Gordon R. Heath
Aerospace Systems Division
Lockheed Electronics Co.
Houston, Texas

Hot Spot Determination

A solution to the hot spot problem is presented with tables and graphs to aid in planning photographic missions.

Abstract: *Hot spots pose serious problems in the photography of forested areas, where color films are used and high sun angles are encountered. A hot spot, when applied to aerial photography, is a bright reflection 180° away from the direction of the sun. Aerial photographers operating in the southern tier of the states in this country, and in the tropics, need to be aware of the hot spot problem and its solution. It is important to avoid this exposure anomaly if high quality products are desired for analysis by photometry and densitometry. The hot spot phenomenon has received very little attention by aerial photographers largely because it is most troublesome over forested area in latitudes where the sun angle is high, such as in the Houston area. A sun altitude nomogram may be used to graphically compute the hot-spot-free time. The paper presents as an example a solution for 30° latitude areas, but similar solutions can be easily worked out for other latitudes. A table and graphs of hot-spot-free times are presented and these can be used to plan photographic missions. Small amounts of hot spotting can occasionally be tolerated for mosaic purposes, and directions are given for computing permissible amounts. Hot spot and sun reflections also affect the data from electro-optical scanners, but this is beyond the scope of this paper.*

Introduction

The computations shown here for locating the hot spot area have been developed for the Houston vicinity, but it is a relatively easy task to work them out for other locations. It is particularly important that aerial photographers in the southern tier of states in this country, and in the tropics, be aware of hot spot problems and their solutions, because hot spots are only troublesome in high sun-angle areas. It is increasingly important to secure high quality color photography free from exposure anomalies, so that scientific analysis, by means of photometry and densitometry, may be conducted. This type of analysis is leading toward one of several automatic interpretation methods, an important goal for earth resources investigators.

A serious problem in securing high quality aerial photography over forested areas is the damage which "hot spots" may do to the photography. A "hot spot," when applied to aerial photography, may be defined as an elliptical area of bright reflections which appears on vertical aerial photography at the antisolar point, 180° from the direction of the sun.* The hot spot appears at the same vertical angle from the principal point of the photography as the solar reflection point, although in the opposite direction. These angular relationships are shown in Figure 1. At the center of the hot spot is a point, where the strongest reflections occur, which is also called the "no-shadow-point." The

* The term "hot spot" is an unfortunate choice for a number of reasons. Instead of a spot it is a wide area of high reflectiveness around a central hot spot. The term is also used by photographers as a synonym for a highlight. However, since the term has been used in the photogrammetric literature (see References 3, 4, and 5), it is continued here to prevent confusion. A better term would have been "retro-reflection," a term recently adopted by researchers in aerospace optics. This new term is used here only to identify the reflective area around the hot spot.

shadow of the photographic aircraft is occasionally visible in the center of this point. This phenomenon is particularly noticeable on photography of forest areas, because of the shadows of the trees, as well as the overall dark color of the foliage, make the forested areas appear much darker than most of the other terrain features, as shown in Figure 2. The tree shadows in the no-shadow-point are blocked out because they fall directly behind each tree and cannot be recorded by the camera. If all the shadows in one area are blocked out, this area then appears lighter than its surroundings. Not all the high reflectivity in the hot spot area is due to lack of shadows, however. There is also an actual increase in reflectivity where there are no trees to cast shadows. This effect is apparently caused by solar energy backscatter, but the physical relationship between the target, the atmosphere, and the camera are not well understood. There are many similarities between hot spots and two phenomena which have been observed by meteorologists for years, called heiligenschein and anti-corona (or glory).[1] Meteorologists explain both these phenomena as caused by diffraction through water droplets. However, the same effect has been observed in lunar photography taken by Apollo astronauts as they circled the moon.[2] The phenomena therefore cannot be explained by a water droplet theory, but it may be one or both of these phenomena, nevertheless.

The hot spot phenomena appears most often on aerial photography when wide angle cameras are in use. It is also more troublesome when color IR film is in use, because the exposure latitude of this film is narrower than that of normal color or of black and white films, and any change in brightness is emphasized. There is also a large amount of infrared light reflected by hot spots, as will be shown later. Because hot spots present problems mainly under this rather narrow set of conditions, the phenomenon has received very little attention by aerial photographers. There have been only three publications in the photogrammetric literature devoted to this subject. In Subchapter 2.2 of the *Manual of Color Aerial Photography*,[3] there is an article on this subject by E. A. Fleming, entitled *Solar Altitude Nomograms*, and there is an abbreviated version by Fleming of the same information in Photogrammetric Engineering.[4] The problem was first called to the attention of the aerial photography community in 1953 by Mason.[5] In these treatments hot spots were described as spots or points only, and no mention was made of the wide area of high reflectivity around them, which is now called "retro-reflection."* Therefore, in the discussion that

* There apparently has been little or no communication between aerial photographers, astrophysicists, meteorologists, and optical researchers on this subject. Each discipline uses different terminology, and they do not refer to each other's work in their publications.

