# *Basic Requirements for Charting Photography**

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ABSTRACT: *This paper describes the information and materials required by the Aeronautical Chart and Information Center to produce aeronautical charts, targeting materials and photo mosaics. It proposes new methods of obtaining horizon-to-horizon charting photography that are compatible with modern high-speed, high-altitude reconnaissance aircraft. It also compares the relative merits of various camera installations with regard to USAF's requirements for small-scale reconnaissance-photography.*

*The Aeronautical Chart and Information Center provides the Air Force with aeronautical charts, geodetic data, aeronautical information publications, maps, terrain models, evaluated intelligence on air facilities, and related cartographic services. This responsibility includes developing and designing Air Force cartographic products, planning production programs, collecting and evaluating source material, compiling, reproducing, and distributing the various cartographic items.*

## A. PRODUCTS SUPPLIED BY ACIC

THE main business of the Aeronautical Chart and Information Center is to furnish charts for all types of Air Force operations—navigation, bombing, planning, and so forth. ACIC produces and maintains various series of standard and special aeronautical charts ranging in scale from 1:25,000 to 1:5,000,000. The more important series include the USAF World Aeronautical Charts (WAC's) at a scale of 1:1,000,000, covering all land areas of the world; USAF Pilotage Charts (PC's) at a scale of 1:500,000, covering selected areas; USAF Aeronautical Approach Charts (AC's) at a scale of 1:250,000, covering selected areas; and USAF Jet Navigation Charts (JN's) at a scale of 1:2,000,000, covering all land areas. Special-purpose charts include Aeronautical Planning Charts, Strategic Planning Charts, Weather Charts, Loran and Consol Charts and Evasion Charts.

ACIC also publishes several aeronautical information publications such as the Pilot's Handbooks. These handbooks contain approved instrument procedures to facilitate approach of land-based aircraft to airfields under controlled instrument flight conditions, and landing charts showing features that are in the immediate vicinity of an airfield.

ACIC publishes other graphic materials of various kinds, such as 1:25,000 charts and photo mosaics, 1:100,000 charts of land areas, and so forth.

## B. ACIC'S BASIC REQUIREMENTS FOR CHARTING PHOTOGRAPHY

To provide the above described services and products, ACIC must procure the following types of basic pictorial information:

1. Topographic and cultural information of sufficient density and accuracy to guide general air navigation.
2. Detailed information to identify and to locate local urban and industrial targets (including airfields), and any features that can be used as checkpoints for low-altitude navigation.
3. Information that identifies natural and cultural features so that predictions can be made of the radar returns to be expected from these features.

The above described information is normally supplied to ACIC by aerial photographs and intelligence information, plus the existing maps and charts. Photogram-

* Presented at the Annual Meeting of the Society, Hotel Shoreham, Washington, D. C., March 5, 1957.

metrists will be particularly interested in the kinds of photographs ACIC requires to produce adequate charts.

### C. Parameters Governing Procurement of Charting Photography

Briefly, ACIC needs complete up-to-date coverage with visual and radar photographs, to produce the required products with maximum speed, accuracy and economy of effort. Visual photographs are used to compile planimetric and hypsographic information shown on aeronautical charts; and to compile photo mosaics. Such photographs may also be used to select navigation check-points and to prepare predictions of radar returns to be obtained from selected areas.

ACIC prefers to use vertical photographs in its work, where the number of such photographs used to cover a given project is held to a minimum in order to reduce compilation costs. This concept implies that ACIC's photography should be obtained at maximum altitude with a super-wide-angle vertical camera having high-resolution; and that such photographs would be viewed under suitable magnification in order to extract all necessary information.

As a minimum requirement for resolution, ACIC desires to distinguish objects on the ground having an area of 100 square feet for preparing radar predictions; about 400 square feet on the ground for preparing photo mosaics and target charts; and about 1,600 square feet for preparing small-scale aeronautical charts. These resolving-powers are roughly equivalent to those provided by a vertical camera having a 6-inch Metrogon lens, at altitudes of 10,000 feet, 20,000 feet, and 40,000 feet respectively. (Assuming that such photographs resolve 15 lines per mm., and that the minimum object resolved is 2/15 mm. square—that is 0.005 inch square.) Oblique photographs providing the same resolution of ground objects are acceptable to ACIC but are more difficult to use. Low-altitude oblique photographs, such as can be accomplished with a trimetrogon camera installation supplemented by a forward-looking oblique, are needed to obtain visual check-points of landmark value for low altitude navigation charts.

With regard to the compilation of aeronautical charts, it should be noted that the location of unmapped planimetric features (in areas where reliable charts already exist) can be established with virtually any type of photography. In all such cases the features can be plotted by the use of simple image-matching techniques. Also, most of ACIC's small-scale charts show land-mark features that ordinarily would be shown only on large-scale products. Consequently small-scale charts cannot be compiled without considering the use of large-scale photo interpretation.

It should be understood that ACIC is prepared to make maximum use of any type of useful photography, even if such photography does not meet the above requirements. Also, that ACIC may need more than one of the above types of photography for any given area, depending upon the cartographic products that are required.

While it would be possible to discuss in more detail the several different kinds of photography that are required by ACIC, the balance of this paper will discuss the procurement of visual photography for aeronautical charting. In ACIC's terms this means the procurement of photographs best suited for producing charts at scales of 1:250,000 and smaller, and photographs suitable for the identification of features of landmark value from the air.

