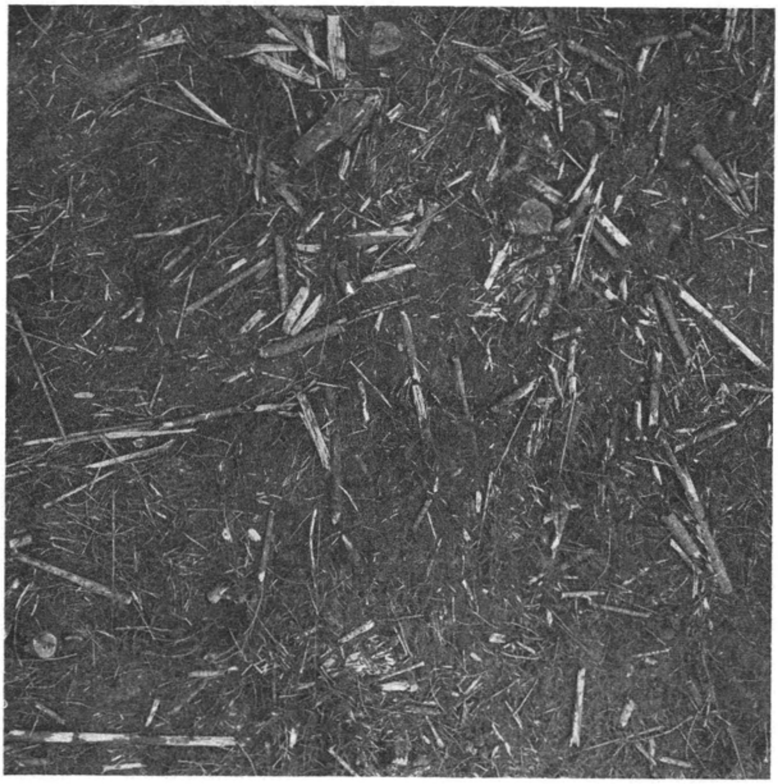

FIG. 1. Photograph from elevation of 180 feet shows 115 feet of the transect marked by a 1.2-inch tape extending from bottom to top in the picture and crossing the largest log in the upper half.

WILLIAM G. MORRIS
*Forest Service, U.S.D.A.**
Portland, Oregon 97208

Photo Inventory of Fine Logging Slash

Diameters and heights of small branches can be measured on 1 : 1,070 photographs

INTRODUCTION

IN THE DOUGLAS-FIR REGION of the Pacific Northwest, where timber is usually harvested in clearcut units, land managers need an appraisal of the fire hazard from the slash to make decisions concerning need for hazard reduction or extra protection. Rate of fire-spread depends on quantity, surface area, and spacing of fuel particles (Fons, 1946); in slash these factors are the number of branches by size classes and the mean depth of the slash. Research in progress will more precisely measure this relationship and improve hazard appraisal. As ground travel in most slash areas is slow, difficult, and somewhat hazardous, obtaining the necessary measurements of the slash components from aerial photos may prove more practicable.

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* Pacific Northwest Forest and Range Experiment Station.

ABSTRACT: *Purpose of the study was to determine feasibility of using large-scale aerial photos to classify size, quantity, and height above ground for branches 0.6 to 4.5 inches in diameter. Ground counts and height measurements of such branches made along a 500-foot line transect through logging slash from clear-cutting were a standard of comparison for similar records made from low-level stereoscopic aerial photos of the transect from elevations of 180, 280, and 500 feet. The photos at nominal scales and elevations above ground of 1:690 (180 feet), 1:1,070 (280), and 1:1,900 (500) were viewed as film positives or enlargements using viewers with different magnifications. Number of branches per 10-foot segment of transect counted on the ground and on the photos showed highly significant correlation. Correlation did not differ significantly among the three scales on film positives. The average heights of all branches measured on 1:220 enlargements and 1:690 or 1:1,070 film positives were nearly the same as the height measured on the ground. Calculated minimum diameters of branches detected on photos from the respective elevations were 0.2, 0.3, and 0.6 inches.*

Ingram (1966) has shown that logs and tops as small as four inches in diameter can be accurately measured on large-scale aerial photos. This large wood mainly obstructs fire control efforts and lengthens duration of great heat; finer components of slash determine how fast fire will spread and how intensely it will burn. The purpose of the present study was to determine, from photos similar to Ingram's, the feasibility of classifying size, quantity, and height above ground for branches 0.6 to 4.5 inches in diameter. The study showed that such classification is feasible.

