

J. Compute the gravity drop correction $\bar{G}$ by the i below and record in Col 49-G. This formula gi in minutes.

$$\bar{G} = (uV_B\, a + b)\, uV_B \cos \varepsilon_c$$

K. Compute α and ε from the formulas l record in Cols 50-B and 49-I.

$$\cot \alpha = \frac{Y - uV_B}{X},$$

$$\sin \varepsilon = -\frac{\sin \varepsilon_o}{\sin \Theta_o} \sin(\lambda + \Theta_o)$$

FLOW CHART IX

FIGHTER VS BOMBER

2

r vs fighter data. Graph and smooth.

onding to and record

A2. Read their values at points corresponding to the bomber film frames to be read and record in Cols 43-F, 43-G and 43-H.

itch correction on α_o' , ε_o' to determine the stabilized coordinates Z-system. Record in Cols 43-I and 43-J.

read their values for every 0.1 sec. Record in Cols 45-B, 45-C and 45-D.

the fighter by the formulas:

cord in Col 45-I,
cord in Col 45-J,
cord in Col 45-K.

X at t-0.1 subtracted from the values of X at t+0.1. Similarly for Y and Z.

ecord in Col 46-J.

$$- Y_{i-1})^2 + (Z_{i+1} - Z_{i-1})^2$$

G. Compute the "angle-off" θ of the fighter relative to the bomber from the formula $\cos\theta_o = \cos\alpha_o \cos\varepsilon_o$ and record in Col 48-C.

H. Compute the kinematic lead angle λ from tables in AMG-N No. 24. In these tables λ is a function of present range r_o and present angle-off θ_o. Record in Col 48-D.

I. Compute the quantity uV_B to the nearest yard from the formula below and record in Col 48-H.

$$uV_B = \frac{r_o \sin\lambda}{\sin(\lambda + \theta_o)}$$

J. Compute the gravity drop correction $\bar{G}$ by the formula below and record in Col 49-G. This formula gives G in minutes.

$$\bar{G} = (uV_B\, a + b)\, uV_B \cos\varepsilon_c$$

)^2

K. Compute α and ε from the formulas below and record in Cols 50-B and 49-I.

$$\cot\alpha = \frac{Y - uV_B}{X},$$

$$\sin\varepsilon = -\frac{\sin\varepsilon_o}{\sin\theta_o}\sin(\lambda + \theta_o)$$

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1 December 1945

A. V_B = ; D. δ =

B. V_M = ; E. c_5 =

C. V_F =

F. $V_M + V_F = B + C =$

G. $h = .00059 \dfrac{\delta}{c_5} \sqrt{30(V_M + V_F)} = \dfrac{.00059 \times D}{E} \times \sqrt{30 \times F} =$

H. $a = \dfrac{6246.671h}{(V_M + V_F)V_B^2} = \dfrac{6246.671 \times G}{F \times A \times A} =$

I. $b = \dfrac{18,427.680}{(V_M + V_F)V_B} = \dfrac{18,427.680}{F \times A} =$

J. $\dfrac{V_F}{V_M} = \dfrac{C}{B} =$

K. $\dfrac{V_M}{V_M + V_F} = \dfrac{B}{F} =$

Flight No. ________
Attack No. ________
F. C. No. ________
Form 41

ATTACK CONSTANTS

By ________
Started ________
Completed ________
Sheet ____ of ____

N.U. P22E 15 Dec. '45

Frame No. (Bomber Camera)	r_o (Yards)	α'_o (Deg-Min)	ε'_o (Deg-Min)	$\cos \alpha'_o$	$\cos \varepsilon'_o$	$\sin \alpha'_o$	$\cot \varepsilon'_o$
	From Bomber vs Fighter Data			cos C	cos D	sin C	cot D
A	B	C	D	E	F	G	H

Flight No. ________
Attack No. ________
F. C. No. ________

BOMBER CAMERA DATA I

By ________
Started ________
Completed ________

Form 42

Sheet of

CONFIDENTIAL

N.U. P22E 15 Dec. '45

Frame No. Bomber Camera	$\cos\sigma'_o$	σ'_o (Deg-Min)	$\cot\varphi'_o$	φ'_o (Deg-Min)	Y (Deg-Min)	R (Deg-Min)	P (Deg-Min)	α_o (Deg-Min)	ε_o (Deg-Min)	
	42Ex42F	$\cos^{-1}$ B	42Gx42H	$\cot^{-1}$ D	**From Bomber vs Fighter Data**			**From 42C, 42D** via GLOOK		
A	B	C	D	E	F	G	H	I	J	

Flight No. __________
Attack No. __________
F. C. No. __________

BOMBER CAMERA DATA II

By __________
Started __________
Completed __________

Form 43

Sheet _____ of _____

CONFIDENTIAL

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N.U. P22E 15 Dec. '45

Frame No. Fighter Camera	σ'_o (Deg-Min)	φ'_o (Deg-Min)	α'_B (Deg-Min)	ε'_B (Deg-Min)	Y (Deg-Min)	R (Deg-Min)	P (Deg-Min)	α_B (Deg-Min)	ε_B (Deg-Min)	
	From Graph of 43C	From Graph of 43E	From Fighter Film via GLOOK		From Bomber vs Fighter Data			From D, E via GLOOK		
A	B	C	D	E	F	G	H	I	J	

Flight No. ____________
Attack No. ____________
F. C. No. ____________

BORE-POINT COORDINATES
(Stabilized Spherical)

By ____________
Started ____________
Completed ____________

Form 44

Sheet ______ of ______

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N.U. P22E 15 Dec. '45

Time	r_o (Yards)	α_o (Deg-Min)	ϵ_o (Deg-Min)	cos ϵ_o	sin α_o	cos α_o	sin ϵ_o	X (Yards)	Y (Yards)	Z (Yards)
	From Graph of 42B	From Graph of 43I	From Graph of 43J	cos D	sin C	cos C	sin D	BxExF	BxExG	B x H
A	B	C	D	E	F	G	H	I	J	K

Flight No. ________
Attack No. ________
F. C. No. ________

FIGHTER COORDINATES
(Stabilized Cartesian)

