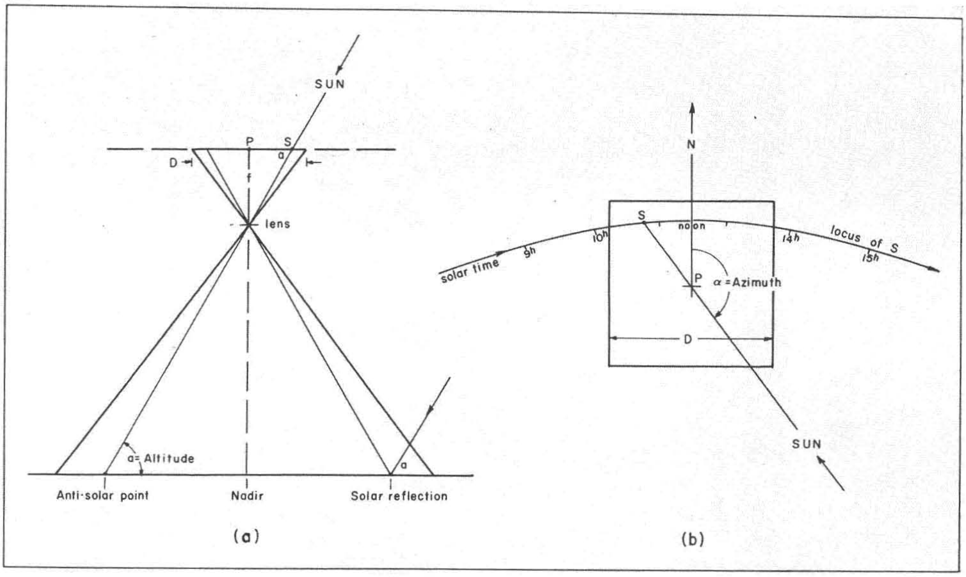

FIG. 1. Geometric considerations.

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Solar Altitude Nomograms

The aerial photographer needs to plan not only relative to the useful length of daylight but also as to whether the "hot spot" condition is likely to be encountered.

INTRODUCTION

FOREKNOWLEDGE of the time during which the sun is above a specified altitude is an integral part of planning a photographic flight. The aerial photographer must have some means of readily determining this information in order to know at what time in the morning photography can be commenced and at what time in the afternoon it must be ended. These times will vary with the date, the latitude of the project area and the requirements of the contract.

In addition to considering *minimum* solar altitudes, there is sometimes a need to consider *maximum* permissible solar altitudes when planning a photo flight. The forester is concerned about the entry of the "hot spot" into the area of the photograph and the hydrographer is concerned about the sun's reflection from water surfaces; both phenomena are associated with high solar altitudes.

Although these recurring problems can be solved from fundamental equations it is usual in survey work to make use of nomograms. Several versions have been published which can be used as aids to aerial photography. These nomograms are often either very general[1,2] or else apply to limited areas or special specifications.[3,4,5] In particular the question of the "hot spot" and sun's reflection does not receive a general treatment.

The nomograms described in this paper are an attempt to provide the air survey photographer with a simple graphical solution to the problems in a form flexible enough to meet a variety of requirements anywhere in the world.

Basic Geometry of the Nomogram

The nomogram is basedon the projection of the solar ray through the camera station to the point at which it intersects the earth. The locus of this anti-solar point, as the sun's altitude and azimuth change, forms the fundamental curve of the nomogram. From Figure 1 it can be seen that the position of the anti-solar point S, at the scale of the photograph, is given by

(in elevation) $\overline{SP} = f/\tan a$ from Figure 1(a) and

(in plan) $\overline{NPS} = \alpha \pm 180°$ from Figure 1(b).

Scope and Use

For the purposes of aerial photography it is believed that sufficient accuracy is achieved at a given latitude if the curves are drawn for each 5° change in solar declination. The latitude intervals are spaced 5° apart between 0° and 70° with the omission of curves for 5° and 15° latitude. This spacing enables time to be estimated to within five minutes.

The curves are published at $\frac{1}{4}$ the scale of the wide-angle survey camera having a 6-inch focal-length lens and a 9-inch square format. A slightly reduced example of the nomogram is shown in Figure 2.

