f, *H*, *ob*, and *R*. So calculated, it may be inserted as a scale factor in formula 19, thus correcting for earth's curvature and atmospheric refraction simultaneously. Equations (19) then become:

$$X_c = (H - h + h_c - h_r)/f \cdot x_c$$
$$Y_c = (H - h + h_c - h_r)/f \cdot y_c \qquad (32)$$

It is apparent that the effect of atmospheric refraction is to radially displace the image-point from the principal-point of the vertical photograph.

CONCLUSIONS

Apparently the effect of atmospheric refraction is to partially offset the effect of earth's curvature. It is, however, nearly negligible, and difficult to accurately evaluate quantitatively.

Because of the difficulty of theoretically evaluating the effect of atmospheric refraction, the possibility of making empirical determinations of atmospheric refraction and earth curvature in combination suggests using balloon photography over an area with sufficient control to permit the precise determination of image point displacements incidental to photography taken at various altitudes with various types of cameras.

The possibility of correcting for earth's curvature and refraction by equations (32) on isolated photographs taken at high altitudes appears to be practical, since the relative ground coordinates so established can be used to determine scalar quantities and areas. The effect of tilt on this technique remains to be investigated.

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Photogrammetric Applications of Radar-Scope Photographs[*]

PAMELA R. HOFFMAN,
Aeronautical Chart & Information Center,
St. Louis, Missouri

ABSTRACT: *The utilization of radar-scope photographs as standard photogrammetric source material has been studied for over ten years. Almost the entire bulk of completed work is experimental in nature but has provided valuable information. It has led to the development of special compilation procedures, and special compilation equipment, as well as the capability of applying these developments in production compilation. Improvement of the basic radar equipment will permit even greater success in this field in the future. This paper describes procedures and techniques for applying a specialized kind of photogrammetric knowledge in extracting topographic information from radar-scope photographs.*

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THE relationship of radar to photogrammetry has been presented to this membership on a number of previous occasions. These presentations have included subjects that provide background information for the present discussion, namely, principles of radar equipment operation, characteristics of radar-scope photographs, certain of the compilation equipment designed for this application, and similar subjects. This paper will specifically concern the extraction of topographic information from radar-scope photographs by applying a specialized kind of photogrammetric proficiency.

The photogrammetrist is concerned with the preparation of a map or chart using some type of photographic source material with other compatible information, such as ground-survey data, published maps or charts, and textual reports. The progressive photogrammetrist is always alert to developments in all subjects related to his science, and is constantly searching for new materials, techniques and equipment to improve the quality and economic feasibility of his cartographic items.

To anyone familiar with photogrammetric compilation techniques, the use of radar-scope photographs as source material for chart construction is a logical innovation—first, because they are photographs, and second, because they furnish a special information, not readily determined from other sources, that is of value in aerial navigation. The radar-photo has certain advantages for charting over the visual photo and these advantages will be discussed throughout this paper. On the other hand, the radar-photo has obvious deficiencies for this purpose. They will certainly never replace visual aerial photos.

The secret, in successfully applying radar data, cartographically, is to have a firm positive attitude about the information that is available in order to derive maximum benefit from the technique. Then, appropriate compensation must be made for the shortcomings of the material so that they do not assume undue significance. Certain basic photogrammetric principles must be modified or even disregarded in considering radar photos for charting purposes.

There are special occasions when the use of radar-photos should be considered for cartographic application. Large areas of the world are poorly charted. In these areas it is sometimes difficult to collect ground data because of inaccessible terrain, and it is inconvenient to obtain aerial photographs because of adverse weather conditions.

The data extracted from radar-photos are limited in quality but meets a vital need when normal sources fail. Two types of requirement may exist. The first case, and the one which is of most practical interest, is that situation where present cartographic materials may be out-dated or of doubtful quality. Detail of more recent date or improved accuracy may be provided through the input of data extracted from radar-photos. This procedure is essentially one of chart revision. A second requirement may be for a completely new compilation made from radar-photos. In either case, radar-identifiable ground-control must be available to insure the accuracy of the final product.

