Fairchild Analyzer[*]

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THE Fairchild Flight Analyzer illustrated in Figure 1 is a photogrammetric instrument which freezes the space-time record of a plane, or other target moving in a path parallel to the focal plane of the analyzer, as a series of photographs of the target on a single plate. In addition to recording vertical and horizontal movement, the analyzer records the time at each instant of exposure by photographing on the same plate the face of a timer capable of measuring to 1/1,000 of a second. The recording of time increments permits the calcution of velocity and acceleration characteristics. A single analyzer will yield a two-dimensional graph. The simultaneous use of two or more analyzers, however to yield several two-dimensional projected trajectories, will permit the construction, by known photogrammetric techniques, of a three-dimensional trajectory of the moving object.

FIG. 1. The Fairchild Model IV A Analyzer with its portable power supply and transmitter case.

The accuracy of the data recorded by the flight analyzer is fully comparable to accuracies achieved by the best cinetheodolite instruments commonly used for this type of recording. The flight analyzer, however, differs radically from other instruments in several important aspects, and its advantages in many applications derive from these unique features.

A test flight recorded by the analyzer appears as 58 strip exposures on a single 8×10 plate, each strip containing a single image of the target. The use of a single plate rather than many feet of motion picture film results in a drastic reduction of time, not only in the processing of the film, but more importantly, in the man hours of engineering needed to compute and assess the recorded data. The basic space curve is instantly available on an analyzer record without time-consuming frame-by-frame projection and data interpolation. An analyzer record makes possible selecting the important portion of the data without having to work up an entire run from hundreds of individual frames. In many tests, comparisons can be made from two or more analyzer record plates with virtually no calculations. Flight analyzer records save much of the valuable time often wasted in checking back over records to assess "wild

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[*] This is one of the papers included in the Report of the Reporter for U.S.A. Commission V of the International Society of Photogrammetry.

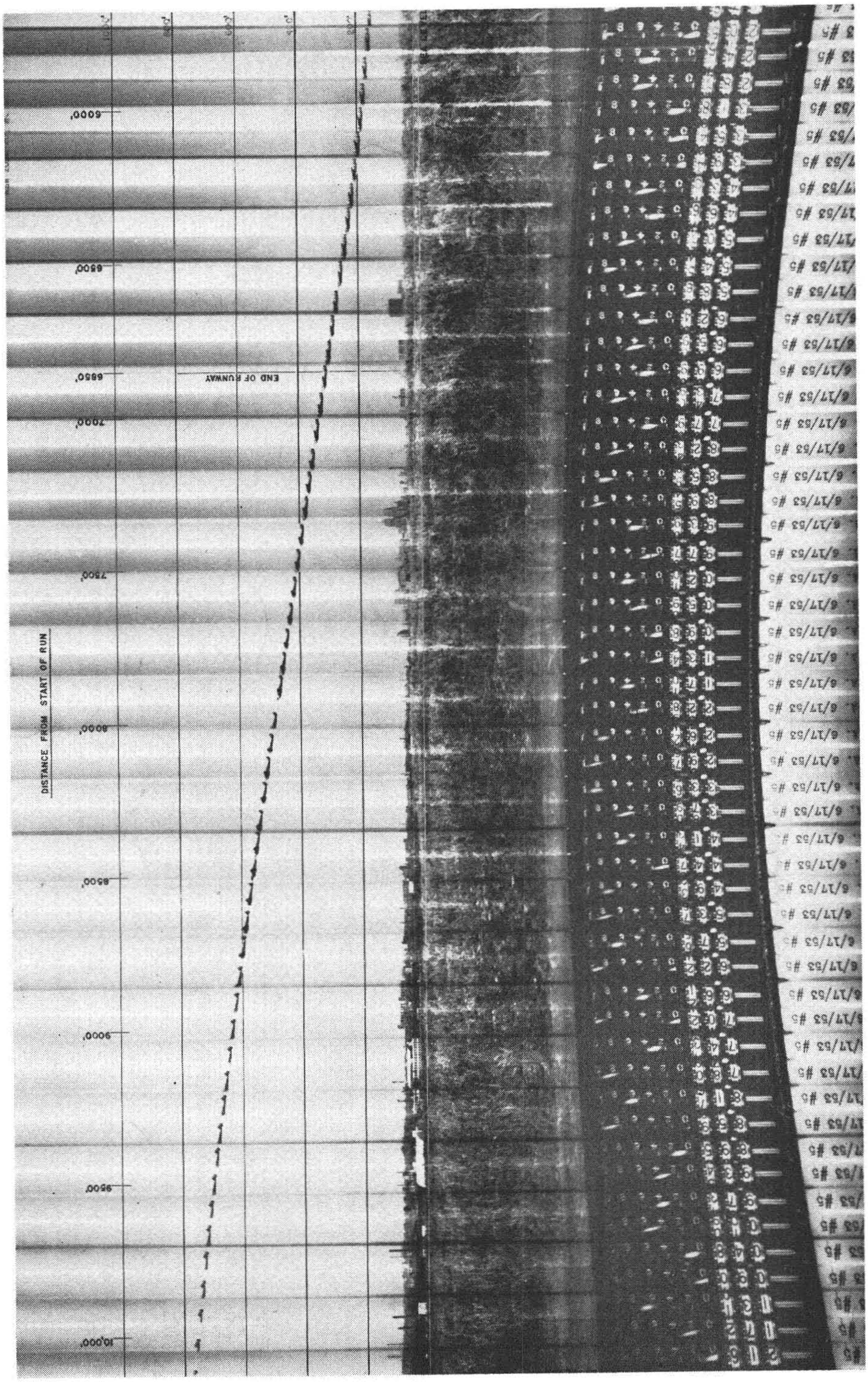


FIG. 2. Fairchild Flight Analyzer record of L749 Constellation takeoff.

points" and find mistakes in reading, or to note wrong figures. Furthermore a number of enlargements can be made from an analyzer plate to permit simultaneous photogrammetric examination and calculation by several men, an important factor when speed in data computation of different characteristics is necessary.

A typical record is shown in Figure 2 where scale lines have been drawn directly on the photographic enlargement to emphasize the concept of a true and constant scale throughout the run; this flight was recorded from 3,500 feet, embraces a total flight of 4,900 feet and the velocity data shows a maximum scatter of one knot which with its random disposition will correspond to data reliable to ±1/3 knot. See Figure 3.