By ________
Started ________
Completed ________

Form 45

Sheet ____ of ____

CONFIDENTIAL

N.U. P22E 15 Dec. '45

Time	$x_{i+1} - x_{i-1}$	$y_{i+1} - y_{i-1}$	$z_{i+1} - z_{i-1}$	$(x_{i+1} - x_{i-1})^2$	$(y_{i+1} - y_{i-1})^2$	$(z_{i+1} - z_{i-1})^2$	Σ	$\sqrt{\Sigma}$	σ	
	From 45I	From 45J	From 45K	B x B	C x C	D x D	E + F + G	$\sqrt{H}$	41J/I	
A	B	C	D	E	F	G	H	I	J	

Flight No. ____________
Attack No. ____________
F. C. No. ____________

TANGENT TO FIGHTER PATH

By ____________
Started ____________
Completed ____________

Form 46

Sheet ______ of ______

CONFIDENTIAL

N.U. P22E 15 Dec. '45

Time	α_B (Deg-Min)	ε_B (Deg-Min)	sin α_B	cos ε_B	cos α_B	sin ε_B	$\sin\alpha_B \cos\varepsilon_B + \sigma(x_{i+1} - x_{i-1})$	$\cos\alpha_B \cos\varepsilon_B + \sigma(y_{i+1} - y_{i-1})$	tan α_c	sin ε_c
	From Graph of 44I	From Graph of 44J	sin B	cos C	cos B	sin C	(DxE) + (46Jx46B)	(ExF) + (46Jx46C)	H/I	{(46Jx46D) + G}x41K
A	B	C	D	E	F	G	H	I	J	K

Flight No. ______ By ______

Attack No. ______ Started ______

F. C. No. ______ Completed ______

EFFECTIVE BORE LINE

Form 47

Sheet ____ of ____

CONFIDENTIAL

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N. U. P22E 15 Dec. '45

Time	cos θ_o	θ_o (Deg-Min)	λ (Deg-Min)	$\lambda + \theta_o$ (Deg-Min)	sin λ	sin($\lambda + \theta_o$)	uV_B (Yards)	Y - uV_B	cot α	sin θ_o
	45E x 45G	$\cos^{-1}$ B	From Tables	C + D	sin D	sin E	$\frac{45B \times F}{G}$	45J - H	I/45I	sin C
A	B	C	D	E	F	G	H	I	J	K

Flight No. ____________
Attack No. ____________
F. C. No. ____________

TIME OF FLIGHT

By ____________
Started ____________
Completed ____________

Form 48

Sheet ______ of ______

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N. U. P22E 15 Dec. '45

Time	sin ε	ε_c (Deg-Min)	cos ε_c	$uV_Ba + b$	$(uV_Ba+b) \times uV_B$	$\bar{G}$ (Min)	$\varepsilon_c - \bar{G}$ (Deg-Min)	ε (Deg-Min)	$\varepsilon_c - \bar{G} - \varepsilon$ (Min)	α_c (Deg-Min)
	$-\frac{45H \times 48G}{48K}$	$\sin^{-1} 47K$	cos C	(48Hx41H) + 41I	E x 48H	F x D	C - G	$\sin^{-1}$ B	H - I	$\tan^{-1}$ 47J
A	B	C	D	E	F	G	H	I	J	K

Flight No. ____________
Attack No. ____________
F. C. No. ____________

GRAVITY DROP CORRECTION

By ____________
Started ____________
Completed ____________

Form 49

Sheet ____ of ____

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N. U. P22L 15 Dec. '45

Time	α (Deg-Min)	$\alpha_c - \alpha$ (Min)	$(\alpha_c - \alpha)^2$	$\cos(\varepsilon_c - \overline{G})$	$\cos \varepsilon$		$(\varepsilon_c - \overline{G} - \varepsilon)^2$			ρ (Millirad)
	$\cot^{-1}$ 48J	49K - B	C x C	cos 49H	cos 49I	D x E xF	49Jx49J	G + H	$\sqrt{I}$	0.2909xJ
A	B	C	D	E	F	G	H	I	J	K

Flight No. ________
Attack No. ________
F. C. No. ________

RADIAL BULLET LINE ERROR

By ________
Started ________
Completed ________

Form 50

Sheet ____ of ____

CONFIDENTIAL

NOMENCLATURE

1. Coordinate Systems

XYZ - Fixed Ground System: Origin at T , XY-plane on the ground, and Z-axis directed upward.

$x_1y_1z_1$ - Fighter's Own System: The plane points along the positive y_1-axis and the right wing along the positive x_1-axis.

xyz - A system with origin at the fighter and parallel to the XYZ-system.

2. Variables (the ranges of the variables are indicated).

α_0 , ε_0 , r_0 - Coordinates of the fighter relative to the XYZ-system. (See Fig. 1.1).

$$0^\circ \leqq \alpha_0 < 360^\circ \qquad 0^\circ \leqq \varepsilon_0 \leqq 90^\circ$$

(α_0 generally will be in the neighborhood of 180°).

α_T , ε_T - Coordinates of the target center T relative to the $x_1y_1z_1$-system.

α_Q , ε_Q - Coordinates relative to the $x_1y_1z_1$-system of the point of intersection of the positive X-axis and the target circle.

β_0 , ψ_0 - Traverse and inclination angles, respectively, of the fighter relative to the XYZ-system (see Fig. 1.4).

$$0^\circ \leqq \beta_0 \leqq 180^\circ \qquad 0^\circ \leqq \psi_0 < 360^\circ$$

α_F , ε_F - Direction of the tangent to the flight path relative to the xyz-system (see Fig. 1.2).

$$0^\circ \leqq \alpha_F < 360^\circ \qquad -90^\circ \leqq \varepsilon_F \leqq 90^\circ$$

α_{F1} , ε_{F1} - Direction of the tangent to the flight path relative to the $x_1y_1z_1$-system (see Fig. 1.2).

μ , ν - Angles of attack and skid, respectively, of the fighter (see Fig. 1.3).

$$-90^\circ \leqq \mu \qquad 0^\circ \leqq \nu < 360^\circ$$

2. Variables (Continued)

R* - Bank Angle: Angle between the plane of symmetry and the vertical plane through the datum line.

$$R^* \leqq 90^\circ$$

P* - Dive Angle: Angle between the datum line and the horizontal plane.

$$P^* \leqq 90^\circ$$

3. Miscellaneous

Datum Line : Optical-axis of the fighter camera.