METHODS

The slash, located on Vancouver Island in British Columbia, was typical of that in old-growth Douglas-fir containing considerable hemlock; it was clearcut and logged by the high-lead cable system on moderate slopes (Figures 1 and 2). It contained numerous small to medium unmerchantable logs, splinters, and chunks. Tallied branches averaged 9 per 10-foot segment of transect. Many were supported 1 to 2 feet above the ground. Many bore large quantities of fine twigs, and some still retained dead needles. Twig and needle litter, duff, rottenwood, moss, and low growing plants covered most of the ground.

To designate the single-line transect to be photographed from the air, a 500-foot length of orange plastic flagging tape 1.2 inches wide was stretched across the top of the slash. Aluminum foil markers were placed at 100-foot intervals to mark the transect for the pilot and to serve as identification and scaling points on the photos. At every 10-foot interval, a short length of flagging tape was stretched at right angles to the transect tape to mark sampling segments.

Simultaneous stereoscopic pairs of photographs of the slash were made on Kodak Tri-X 70-mm. film with 80-mm. focal-length Linhof aeroelectric cameras at the ends of a 15-foot boom suspended from a helicopter. The camera mounting was designed by E. H. Lyons (1966).

The slash was photographed under a cloudy sky which gave good lighting and few shadows among the slash components. This condition is important if one attempts to distinguish and measure branches at lower levels in jumbled groups.

The photographs were repeated at the following nominal scales and elevations in feet above ground: 1:690 (180 feet), 1:1,070 (280), and 1:1,900 (500).

All the branches were then tallied on the ground within each 10-foot segment of transect that lay beneath the tape, i.e., intersected the vertical plane of the transect. The tallies were by 1-inch diameter classes ranging from 0.6 to 4.5 inches at the point of intersection. The diameters were estimated but were occasionally checked with measurements. In each 2-foot interval of transect, the height above ground was measured for the highest branch that was 0.6 to 2.5 inches in diameter.

To compare branch counts and measurements made from the photographs with those made on the ground, the interpreter followed

FIG. 2. Ground view of the same part of the transect as in Figure 1 showing the large log in the distance.

the image of each 10-foot segment of transect tape and counted the intersections of branches according to their diameter class. He laid a reticle with 0.1-mm. divisions on the photograph and used a table of equivalent photo and ground dimensions to measure diameters. With a little practice he could separate most of the material into diameter classes by estimate, and needed to measure only a few branches as a check.

To determine practicable and reliable methods for counting branches by size classes, 11 different combinations of camera elevation, photo print scale, stereoscopic viewer and magnification, branch size classes, and interpreter were tried (Table 1). Increasing magnification facilitated measurement of diameters with the 0.1-mm. units of the reticle because they likewise were magnified. As shown by the hand-lens tests, stereoscopic viewing was not essential for recognition and classification of branch images, but it facilitated keeping one's place where they were closely spaced. Interpreters preferred using the pocket stereoscope but often used a 10X hand lens to check diameters.

In addition to branch counts, interpreters also recorded branch heights. On the 1:220-scale enlargements of the 180-foot photos within each 2-foot interval of transect, interpreters measured with a parallax bar the height above ground of the highest branch that was 0.6 to 2.5 inches in diameter at the measuring point on the transect planes. This procedure proved impracticable at the smaller scale of the film positives. However, on film positives for the 180- and 280-foot elevations, the interpreter was able to estimate similar branch heights in each half of each 10-foot segment of the transect by com-

TABLE 1. CORRELATION COEFFICIENTS (*r*) OF GROUND AND PHOTO COUNTS OF NUMBER OF BRANCHES BY THREE DIAMETER CLASSES IN 10-FOOT SEGMENTS OF GROUND TRANSECT FOR DIFFERENT SCALES, EQUIPMENT, AND INTERPRETERS TABULATED WITH AVERAGE NUMBERS OF BRANCHES COUNTED