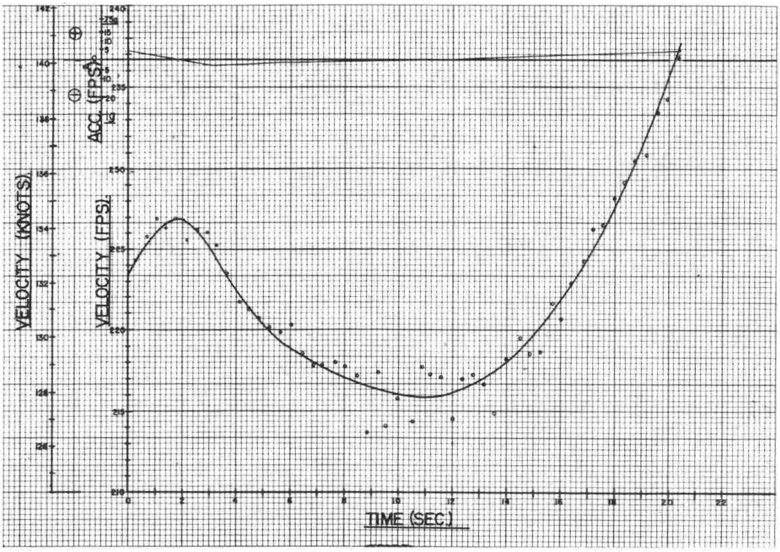
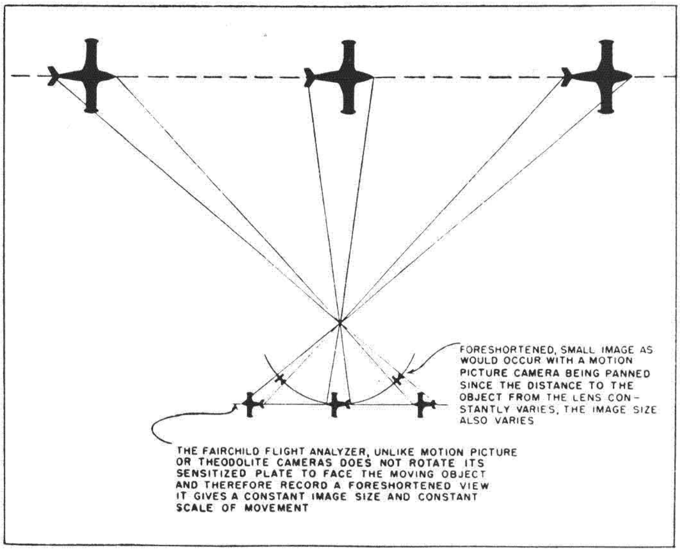


FIG. 3. Velocity and acceleration data taken from record in Figure 2.

A recent classified test offers a good demonstration of the time-saving capabilities of the flight analyzer. Within two hours after the run the observers were in possession of data showing the point and the altitude where the first phenomenon occurred, the maximum altitude reached in the trajectory, and the total trajectory down range. This information was obtained in less than half the time that would normally have been required merely to complete the processing of the 35 mm motion picture film more commonly used in recording such a flight. It is conservatively estimated that the total time saved in this test was a full day.

In another classified test, in which the missile failed, a complete history of the failure—frozen on a single photographic plate—was in the hands of the observers within three hours after the run and was immediately flown back to the manufacturer's plant where the engineers and designers had the whole story indisputably staged for them as well or better than if they had personally observed it.

Although the analyzer tracks the target optically, the parallel relationship between the photographic plate and the flight course is unchanged. This is shown in principle in Figure 4. There is, therefore, no image distortion because of foreshortening, or change in image size, because of the greater distance between the target and the camera at the beginning and end of the recorded flight course. The images on the plate appear essentially as if the camera were moving in step with the target and at the same rate of speed. The instrument is, in effect, a coordinate plotter, and the resulting target-plotted curve is an accurate graph, with no possibility of error due to plotting, or reference to fiducial or other reference lines or bases. As in the case of an aerial photograph, all linear distances on an analyzer record can be measured by a single scale. Some data, such as angular attitude, can be measured directly without the use of azimuth or angular computations, or trigonometric corrections. The capture of time and space data on the plate, in constant size and scale, simplifies tracking the target because tracking errors cannot displace the true position of the vehicle or missile. The accuracy of the record will not be destroyed even if the target is missed entirely and one exposure strip is blank, because the adjacent images will carry the line accurately over the gap.



FORESHORTENED, SMALL IMAGE AS WOULD OCCUR WITH A MOTION PICTURE CAMERA BEING PANNED SINCE THE DISTANCE TO THE OBJECT FROM THE LENS CONSTANTLY VARIES, THE IMAGE SIZE ALSO VARIES

THE FAIRCHILD FLIGHT ANALYZER, UNLIKE MOTION PICTURE OR THEODOLITE CAMERAS DOES NOT ROTATE ITS SENSITIZED PLATE TO FACE THE MOVING OBJECT AND THEREFORE RECORD A FORESHORTENED VIEW IT GIVES A CONSTANT IMAGE SIZE AND CONSTANT SCALE OF MOVEMENT

FIG. 4. The parallel relationship.

The analyzer records the target's position each time it has *moved a fixed distance*, and not in accordance with predetermined time intervals. This results in equal spacing of points along the length of the graph, as opposed to a clumping of points at the slow-speed end of a run and a scarcity of points along the high-speed portions, as would be the case if the analyzer were time-controlled.

Since all analyzer records are of constant scale and constant image size, it is possible to station a bank of these instruments along a flight course or runway (Figure 5), and mosaic the individual plates thus obtained into a single long record covering a flight range far beyond the limitations of any individual camera. The practicability of coupling one flight analyzer to another, or to other types of recording devices, has resulted in the evolution of a flight-recording system capable of great flexibility and scope.

The mobility and ease of operation of the flight analyzer adds immeasurably to its utility. This is particularly true in field testing, where such factors as wind shifts, delays due to mechanical failure of the vehicle, and shifting light conditions frequently demand the moving of the instruments during the test period. Provided the base points for aligning the instrument have previously been surveyed, a flight analyzer can be set up ready for operation in about ten minutes. The installation can be dismantled and repacked in cases ready for transportation in half that time.