Plane of Symmetry : Plane perpendicular to the airplane's wings and containing the datum line.

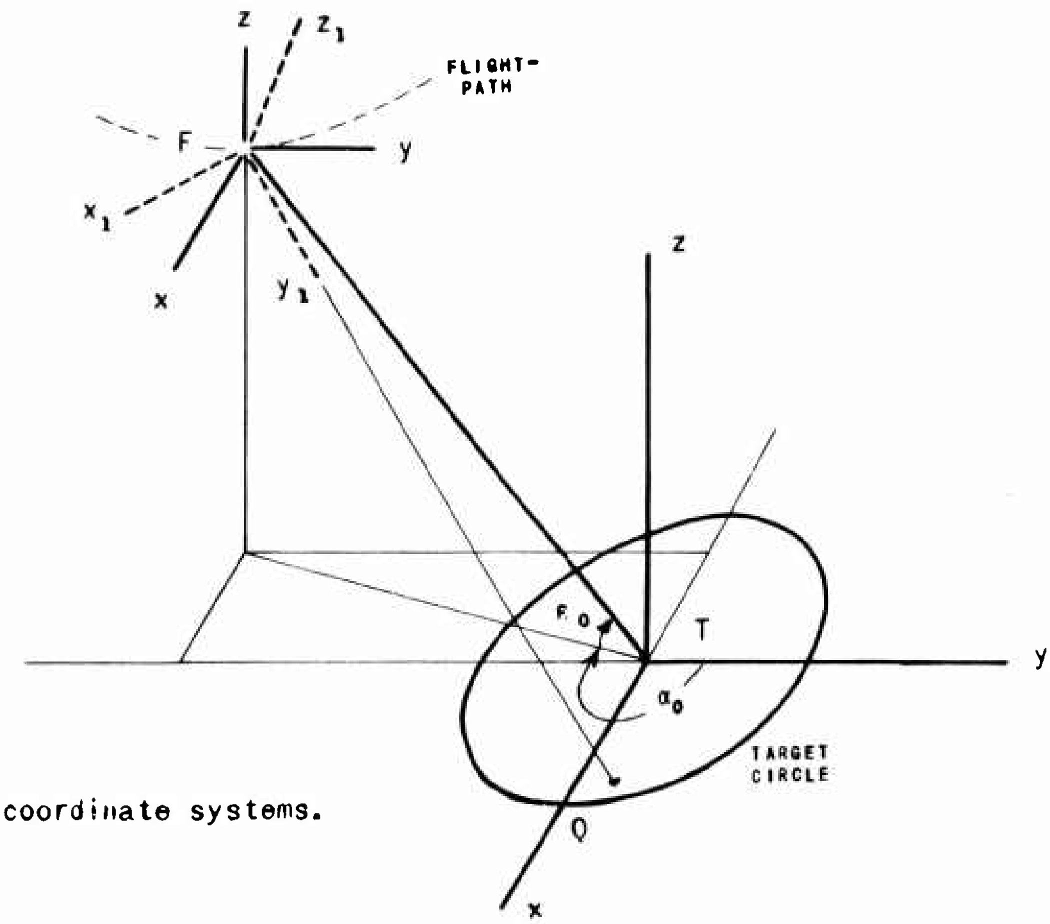

Fig. I.I. The coordinate systems.