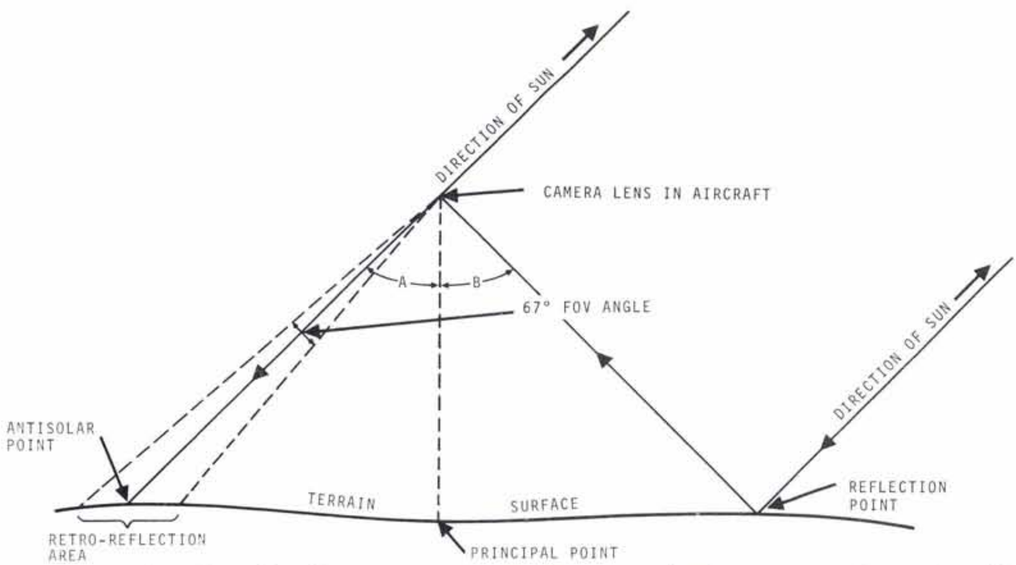


FIG. 1. Angular relationships between sun, camera, hot spot, and reflection point. Angles A and B are equal.

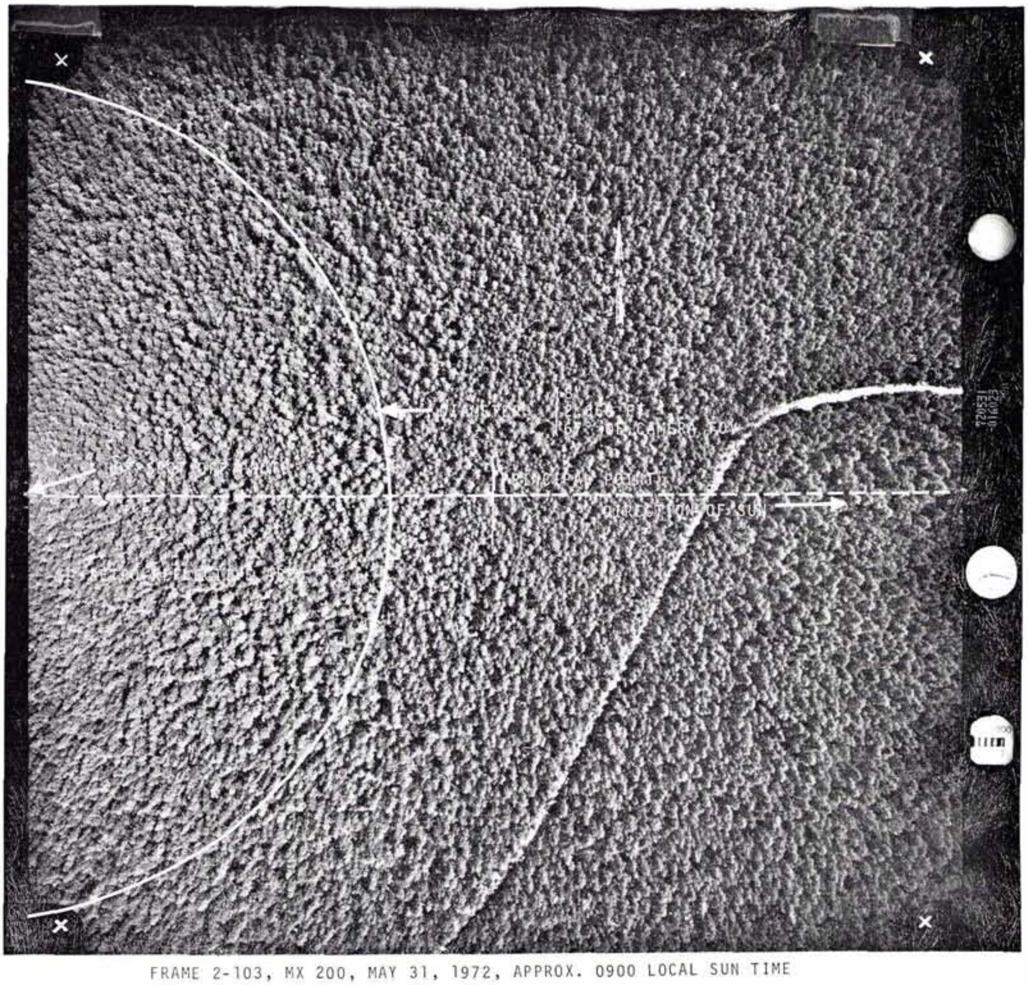
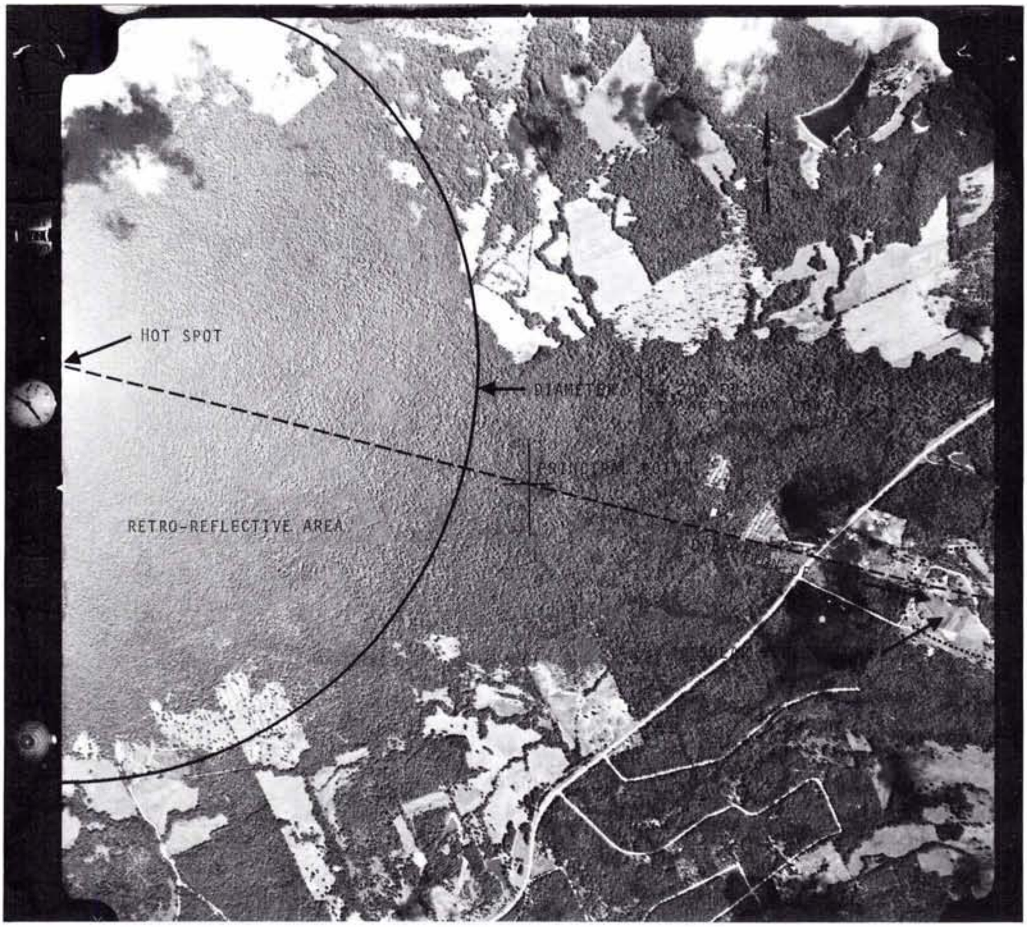