Before going into any technical discussion, the nature of the illustration material will be explained. By Executive Order most radar-scope photographs presently carry a military security classification; therefore actual photographs cannot be used to illustrate this paper. Where it is necessary to demonstrate photographic characteristics and relationships, fictitious photos will be used.

The expression "radar-scope photograph" as it will be used in this paper describes the product of photographically recording the presentation displayed on an airborne radar-scope (Figure 1). This presentation has a circular format. The center of the scope represents the position of the aircraft, and the entire circular area displays the radar returns received from the surrounding terrain in all directions from this position to a range, or distance, determined by a control in the radar equipment. This illustration shows the range marks, a series of bright concentric circles that are a part of the presentation. They are used in measuring distances on the photo.

The direct use of radar information as cartographic source material has been studied for more than ten years. It is probably not possible to say who originated the idea of extracting photogrammetric data from radar-photos. Actually, the use probably occurred, sooner or later, to a number of people who were familiar with both

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radar and photogrammetry. At any rate, photos of radar-scopes were taken during World War II for various reasons, and at least as early as 1946, an attempt was made to use such photos to fill in detail on charts for which conventional source materials were not available. This particular project was not completely successful because the relatively poor quality of the radar-photos available at that time did not permit a satisfactory radar compilation, but it demonstrated a potential which has been realized and considerably expanded in the intervening years. Through investigation and development activity, government agencies and private companies have contributed to the increasing fund of knowledge on radar charting. The majority of this work has been experimental in nature, but successful applications of such data have been made in a limited number of production assignments.

Today the radar equipment has been so improved that the radar-photo presents better resolution and better geometric fidelity. A certain amount of information on radar-photo interpretation has been collected. Equipment has been developed to enhance the fundamental compilation process. Various compilation techniques have been developed and tested. There is still much to be learned on all of these subjects, but adequate procedures for cartographic radar input are available.

One of the fundamental methods of photogrammetric compilation, as all of you know, is the extension of a control network by assembling radial templets which represent specific data extracted from overlapping aerial photos. Since the radar-photo is a radially generated display, it lends itself easily to a similar compilation technique. That is, common detail can be identified on overlapping radar-photos, radial templets may be made to relate this detail, and compilation can be accomplished wherever suitable source material exists.

One of the characteristics of the radar-photo is the presence of a series of bright concentric circles, known as range marks. They indicate the extent of the area scanned by the radar equipment. The inclusion of this range information on radar-photos is one advantage over conventional charting photos. It permits the scale of the photo to be determined and also defines more exactly the final position of intersecting radials from several exposures for common point.

The *sine qua non* in radar charting is the availability of suitable photos. Specifications for radar charting photography have been standardized to some extent, although there will be variation to meet requirements of individual assignments. These specifications usually include:

(1) Range setting of the radar presentation, to determine the extent of area displayed.

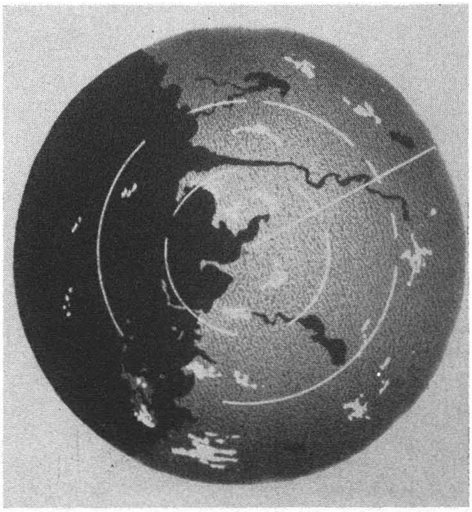

Fig. 1. A simulated radar-scope photograph.