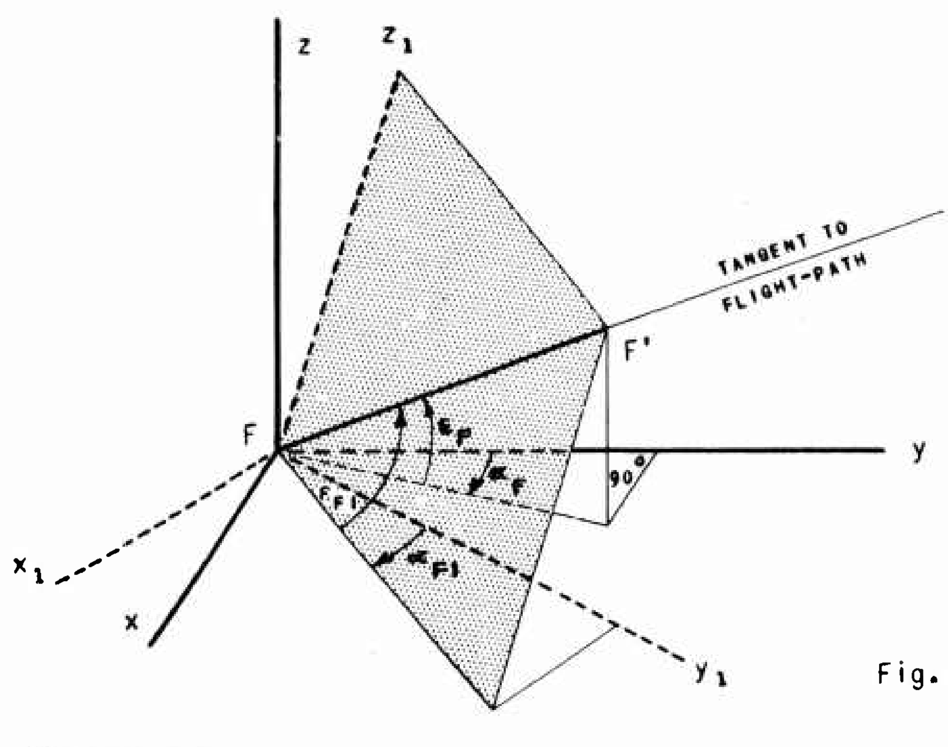

Fig. I.2

D

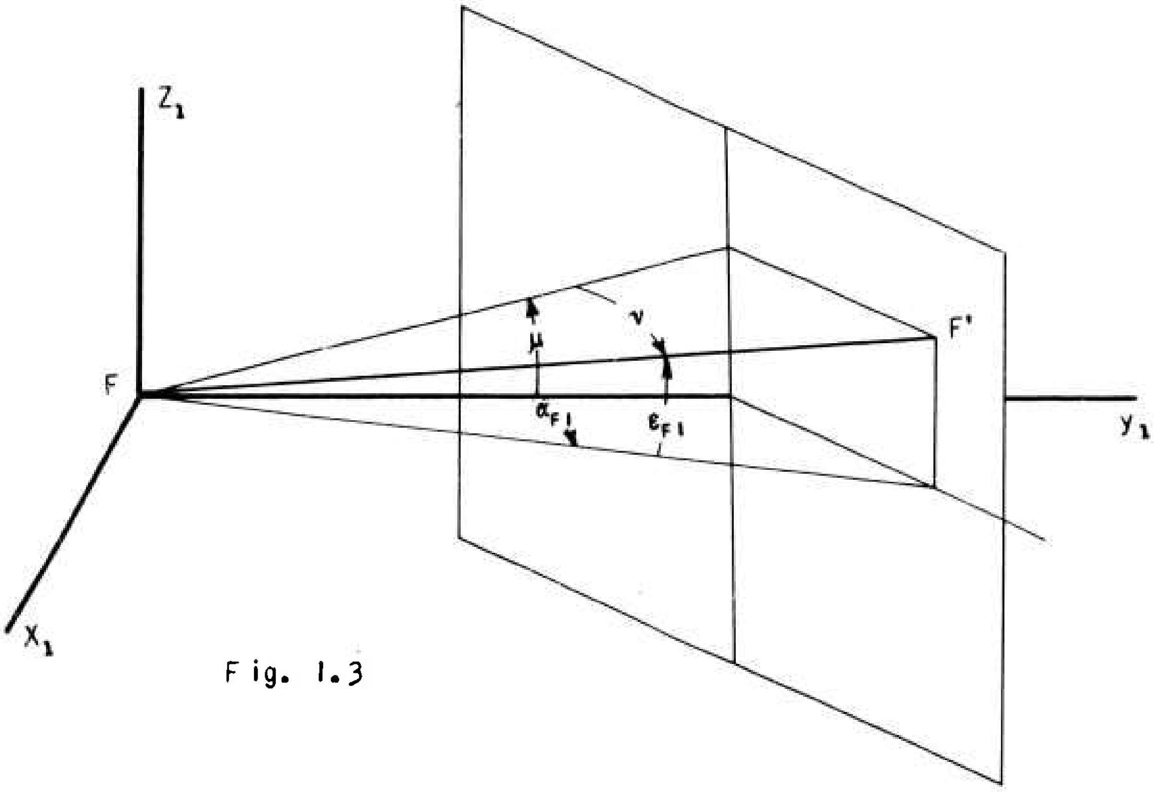

Fig. 1.3

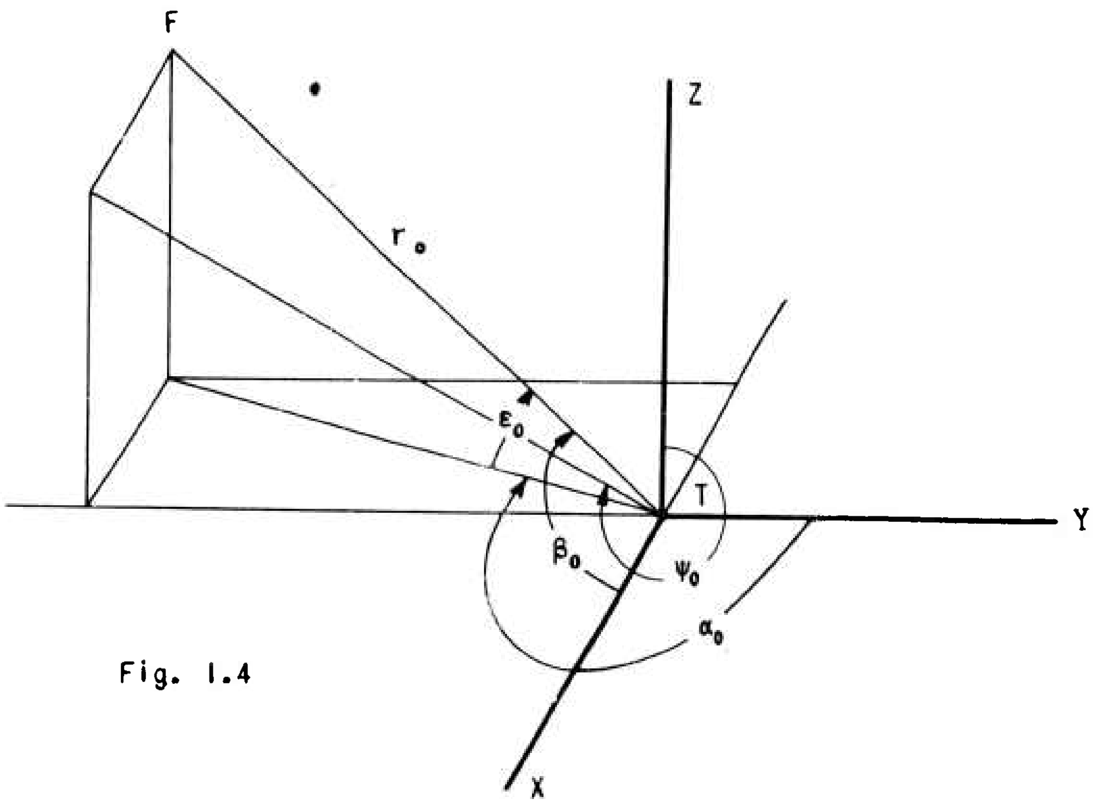

Fig. 1.4

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1. Using CRADLE read β_0' , ψ_0' , from target camera film and record in Cols 61-B and 61-C.

2. Compute the range r_0 from the formula $r_0 = \frac{k}{s}$ and record in Col 61-J (get value of k from the supervisor).

3. Plot β_0' , ψ_0' , r_0, smooth and read their values for every 0.1 sec. Record in Cols 62-B, 62-C, and 62-D.

4. Compute the coordinates X, Y, Z of the fighter by the formulas

$$X = -r_0 \sin \beta_0' ,$$

$$Y = -r_0 \cos \beta_0' \cos \psi_0' ,$$

$$Z = r_0 \cos \beta_0' \sin \psi_0' ,$$

and record in Cols 62-I, 62-J, and 62-K.

5. Compute $X_{i+1} - X_{i-1}$, the values of X at t-0.1 subtracted from the value of X at t+0.1. Similarly for Y and Z, and record in Cols 63-B, 63-C, and 63-D.