The date-scale is set off on the 20° solar altitude circle, to correspond with the appro-

Abstract: *Solar altitude nomograms in various forms have been used for many years to determine the length of the photo day. Recently nomograms have been produced to meet the particular requirements of modern air survey photography. In addition to the length of the photo day, they provide information regarding the time of entry and exit, and the location of the "hot spot" and the reflected image of the sun within the field of view of the camera. The curves are applicable throughout the world and for any type of vertical camera.*

The altitude and azimuth of the sun are given by

$$\sin a = \sin \phi \sin \delta + \cos \phi \cos \delta \cos h$$

$$\sin \alpha = -\cos \delta \sin n / \cos a$$

where

a = altitude of the sun
ϕ = latitude of the observer
δ = declination of the sun
h = hour angle of the sun
α = azimuth of the sun.

Since for most purposes a minimum solar altitude of 20° is considered necessary for satisfactory aerial photography, the equations were not solved for altitudes less than this value in the construction of the nomograms.

The locus of the anti-solar point in relation to the area covered by a north-south oriented photograph of format dimension "D" and principal distance "f" is shown in Figure 1 (b). The time during which the point remains within the picture is determined from the hour angle of the sun at the points of entry and exit. To facilitate reading this value the locus is subdivided by a solar time scale.

priate declinations. Since the same declination occurs twice a year, the left side of the nomogram is used to mark the dates from December 22 to June 22, and the right side for dates from June 22 to December 22. These dates can be transferred to either side of the nomogram as required. This date scale is for use in northern latitudes. For southern latitudes the dates must be changed by six months. This change makes the nomograms applicable throughout the world.

To Determine the Length of the Photo Day

To determine the length of the photo day in an area, the nomogram appropriate to the latitude of the area is selected. If the requirements of the contract permit photography to start at a solar altitude of 20°, the points at which the time scale intersect the date on the 20° arc gives the start and finish of the photo day. For example, using the nomogram illustrated in Figure 2, it can be seen that, on May 1, the photo day would start at 0650 and end at 1710 local solar time.

The length of the photo day for higher solar altitudes may be determined similarly by drawing the appropriate solar altitude arc and