The following discussion assumes that such photography may be procured primarily for search reconnaissance and that the requirements for search reconnaissance may be of paramount importance. In this connection, it should be noted that USAF generally cannot afford to maintain a cartographic reconnaissance capability that differs significantly from an optimum search reconnaissance capability.

The relative value of various possible types of photo coverage for aeronautical charting depends upon the following restrictions:

1. Circumstances that restrict the procurement of photography.
2. Ability to precisely navigate predetermined flight-lines.
3. The specifications governing the accuracy and information content of the cartographic products that must be compiled from the resulting photographs.
4. The geometrical qualities of the resulting photographs.
5. The pictorial qualities of the resulting photographs.
6. The physical limitations of the

photographic aircraft which govern the length and altitude of the flight-lines, and the location, size and number of cameras.

7. The amount and distribution of ground-control that is available.
8. The variety of compilation equipment and procedures available to the using organizations.
9. Amount of manpower available to process the photography.
10. Availability of reconnaissance-aircraft.

Some of these restrictions will now be discussed in more detail.

With regard to the accomplishment of photo reconnaissance under *Combat* conditions, it appears that the photographic mission must be flown at maximum altitudes and at speeds with maximum flight-line spacing, using evasive action whenever necessary. This situation provides an overwhelming justification for the use, under *Combat* conditions, of a camera installation providing horizon-to-horizon photo-coverage having good geometrical qualities and high resolving-power. In effect, this requires the use of wide-angle cameras for control extension and high acuity cameras for detailed information.

With regard to the procurement of charting photography under peacetime conditions, ACIC believes that the practical value of horizon-to-horizon photo-coverage gradually decreases and the need for precise chart compilation methods increases as the flying height becomes greater. At some altitude, perhaps 40,000 or 50,000 feet, the wide-angle vertical camera begins to provide optimum photo-coverage for medium- and small-scale charting—if adequate means are available for extending control. At this altitude, a large area can be covered by a reasonable number of such photographs—and no photograph is too far away from adequate ground-control. It appears that the Wild Super-Aviogon camera begins to provide optimum vertical coverage for charting at an altitude of about 25,000 or 30,000 feet.

Most of USAF's requirements for charting photography are located in foreign areas where photo-identifiable ground-control is relatively scarce and unreliable, and where additional ground-control cannot be obtained. Under these conditions, the photogrammetric extension of control becomes of great importance to ACIC. For this reason, and for others, ACIC recommends that (1) charting photography be obtained at high altitudes, and (2) high oblique cartographic photographs be obtained for use in the photo alidade. However, this recommendation does not preclude the procurement and use of complete vertical coverage for charting.

It should be noted that the photogrammetric compilation of a network of correctly positioned control-points depends in part upon the use of geometrically precise photographs. It is for this reason that precise surveying cameras are essential in the procurement of charting photography. Reconnaissance-type cameras can be used for this purpose only at the expense of speed and accuracy of compilation.

The navigation of flight-lines appears to be a serious problem in the Air Force due to the lack of adequate flight-charts in areas of primary interest, and to the lack of navigators who are skilled in the precise navigation of photographic flight-lines. This problem can be reduced to a minimum by using horizon-to-horizon photo coverage.

The pictorial quality of the photographs is of critical importance as the altitude increases and as the size of the photographic aircraft decreases. In past years, the tendency has been to improve pictorial quality by using long-focal-length cameras. After much study, ACIC concludes that the Air Force should use short-focal-length cameras for charting and search reconnaissance with emphasis placed on the use of a lens-film-observer system that has maximum resolving-power. The author merely wishes to note here that the maximum resolving-power of the unaided human eye is only about 4.5 lines per mm.* As a result, whenever it is desired to extract maximum information from aerial photographs, the observer must be provided with a viewing system that has provision for adequate magnification. For example, if the resolution of the photographs is 50 lines per mm., the viewing system should provide a magnification of about 10 diameters. This problem will become of critical importance whenever we begin to use very-small-scale photography. In this connection, it should be noted the Metrogon and Planigon aerial survey

* "Interpretability" by Dr. Duncan E. MacDoneld. PHOTOGRAMMETRIC ENGINEERING, XIX, no. 1, p. 102.

lenses, being modifications of the basic Topogon design, are soft-focus lenses and have comparatively poor resolving power.† Also, there is no definite value of camera-film-observer acuity that is required for chart compilation. Acuity that would be fairly adequate over the North Pole would be inadequate over a large industrial complex—for a given altitude.

These considerations stress the need for a horizon-to-horizon camera system, plus auxiliary equipment, that has the following four characteristics:

1. It is specifically suited for search reconnaissance and aeronautical charting.
2. It is specifically suited for both combat and non-combat conditions.
3. It is specifically suited for publication scales of 1:100,000 or smaller.
4. It represents the optimum compromise between conflicting needs for horizon-to-horizon coverage, large image scales, maximum image definition, good geometrical characteristics, and reasonable size-weight characteristics.

These four essential qualities tend to be mutually exclusive. In other words, one of these desirable qualities can be obtained in adequate degree only if other desirable qualities are allowed to be less fully satisfied. No one camera can meet these requirements with complete satisfaction.

Now that certain new cameras have been developed, it becomes possible to design improved camera installations that provide horizon-to-horizon coverage with greatly increased resolving-power and improved geometrical characteristics.