Why the Flight Analyzer Was Developed

The flight analyzer was conceived as a result of the failure of a program of research on Thrust Developed During Takeoff Run. The reasons for the failure were twofold: the high cost of data reduction exhausted the project funds before any goals were reached; and the scatter of second derivative data, acceleration, was so extensive as to cast grave doubts on the reliability of any conclusions reached from these data.

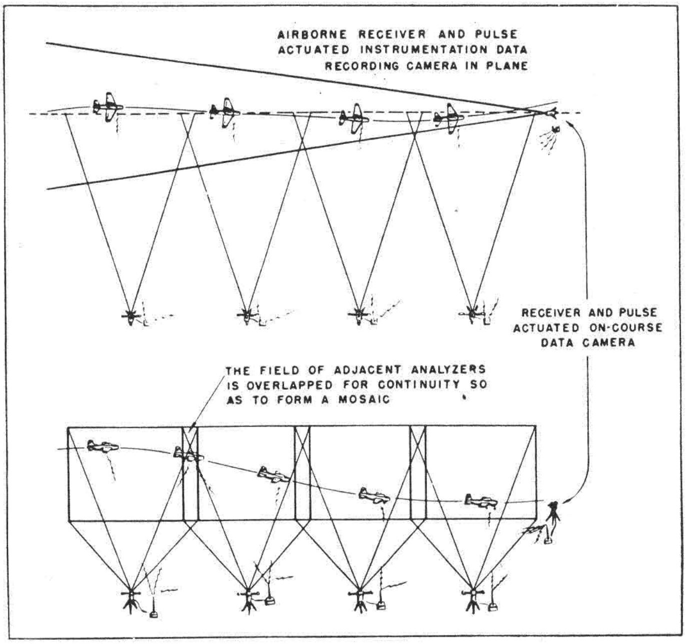


FIG. 5. Multiple Analyzer set up covering a wide field at close range.

When, as Chairman of the Board of the Fairchild Engine and Airplane Corporation, Sherman M. Fairchild found it advisable to terminate this project some thirteen years ago, the lack of success prompted him to undertake an evaluation of the flight test instrumentation systems then available for such tests. Drawing on his own extensive background in aerial photography and photogrammetrics, and on the accumulated experience of the organizations with which he had been connected for many years, Mr. Fairchild concluded that a need existed for a new approach to the problem of flight recording which would overcome the drawbacks inherent in existing flight recording instruments.

The motion picture camera or its big brother, the photo-theodolite, the prevalent basic tools, impose certain incontrovertible difficulties, whether used in a fixed grid camera system or in pure azimuth-ordinate recording. A screen grid system is a permanent installation and, because the camera is panned, it always records the target as a foreshortened image moving with a variable scale. Furthermore the recording accuracy falls off sharply on either side of the center of the picture range. Hence mobility, improved over-all accuracy, and constant scale and image size were among the first requirements of any new recording instrument.

Azimuth theodolite cameras exhibit their greatest application in high altitude work, where the distances to be covered are great and the extremely long focal length lenses can track a target even at altitudes of 200 miles. Such equipment was not suitable for closeup work where high angular tracking rates are found and moreover, their high initial cost and subsequent expensive maintenance made them impractical for the average flight test group. Furthermore tracking a theodolite camera generally involves the use of two skilled operators, because the instrument must be tracked vertically as well as horizontally. And since it is impossible to keep the target centered in the reticle or within the fiducial marks, a substantial amount of calculation is necessary to compute a target's deviation from its true position. Thus other advantageous features of a new flight test instrument were also envisioned: simplified one-directional tracking, and the elimination of target-displacement calculations. Still another drawback of the cine-theodolite camera is the fact that it records a series of individual frames which must be read out frame by frame, frequently reading many feet of film before locating the area of critical data being sought. Therefore one further desirable feature was added to those demanded of a new flight test tool: the ability to produce a frozen flight trajectory record on a single large photograph, or a series of records which could easily be made into a constant scale mosaic for subsequent examination, and most important of all *the reduction of the work and time required to reduce the data from these records.*

It is obvious then that the conception of the Flight Analyzer was the result of certain definite needs in the field of flight test and which seemed best solved using a photogrammetric approach. By keeping these needs always in view during its long development program, the new tool that was evolved fulfilled its requirements and is consequently finding a wide and constantly expanding field of utility.

How the Analyzer Operates

The basic principles of operation of the flight analyzer are: 1) that it tracks a moving object without a camera rotation (Figure 4), 2) that it photographs the target in motion in a series of strips on a single photographic plate, and 3) that the operation of the shutter is controlled by target motion and not by elapsed time.

The use of a wide-angle lens makes it possible to track a moving object and cover a large range without panning the camera. Tracking is accomplished through a binocular sighting device which aligns a traverse-moving focal-plane shutter with the position of the object in space. This mechanism yields a series of vertical strip exposures on the plate, producing in miniature an exact reproduction of the target flight, through the multiple images recorded.

The triggering and actuation of the shutter is automatic. When the focal plane shutter has progressed 0.147 inch laterally across the plate the electrical shutter is tripped, exposing a vertical strip of that width. As the next position is reached the shutter is automatically tripped again. A timing device attached to the tracking mechanism moves with it and is kept in line with the strip to be recorded. Each time the shutter trips, the face of the timer is also photographed, and its image is superimposed on the base of the strip to provide correlated time-sequence data.

The incorporation of these features into the instrument involved special, and in some instances novel, design of optical, electrical and mechanical components.

Optical Components

The various models of flight analyzers are equipped with lenses particularly adapted to their requirements. The Model IV uses a coated element, 93 degree field, wide-angle Bausch & Lomb 6 inch f:6.3. Metrogon lens. The Model VI analyzer uses a coated element 12 inch f:5 Eastman Kodak lens. The Model VII-B analyzer uses a 24 inch Bausch & Lomb Aero Tessar.

Since the targets being photographed are generally at a great distance, the amount of light reflected from the object is of a very low order. Also because of the distances involved, and because the background is usually extremely bright and tends to diminish the apparent density of the target, the contrast ratio is very low. These factors, plus the fact that the target background may be the earth at one phase of its flight and bright sky at another result in a sharp loss of the resolving power of the lens. Consequently the optical system of the flight analyzer has been modified to overcome these generally poor photographic conditions.