Scale, Elevation, and Kind of Print	*Viewing Equipment*[1] *& Magnification*	*Interpreter*	*Diameter Classes*						*No. of 10-foot Ground Segments*
			0.6–1.5 inches		*1.6–4.5 inches*		*0.6–4.5 inches*		
			r[2]	*Ave. no.*	*r*[2]	*Ave. no.*	*r*[2]	*Ave. no.*	
1:220 (180 ft.)									
Glossy enlargement (3.1 ×)	Pocket, 2 ×	B					0.52	12.8	50
Glossy enlargement (3.1 ×)	Mirror, 2 ×[3]	C	0.47 (a)	11.7	0.50 (a)	3.8	0.48	15.5	50
Glossy enlargement (3.1 ×)	Mirror, 4.5 ×[3]	A	0.51	9.1	0.41 (b) (c)	5.0	0.42 (a)	14.1	50
Glossy enlargement (3.1 ×)	Mirror, 6 ×	B	0.73 (a)	7.3	0.78 (a) (b)	2.7	0.70	10.0	50
Glossy enlargement (3.1 ×)	Hand lens, 10 ×	B					0.51	11.9	40
1:690 (180 ft.)									
Film positive[4]	Mirror, 9 ×	A	0.53	6.0	0.60	3.8	0.68	9.8	50
Film positive[4]	Mirror, 9 ×	B	0.52	4.6	0.65	4.0	0.62	8.6	50
1:1,070 (280 ft.)									
Film positive[4]	Mirror, 9 ×	A	0.48	6.3	0.68	3.5	0.69	9.8	50
Film positive[4]	Mirror, 9 ×	B	0.62	5.7	0.74 (c)	3.1	0.70	8.8	50
1:1,900 (500 ft.)									
Film positive[4]	Mirror, 9 ×	A					0.82 (a)	8.9	30
Film positive[4]	Mirror, 9 ×	B					0.64	7.9	30
Ground count				5.7		3.6		9.3	50

[1] All equipment except the hand lens was stereoscopic. The mirror stereoscope was manufactured by Old Delft.

[2] All *r*-values are significant at the 0.01 level. In a given diameter class, those differing from each other in the *t*-test at the 0.05 level are followed by the same letter in parentheses.

[3] Viewed by transmitted light from light table to avoid reflections.

[4] Kodak aero duplicating film.

paring the measured or estimated diameter of a nearby log.

RESULTS

Branch counts

Table 1 gives coefficients of correlation between ground and photo counts of branches by 10-foot segments of transect. It also gives average numbers of branches per segment counted on the ground and photos. All coefficients differed significantly from 0 as judged by the 0.01 probability level; thus the ground and photo counts were undoubtedly related. Even though all relationships were statistically highly significant, some were weak.

To determine if any given scale, equipment, or interpreter gave significantly higher correlation than another for counts of the same diameter class, differences were tested by t at the 0.05 level. Those differing significantly are designated in Table 1. Correlation did not differ significantly among the three scales or between the two observers tested on film positives. Although differences in viewing equipment and lighting did not permit equal tests of enlargements vs. film positives, coefficients for observer *B* using 6× magnification on enlargements and 9X on film positives suggest no difference in the effect of kind of print. The low correlation coefficients and excess average numbers counted with transmitted light show that this lighting gave both inconsistent and biased results. For the counts on film positives, the trend in correlation coefficients, though not significant, suggests higher correlation in counts of the larger diameter limbs.

After the branches were counted, some of the smaller images were measured under higher magnification to estimate the minimum size of objects reproduced by the photos. The image of the 1.2-inch tape marking the transect was distinct on the smallest scale photos (1:1,900). Its image on the low-elevation film positives measured with 100× magnification proved to be 0.0007 inch wider on the film than it should be, thereby appearing to be 1.7 inches in width. On the higher-elevation photos it likewise showed an excess width of 0.0007 inch or more, which was a greater proportion of the narrower image width. Factors involving camera vibration, camera geometry, lens, film, and photo-processing probably produced this bias. (Flight was parallel to the tape.) The same bias would affect width of branch images. Such errors were assumed to be nearly constant in units of width and therefore an increasing percentage of diameter for the smaller branches and smaller scale photos. With 0.0007 inch used as a constant addition to width of all images on all negatives, the bias in ground dimensions was as follows for each elevation: 180 feet, 0.5 inch; 280 feet, 0.7 inch; 500 feet, 1.3 inch. Thus on the 180-foot photo, a limb that scaled 1 inch was actually 0.5 inch on the ground.