### D. Proposals for an Improved Reconnaissance Camera System

The author proposes that a better allowance for all of the above restricting factors be provided by one of the four camera systems now to be described. Each of these systems is designed to provide horizon-to-horizon photo-coverage at high altitudes. Each can be easily adapted to peacetime or combat conditions, and involves the use of a precise super-wide-angle vertical camera.

† See "Spherically Symmetrical Lenses and Associated Equipment for Wide-Angle Aerial Photography" by the Optical Research Laboratory of Harvard University. O.S.R.D. Report Nr. 6016, 30 November 1945.

The first camera system consists of four cameras—one vertical camera, two lateral high-oblique cameras, and one high-acuity panoramic camera. The vertical camera would have a focal-length of 3.5 inches, and a negative format 9 inches square. The oblique cameras would be tilted 65 degrees, have focal-lengths of 12 inches, and formats of 9×18 inches. (Smaller oblique cameras would be acceptable if their resolving-power is adequate.) The panoramic camera would cover a narrow strip perpendicular to the flight-line. The photographs supplied by the vertical and oblique cameras would be used for search and charting, while the panoramic photographs would be used as required for photo interpretation and photo mosaics. Figures 1 and 4A illustrate the photo-coverage supplied by this proposed camera installation. Figure 2 illustrates a stereo pair of panoramic photographs obtained by an experimental camera developed by the Wright Air Development Center. The Photographic Reconnaissance Branch of WADC has supplied ACIC with these photographs.

The second camera system proposed by this study is identical with the first, except that the obliques are not used. Figures 1 and 5A also illustrate this proposed camera installation. The resulting vertical photographs could be used to establish a network of control for each strip of photographs. The panoramic photographs could then be graphically resected to this network of control to provide radial intersections common to adjacent flights of photographs—if complete vertical coverage was not obtained. Planimetric detail could be plotted on the chart manuscripts from the panoramic photographs for areas outside the vertical coverage.

The third camera system proposed by this study consists of one vertical camera and two lateral high-oblique cameras. The vertical camera would have a nominal focal-length of 6 inches and a negative format of 9×18 inches, while the obliques would be tilted 70 degrees, have focal-lengths of 12 inches, and formats of 9×11 inches. (It is assumed that this cartographic camera installation would be supplemented by a panoramic camera to provide high-resolution photography for photo interpretation and for the compilation of photo mosaics, and large-scale charts, radar predictions, etc.) Figures 3

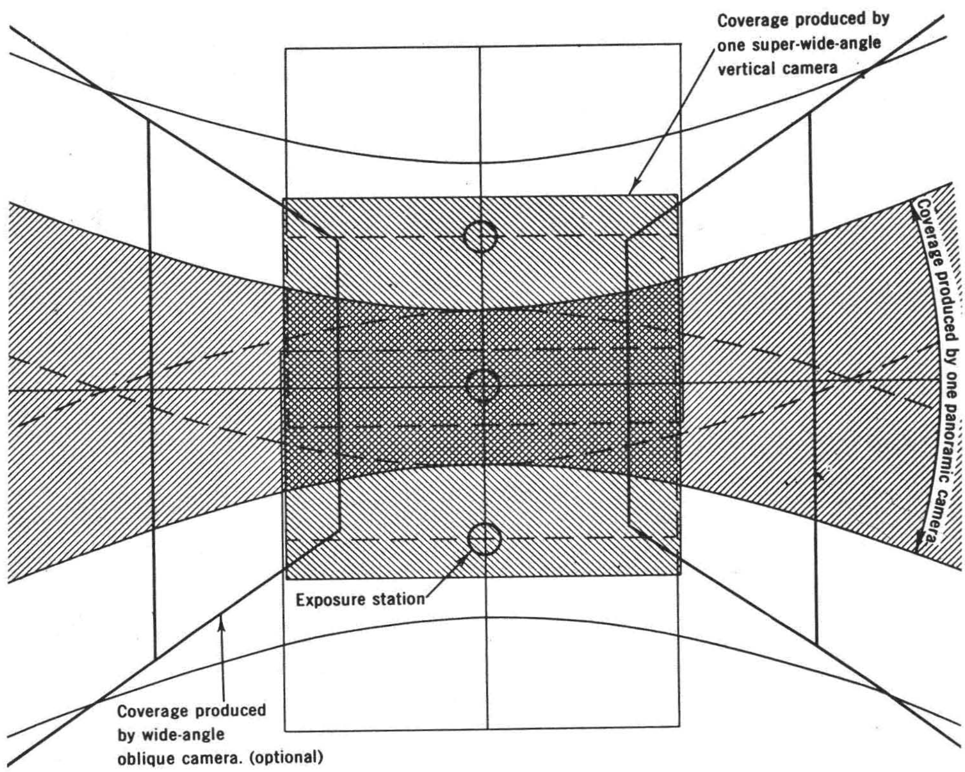


FIG. 1. Ground coverage diagram for a series of photographs obtained by a super-wide-angle vertical camera in combination with a panoramic camera. (The vertical photographs overlap sixty per cent.)

and 5E illustrate the photo coverage provided by this proposed camera installation. The overlap illustrated in Figure 3 is required if the obliques are to be used in establishing horizontal control. Similar results could be obtained by replacing the oblique cameras of this proposed camera system with others having formats 9 inches square, tilts of 70 degrees, and focal-lengths of 10 inches. The image scales of the 10-inch oblique cameras are not quite as good as those of the 12-inch cameras proposed in this paper, although the ground-coverage would be somewhat better geometrically for purposes of chart compilation.