FIG. 2. Vertical photo taken by NASA C-130 over Sam Houston National Forest from an altitude of 2,000 feet. The camera was a 6″ f.l. Wild RC-8 with 2443 color IR film.

follows a strong distinction is made between the hot spot and the retro-reflective area, with emphasis on the latter. It is the purpose of this paper to give directions for determining the size of the retro-reflective area, and for planning photographic missions so that retro-reflections may be avoided or minimized.

Computation of Time Limits

Observation of representative retro-reflections on photography taken with a 6 inch focal length RC-8 camera at 2,000 and 10,000 feet altitude, shows that the retro-reflective area is approximately 67° from edge to edge with respect to the geometry of the camera. (See Figure 3 for an example taken at 10,000 feet). This is an approximate figure because retro-reflection gradually decreases in intensity toward the outer edge, and the amount of contrast in the photographic print influences its size. The RC-8 camera has a field of view (FOV) of 91°, therefore the retro-reflective area is slightly more than half the size of the field of view, or 8 inches in diameter on a 9×9 format. (Since the ellipse of the retro-reflective area is nearly circular when it is viewed in vertical photography, it is treated as though it were a circle in this paper). The same diameter dimension relationships hold true for cameras with other focal lengths, because the physical cause of the phenomenon is independent of the camera. However, the angular relationship varies with the focal length of the cam-



FRAME 2734, MX 182, AUG. 8, 1971, 0930 LOCAL SUN TIME

FIG. 3. Vertical photograph taken by NASA C-130 over the Sam Houston National Forest from an altitude of 10,000 feet. The camera was a 6″ f.l. Wild RC-8 with 2443 color IR film.

era. For example, if the focal length doubles the angle subtended by the diameter of the retro-reflective circle doubles. Such a camera would be the 12 inch focal length Zeiss camera.

The following computations hold true for photographic missions flown with a 6 inch focal length camera between 2,000 and 10,000 feet, and they are approximately valid up to 20,000 feet. For higher altitudes the angular diameter decreases in size, as shown in Figure 4. To make a graphical solution possible for 2,000 to 20,000 foot altitudes, a template was drawn representing a 67° diameter circle for placement over the solar altitude nomogram published in the previously mentioned manual. (See Figure 5) The template for the camera is first placed over the principal point of the nomogram for the area to be surveyed. For this discussion the 30° latitude nomogram was used because this is the latitude of the Houston Area Test Site.