Many of the very small images of branches were measured with 50× magnification on the film positives for each elevation. The prevailing minimum was 0.001 inch in diameter at all scales. As this diameter was likewise corrected for the 0.0007-inch bias and multiplied by each photo scale number, the result for each elevation was: 180 feet, 0.21 inch; 280 feet, 0.32 inch; 500 feet, 0.57 inch. These are the corrected ground sizes for the prevailing minimum sizes seen on the photos under 50× magnification.

Branch heights

Average heights of branches above ground recorded to the nearest 0.1 foot on the ground and from the 180- and 280-foot elevation photos are shown in Table 2. As previously described, heights from the enlargements were measured with a parallax bar, but those from film positives were estimated by comparison with log diameters. Branches measured on the photos were not necessarily the same ones measured on the ground, because

TABLE 2. AVERAGE HEIGHT[1] OF BRANCHES MEASURED ON THE GROUND AND FROM THE PHOTOS FOR SEVERAL COMBINATIONS OF PHOTO AND INTERPRETER FACTORS

Camera Elevation	*Kind of Print*	*Scale of Print*	*Mirror Stereoscope Magnification*	*Interpreter*	*Average Height (feet)*
180 feet	3.1× enlargement	1:220	2×[2]	C	1.8
			4.5×[2]	A	1.5
	Film positive[3]	1:690	9×	A	1.5
280 feet	Film positive[3]	1:1,070	9×	A	1.5
Ground measurement					1.5

[1] Measured on enlargements (parallax bar); estimated on film positives by comparison with log diameters. Basis 91 branches for ground measurements, 84 for parallax bar, 42 for estimates.

[2] Viewed by transmitted light from light table to avoid reflections.

[3] Kodak aero duplicating film.

those selected depended on an estimate or measurement of the diameter class and subdivision of the 10-foot segment of transect. Height measurements and estimates on the photos were affected by judgment of the ground level. At many points, the ground was hidden by litter or coarse debris and was very uneven.

Discussion and Conclusions

With good quality aerial photos from equipment equivalent to that used in this study, interpreters can distinguish and count nearly all branches larger than a given minimum diameter in recent cable-logged slash which has dropped most of its needles. Calculations and trial on one area indicate that the minimum diameters for given negative scales and photo elevations with an 80-mm. lens are approximately as follows: 1:690 (180 feet), 0.2 inch; 1:1,070 (280 feet), 0.3 inch; 1:1,900 (500 feet), 0.6 inch. Given these minimum diameters, any of the combinations of photo type, scale, and viewing equipment listed in Table 1 is suitable for counting branches. The lighting must be adequate for photography and evenly dispersed as provided by a cloudy sky to outline the branches in jumbled groups and deeper recesses.

From photos at the two lower elevations, interpreters can readily measure and estimate image diameters of branches by two or more classes. In application, estimates of average numbers of limbs by diameter classes could be improved by double sampling in which a regression of ground counts on photo counts in a sample area is used to adjust the estimated numbers obtained from extensive photo counts.

This test lacked precision in comparison with photo measurements and actual diameters of branches for two reasons: (1) most of the ground recorded diameters were estimates by 1-inch classes, with occasional measurements of borderline cases; (2) as the transect was not on the center line of all photos, the photo view of branches in line with the tape was not exactly vertical and may have differed from the vertical ground view and measuring point.

Because the image of the 1.2-inch tape indicated a bias in the scaled width, future similar studies and practical applications of these would be facilitated if standard objects such as slats or dowels equal to the diameters bounding the necessary classes were placed at several points along the transect before the photos are made. These would give calibration measurements for the interpreter's scale and for his ocular estimates.

With stereoscopic photos, interpreters can determine the average depth of slash either by measurement with a parallax bar on 1:220 scale paper images or by estimates based on measured diameters of log images on smaller scale photos down to at least 1:1,070 scale.