The general attack on the problem has been along the line of reducing flare lighting to a minimum to maintain the contrast level as high as possible. Because only a small portion of the negative is exposed at one time, it was possible to use a traveling hood equipped with knife-edge baffles and masked by a curtain. The hooding system successfully excludes light from all areas except the narrow vertical field to be recorded, and good records have been made under very adverse conditions. In one instance an aircraft flight was recorded successfully in a freezing sleet storm, with the light reading well below a Weston rating of 50.

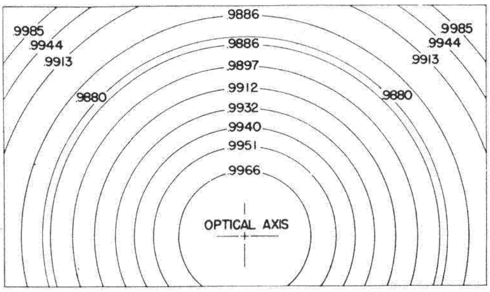


FIG. 6. Distortion overlay chart.

The fact that short exposure times are vital to the recording of rapidly moving targets has led to some lens modification. The minus blue filter and vignetted spatter filter, ordinarily incorporated in the Metrogon lens to reduce flaring in the center of the negative, cuts the effective lens speed by 4.5 stops. To reduce this loss of speed, a clear vignette, with a speed loss of only 2 stops, was substituted.

The Shutter

The focal-plane shutter is composed of a slotted cylindrical blade oscillating behind a segment of a cylindrical surface incorporating a masking aperture. On either side of the shutter mechanism, and attached to it, are opaque curtains that extend to spring-loaded rollers on each side of the camera body. These curtains move with the shutter, keeping the plate constantly covered except for that portion which lies directly behind the shutter mask opening.

As the shutter moves across the masking aperture it subjects the picture area of the film to an effective exposure of 1/3,000th second. At the same time a narrower slot in the same blade permits photographing the timer face at an effective speed of 1/6,000th second.

The shutter oscillates through an angle of approximately 90° (45° on either side of the mid-shutter position). The mechanism is driven through a yoke by a pair of matched and diametrically opposed solenoids. Although the shutter blade must move in the direction of the tracking in one phase of its operation, its speed is so great that no relative shutter motion is visible on the photographic image.

The pulses that energize each solenoid are received through a cam-operated switching device. The cam is rotated through a train of gears off a rack on the cross-support bar. As the shutter moves laterally along this bar the gear train rotates the cam which fires the solenoids alternately, flipping the shutter blade back and forth. The gearing is designed to make an exposure each time the shutter has moved laterally 0.147 inch.

The shutter is capable of being random pulsed up to 40 times per second without misfiring. It can freeze target motion at speeds up to 600 MPH. Its maximum speed is 60 frames per second. Although it occasionally misfires at this maximum speed—a rate equivalent to tracking at 72 degrees per second—misfiring is so infrequent that the record will contain more than a sufficient number of points to establish a true curve.

The electric impulse that fires the shutter generates a square wave pulse each time the shutter is tripped. This wave pulse can be beamed out through radio linkage transmitters to pulse other data-recording apparatus in synchronism.

Glass Plates

The use of glass plates in the analyzer, rather than the more common film, is dictated primarily by accuracy requirements. Glass plates can be positioned and maintained in accurate focal plane registry without the vacuum back necessary to keep flexible film stock perfectly flat and which would require extensive power to draw down in the field. Furthermore glass plates yield a stable record, immune to changes in humidity, and essentially immune to changes in temperature. Still another advantage of glass plates is their rapid drying rate owing to the thinness of the emulsion they carry.

Plate Holders

The flight analyzer does not use commercial plate holders because it was found that they varied from 0.005 to 0.020 of an inch in positioning the plate in the focal plane. The precision one-piece metal plate holders used in the analyzer are hand-lapped to a tolerance of plus or minus 0.001 inch.

Photographic Techniques

Lenses generally yield their highest definition 2 stops below maximum opening. With the Metrogon this setting is f:11. The clear vignette effectively reduces this to f:22. It is therefore necessary to use the fastest film obtainable to achieve maximum photographic quality at the very high shutter speeds used in the flight analyzer. The film being used at present is Eastman Kodak Tri X-B emulsion, with a rated speed of 160 ASA daylight. In actual practice, however, this emulsion is exposed at an approximate rating of 2000 ASA and, by overdevelopment, is forced to yield negatives of excellent quality. It is also possible, under most field light conditions, to leave the diaphragm setting at f:11, the best position for resolution, and to compensate for light variation entirely by altering the time of development. The developer which has proven best is the old reliable Kodak D-19.

The following values indicate the range of this technique. For a normal reflected daylight reading of Weston 200 off the palm of the hand, the film should be developed 15 or 16 minutes. at 68°F. With a Weston reading of 100, the development time can be increased to 18 minutes. With readings below 100 Weston the development time can be increased to a maximum of 21 minutes, at which point the fog level begins to rise noticeably. With Weston readings of 800 or over, the development time should be kept at 10 or 11 minutes. Of course, if the light reading falls to 75 Weston, the diaphragm may be opened to f:8, and if the reading is as low as Weston 50 it is generally necessary to use an opening of f:6.3.

THE TIMER

The timer used in the analyzer includes a three-wheel digital counter and a rotating drum marked with ten helical lines visible through a slit, a lamp to illuminate the timer face, and a constant speed motor to drive the mechanism.

The digital counter may be read directly in seconds, tenths of seconds, and hundredths of seconds. Still smaller time divisions are recorded by the rotating helical lines, visible through the viewing slit as white dashes which move from the bottom to the top of the slot in 0.01 second. Markings behind the slit make it easy to read to thousandths of a second because the 1/6,000th second exposure freezes the dash and yields an image of great clarity.

The unit is driven by a 6-volt D.C. motor, accurately controlled by a vibrating tuned reed to a speed of 900 R.P.M.

TRACKING MECHANISM

Tracking is accomplished by manually swinging the crossbar that extends across the top of the camera parallel to the focal plane. Tracking with the analyzer has been facilitated by the incorporation of an automatic pick-up and release mechanism that enables the operator to track through 74 degrees before the shutter mechanism becomes operative, and to track through a similar angular distance after the shutter has crossed the plate and has ceased to operate. This lead-in and follow-out tracking of the target before and after recording permits the operator to find the target and to accommodate his tracking speed to it before any exposures are made. The pick-up and release mechanism operates in either direction, from left to right, or from right to left.