The fourth camera system now proposed consists of a pair of lateral low obliques and one panoramic camera. The low obliques would have a focal-length of 6 inches, a tilt of 30 degrees, and a negative format of $9\times18$ inches. The long dimension of the negatives would be parallel to the flight line. Figures 4 and 5D illustrate this proposed camera installation.

Figures 1, 3 and 4 are shown here at the same scale to assist the reader in making an easy comparison of the ground coverage attained by each of the proposed camera combinations. With regard to the above proposed camera systems it should be noted that all of them use standard rolls of film. Also, that two Hi-Ac cameras (modifications of Dr. Baker's spherical shell camera) could be used instead of the panoramic camera in each of these four camera installations. Finally, these proposed camera installations can be easily adapted to procuring high-altitude photocoverage for large-scale topographic mapping. For example, the lateral low obliques of the author's fourth proposal (see last preceding paragraph) could be turned 90 degrees in their mount and tilted 18 degrees. The resulting convergent obliques would have the base-altitude ratio of the Twinplex camera installation, but provide twice the lateral coverage.

Figure 5 illustrates ground coverage diagrams for representative camera in-

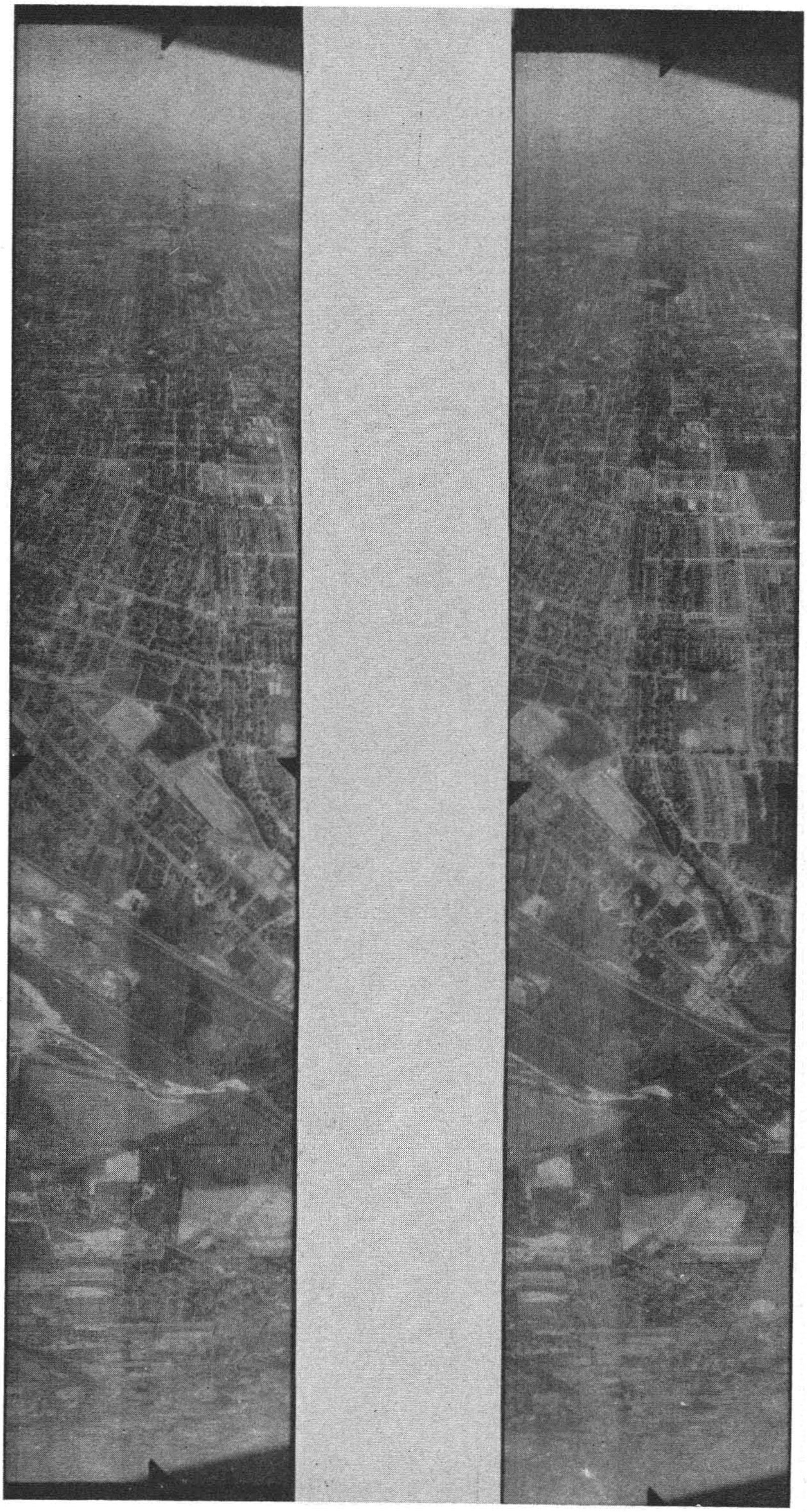

FIG. 2. Stereo pair of panoramic photographs—long dimension being perpendicular to flight line. (Courtesy WADC.)