The retro-reflective area template is then placed with its center point A on the date line of the nomogram in question. The circumference of the circle is permitted to touch the edge of the frame of the camera template, with the line B passing through the principal point. The time on the date line of the nomogram at point A is then read. This is the time when the retro-reflective area is just outside the frame. A series of these times was determined graphically, and they appear

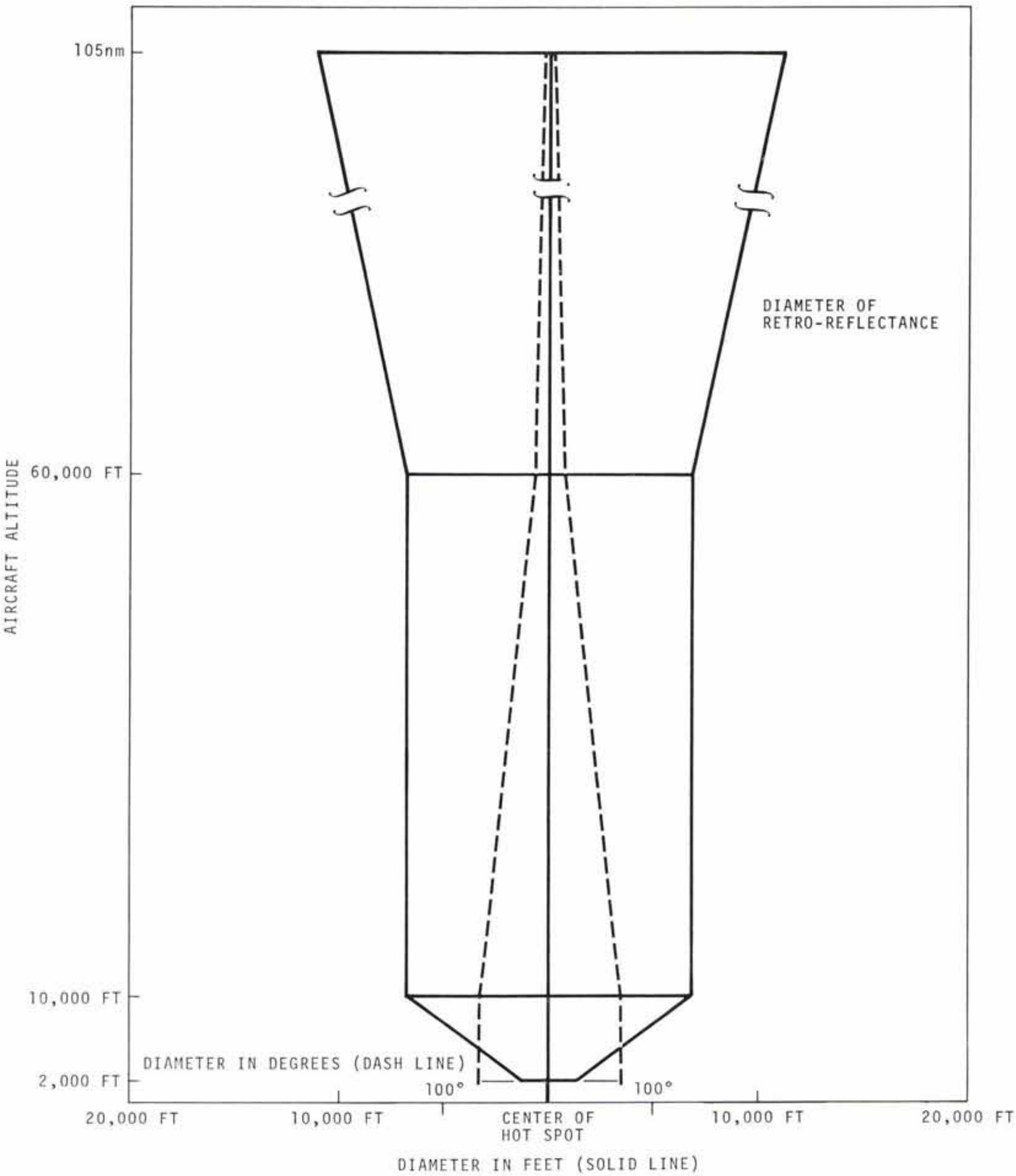


FIG. 4. A graph of the size of retro-reflections recorded from varying altitudes for 6″ focal length cameras, or the equivalent.

in Table 1 and plotted as graphs in Figures 6 and 7. All times are local sun times and they can be converted to standard time by use of the following formula:

$$\textit{Standard Time} = \textit{Solar Time} + \frac{\textit{Local Longitude}}{15}$$

These graphs also show the times when the sun is 30° above the horizon, the lower limit generally accepted by aerial photographers for good photography. These graphs can be used to determine hot-spot-free flying time. This presents severe restrictions in the Houston area because flying time is reduced to an hour in the morning and an hour in the afternoon, except for the low sun angle period from November 10 to February 1, when the RC-8 camera is to be used. Flying time

TABLE 1. TIMES WHEN SUN IS 30° ABOVE HORIZON AND RETRO-REFLECTIVE AREAS WILL APPEAR ON PHOTOGRAPHY OF HOUSTON AREA TEST SITE