Another device calculated to aid in tracking consists of the weights attached to the tracking arms. The use of inertia weights was decided upon after experimentation with other inertia devices, such as flywheels and friction slip clutches, because inertia weights offered the most flexible and versatile method of smoothing out the tracking process. If a particular test requires very rapid tracking acceleration, for example, the weights can be omitted entirely or smaller weights used instead of heavy ones. Similarly it is possible to use shorter tracking arms for certain types of tests.

The conversion of the rotary motion of the tracking head into the linear motion of the traversing shutter is done by the use of a tangent bar, slotted on its rearward end to engage a pin that actuates the shutter-moving mechanism. The tangent bar moves in an arc with the tracking head; and as this bar moves, the pin in its slot (and the entire shutter mechanism) moves laterally in a path parallel to the focal plane. The tangent bar and the slotted pin mechanically perform the trigonometric corrections necessary to convert angular motion to constant scale linear motion. Thus the progression of images on an analyzer plate form an accurate reproduction of the forward motion of the target, and mathematical trigonometric correction of the values on the plate is unnecessary.

TRACKING OPTICAL SYSTEM

The target is tracked visually through 6×30 binoculars (10×50 on the Model VI analyzer) equipped with a reticle showing two vertical lines representing the camera's horizontal field of acceptance. A binocular viewing instrument was chosen in preference to the monocular type because it was found that less eye fatigue resulted when both eyes received the same amount of light. The binoculars accept a larger field than is demarcated by the reticle, which helps the operator find the target easily and facilitates tracking to keep the target within the lines.

The binoculars have an acceptance range of about 7.1 degrees, about 1/10th that of the vertical acceptance range of the camera. Therefore the binoculars are pivoted to provide a vertical binocular movement ranging from 10 degrees below the horizon to 40 degrees above. The binocular support is spring loaded with the pressure exerted rearward. The operator merely presses his eyes against the rubber eyecups to depress the instrument or raises his head to allow it to increase its angle of elevation.

Alignment Components

The ordinary Analyzer is equipped with an all-way spirit level which permits levelling accuracy to within 2 minutes of a degree. This is sufficient for most testing operations since the camera is provided with two fiducial markers, one on each side of the plate, each projecting a symmetric eight dot pattern. Six larger dots form two adjacent squares and aid in finding the small dot centered in each square. This method of fiducial marking provides very accurate determination of the orientation of the glass plate within the holder, and also in reference to the camera itself. A line drawn through the markers passes through the axis of the optics of each individual Analyzer, and permits easy correction for slight errors in horizontal levelling. The ballistics Analyzers are equipped with ground steel levelling pads to accommodate 15-second precision levels for more accurate horizontal alignment.

The alignment of the Analyzer to the flight path is accomplished by the use of a calibrated telescope optically aligned with the lens of the Analyzer. By sighting this telescope at a pre-surveyed target along the flight path it is possible to align the Analyzer to within one minute of a degree perpendicular to the flight path. The ballistics Analyzer is equipped with a second bore-sighting telescope to provide a right-angle bore-sighting line. This permits accurate alignment of two Analyzers set up on the same side of the flight path.

Power Requirements

The flight Analyzer is self-powered by six 6-volt dry cells, Burgess 4F-4H or equivalent, electrically and dimensionally. The pilot and the timing display unit lights and the shutter solenoids operate on 36 volts. The timer drive motor operates on 6 volts.

What the Flight Analyzer can do

The flight Analyzer was conceived, as previously noted, out of fairly specific photogrammetric needs. Before the early test models were functioning smoothly, however, it became apparent that the envisioned scope of utility was far too narrow. Modifications of the Analyzer itself, and the design of auxiliary equipment became collateral developments as new uses for the instrument were evolved by photogrammetrists. Some of the results of these developments are mentioned below.

High Trajectory Data Recording

It was originally believed that trajectories to be recorded by the Analyzer would generally be fairly flat and not exceeding 30 degrees. This limit would encompass of data recording the approach glide slope paths, altimeter calibrations, air speed calibration and other similar types of maneuvers. This limitation was soon recognized as erroneous. Observation of helicopter phenomena demanded the recording of trajectories much steeper, sometimes as high as 90 degrees, and early Analyzers were unable to record these because they demanded a lateral tracking motion to actuate the shutter.

This problem was solved by the design of a tilt head bracket which permitted the camera to be tilted, and a bracket which allows mounting the instrument on its side so that the strips on the plate are horizontal instead of vertical. Coincident with the development of these accessories, the shutter was improved so that it would operate as accurately and rapidly in a tilted or horizontal position as it did in its normal vertical position (Figure 7).

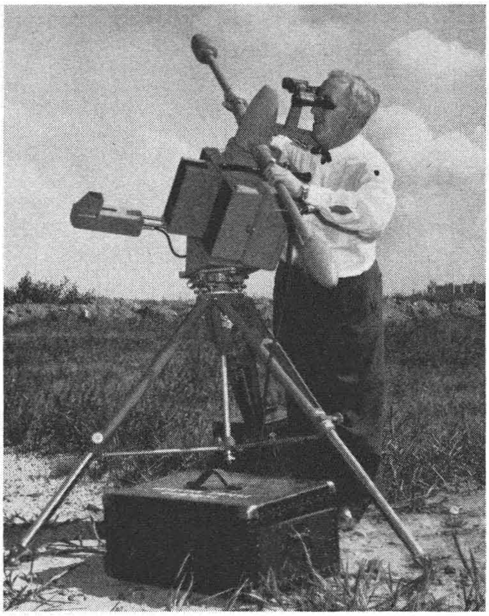


FIG. 7. Author tracking with a Model IV A Flight Analyzer on tilting bracket.

THREE DIMENSIONAL SPACE DETERMINATION BY USE OF THE FLIGHT ANALYZER

Once the principles of Flight Analyzer recording are understood, the question arises as to what methods exist for obtaining accurate space positional data when the flight course *is neither straight nor parallel* to the Analyzer focal plane as oriented. Or to put it in simple terms, how can Flight Analyzers be used for three dimensional space trajectories?

Fortunately there are several approaches. It will be remembered that the images on the recorded projection of the trajectory have known time histories or records, but since it is necessary to use at least *two* Analyzers for three-dimensional recording, there is no relation whatever between the points on the individual records or their time history. (If desired, it is possible to "slave" one Analyzer to another, but that is another story.)