If a 9× magnification stereoscopic viewer is available, film positive prints from a 280-foot elevation (1:1,070 scale) give more economical photography than the larger-scale prints listed in Table 1 and still allow height estimates and counts of branches by two diameter classes from approximately 3/4 to $4\frac{1}{2}$ inches.

Large-scale aerial photographs can provide a practicable substitute for slow, difficult, and somewhat hazardous ground counts and measurements of branches for appraising forest fire hazard in logging slash. With the aid of further studies of slash on the ground, these counts and measurements can undoubtedly be translated into slash volume or weights by size classes (Van Wagner, 1968).

Acknowledgments

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H. G. Lund and N. R. Munn, Pacific Northwest Forest and Range Experiment Station, made many of the interpretations and measurements.

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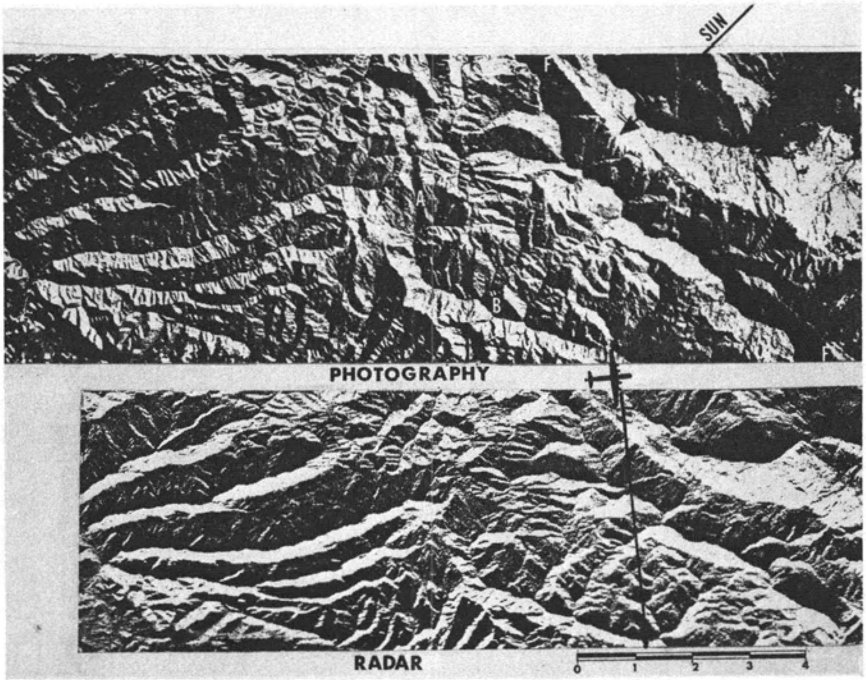

FRONTISPIECE. Low Sun-Angle Photography (LSAP), top, with Side-Looking Radar (SLAR) below. Sun azimuth as shown at 27° elevation, Radar illumination almost normal to strip. A strong "Fault" lineament is shown as *F–F*, a curvilinear structure at *A–B*. Scale is in miles.

R. J. P. LYON*
JOSE MERCADO†
ROBERT CAMPBELL, JR.‡

Pseudo Radar

Very high-contrast aerial photographs at low sun angles aid in the analysis of structural geology.

INTRODUCTION

SEVERAL PUBLISHED papers (Hackman, 1967, *a*, *b*; Wise 1968, 1969) have emphasized the advantageous effect of illuminations at a low angle above the horizon, on the geological interpretation of vertical aerial photography.

As a class exercise in "Geologic Remote Sensing" at Stanford in January, 1969, similarities between *K*-band side-looking radar (SLAR) and conventional aerial photography were explored for *geological* interpretational purposes. This reinforced the idea that the use of a low sun-angle,* when combined also with an increase in the γ-contrast of the prints, could reproduce some of the features of radar imagery (like topographic shadowing, deep black shadows, etc.), that make SLAR imagery so interesting to the geoscientist.

Out of this study came the plan to fly new photography, along a line previously over-

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* Stanford University, Stanford, Calif. 94305
† J. Mercado Aerial Surveys, 3652 Highland Ave., Redwood City, Calif. 94062
‡ Graduate Student, now with the U.S. Coast Guard.