	30° above Hor.	*RC-8*	*Zeiss*
Jun 22	0730–1630	0825–1535	0910–1450
Jul 22	0740–1620	0830–1530	0920–1440
Aug 13	0747–1613	0840–1520	0925–1435
Aug 27	0755–1605	0850–1510	0930–1430
Sep 10	0810–1550	0900–1500	0940–1420
Sep 24	0820–1540	0905–1455	1000–1400
Oct 6	0835–1525	0910–1450	1030–1330
Oct 20	0845–1515	0930–1430	
Nov 4	0915–1445	1000–1400	
Nov 22	0945–1415		
Dec 22	1005–1355		
Jan 21	0945–1415		
Feb 10	0915–1445	1000–1400	
Feb 23	0845–1515	0930–1430	
Mar 8	0835–1525	0910–1450	1030–1330
Mar 20	0820–1540	0905–1455	1000–1400
Apr 3	0810–1550	0900–1500	0940–1420
Apr 16	0755–1605	0850–1510	0930–1430
May 1	0747–1613	0840–1520	0925–1435
May 21	0740–1620	0830–1530	0920–1440
Jun 22	0730–1630	0825–1535	0910–1450

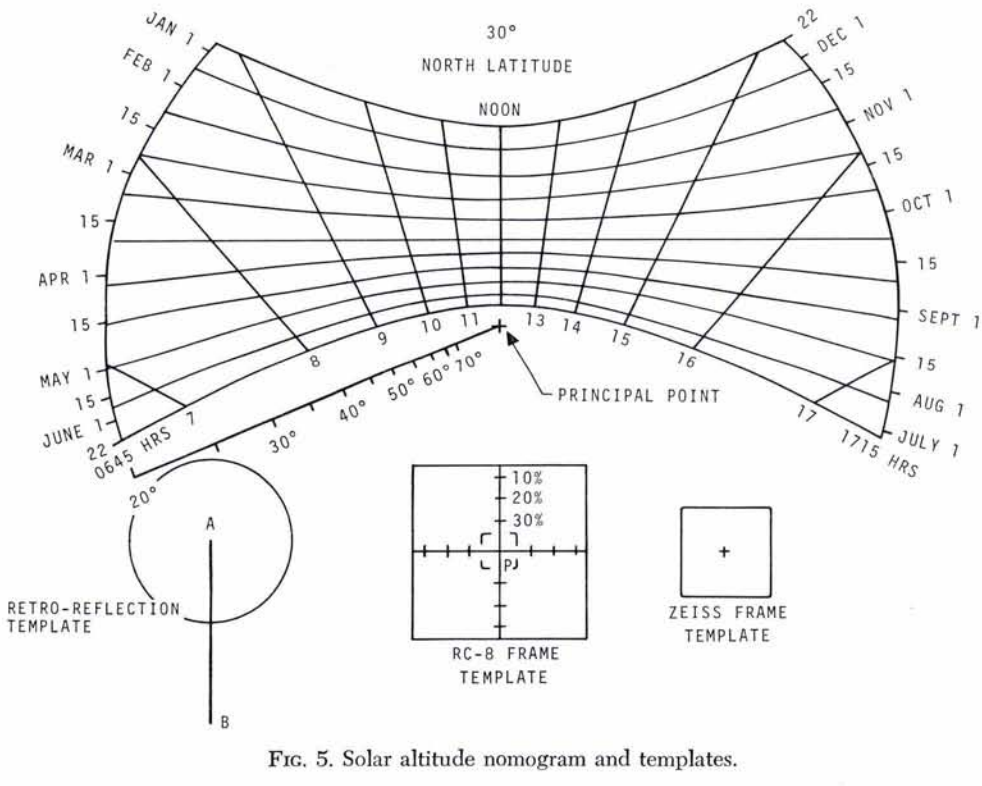


FIG. 5. Solar altitude nomogram and templates.

is only slightly longer for the longer length Zeiss camera. There is a one and a half hour period in the morning and the same in the afternoon, except for October 1 to March 5, when the sun is low enough to present no problems. These times may also present a