6. Compute α_f , ε_f by the formulas

$$\tan \alpha_f = \frac{X_{i+1} - X_{i-1}}{Y_{i+1} - Y_{i-1}}$$

$$\tan \varepsilon_f = \cos \alpha_f \frac{Z_{i+1} - Z_{i-1}}{Y_{i+1} - Y_{i-1}}$$

and record in Cols 63-F and 63-J.

7. Using the GLOOK find μ , ν , R*, P* and record in Cols 64-F, 64-G, 64-H, and 64-I.

A. (a) From fighter camera film read α_T , ε_T , α_Q , ε_Q , using CRADLE, and record in Cols 61-E, 61-F, 61-G, and 61-H.

(b) Measure the length s (inches) of the major axis of the elliptical image on the screen and record in Col 61-I.

B. Plot α_T , ε_T , α_Q , ε_Q , smooth and read their values for every 0.1 sec. Record in Cols 64-B, 64-C, 64-D, and 64-E.

FLOW CHART X

ANGLE OF ATTACK AND SKID PROBLEM

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N.U. P22E 1 Dec. '45

Target Camera			Fighter Camera							
Frame Number	β_o' (Deg–Min)	ψ_o' (Deg–Min)	Frame Number	α_T (Deg–Min)	ε_T (Deg–Min)	α_Q (Deg–Min)	ε_Q (Deg–Min)	s (Inches)	r_o (yards)	
	From Target Camera Film via CRADLE			From Fighter Camera Film via CRADLE				From Fighter Film	From I	
A	B	C	D	E	F	G	H	I	J	

Flight No. ________
Attack No. ________
F. C. No. ________

CAMERA DATA

By ________
Started ________
Completed ________

Form 61

Sheet ______ of ______

CONFIDENTIAL

N. U. P22E 1 Dec. '45

Time	β_o' (Deg-Min)	ψ_o' (Deg-Min)	r_o (Yards)	sin β_o'	cos β_o'	cos ψ_o'	sin ψ_o'	X (Yards)	Y (Yards)	Z (Yards)
	From Graphs of 61-B and 61-C		From Graph of 61-J	sin B	cos B	cos C	sin C	- D x E	-DxFxG	DxFxH
A	B	C	D	E	F	G	H	I	J	K

Flight No. ____________
Attack No. ____________
F. C. No. ____________

FLIGHT PATH COORDINATES
(Rectangular)

By ____________
Started ____________
Completed ____________

Form 62

Sheet ______ of ______

CONFIDENTIAL

N. U. P22E 1 Dec. '45

Time	$X_{i+1} - X_{i-1}$	$Y_{i+1} - Y_{i-1}$	$Z_{i+1} - Z_{i-1}$	$\tan \alpha_F$	α_F (Deg-Min)	$\cos \alpha_F$	$\frac{Z_{i+1} - Z_{i-1}}{Y_{i+1} - Y_{i-1}}$	$\tan \epsilon_F$	ϵ_F (Deg-Min)	
	From 62I	From 62J	From 62K	B/C	$\tan^{-1}$ E	cos F	D/C	G x H	$\tan^{-1}$ I	
A	B	C	D	E	F	G	H	I	J	

Flight No. ________
Attack No. ________
F. C. No. ________

FLIGHT PATH COORDINATES
(Spherical)

By ________
Started ________
Completed ________

Form 63

Sheet ______ of ______

CONFIDENTIAL

N.U. P22E 1 Dec. '45

Time	α_T (Deg-Min)	ε_T (Deg-Min)	α_Q (Deg-Min)	ε_Q (Deg-Min)	μ (Deg-Min)	ν (Deg-Min)	R* (Deg-Min)	P* (Deg-Min)
	From Graphs of 61E, F, G, H				Via GLOOK			
A	B	C	D	E	F	G	H	I

Flight No. ________
Attack No. ________
F. C. No. ________

ANGLES OF ATTACK, SKID, ROLL AND PITCH

By ________
Started ________
Completed ________
Sheet ____ of ____

Form 64

GLOSSARY

(see also Section A)

<u>ACTUAL CURVES</u>: the projections of the fighter's path relative to the air mass onto the XY-, YZ- and ZX-planes (see Fig. 1.03).

<u>AIR MASS AXES</u> (X Y' Z): a rectangular coordinate system fixed relative to the air mass and coinciding initially (at the beginning of an attack) with the stabilized axes (XYZ).

<u>PLANE OF ACTION</u>: the plane of the bomber's path and the fighter's position at the <u>beginning</u> of an attack (really the <u>initial</u> plane of action).

<u>RELATIVE CURVES</u>: the projections of the fighter's path relative to the bomber onto the XY-, YZ and ZX-plane (see Fig. 1.03).

<u>STABILIZED AXES</u> (XYZ): a rectangular coordinate system whose origin is at the center of the Martin forward crown-turret, whose XY-plane is horizontal, and whose positive Y-axis coincides with the bomber's flight.

<u>STABILIZED AZIMUTH</u> (α): with respect to stabilized axes (XYZ), the angle between the positive Y-axis and the projection of a direction from the origin onto the XY-plane.

<u>STABILIZED ELEVATION</u> (ε): with respect to stabilized axes (XYZ), the angle between the projection of a given direction from the origin onto the XY-plane and the direction itself.

NOTATION AND ABBREVIATIONS

(see also Section A)

α: stabilized azimuth.

ε: stabilized elevation.

ε': stabilized elevation if the fighter stays in the plane of action.

RP-63: an Army fighter, a modified Kingcobra, manufactured by Bell Aircraft Corporation.

t: time (seconds) since the start of an attack.

v_b: bomber's TAS.

XYZ: stabilized axes.

XY'Z: air mass axes.

x, y, z: rectangular coordinates of a point with respect to stabilized axes.

x, y', z: rectangular coordinates of a point with respect to air mass axes.