* Considered equivalent to "solar altitude," "angle of illumination," or "low angle solar illumination."

ABSTRACT: *An analysis of side-looking,* K-*band radar imagery indicated that most of its geological usefulness came from (a) its small-scale presentation (around 1:200,000), and (b) its strong, jet-black shadows, which markedly emphasized the topographic relief. Several published papers have emphasized the effect of low sun-angle on the appearance of vertical aerial photography, so we developed from this a technique for simulating side-looking radar (SLAR) by conventional aerial photography, but with the sun around 20–30° above the horizon. It is proposed that this unconventional type of aerial photography be termed Low Sun-Angle Photography (LSAP).*

flown† by the *K*-band SLAR aircraft. This backwards-sounding approach was necessitated by the relatively small amount of SLAR imagery available, but, more specifically, by the very low percentage of that available, which is flown in California, having a suitable azimuth angle for simulation by this new technique.

We selected a 250-mile-long flight line from near Patterson in the California Central Valley, on a bearing of 284° towards Hayward on the East Bay just south of Oakland (Figure 1). Segments of this were re-flown during a 7-day period while we evaluated flight-exposure changes and dark-room procedures for optimum simulation of the specific grey-scale rendition of SLAR (see Figure 2 and Table 1). We have chosen a 16-mile segment to illustrate here as the Frontispiece.

Table 2 and Figure 3 were prepared to help plan other missions. Both are for the local San Francisco Bay area (approx. 40°N latitude) but other variations for different localities can be simply prepared. Table 2 lists the elevations for the sun in a seasonal matrix.

Figure 3 is to be used also to provide the solar azimuth. It is an upper hemisphere equal-area projection showing (as dots) the projections of the solar position for the summer and winter solstices (maximum variability). The shorter dotted lines are equal (standard) time arcs and the specific sun track for March 17 is shown. Elevation angles are measured off the projection by conventional techniques of revolving a tracing of

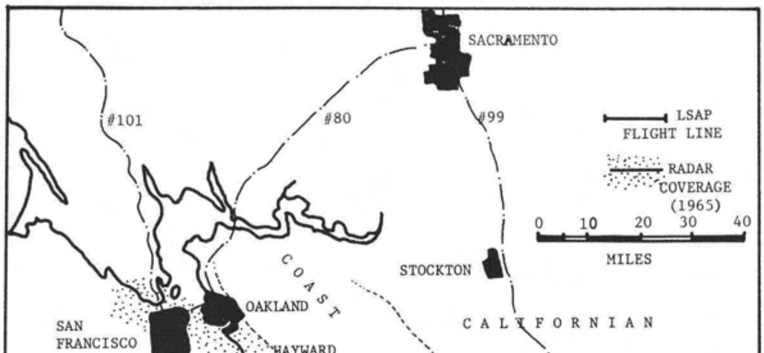

FIG. 1. Location Map of area flown for Low Sun-Angle Photography (LSAP) flight.

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† Imagery flown by Westinghouse Aerospace Corporation for the U.S. Geological Survey under a NASA Contract, and made available to us by the USGS.

TABLE 1. EXPERIMENTAL PARAMETERS

Equipment:
1. Camera: K17B, with 6-inch Metrogon lens minus blue filter
2. Film Type: Plus-X Aerographic
3. Aircraft: Piper Apache—(P.A. 23–160) Turbocharged.
Pilot—Jose Mercado
Photographic Assistant — Robert Campbell, Jr.

Altitude: 20,000 feet Conventional vertical photography with 60 percent overlap
1:40,000 scale on the negative

Date Selected: March 17, 1969, 1530–1600 hours (see Table 2).
Solar Altitude: 27° above horizon (rate of change 10°/hour)
Solar Azimuth: approximately 241° true
Flight Azimuth: 284° true

Exposure: Several flight tests were made, and, based upon the target color (dark green) a value of "2.5 stops over-exposed" was chosen, so as to bring the highlight density within the middle of the straight line portion of the characteristic *H&D* curve.