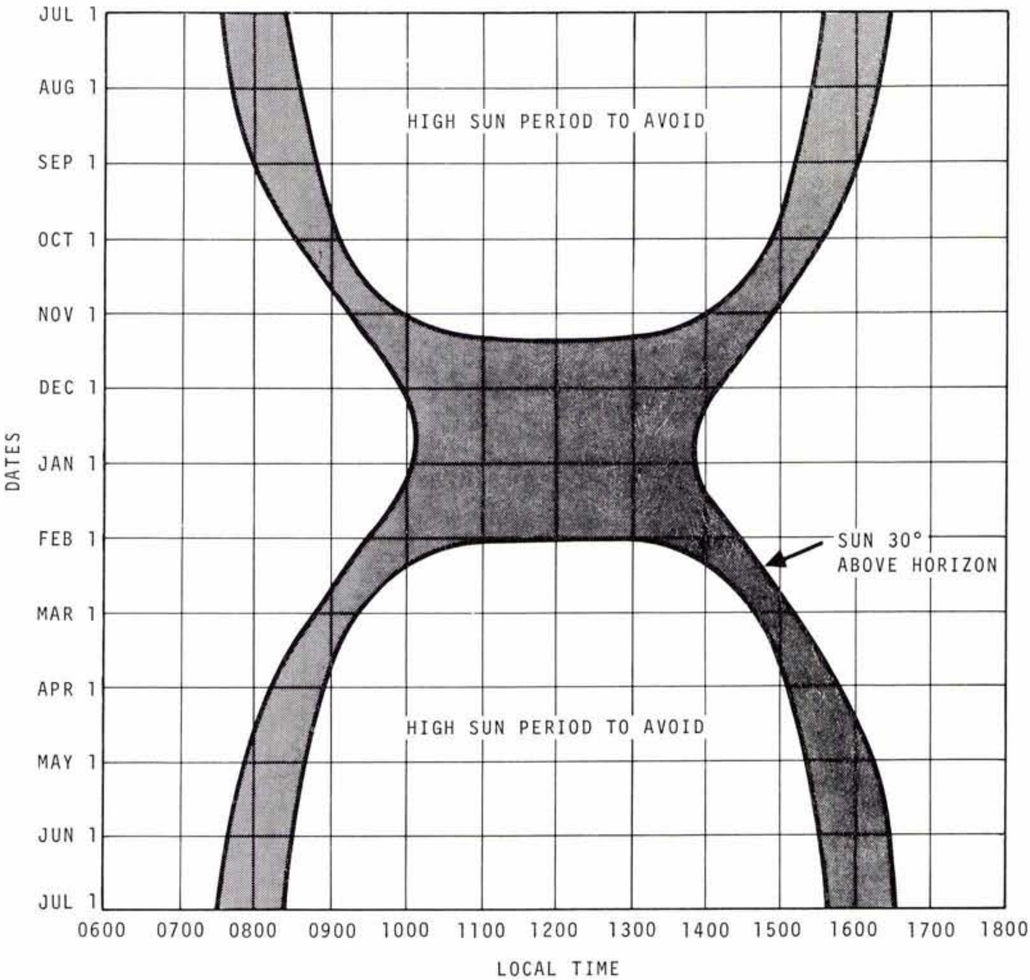


FIG. 6. Effective time of photography to avoid retro-reflections with RC 8 camera in E-W flight lines, Sam Houston National Forest.

restriction in the use of certain slow films which would need greater illumination than is provided at the times listed. Further study into this subject may now be warranted.

Occasionally small amounts of retro-reflection can be tolerated. When (1) the usual 30 percent sidelap is provided for, (2) east-west flight lines are used, (3) the photography is to be used for mosaicking, and (4) the photography is flown near the middle of the day, then retro-reflective areas will appear along the northern edge of each frame. A graphical solution can be found permitting up to 30 percent intrusion of the retro-reflective area. The percentages of sidelap are shown on the RC-8 template in Figure 5. The retro-reflective areas can then be eliminated in the overlap of the mosaic.

Hot spots and retro-reflections have also been found on color IR photographs taken from 60,000 feet (see Figures 4 and 8). Oddly, the retro-reflection has approximately the same spatial diameter (approximately 13,000 ft.) as the retro-reflections observed on photographs from 10,000 feet, although at 60,000 feet the angular diameter is much smaller, dropping from 67° to 12°.

The retro-reflection phenomenon has also been observed a number of times on Gemini and Apollo photography, taken while in earth orbit. An example is shown in Figure 9. Unfortunately, this photograph was recorded over grasslands on Ektachrome film and therefore the retro-reflection is not very prominent. If color IR film has been used and the terrain had been forested, the retro-