F.C. #36 N.U. P14E 8/22/45

Position of RP-63 with respect to forward crown-turret on PB4Y-2
Flight IC, Attack 2, Type a_2v_1

Time (sec)	Range (yards)	Stabilized Azimuth (deg-min)	Stabilized Elevation (deg-min)
0.0	825	246° 54'	7° 58'
0.2	812	245 51	7 55
0.4	799	244 49	7 51
0.6	786	243 48	7 45
0.8	773	242 45	7 39
1.0	761	241 42	7 35
1.2	748	240 40	7 26
1.4	734	239 38	7 20
1.6	720	238 33	7 13
1.8	707	237 24	7 06
2.0	694	236 17	6 56
2.2	682	235 09	6 52
2.4	670	234 00	6 45
2.6	659	232 52	6 39
2.8	648	231 45	6 30
3.0	637	230 36	6 24
3.2	627	229 31	6 15
3.4	616	228 24	6 07
3.6	605	227 15	5 58
3.8	595	226 06	5 50
4.0	585	224 56	5 40
4.2	575	223 48	5 32
4.4	566	222 41	5 22
4.6	557	221 33	5 12
4.8	548	220 24	5 02
5.0	539	219 18	4 52
5.2	530	218 12	4 42
5.4	522	217 09	4 31
5.6	514	216 05	4 21
5.8	506	215 01	4 10
6.0	497	213 59	4 00
6.2	489	212 55	3 49
6.4	481	211 54	3 38
6.6	474	210 53	3 27
6.8	467	209 52	3 16
7.0	459	208 53	3 04
7.2	452	207 54	2 52
7.4	445	206 55	2 40
7.6	437	206 00	2 28
7.8	430	205 07	2 16
8.0	424	204 15	2 04
8.2	417	203 24	1 52
8.4	410	202 33	1 40

Fig. 1.01. Sample fighter-position data.

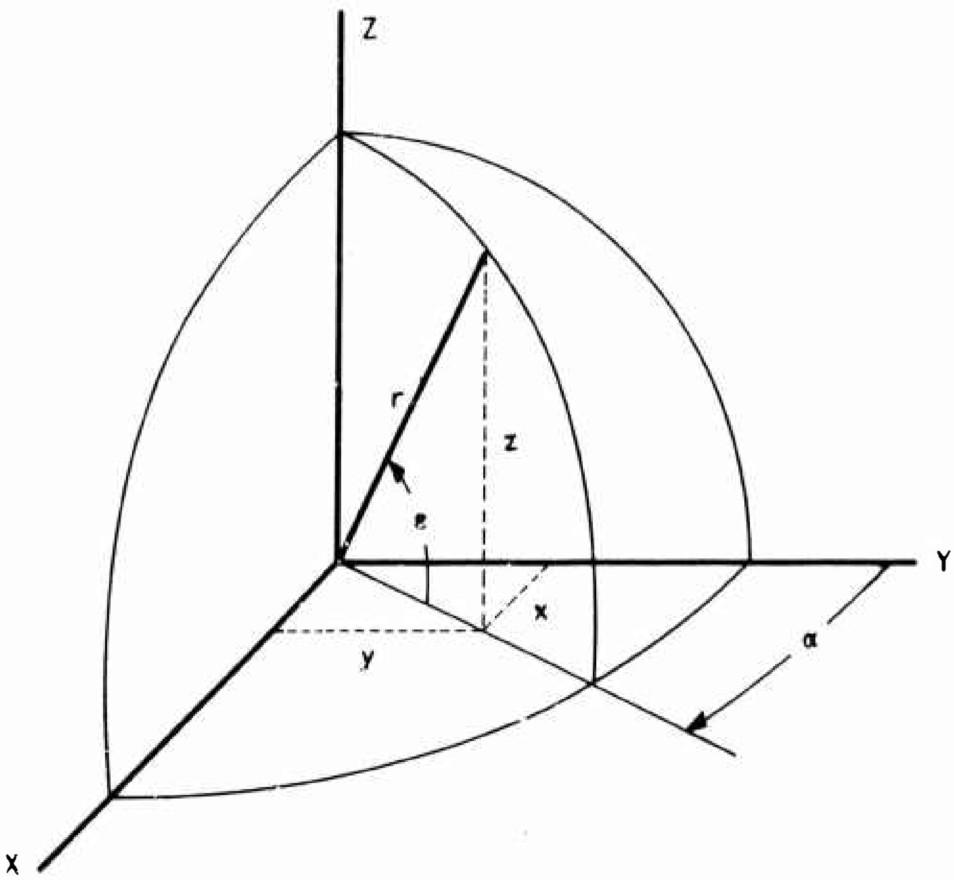
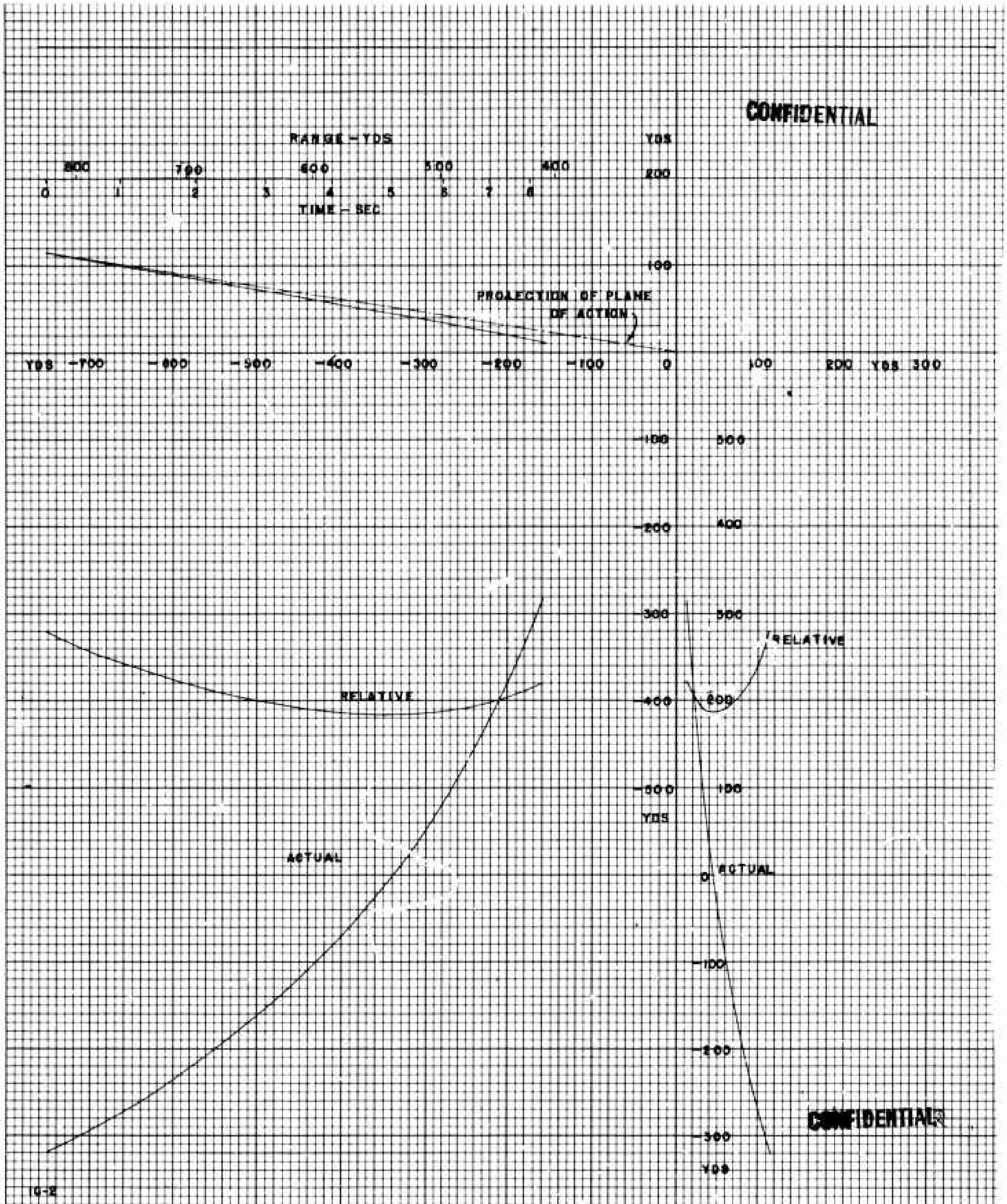