Laboratory: Used *High-Contrast* developer, specially developed by one of us (J.M.) to increase the γ above the 2.2 maximum possible with D-19 developer (see Figure 2). Contact prints for the *first mosaic* (1:40,000) were made on No. 4 Kodak Resisto Rapid paper using the maximum exposure to get detail into the highlights.

Final Mosaic: Optical reduction of the first mosaic to an arbitrarily selected 1:86,000 scale was made with a copy camera on very-high contrast Ortho film. At this stage one could control percent-density *drop-off*. Final prints then were contact-printed from these high contrast negatives, and assembled to form the original of Figure 3.

this to the N-S line and directly reading off the elevation.

ANALYSIS

SIMILARITIES

The following points of similarity were noted:

- Both methods utilize a strong illumination source, and measure the energy reflected back from the target.
- Both methods emphasize the third-dimension by heavy, black shadowing. Accordingly, a relationship exists (for both) as to topographic relief and the optimum shadowing angle required. Hackman (1967) had found this to be about 20° for average, hilly terrain (Appalachian Mountains).

DIFFERENCES

The following differences were noted:

- ⋆ The radar beam fans out in a plane normal to the flight-line, making shadow lengths on the surface below which increase with increasing range from the aircraft. For mid-range, 30° is one useful approximation for this shadowing angle. The shadowing angles in radar imagery vary from 70° at near-range to about 18° or less at the far-range limit, whereas the sun's rays are essentially parallel to all points in a field of view beneath the aircraft. (The section from about 30° to 20° illumination has been used in Figure 3, that is 52 percent of the radar ground swath at the low angle edge.)
- ⋆ Extensive electronic equipment is required in the SLAR aircraft, which also has to be equipped with the radar antennas. On the contrary, any light-aircraft may be used for this photographic technique as long as it can reach a high enough altitude for the small-scale photography required, and can carry the camera.
- ⋆ Photographic geometry is well understood, whereas SLAR geometry is complicated both by the slant-range presentations and the differing *down-flight* and *down-range* resolutions (Moore, R. K., 1969).
- ⋆ Both original photos and final prints (for the radar-like mosaic) retain full stereo, if this aspect of viewing is desired for further detailed study. The original photos still show reasonable detail in the shadows, but this has been lost (intentionally) during the final re-copying steps used in degrading the photography to simulate the radar image.
- ⋆ Radar shadowing can emphasize any preselected direction of topography, provided enough (3 to 4) flight directions around the target are used, whereas sun angles can only be

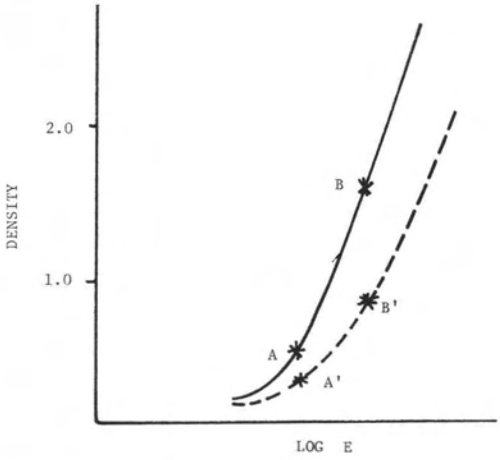

FIG. 2. Approximate curves obtained on Plus-X Aerographic film. Points *A* and *B* are the brightness ranges of dark green foliage with High Contrast developer (modified D-11, Solid Line, and *A'* and *B'* are the same points for D-19 (dashed curve).

TABLE 2. ACTUAL VERTICAL SUN ANGLES FOR OPTIMUM LSAP AT LATITUDE 40°N

	1800 *0600*		*1700* *0700*		*1600* *0800*		*1500* *0900*		*1400* *1000*		*1300* *1100*		*1200*
Dec. 21								17	21	23	25	26	27
Dec. 5 Jan. 5								18	22	24	27		
Nov. 20 Jan. 20							16	20	24	26			
Nov. 4 Feb. 5						16	20	23	27				
Oct. 20 Feb. 20					14	19	24						
Oct. 5 Mar. 7						18	23						
Sept. 20 Mar. 22					17	23							
Sept. 5 Apr. 6				15	21	27							
Aug. 20 Apr. 22				19	25								
Aug. 5 May 7			16	22									
July 21 May 22			18	24									
July 6 June 26			20	26									
June 21			21	26									

After Eastman Kodak (1966)
NOTE: Azimuth changes must be taken into account.

chosen from a finite set of azimuth and elevation angles. For example, low sun shadowing from the north is clearly impractical in the northern latitudes (above 23°N).