Three possible methods will be examined by referring to Figures 8 and 9. In Fig. 8 two Analyzers are set on opposite sides of a test site and are aligned on each other. Midway between them a reference plane GHIJ can be imaged. The Analyzer trajectory records will be reproductions of the trajectory of the aircraft as projected from *A* and *B* on this plane. These will coincide in only one case; where the aircraft flies in this plane of symmetry. For all other courses the two projected trajectories will be separated vertically. For example, when the aircraft is at *P*, Analyzer *A* will see it at *F* and Analyzer *B* will see it at *E*. Now referring to the small view, which is an end projection of the plane of symmetry, it can be seen that the vertical projection of the spacing between the two intercept points in the plane of symmetry is sufficient to calculate its displacement from this plane and the offset scale could be shifted for Analyzer *B*(*M*) to the new offset (*M*–*O*) and the space position may then be determined.

One assumption in the previous description—this was made for simplicity—

was that both Analyzers were taking records simultaneously. This is, of course, not true, as in practice each Analyzer is being tracked independently and there is no direct relation between the times of exposure. To overcome this requires only a realization that, if it is possible to locate on the projected trajectory of Analyzer *B* a point which would correspond to an image on the record of Analyzer *A*, the problem returns to the one previously described. By examining the sighting rays *BR* and *AQ* on the airplane image just to the right of *P*, it is realized that together with the base line *AB* they form a plane, and, of course, if the pictures were simultaneously recorded their rays must lie in such a plane.

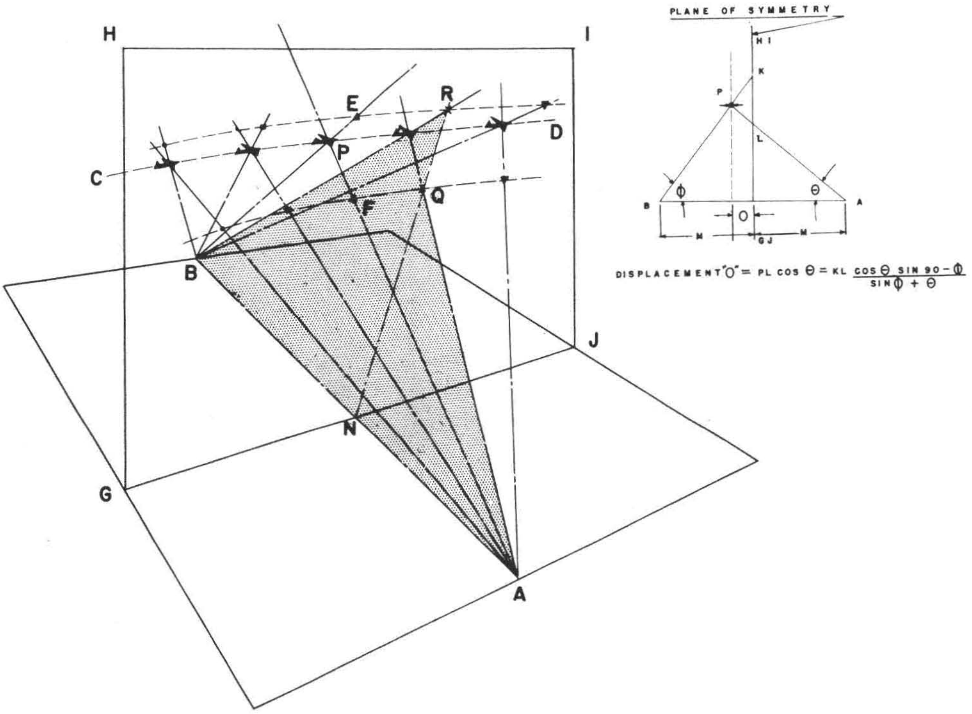


FIG. 8.

Now suppose the location of point *R* is not known but had to be found. If mentally a line from point *N* is drawn in the plane of symmetry and on the base line through *Q*, and is projected on to the other projected trajectory *ER*, it would intersect at *R* which is the position of the target on this trajectory at the same instant as the record point *Q* was recorded.

In practice then, one would make such a determination and then obtain *KL* by subtracting the vertical ordinates of these two points and compute *O*.

A second method uses two Analyzers set up on the same side of the flight course along a base line *A–B* (See Figure 9). Here the aircraft is flying a climbing curved course such as a missile might take on launching, *OG* and *OF* are the projections on a vertical plane *OCDE* as recorded by Analyzers *A* and *B* which are located on a base line parallel to plane *OCDE* and set *R* feet apart and $M+L$ feet from the base of the reference plane *OE*. It is again apparent that the two operators will track individually and the missile images will not be recorded simultaneously by both Analyzers. The condition necessary for two images to be recorded simultaneously is that the image on the trajectory trace *OF* lies

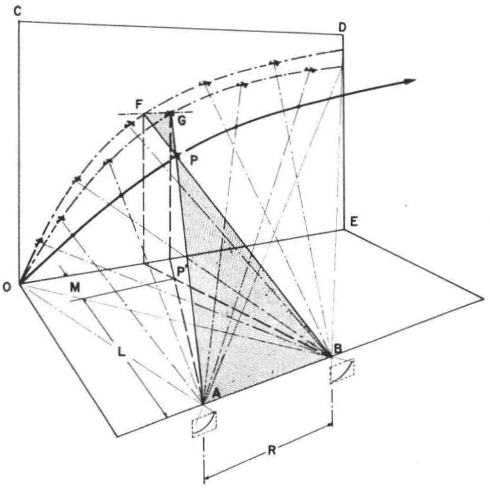


FIG. 9.

in a plane established by the base line and the line of sight rays *AP* and *BD*. It can be seen by the shading that extending this plane until it cuts the vertical plane *OCDE* will result in a horizontal trace in that plane (parallel to *AM*).

If one then takes *any* image on the trajectory trace *OG* (for which the time history is known), and extends a horizontal line until it cuts the other trajectory trace *OF*, this intersection will establish the place on *OF* where the missile would have been at the same instant. From here on it is apparent that the horizontal displacement of the two curves *OF* and *OG* is a measure of the distance which the missile is offset from the reference plane. To compute this offset M one can use the simple geometric relation of similar triangles PFG and PAB; $M:L = FG:AB$, or $M = (L \times FG)/R$. But, since offset $= M + L$ or $L =$ offset $- M$, the final relation is:

$$M = \text{offset} \times \frac{FG}{R + FG}$$

Once L is known, the scale for either Analyzer record is established, and all three coordinates in space may be found.