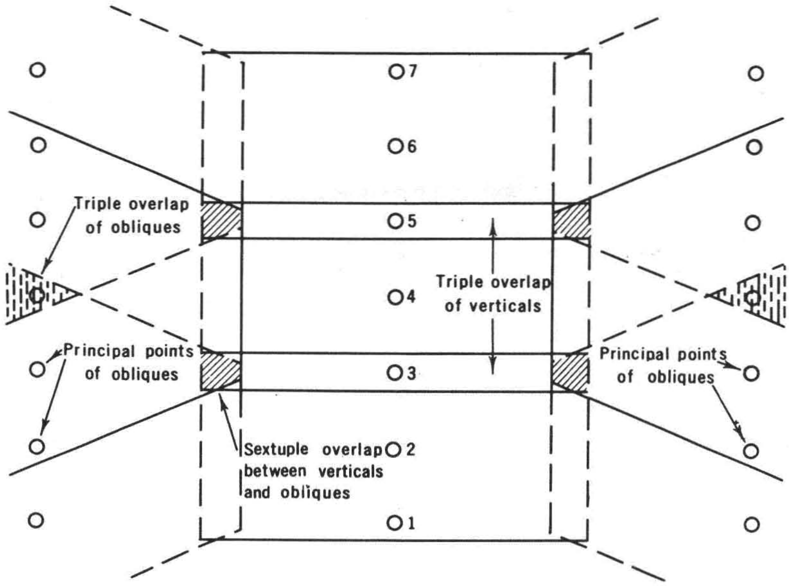


FIG. 3. Ground coverage diagram for a series of photographs obtained with camera combination proposed by this paper, where consecutive verticals overlap sixty per cent. (For purposes of legibility the outlines of the odd numbered photographs are now shown.)

stallations which are capable of satisfying the requirement for horizon-to-horizon photography. All of these diagrams are at the same scale. Figures 5A, 5D and 5E represent coverage by installations using super-wide-angle cameras. With regard only to those properties involved in chart compilation, it appears that Figure 5D probably represents the best all around installation. However, the lack of image motion compensation would tend to limit its practical utility if the ratio of ground speed versus flying height exceeds 800 mph/20,000 feet. When we consider the additional restrictions imposed by the size and speed of the reconnaissance aircraft, it then appears that our second proposal (one super-wide-angle vertical plus high-acuity coverage) probably represents the best compromise from all points of view. This installation has several advantages:

First, the vertical camera provides lateral coverage almost out to the principal points of the ordinary trimetrogon obliques.

Second, the use of the super-wide-angle vertical camera permits maximum compensation of image motion caused by the high speed of the aircraft and its angular oscillations.

Third, with a flight-line spacing of 15 miles, complete vertical-coverage would be obtained at a flight altitude of 40,000 feet.

The vertical camera of Figure 5A produces photographs that are equivalent to present 6-inch focal length Twin-plex photography in terms of base-altitude ratio although the lateral coverage is much wider.

Figure 6 illustrates the tilts and focal-lengths of the cameras illustrated by Figure 5. Figure 7 compares the relative sizes of areas occupied by small images common to each of several representative photographs having the same perspective center and the same principal line—where the 6-inch vertical camera is assumed to equal 100 per cent. With regard only to image areas, it is obvious that the proposed camera installations will give much better results than the standard trimet installation.

Figure 8 compares the estimated relative ground resolving power (image definition) on various photographs, where the resolving power at the nadir point of a 6-inch Metrogon vertical is assumed to equal 100 per cent. With regard only to estimated resolving power, it appears that the four camera installations proposed by this study are much superior to the other re-