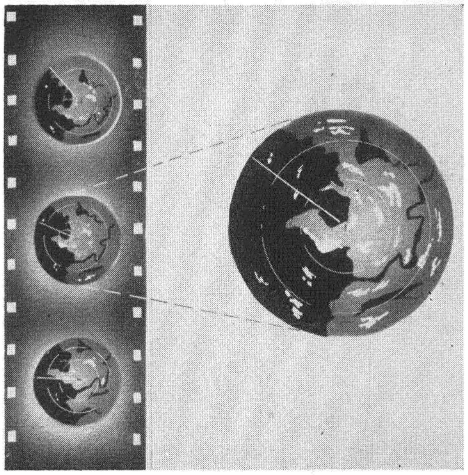

FIG. 2. A simulated strip of 35 mm. film with radar images and an enlargement of one frame from this strip.

(2) Frequency of exposures and spacing of flight lines, to establish the overlap area of the photos.
(3) Range marker spacing, to furnish scale data for the compilation.
(4) Radar display control settings, to provide for optimum cartographic detail.
(5) Auxiliary data, such as notation of type of equipment, date of photography, flight altitude, special weather conditions, etc., to aid the compiler in planning and compilation operations.

Assuming that the necessary photos are available, the simple procedures of manual compilation will be presented first, and then certain equipment which has been developed to improve and accelerate this procedure will be described.

The first step in radar charting is the selection of a compilation scale. This scale will be relatively small in terms of standard photogrammetric thinking, but the choice is limited by the scale and quality of the available radar-photos which in turn depends on the range setting of the radar set. Radar-photos are normally recorded on 35 mm. film (although some experimental sets use 5″ film). For present manual compilation procedures, photographic enlargements of the selected exposures are used.

A radar-photo on a 30 nautical mile range setting recorded on 35 mm. film and enlarged to normal scope size (about 4.5 inches in diameter) will have a scale of approximately 1:1,000,000. If it is enlarged to 1:500,000 scale, it will be near the limit of resolution of the original film (Figure 2). Greater enlargements therefore are not practical at present. However, the radial templets may be constructed at still larger scales if desired. The majority of experimental compilation has been accomplished at 1:500,000 for publication at 1:1,000,000. This procedure has been entirely satisfactory for present conditions. With exceptionally good quality photos now, or with improved photos in the future, a standard compilation scale of 1:250,000 or larger may become feasible.

Radar photos are usually taken with a greater overlap than is necessary for the compilation of a control base. The number of exposures required for this purpose again will depend on a number of variable factors, such as, type of terrain, range setting, and photo quality. For example, if the radar-photos are taken on a 30 nautical mile range setting, the control exposures may be separated by 5 to 10 nautical miles. The criterion is not a specific number of exposures for a particular area, but rather the number needed to provide satisfactory results.

The compiler may consider various types of material in obtaining the enlargements for the actual compilation process. Some prefer negative transparencies, others are better satisfied with film positives or paper prints—not only in this initial stage but throughout the entire operation. This is a matter of personal preference as there are advantages in each case. Figure 3 illustrates several steps in compilation. These two consecutive exposures have several common features indicated as control points. They are identified directly on the photo. These points are photogrammetric or, in this case, "radargrammetric" control points as opposed to surveyed ground-control stations.

Selected control-points should be easily identifiable on successive photos. In identifying these points the compiler must consider the change in the return from a particular terrain feature as the scanning aspect changes. The number of control-points per photo will vary with the photo quality, the range settings and the type of terrain. The minimum number of points per photo is three and the maximum num-

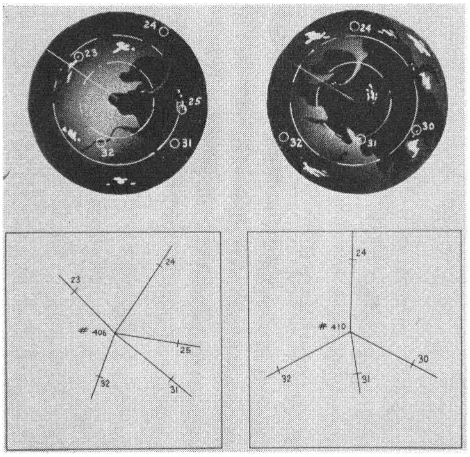

FIG. 3. Two consecutive radar control photos, with common features identified, and templets for both photos illustrating construction techniques.

ber must be determined for each case, but every control-point should appear on at least three photos. Thus, when all points from overlapping photos have been transferred to an individual exposure it will contain nine or more control points.