★ The sun angle *and* azimuth are always changing with time (around 10° per hour for this study) and, hence, these rates must be considered in scheduling the flights. On the other hand, radar shadow angles will always vary from near range to far range over about a 50-degree spread.

GEOLOGICAL ANALYSIS OF THE LOW SUN-ANGLE PHOTOGRAPHY

Analysis of the structural geology of an area often consists of identifying as many linear elements as possible in a set of aerial photographs. Traditionally these are observed under stereoscopic examination and then marked by wax pencil. This new method seeks to emphasize these same linear features by (1) accentuating the shadows they throw, under low illumination, and (2) by increasing the blackness of the shadows themselves by λ-increase in the photographic steps. Radar shadows are long, and black, as the atmosphere shows no scattering of the K-band radar under non-raining conditions.

The Frontispiece shows these two enhancing systems in a comparison. Photography (top) and radar (below) clearly both show the fault (FF) across the right-hand corner, and the 3 or 4 well-developed ridges in the left-hand corner.

The inverted *fish hook-like* curvilinear feature (AB) just right of lower center appears

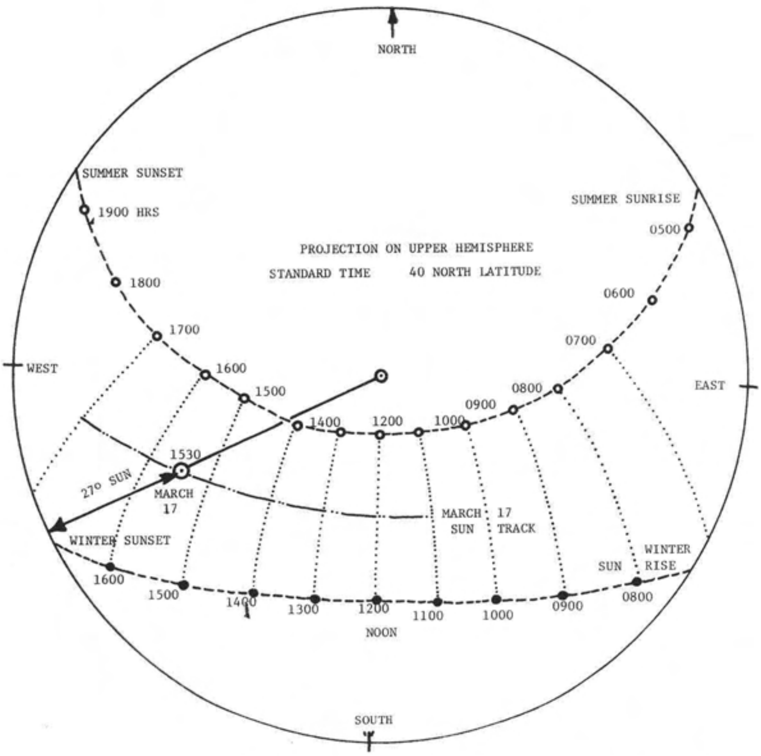

FIG. 3. Upper Hemisphere projection for 40°N, Standard Time, and showing calculation for March 17 flight, 1530Hrs.

well on both views, but the strongly shadowed linear, passing vertically up the photographic print at *A*, is not seen at all on the radar image. In a comparable manner a whole family of small linears striking roughly parallel to *A* may be seen on the photography, and are absent on the radar. These features are almost exactly *parallel* to the radar beam and, hence, are not accentuated. They happen to be at a *different* angle to the sun and are so emphasized.

Clearly, the method is not a *cure-all*. One should plan the use of the sun in azimuth, as well as in elevation, to enhance the lineations (see Figure 3). If north-south linears are present, one should use the dawn or dusk sunlight; if east-west, the winter sun, and so on. Above all, one should *plan* to use *several* illumination angles.

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