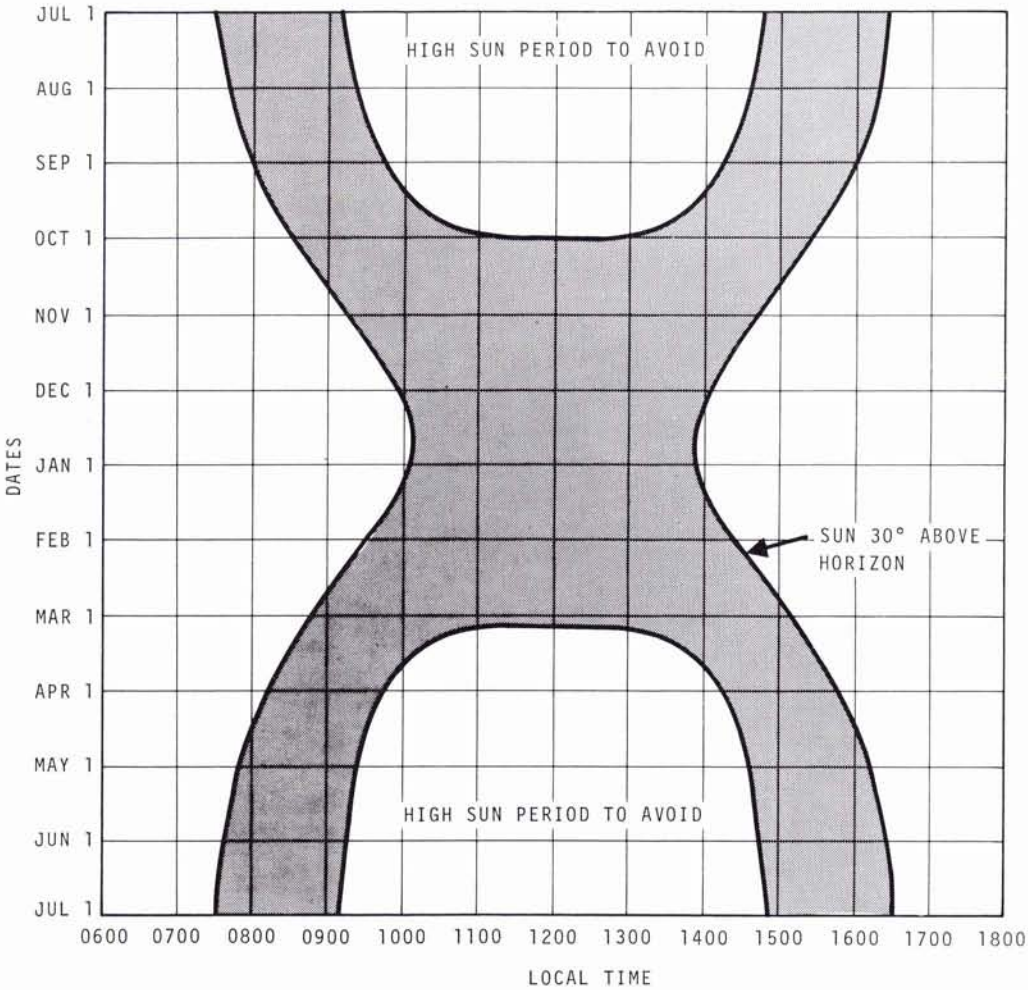


FIG. 7. Effective time of photography to avoid retro-reflections with Zeiss camera in E-W flight lines, Sam Houston National Forest.

reflection would undoubtedly have been larger in diameter and brighter.

Infrared Light in Retro-Reflection

A recent mission in which a multispectral scanner was used provided an unusual opportunity to measure the spectra of the edge or tail of a retro-reflective area as it trailed off into infinity over a forested area.[6] On November 11, 1971 Mission 51M was flown with the Michigan 12 channel scanner. Afterward it was discovered that a hot spot and the major portion of the retro-reflective area lay just outside the field of view of both the scanner and the camera which was exposed at the same time. The effects of the tail of the retro-reflection were visible on both records, however, and it permitted a measurement of the spectral distribution of the light in this reflection to be made. As shown in the graph in Figure 10, the infrared values were the greatest, followed by the red, green, and blue light values. This is the first conclusive evidence that the retro-reflection is largely infrared light.

Related Problems

There are times when hot spots, and solar reflections, are desirable. This is because oceanographers are able to analyze sea state from the solar reflection, or sun glint, observed on a water surface.[7] For such an application the hot spot and solar reflection phenomenon should be sought instead of avoided.

There is related problems, as shown above,

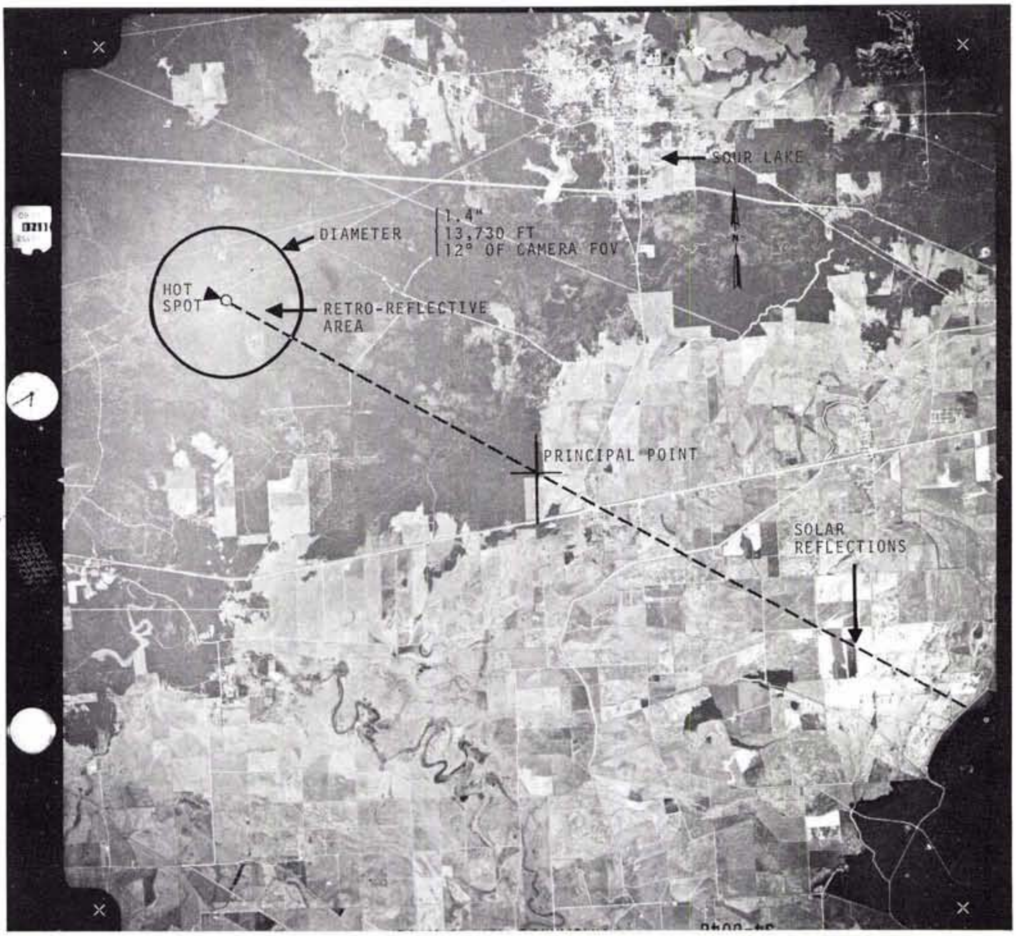


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FIG. 8. Vertical photo taken by NASA RB-57 over Liberty County, Texas from an altitude of 60,000 feet. The camera was a 6" f.l. Wild RC-8 with 2443 color IR film.

in the use of electro-optical scanners over different types of terrain. Data from these scanners are also affected by hot spots and solar reflections when the scanner is flown at right angles to the direction of the sun. This is a subject which needs further study and it is beyond the scope of this paper.