After selecting and identifying these points, the compiler makes the radial-templets, which are graphic representations of the range and azimuth of each selected point on every photo. They may be made of any suitable material with reasonable dimensional stability, such as safety base film, vinylite or dy-rite. Transparency is a required characteristic because they must later be assembled to form the control network. Pertinent detail is etched with a needle. The step-by-step procedure is:

(1) Identify the photo-center.
(2) Measure the slant range or ground range distance to each point.
(3) Convert slant range to ground range, if necessary, by one of several suitable methods.
(4) Place the templet material over the radar photo.
(5) Transfer the photo-center to this overlay and etch a radial through each control point.
(6) Plot the ground distance to each control point at compilation scale on its corresponding radial, by laying off the range and swinging an intersecting arc from the photo-center.
(7) Identify these intersections with the point number from the photograph, and label each templet with the proper exposure number.

The templets are usually assembled on a light table to facilitate point identification (Figure 4). Templets on which ground control can be identified are fitted first to plotted positions on a projection base. Additional bridging templets are fitted to this rigid position by matching the common photo-points. As each templet is placed in position it is fastened to the assembly with tape. The similarity of this procedure to standard photogrammetric compilation is easily noticed but the range information included in the radar presentation permits a more positive intersection of radials in the initial assembly. The range data also control the scale so that ground control-points are not required except to improve the accuracy of the final assembly. If exact intersections of the point-positions are not achieved initially, the templets should be adjusted to obtain the best average position. In those instances where either range or azimuth of a point is more reliable, the position may be weighted accordingly.

A large sheet of vinylite or a similar material is placed over the completed templet assembly and all final point-positions are transferred to this overlay and identified. Photo-centers are usually also identified as shown in Figure 5. This overlay becomes the final control base and is now ready for the addition of planimetric and hypsographic detail.

It is presumed that anyone using radar-photos for charting will be familiar with the nature of the radar-scope presentation and with the equipment that produces it, to the extent that he is able to interpret

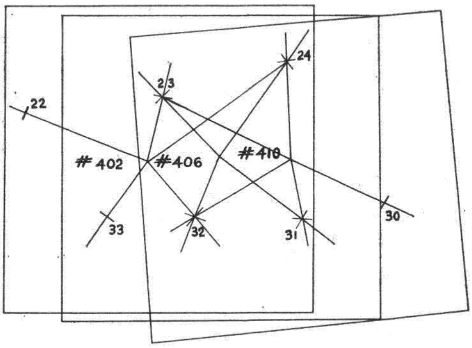

FIG. 4. An assembly of several templets.

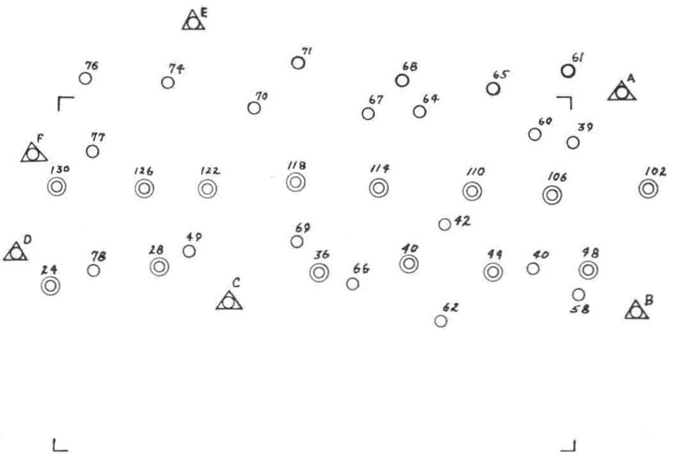

FIG. 5. Compilation base with photo centers and final control point position shown.

the detail on the photo and determine its significance for his particular purpose. The importance of radar-photo interpretation in radar charting cannot be overemphasized. A knowledge of aerial photographic interpretation will be helpful to the "radargrammetrist," but of more importance is the clear understanding of the differences between radar photographs and conventional photographs. Many of the problems encountered in radar interpretation, and hence, in related compilation, are due to the compiler's inability to keep these differences constantly in mind. In this respect there is no substitute for continual study of all types of radar photos.