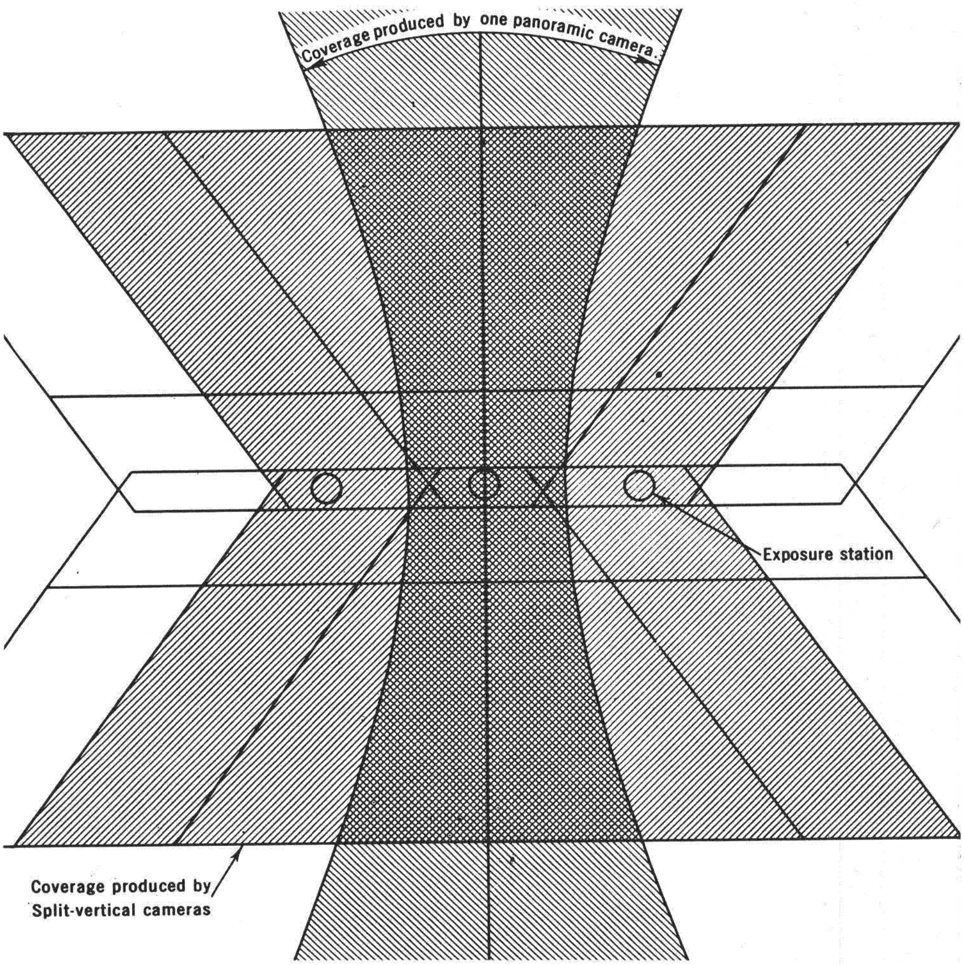


FIG. 4. Ground coverage diagram for a series of photographs obtained with camera combination proposed by this paper, where consecutive pairs of split-vertical photographs overlap 60% along the flight line.

presentative camera installations giving horizon-to-horizon coverage.

### E. Relative Merits of Various Camera Installations

The relative merits of various camera installations depend upon the conditions which govern the procurement of the photographs, upon the nature of the terrain, and upon the type of cartographic product that is required. Their relative merits also depend upon the speed, accuracy and economy of the corresponding photographic and photogrammetric procedures. For example, the relative merits of vertical photographs are not the same with respect to the compilation of topographic maps for publication at 1:100,000 as they are with respect to the compilation of aeronautical charts at 1:250,000—because of different scales, and different applications of the resulting charts. As a further example, the relative merits of the photographs depend somewhat upon the contour interval, upon the available ground-control, and upon the compilation specifications governing the amount, density, and classification of planimetric detail.

The standard trimetrogon camera installation represents an adequate compromise between ACIC's conflicting requirements, at altitudes under 30,000 feet or so. For example, trimet photography furnishes maximum photo-coverage for any given number of flight-lines, and thus permits maximum flexibility of flight-line spacing. It also guarantees maximum protection against undesirable gaps in the

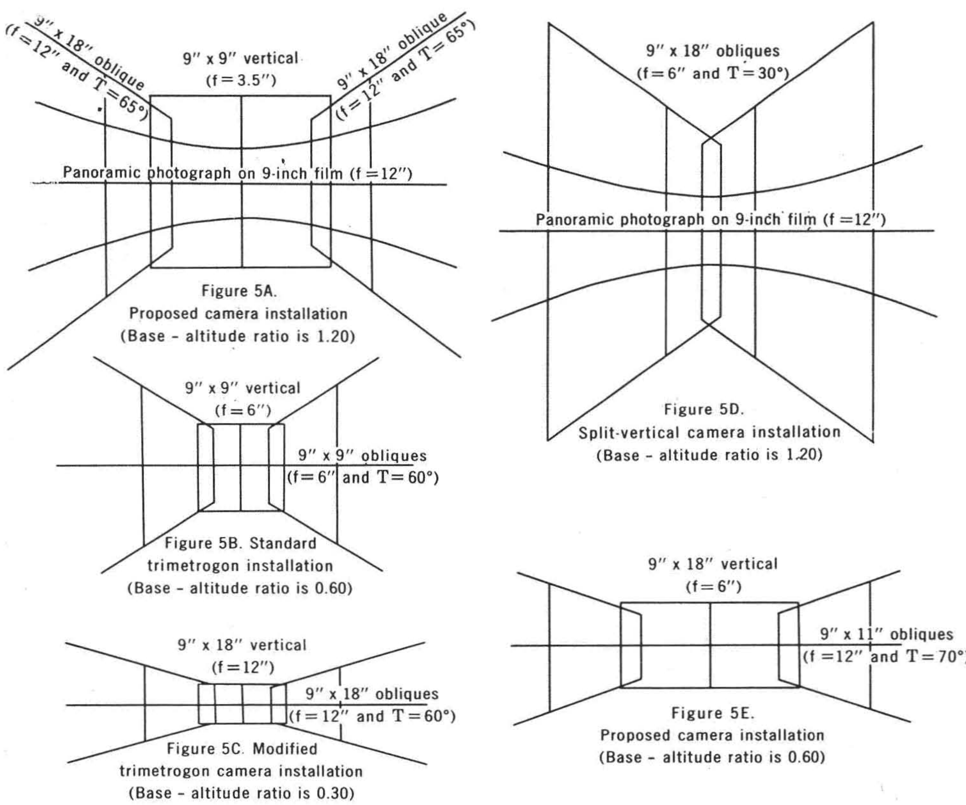


FIG. 5. Ground coverage diagrams for representative camera installations which provide horizon-to-horizon photo coverage. (These drawings are all at the same scale.)