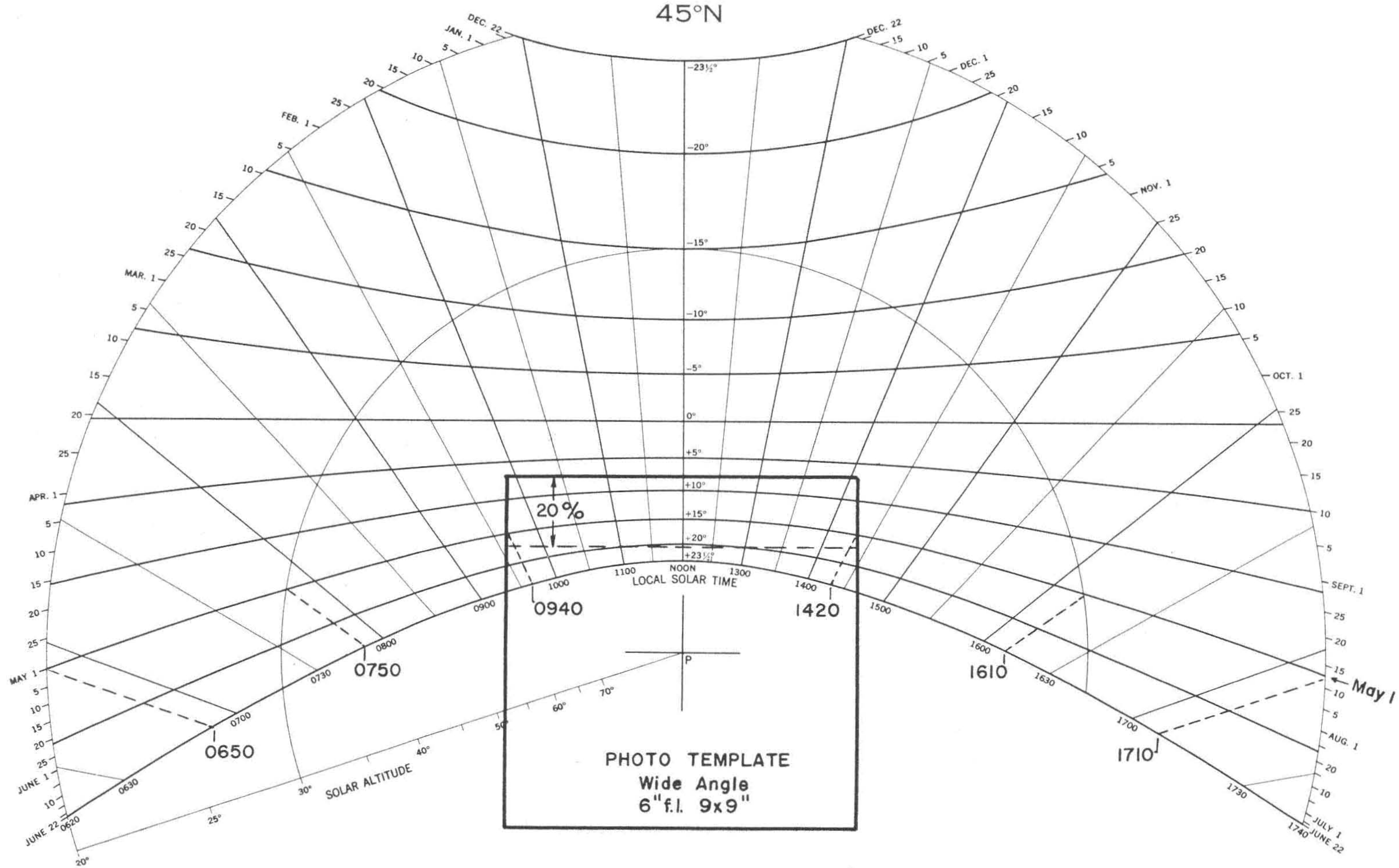

FIG. 2. A slightly reduced example of a solar altitude nomogram.

reading the time intercepts on this arc. Thus in the above example, the photo day for 30° minimum altitude would be from 0750 to 1610.

The times determined from the nomogram are converted to Greenwich Mean Time or Standard Time according to the longitude of the project area.

To Determine the Time of Entry of the "Hot Spot" Into the Field of View of the Camera

The "hot spot" or "no shadow point" in a photograph appears as a bright area lacking in detail immediately surrounding the anti-solar point. It is particularly noticeable over forested areas and presents problems in forestry interpretation. Therefore, for forestry purposes, it may be desirable to avoid its occurrence within the area of the photograph or, alternately, to ensure full stereoscopic coverage of the area affected by adjusting the end- or side-lap.

The passage of the "hot spot" across the photograph can be determined by centering a template representing the field of view of the camera at point 'P' of the nomogram. If this template is oriented to correspond to the flight direction—north being considered as the upward direction of the noon line—the time of entry and exit of the "hot spot" can be read at the points where the date line cuts the template area.

For the east-west orientation of the template indicated in Figure 2 the "hot spot" would fall within the photo area between 0940 and 1420 on May 1. It can also be seen that the area affected by the "hot spot" could be covered stereoscopically if the flight line to the north had about 20–25% side-lap with the line under consideration. If the lines of photography were oriented north-south, then an end-lap of at least 65–75% would be required to ensure stereoscopic coverage of the affected area. If mapping as well as interpretation were involved then a choice of 80% end-lap would permit alternate pictures to be discarded for the mapping operation.

To Determine the Time of Entry of the Sun's Reflection Into the Area of the Photograph

Where water areas are being photographed for hydrographic purposes the reflection of the sun's image into the camera lens can seriously diminish the amount of recorded detail in the area of the reflection.

The time of entry of the center of this reflection into the area of the photograph can be determined in the same manner as for the "hot spot" with the exception that its position is given by letting the upward direction of the noon line represent south.

The size of the area affected by reflection will vary depending on the roughness of the water and the obliquity of the sun's rays. Studies by the U. S. Coast and Geodetic Survey have indicated that the sun spot may range in size from $1\frac{1}{2}$ to 2 inches in calm water to as large as 7 inches in rough water on a 9- by 9-inch photograph taken with a 6-inch lens. Under these conditions reflections will occur well into the area of the photograph even though the center of the sun's reflection may fall outside the field of view.

A template can be constructed which will indicate the maximum area of the photograph that may be affected by solar reflections. Using such a template it is possible to plan photo flights so as to avoid the occurrence of the reflection within the photo area or, alternatively, to ensure that it is covered stereoscopically by either end- or side-lap.

Conclusion

Nomograms as described in this paper, but limited to latitudes north of 40°, have been used in Canadian air survey operations. As a result of the interest expressed in other countries by those engaged in survey operations and training, the curves were expanded to cover latitudes from the equator to 35°.

The complete set of nomograms has been published by the Surveys and Mapping Branch of the Department of Mines and Technical Surveys, Ottawa, Canada. This publication, entitled "Solar Altitude Nomograms for Aerial Photography" is available upon request and contains, in addition to the nomograms, directions for their use, a conversion table of longitude to time and photo templates for wide-angle and super-wide-angle survey cameras.

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