Thorough understanding of the detail presented in the radar-photo is critical when selecting the radar-control points and is of equal importance in selecting the planimetric detail to appear on the final chart. This detail will include all cartographically significant items such as rivers, lakes, coastlines, islands, cities, towns, airfields, traffic routes, bridges, dams and relief features. A primary requirement is the ability to relate the planimetric detail to the control network. The control photos are used as the framework for planimetric delineation. The selected detail may be delineated on these photos, on the control templets, on separate templets, or directly on the compilation base. Standard delineation and drafting techniques are used.

It will be remembered that the minimum practical number of photos was selected for the control network. However, all exposures contain detail that may be of value in the final compilation. As time permits, a maximum number of exposures should be checked against the completed base in order to insure that every pertinent item of information is included.

It will often be necessary to indicate the nature of relief features in this type of assignment. Terrain elevations on which to base an approximate relief pattern can sometimes be obtained from radar-photos. One method of obtaining elevation data is based on measuring the altitude hole of the radar-photo; short-range photos give the most accurate results because of their large scale (Figure 6). A radar-photo over terrain of known elevation is selected and the measured radius of its altitude hole is

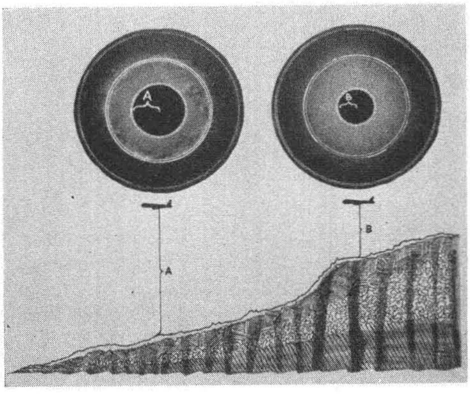

FIG. 6. Altitude hole comparison for varied altitude on two separate photos.

used as a reference base. The average radii of the altitude holes on all other photos of the same flight are measured and compared to the base photos. The procedure is completed by establishing the geometric relationship and using the appropriate formula.

The altitude of the aircraft may also be used as a reference base, and again, best results will be obtained if short-range photos are used. It should be noted that these methods provide elevation data for a point directly beneath the aircraft. This information can be combined with topographic knowledge of terrain forms to enable the compiler to fill in form lines, hachures or other relief symbols to indicate the general nature of the relief for a particular area.

There is an additional procedure which will be of some assistance in this technique but is limited to particular terrain conditions which are seldom available. Radar shadows caused by the interception of radar energy by mountains or other high objects sometimes indicate the height of the objects. The standard formula based on two similar right triangles is used for this determination. The success of the procedure depends on the accuracy of the given aircraft altitude, the compiler's ability to measure correctly the extent of the shadow, and the nature of the terrain on which the shadow falls. For example, if the radar shadow falls on water or on a flat plain, good results can be obtained. However, if it falls on another relief feature, the procedure will be useless unless the elevation at the limit of the shadow can be determined. In sketching the relief, the compiler uses the drainage pattern, the positions of ridge lines and peaks, and as many elevations as he is able to determine. The addition of this relief information will complete the compilation. Figure 7 shows a completed compilation base. Standard photogrammetric editing procedures may be used to review the base, with appropriate modifications to meet the particular requirements of the assignment.