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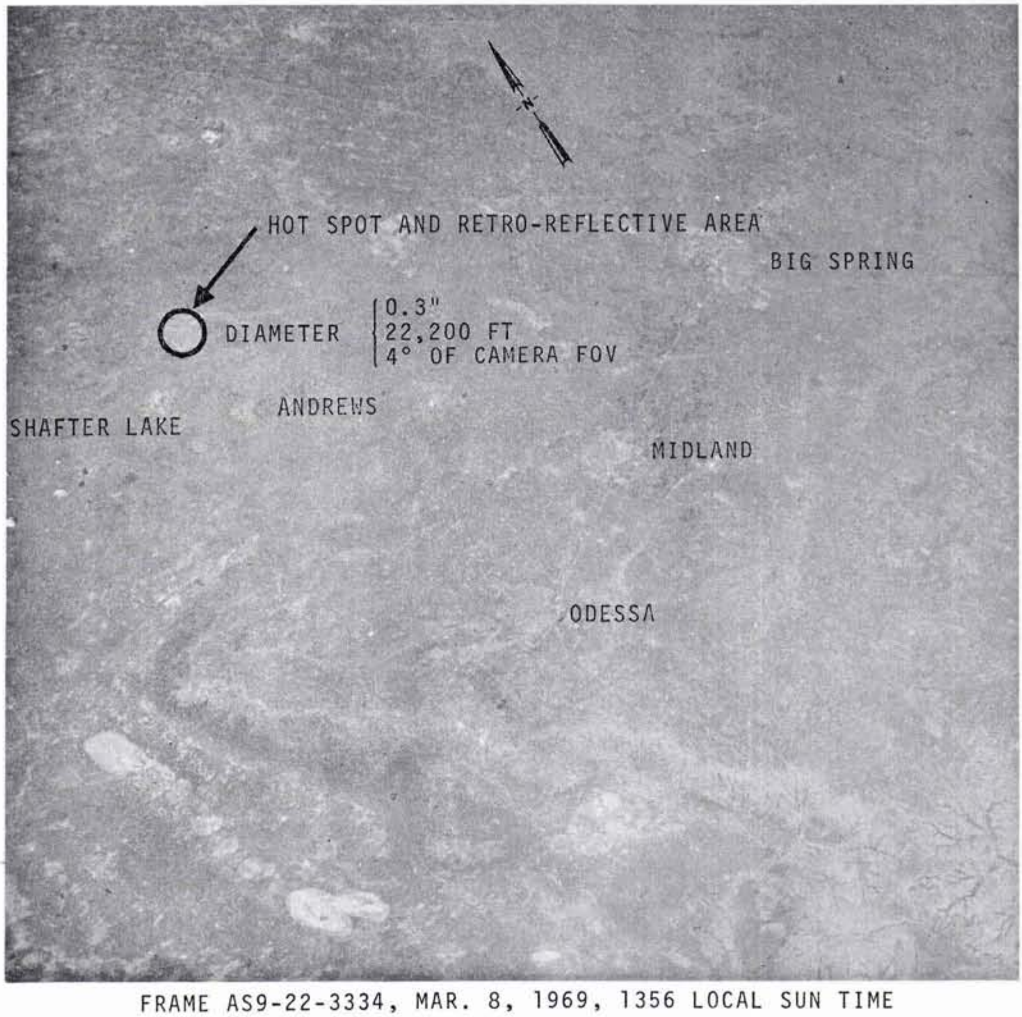

FIG. 9. Oblique photo taken by Apollo 9 over northwest Texas from an altitude of 105 n.m. The camera was a Hasselblad 500E with a 80mm f.l. lens and Ektachrome film.

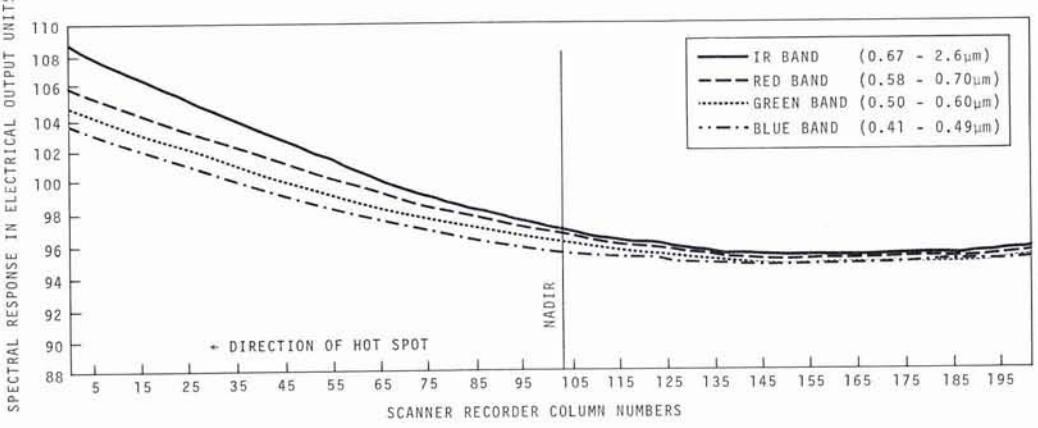

FIG. 10. Curves of spectral response from the means of four spectral bands in the tail of retro-reflectance, recorded by the Michigan 12 Channel Scanner.