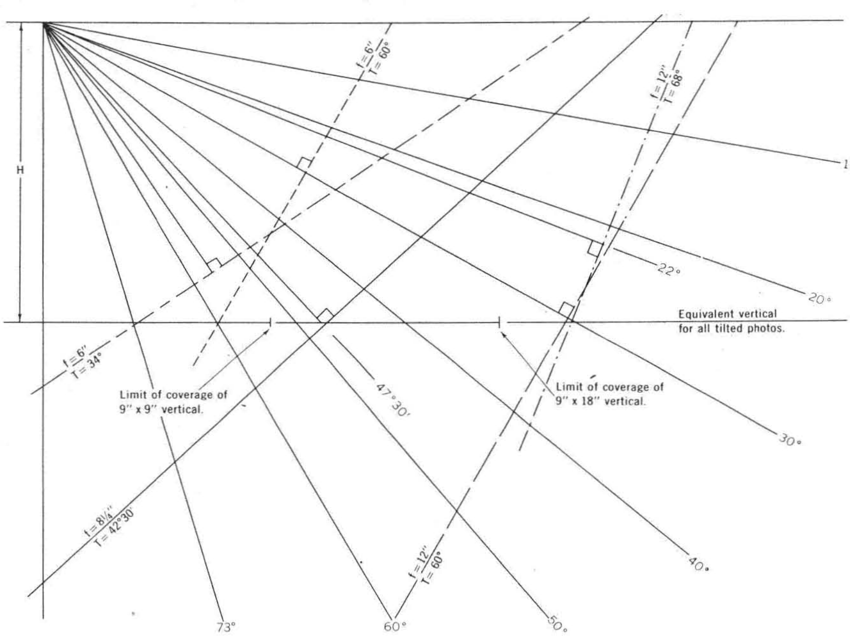


FIG. 6. Diagram illustrating tilts and focal lengths of representative cameras considered in this staff study.

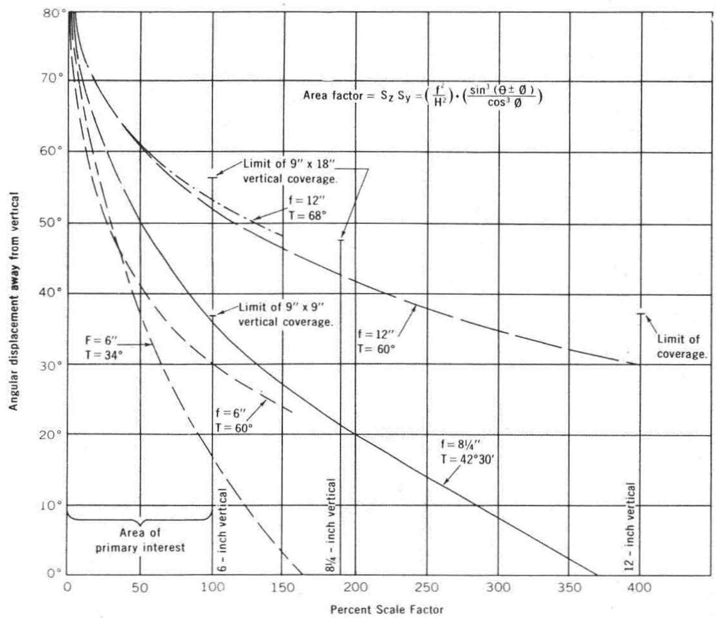


FIG. 7. Comparison of the relative sizes (areas) of small images common to each of several photographs having the same perspective center and the same principal plane, where the six-inch vertical photograph is assumed to equal 100 per cent.

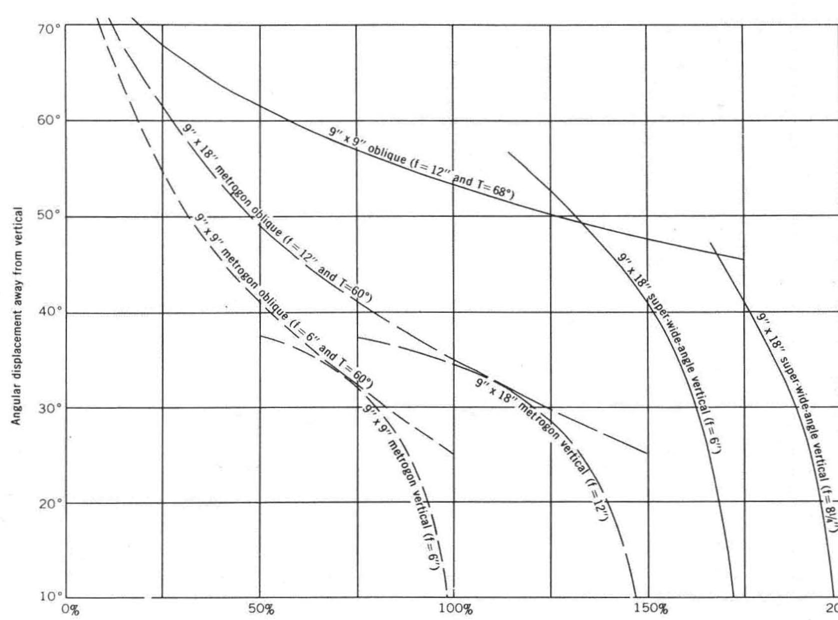


FIG. 8. Comparison of the estimated relative ground resolving power (image definition) on various photographs, where resolving power at the nadir point of a six-inch Metrogon vertical is assumed to equal 100 per cent.

photo-coverage, and maximum use of the available ground-control in poorly surveyed areas inaccessible to ground parties. For use at altitudes above 40,000 feet or so, the obliques of the trimet installation do not provide adequate image definition and scale characteristics. ACIC has service tested various modifications of the trimetrogon installation which involve the use of 12-inch obliques having formats of 9×18 inches. These modifications have not been accepted for general use by USAF for two reasons:

First, they do not appear to produce a significant increase in the resolution of ground objects.