The application of the procedures described in this paper will furnish compilation data, adequate at least for small-scale navigation charts. The accuracy of these data will vary with many of the same factors that influenced the individual compilation steps, such as photo quality, range settings, exposure spacing, terrain type, and others. With photos available at present, compilations have been produced which, on the average, are equivalent in ground accuracy to standard World Aeronautical Charts. Specific cases cannot be quoted but this accuracy has been in terms of errors of one mile in 500 miles, as an example. The amount of recoverable planimetric detail is less, percentage-wise, than standard navigation charts, but reflects radar significance throughout. Compilations made from radar-photos can, if desired, also show the nature of radar returns from areas of interest to effect correlation with inflight radar navigation data.

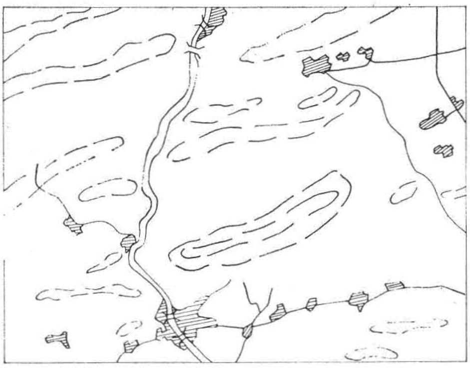

FIG. 7. A completed compilation base.

This discussion should show that there is no particular problem in using radar-photos for cartographic application if the compiler is familiar with the peculiarities of the material, and if proper precautionary measures are taken in adapting the standard procedures for these special cases. It must be re-emphasized that the skill of the compiler developed through continued experience is a most important factor in achieving optimum results in any phase of this work.

There are some items of equipment which have been developed during the past few years to improve these basic operations. The majority of these developments have been accomplished under the direction of the Air Research and Development Command and other agencies, such as the Engineer Research and Development Laboratories at Fort Belvoir, Virginia. There are other devices that have been proposed and investigated from time to time and some of these are in process of development at present. The ones that will be mentioned are those which have attracted

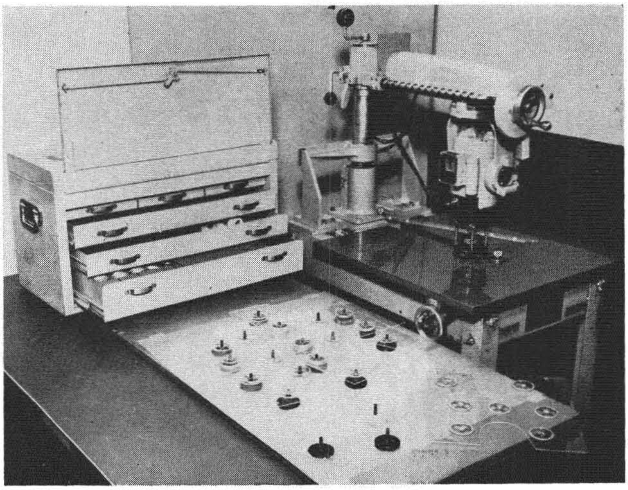

FIG. 8. Radar templet set.

the most notice and which are presently available.

The often-required adjustment of templets in any radar compilation is a time-consuming procedure, and a radar templet set has been developed to eliminate this problem (Figure 8). This equipment is similar in principle to the slotted templet set used in photogrammetric compilation. It employs spring-loaded stud holders

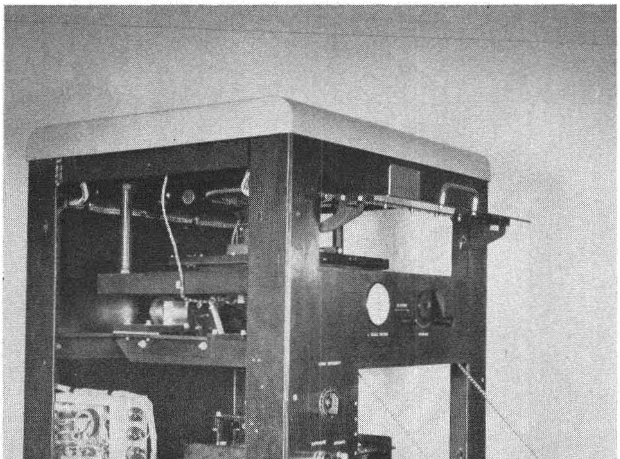

FIG. 9. Radar presentation restitutor.