Fig. 1.02. Transformation of coordinates.



PROJECTIONS OF
RP-63 FLIGHT PATH
ATTACK TYPE $A_2 V_1$

FIG. 1.03. SAMPLE FINAL GRAPH

NU PI4E
8-24-46

RAZEL FILM
Forward crown-turret

1. Read scales at selected frame intervals and record gun Az. and El. w.r.t.* turret axes in Col 10-C and 10-D.**

2. Correct Cols 10-C and 10-D, recording in Cols 10-F and 10-G.

3. Plot these gun Az. and El. readings against frame numbers and corresponding time scale.

GUN-CAMERA FILM
Forward crown-turret

1. Using 35 mm projector and screen in Booth No. 2 plot target-points on screen.

2. Using CRADLE, obtain target Az. and El. readings w.r.t.* bomber axes centered at forward crown-turret.** Record in Cols 11-F and 11-G.

3. Plot these unstabilized target Az. and El. readings against frame numbers and corresponding time scale as a check on Step 2.

4. Record in Cols 24-C and 24-D the unstabilized target Az. and El. w.r.t.* turret axes.

1. F
2. (
3. I
4. F

5. Use GLOOK to compute stabil target Az. and El. w.r.t.* axes.

6. Plot and smooth these stabi target Az. and El. readings frame numbers and correspon time scale. Record smoothe data (intervals of 0.2 sec) Cols 25-C and 25-D.

7. Record in Cols 25-E, 25-F, 25-H the values of sin El., sin Az., and cos Az.

8. Compute the rectangular coo

$$X = r \cos \varepsilon \sin \alpha$$
$$Y = r \cos \varepsilon \cos \alpha$$
$$Z = r \sin \varepsilon$$

of the fighter w.r.t.* the Record in Cols 25-J, 25-K

9. Compute the actual coordina of the fighter w.r.t.* the $Y' = Y + V_0 t$, where $V_0 =$ b $t =$ time (Col 25-A).

---

* w.r.t. = with respect to

** These instructions assume that all films correspond frame by frame. If they do not, interpolation of the graphs will be required to "synchronize" data.

*** Supervisor will supply values of K_6 or K_7 depending on use of wing-lights or wing-marks.

GYRO FILM

1. Read dials at selected frame intervals and record yaw, pitch and roll angles in Cols 21-C, 21-D, and 21-E.

2. Correct yaw, pitch, and roll for initial gyro readings (see supervisor). Record in Cols 21-F, 21-G and 21-H.

3. If necessary (see supervisor) correct roll and yaw readings for use in GLOOK (using AMG-N Table I).

4. Plot pitch, roll, and yaw against frame numbers and corresponding time scale. Record in Cols 24-E, 24-F and 24-G at forward gun camera frame numbers.

GUN-CAMERA FILM
Rear crown-turret

A. Using 35 mm projector and screen in Booth No. 2, scale wing-lights and/or wing-marks, and record in Cols 11-B and 11-D.

B. Calculate range data from the formula:

$r = \frac{K_6}{s}$ or $\frac{K_7}{m}$ ***. Record

in Cols 11-C and 11-E.

C. Plot and smooth range data against frame numbers and corresponding time scale.

D. Read smoothed range data (intervals of 0.2 sec). Correct for the forward turret from the table provided. Record in Col 25-B.

ıpute stabilized
ɪl. w.r.t.* turret

these stabilized
ɪl. readings against
d corresponding
ord smoothed
of 0.2 sec), in
-D.

5-E, 25-F, 25-G and
of sin El., cos El.,
Az.

angular coordinates

sin α
cos α

w.r.t.* the bomber.
25-J, 25-K and 25-L.

ɪl coordinates X, Y', Z
,r.t.* the
ɪere V_o = elocity and
ɪ).

FLOW CHART XI

FLIGHT PATH OF FIGHTER RELATIVE TO BOMBER

Using the GLOOK for Roll, Yaw and Pitch Corrections, but

Neglecting: (1) Range-Correction of Fighter Aspect;

(2) Amount Fighter is off Gun-Camera's Optical Axis.