One variant of this second method covers the case where the path is horizontal, and as a result both trajectory traces are horizontal. In this situation it is impossible to work with the horizontal displacement of the two curves and it is necessary to use two Analyzers set up on a base line perpendicular to the reference plane. This case then becomes very similar to the situation presented in the first method, and is in reality a variant of it.

DETERMINATION OF DEVIATION FROM FLIGHT PATH

The third method is more applicable to flight trajectories where the deviation from a planned reference plane is slight, such as would be the case in an *ILS* approach, a high speed pass, take-off, or in landing tests. Although the other methods may be used, this method does not require the use of two or more Analyzers. In this method a pulse-actuated 35 mm. camera provided with a reticle plate which superimposes a cross hair on each frame is used. This camera is located either facing down-range or up-range and boresighted along the planned flight path. Its site must be accurately established with respect to the Flight Analyzer position. A radio interlink beams a pulse each time the Analyzer records to a receiver which in turn pulses the down-range camera taking one frame for each image on the Analyzer record. The position of the aircraft from the down-range camera is established by each image on the Analyzer record so the range of the pulsed camera is known for each frame, and deviations from the cross hairs may thus be translated into feet and the offset value of the Analyzer record established. Generally, in this method, only four or five points are necessary to establish the deviation from true course, so it is not as laborious as it might appear to be. If the flight course is at a slight angle instead of parallel, the Analyzer record may then be rectified for that angle by usual photogrammetric methods.

One last point on this third method should be mentioned. Mid-shutter position on the Flight Analyzer occurs between 3 and 10 milliseconds from the front of the pulse wave beamed out. The time delay through the radio linkage (chiefly in the relays) is 10 milliseconds. Therefore the command signal for the pulse camera is very close to being in synchronization with the Analyzer. Any pulse actuated camera will require some small time period for response, and thus lag the Analyzer by that amount. Except in violent maneuvers, however, this would be so slight as to be ignored in most cases.

SLAVE-MASTER ANALYZER SET-UP

For some data-recording work it is advantageous to slave a second analyzer to the first in such a way that the shutter of the second is fired not by its lateral tracking motion, but by pulses from the shutter of the master Analyzer. This results in absolutely synchronous photographs of the space position of the target, and greatly simplifies the data-reduction problem. Even if the slave instrument is not tracked exactly with the master, it will record exactly the same number of images. The pictorial value of the plate might deteriorate somewhat if the slave Analyzer is tracked slightly differently than the master, but the pictorial quality has no effect on a record's statistical or data value.

RADIO INTERLINKAGE SYSTEM

The Radio Interlinkage system consists of dry-cell powered crystal-controlled 5 watt transmitters (Figure 10), and crystal-controlled dual-channel receivers (Figure 11), also dry-cell powered. Two channels have been assigned to the system by the Federal Communications Commission 217.550 and 219.450 megacycles. The square wave pulse, generated at the Analyzer each time the shutter is tripped, is transmitted over this system to trigger the operation of auxiliary cameras or other types of recording equipment. This makes it possible to record such factors as aircraft instrument calibration, instrument time lag, configuration, flap settings and propeller position, for point-by-point correlation with the physical performance as established by the Analyzer record.

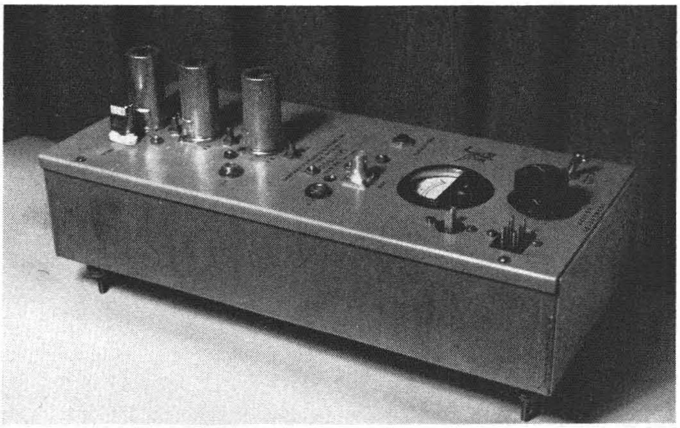


FIG. 10. Pulse linking radio transmitter.

When fields of recording overlap, there are intervals when two pulses will be transmitted to the auxiliary cameras. This danger is eliminated by using different transmission frequencies for adjacent Analyzers. In a four Analyzer set-up, for example, the first will beam its pulse on the 217.550 megacycle band, the second the 219.450 megacycle band; the third the 217.550 megacycle band again, and the fourth will use the 219.450 channel. Each receiver is equipped with a multivibrator type selector gate which locks out the 217.550 megacycle signal the instant the first pulse is received on the 219.450 megacycle band. After a brief interval the device resets itself and is ready to lock out the 219.450 megacycle band the instant it receives its first pulse from the third Analyzer on the 217.550 megacycle band. This pattern of operation repeats each time another Analyzer begins to track the target.

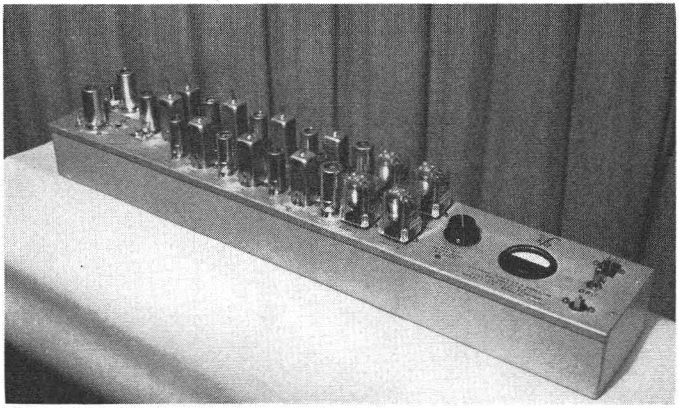


FIG. 11. Dual channel pulse linking receiver.

For short and spasmodic flight test work, the enlargements of the Analyzer give quick and simple media for data reduction and computation. Where a large volume of test work is being done, it is essential that accessory equipment be provided for data reduction. Just as aerial photography requires stereo-planigraphs or stereo-plotters, so it has become necessary to develop a Data Reader for Flight Analyzer recording work.