which automatically adjust to distortional stresses in the assembly, and assume the most correctly weighted position for radar-control points—performing a mechanical least squares adjustment. The disadvantage of this technique is that, in our own experience at least, it is more expensive than the manual method described, does not save any time, and with present source material does not result in any significant improvement in compilation accuracy. The continuing improvements in radar equipment are gradually eliminating the requirement for this type of correction in radar compilation.

Another instrument which was discussed in a paper at last year's Annual Meeting has been developed by ERDL (Figure 9). This is the radar presentation restitutor and may be best described as a radar-photo rectifier. Its purpose is to provide distortion-free enlargements of 35 mm. radar exposures. It corrects for slant range distortion, aircraft movement distortion, and sweep delay distortion primarily and for a number of lesser distortions inherent to the radar display. Again, improvements in radar equipment will eventually preclude the need for this type of instrument, but for use with film obtained prior to the present time it undoubtedly has a valid application. This instrument is still undergoing tests which may result in standardization of the item.

The instrument of greatest promise today has only recently become available (Figure 10). This is the AR-8 Radar Data Plotting Board which provides the capability of enlarging 35 mm. film up to 125 times and projecting it on a convenient drafting surface. It is a highly mechanized autofocus instrument with automatic film drive in two directions, and a number of adjustment refinements. The enlarging range is far beyond present and foreseeable future requirements. This instrument is being tested by the Air Force and numerous improvements in the basic radar charting procedures will undoubtedly result from its use. The need for elaborate distortion correction devices is no longer critical and, with the AR-8, it may be possible to compile directly from the original film.

These three items of equipment are intended primarily to support the manual compilation process. In addition, there are in development and under consideration a number of proposed systems for application of electronic data processing techniques to the basic problem of radar compilation. Eventually, these techniques can be expected to replace, at least under certain conditions, the manual procedures because of providing improvement in cost and accuracy. For the present, the manual methods produce equal or better results.

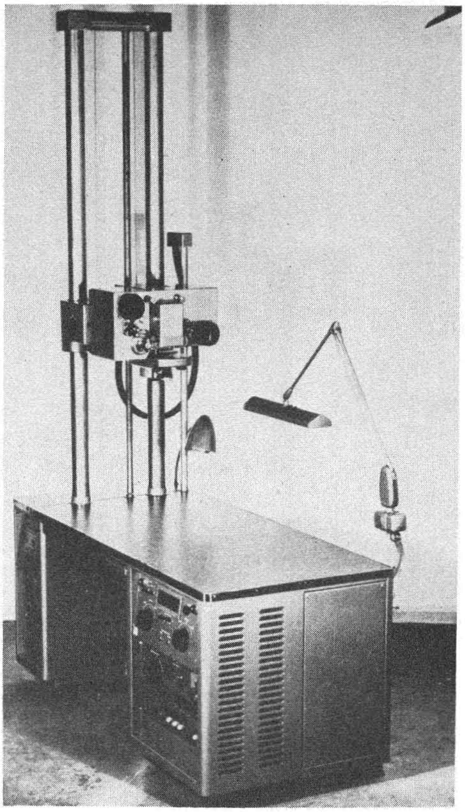

FIG. 10. AR-8 radar data plotting board.

It is inevitable that the future will bring additional improvements in the basic radar equipment and consequently in the techniques and equipment necessary for cartographic application of radar data, as the author has indicated. These developments are not far off and certainly they should be used to maximum advantage as soon as they are available; but meanwhile, the present capability of using radar data in chart compilation has been successfully demonstrated and should be applied wherever it will improve existing cartographic materials. We live today in the age of electronics—we should use the electronic eyes of radar to help us chart our path into the future.