Second, if the long axis is parallel to the flight-line, they do not provide horizon-to-horizon coverage, and if the long axis is perpendicular to the flight-line, they require twice as many photogrpahs to cover the same amount of terrain.

If they are procured at comparatively high altitudes (small scales), vertical photographs possess the following advantages, with respect to trimetrogon photographs taken at same altitude, in compiling charts for publication at 1:250,000:

a. Photo interpretation can be performed more quickly and surely.
b. Speed, accuracy, and economy of every part of the compilation procedure is better. (These qualities result from the comparative simplicity and precision of all compilation procedures involving the use of vertical photographs.)

The first two of these advantages would also be partially attained by the use of trimetrogon photographs—if they were obtained at altitudes of at least 30,000 to 35,000 feet. In any event, ACIC believes very strongly that when complete vertical coverage is obtained for charting it should always be supplemented by high obliques obtained simultaneously. (These obliques can be used to establish the basic network of control with maximum speed, accuracy and economy, and provide insurance against gaps between adjacent strips of photographs.)

The principal disadvantages of high-altitude vertical photographs, with respect to trimetrogon photographs taken at the same altitude, are as follows:

a. The danger of obtaining gaps in the photo coverage. (This is of major importance in procuring photography over relatively unexplored areas.)
b. The bridging of vertical control by stereoscopic means is comparatively difficult and time-consuming when little or no ground-control is available. (ACIC is convinced that the required vertical-control could be established with comparatively great speed, accuracy, and economy by the use of auxiliary lateral high-oblique photographs in the photo alidade.)
c. A greater number of flight-lines are required to provide complete coverage of a given area, at operational altitudes.
d. The necessity of flying closely spaced parallel flight-lines with the proper overlap.

ACIC does not normally use vertical photographs for compiling 1:250,000 charts for the following reasons:

a. ACIC cannot justify the military hazards involved in flying, under combat conditions, the parallel, closely-spaced flight-lines required in procuring complete vertical photographic-coverage.
b. ACIC cannot justify the procurement and use of vertical photographs because it is so much easier to procure trimetrogon photographs.
c. ACIC photographic compilation procedures and equipment have been established to process the large volume of trimetrogon photographs that have already been procured.
d. ACIC has not been able to justify the use of low-altitude vertical photographs in compiling 1:250,000 charts because of the large number of photographs that must be processed.

With regard to split-vertical camera installations, we may consider two orientations—lateral-obliques and convergent-obliques. This Center believes that either type of split-vertical installation is not satisfactory for aeronautical charting because:

1. The lateral-orientation generally tends to have a weak azimuth (base line) and an excessive number of photographs.
2. The convergent-orientation has quite poor lateral coverage, and the con-

tact prints cannot be examined with a simple stereoscope.
3. Unnecessary difficulties of flying straight, parallel, flight lines.
4. Specialized equipment and techniques must be used.
5. The camera mounts do not lend themselves to image motion compensation and tilt stabilization.

The split-vertical camera installation proposed by Figure 4 does not have the first three of these disadvantages.

The relative merit of various camera installations depends in part upon the compilation equipment and techniques that must be used. In considering the development of a new system we must consider the suitability of our present equipment and techniques. With regard to the camera systems proposed by this study, it should be noted that:

1. Selected points could be located by the use of normal equipment and techniques with only minor changes.
2. Aeronautical charts could be revised by the use of normal equipment and techniques with only minor changes.
3. Aeronautical charts could be compiled by the use of normal techniques except for minor changes. Except for the Radial Line Plotter, the Autofocus Rectifier and the Kelsh Plotter, standardized USAF equipment would be adequate.
4. Photo mosaics could be made verticals having a format of 9×18 inches using normal equipment and techniques—if each half of each negative is rectified separately. (Optical quality of resulting prints would leave something to be desired.) Photo mosaics could not be made from the obliques using normal single-stage techniques because of the high tilts. Rectified prints can be made of the area inside the principal points of these obliques if "copy negative" methods are used with normal USAF equipment.
5. Photo interpretation could be accomplished by the use of normal equipment and techniques.

## F. Summary

With regard to the principal requirements of large images, good resolving-power, image-motion compensation, reasonable size-weight characteristics and operational utility, it appears that the four camera installations proposed by this study would be superior for search reconnaissance and aeronautical charting while providing horizon-to-horizon coverage. However, in this connection, it should be noted that the importance of these characteristics depends upon the circumstances involved in aerial reconnaissance. For this reason, only a careful study of the problem would lead to a more specific statement of the requirements that should govern the procurement of cartographic photography for USAF.

In this connection it seems desirable to summarize the desirable qualities of horizon-to-horizon cartographic photography in the following terms:

1. Permits maximum flexibility in navigating the photographic flight lines.
2. Permits wider spacing of the photographic flight lines, and thus makes the most effective use of the limited number of photographic aircraft that is normally available.
3. Makes better use of a skimpy network of ground control.

## news note

### High Speed Camera

Up to 2800 pictures per second can be made with new Photo-Sonics 4B camera, which has both rotating disc shutter and rotating prism for image compensation, to give full-frame 35mm pictures with highest resolution and minimum distortion. Gordon Enterprises, North Hollywood, Calif., is representative of the new equipment.