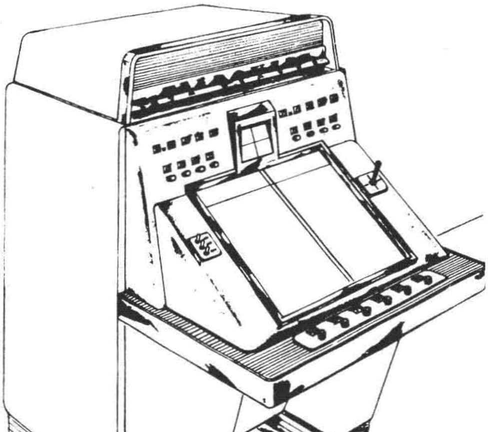


FIG. 12. Fairchild Data-Reader. A powered comparator with Analog-Digitator Output.

DATA READER

Such a powered comparator Data Reader is illustrated in Figure 12. It incorporates a unique power-driven comparator stage with large projected image screen for selection, and identification of the target to be measured. At the same time a highly magnified projection of the image (30×) is given on a small second screen where it may be very accurately positioned with respect to the cross hair fiducials. It's accuracy is .0001″. The output of the comparator may be read directly in inches from two back-lighted integer panels, but it also has incorporated the Fairchild Visa-Log analog-digitalizer whose output may be directed to a card punch of either the key-punch or summary-punch type, or to an automatic typewriter of the Flexiwriter type. Provision is also made for feeding or setting in time history records and for recording test numbers of frame numbers or other reference numerals.

This accessory is material for a paper in itself and is an unique contribution to the extension of the use of photogrammetric records as it brings the potential of electronic computation to this field.

WIDE RANGE OF APPLICATION

The flexibility and adaptability of the Analyzer system of data recording is probably best demonstrated by listing some of the recording tasks that have been successfully completed by these instruments alone or in conjunction with their auxiliaries (Figure 13):

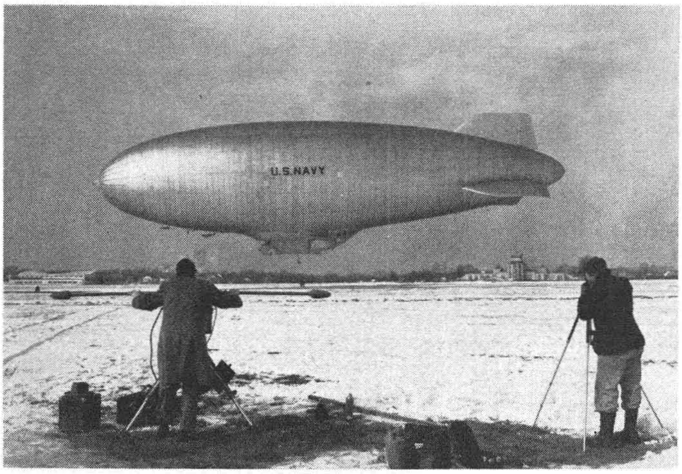


FIG. 13. Determining Rate of Sink of a Non-Rigid Airship in Landing.

- High speed level passes at speeds over Mach 1
- Maximum performance take-off
- Glide slope approach and automatic landing under complete electronic and instrument control
- Missile launchings
- Zero-launch types of tests
- Helicopter performance studies
  - vertical climb
  - loss of altitude to obtain full autorotation
  - maximum rearward and sideward velocity for gust conditions
- Aerial torpedo drop trajectories and water entry angles
- Aircraft take-off distance, and distance to clear 50 feet
- Landing over obstacles
- Air to ground missile trajectories
- Altimeter calibrations
- Accurate altitude determination over surrounding territory

Determination of angular attitudes of certain classes of aircraft where vision is extremely important
Determination of trajectories of snatched aircraft targets
Comparison of piloting techniques for optimum aircraft performance
Aircraft performance with simulated engine failure
Determination of aircraft runway acceleration where performance was marginal.

INDICATIONS FOR THE FUTURE

The Flight Analyzer is so new an instrument that the flight test instrumentation field is only beginning to comprehend its utility and promise. The improvements made in the basic instrument during the past few years, and the development of new Analyzer models and new types of auxiliary equipment, were largely the result of requests from flight test engineers who envisioned new uses for this tool. This process will almost certainly continue at an accelerated rate as the instruments are put into the hands of an increasing number of scientists and technicians.

In fact, the only restriction to a constantly widening scope of application, for the Flight Analyzer type of data recording device, appears to be the limitation imposed by the available lens optics. If, for example, there were at hand a 24 inch wide-angle lens with a 90 degree acceptance angle, it is obvious that a Flight Analyzer could cover twice the range at altitudes now recorded by the 24 inch Aero Tessar. If the resolution of the Metrogon were increased to 50 or more lines per mm., the quality and definition of the Analyzer would be so improved that new fields would be open to the instrument.

Obviously the number of lenses used in the construction of Flight Analyzers alone would not suffice to underwrite the great expense of the development work necessary to create such new optics. Fortunately, however, the entire field of photogrammetric engineering looks forward to improved optical systems. When better lenses are developed for aerial reconnaissance work, the Flight Analyzer designers will fall heir to them. And then these data recording instruments will enter new and more extensive data recording fields.

NEWS NOTE

GETS PATENT ON AIR MAPPING DEVICE

W. S. Karr, executive vice-president of *Abrams Aerial Survey Corporation* has received notice of approval of his application for a patent covering equipment and a method for assembling a large aerial photo mosaic map in small units and maintaining precision match of the units and geographical control over the entire area.

The invention solves the problem of making an aerial map of a large area on a flat surface when the pictures actually are of the earth's curved surface. Such maps are made in quadrangles, the edges of which fall along parallels of latitude and meridians of longitude. The meridians of polyconic maps usually converge slightly, creating a problem to the mosaicers in making an accurate map.

With the Karr invention the quadrangle configurations are cut from hard board to exact size and shape and then known control points indicated on their surfaces. The pictures are then mounted on the boards with care to keep the control points on each picture over the control points on the boards.

The quadrangles are grouped in a frame so control can be carried from one to another. A row of quadrangles can be made, moved along so the next row can be completed. As rows are completed and the controls carried over to the next row, the finished sections can be removed.

As such units are usually photographed for reproduction of the maps in quantity, the new invention includes the design of a frame which fits over a completed quadrangle for the photography. The frame carries such information as latitude and longitude, scale, title of the area and other indicia common to maps.