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2

28 December 1945

N. U. P14E 25 May '45

Frame Number	Film Dial Readings			Corrected Values			Time (Sec)
	Range Input (Feet)	Azimuth-2° (Deg - Min)	Elevation (Deg - Min)	Range Input (Yards)	Gun Azimuth (Deg-Min)	Gun Elevation (Deg - Min)	
A	B	C	D	E	F	G	H
RAZEL frame numbers		nearest min Gun Az. - 2° read from RAZEL film (See Sect. E on Film Reading)	nearest min Gun El. read from RAZEL film (See Sect. E on Film Reading)		nearest min Same as Col 10-C + 2° unless corrected (consult supervisor) P10-F: plot Col 10-F vs Col 10-H	nearest min Same as Col 10-D unless corrected (consult supervisor) P10-G: plot Col 10-G vs Col 10-H	nearest .001 sec Col 10-A converted to seconds

Flight No. __________
Attack No. __________
F. C. No. __________

RAZEL DATA
Martin forward crown-turret

By __________
Started __________
Completed __________

Form 10

Sheet ____ of ____

N. U. P14E 25 May '45

Frame Number	Wing Tip Lights K_1 = _____		Wing Marks K_2 = _____		Target Position		Time (Sec)
	Screen Length (Inches)	Range (Yards) $r = K_1/B$	Screen Length (Inches)	Range (Yards) $r = K_2/B$	Azimuth (Deg-Min)	Elevation (Deg-Min)	
A	B	C	D	E	F	G	H
Martin fwd gun-camera frame numbers	Measure target (Martin rear gun-camera) from wing-light to wing-light on screen (Range-Scaling Procedure, see Sect. F) nearest .01 inch	Range = $\frac{K_6}{\text{Col 11-B}}$ Use Martin rear range conversion table (or consult supervisor for value of K_6) P11-C: plot Col 11-C vs Col 11-H S11-C: draw in smooth curve nearest yard	Measure target (Martin rear gun-camera) from wing mark to wing mark on screen (Range-Scaling Procedure, see Sect. F) nearest .01 inch	Range = $\frac{K_7}{\text{Col 11-D}}$ Compute and plot ra[illegible] this column only if so directe[illegible] [illegible]visor nearest yard	Obtain target Az. (Martin fwd gun-camera) using CRADLE Problem Solution No. 2 P11-F: plot Col 11-F vs Col 11-H nearest min	Obtain target El. (Martin fwd gun-camera) using CRADLE Problem Solution No. 2 nearest min	Col 11-A converted to seconds nearest .001 sec

Flight No. ________
Attack No. ________
F. C. No. ________

RANGE AND TARGET POSITION
via CRADLE in Booth No. ___
Martin Turret

By ________
Started ________
Completed ________

Form 11

Sheet _____ of _____

CONFIDENTIAL

N.U. P14E 25 May '45

Gyro Camera Frame Number	Time (Sec)	Film Dial Readings Initial Readings			Corrected Values			GLOOK Pitch, $P + P_o$
		Yaw, Y'y (Deg-Min)	Pitch, P'z (Deg-Min)	Roll, R'z (Deg-Min)	Yaw, Yy (Deg-Min)	Pitch, Pz = P (Deg-Min)	Roll, Rz (Deg-Min)	(Deg-Min)
A	B	C	D	E	F	G	H	J
Gyro camera frame numbers	nearest .001 sec Col 21-A converted to seconds	nearest min	nearest min Readings from gyro film (see Sect. E on Film Reading)	nearest min	nearest min (Col 21-C) - (initial yaw reading) P21-F: plot Col 21-F vs Col 21-B	nearest min -(Col 21-D) P21-G: plot Col 21-G vs Col 21-B	nearest min (initial roll reading) - (Col 21-E) P21-H: plot Col 21-H vs Col 21-B	

Flight No. ________
Attack No. ________
F. C. No. ________

GYRO FILM DATA
Gyro Set No. 2
Flight Angle, P_o = ____

By ________
Started ________
Completed ________

Form 21

Sheet ____ of ____

CONFIDENTIAL

Gun Camera Frame Number	Time (Sec)	Unstabilized Fighter Position		Pitch, P (Deg-Min)	Roll, R (Deg-Min)	Yaw, Y (Deg-Min)	Stabilized Fighter Position	
		Azimuth (Deg-Min)	Elevation (Deg-Min)				Azimuth (Deg-Min)	Elevation (Deg-Min)
A	B	C	D	E	F	G	H	J
Martin fwd gun camera frame numbers	Col 24-A converted to seconds nearest .001 sec	nearest min	nearest min	Read from P21-G at times in Col 24-B nearest min	Read from P21-H at times in Col 24-B nearest min	Read from P21-F at times in Col 24-B nearest min	Stabilized target Az. obtained by GLOOK Problem Solution No. 3 P24-H: plot Col 24-H vs Col 24-B S24-H: draw in smooth curve nearest min	Stabilized target El. obtained by GLOOK Problem Solution No. 3 P24-J: plot Col 24-J vs Col 24-B S24-J: draw in smooth curve nearest min
		Target Az. and El. at Martin fwd crown-turret (same as Cols 11-F and 11-G)						

Flight No. ________
Attack No. ________
F. C. No. ________

STABILIZATION
OF
COORDINATES

Martin turret

By ________
Started ________
Completed ________

Form 24

Sheet ______ of ______

CONFIDENTIAL

N. U. P14E 1 Aug. 45

Time (Sec)	Smoothed Stabilized Fighter Position			sin ε	cos ε	sin α	cos α	Fighter Relative to bomber		
	Range r (Yds)	Azimuth α Deg-Min	Elevation ε (Deg-Min)					Z (Yds)	Y (Yds)	X (Yds)
A	B	C	D	E	F	G	H	J = BE	K = BFH	L = BFG
List time every 0.2's second	Read from S11-C (rear) at times in Col 25-A and correct to Fwd by Rear to Fwd Table (using Cols 25-C and 25-D to find Θ) nearest yard	Read from S24-H at times in Col 25-A nearest min	Read from S24-J at times in Col 25-A nearest min	Sine (Col 25-D) nearest .001	Cosine (Col 25-D) nearest .001	Sine (Col 25-C) nearest .001	Cosine (Col 25-C) nearest .001	(Col 25-B) x (Col 25-E) nearest yard	(Col 25-B) x (Col 25-F) x (Col 25-H) nearest yard	(Col 25-B) x (Col 25-F) x (Col 25-G) nearest yard

Flight No. ________
Attack No. ________
F. C. No. ________

RECTANGULAR COORDINATES

Martin Fwd Turret

By ________
Started ________
Completed ________

Form 25

Sheet ____ of ____

CONFIDENTIAL