camera at the instant of exposure. To accomplish this, the angle between the optical axis of the stellar camera and the frame camera must be determined to accuracies commensurate with mission objectives.

A spacecraft equipped with all three types of cameras would have photographic "footprints" as shown in figure 17-45. Figure 17-44 shows how frame-camera and panoramic-camera pictures would be combined.

More detailed descriptions of each type of camera will be found in chapter IV. The cameras described there are used in aircraft, but the essential features are identical to those used in spacecraft.

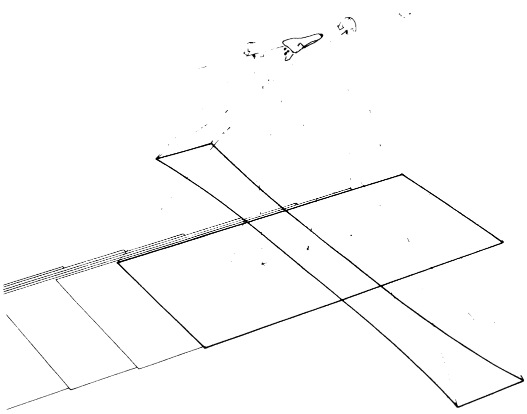


FIGURE 17-45. Photographic foot prints.

17.8.2 MAPPING PHOTOGRAPHY

17.8.2.1 MISSION CONSIDERATIONS

The planning of a space mission intended to acquire photogrammetric and interpretive photography should be guided by certain basic ideas.

It is desirable that the orbit be nearly polar in order to be able to photograph every part of the planet.
It is desirable that the orbit be sun-synchronous in order that illumination conditions at each latitude remain unchanged during the mission.
It is desirable that the orbit be nearly circular in order to equalize ground resolution and photogrammetric accuracy over the entire planet.

As an example, the coverage plot for a 14-day photographic mission using the Large-format Camera (LFC) in a circular, 70-degree inclination orbit is pictured in figure 17-46. For this mission, the area of first priority is the United States of America, with Northern Africa having second priority. Because the U.S.A. has first priority, an October launch date was planned. Statistics on weather governed this choice. The altitude was planned to be on the order of 250 kilometres. However, to achieve uniform lateral coverage, the LFC requires an altitude very close to 270 kilometres. At 250 kilometres, the ground track of the spacecraft would be repetitive and, therefore, a poor choice for a photographic mission.

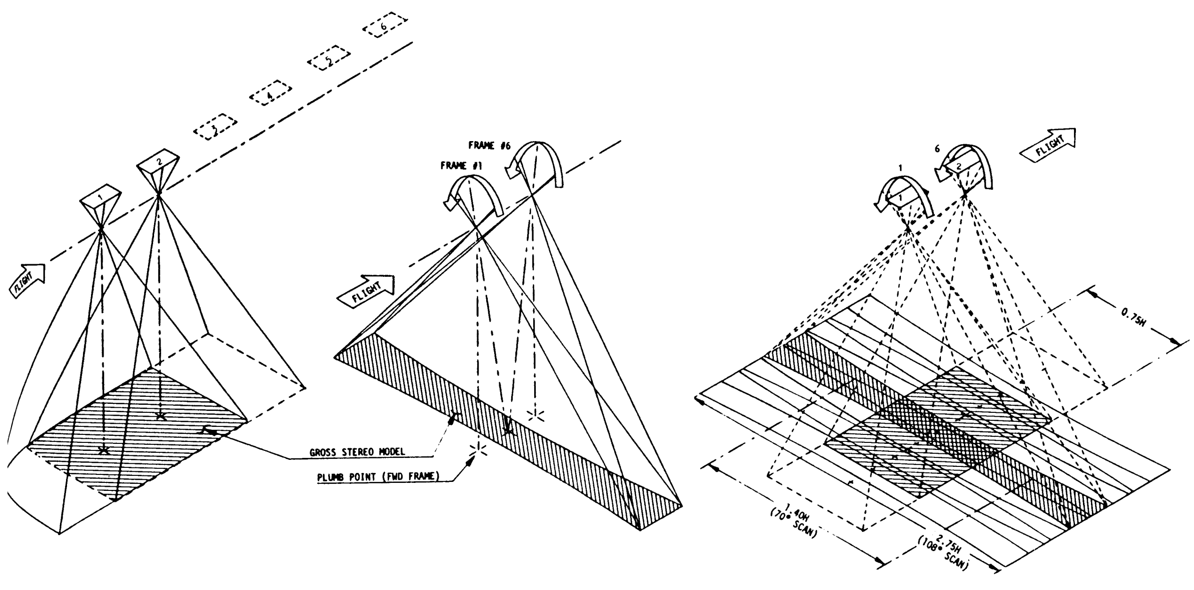
17.8.2.2 ESTIMATING PHOTOGRAPHIC COVERAGE

The ground coverage (A) per frame for either frame or panoramic photography can readily be estimated from the following equation:

$$A = 2h^2\left(\frac{\tan\theta}{\cos^3 t}\right)\left[\frac{\tan\delta}{\cos\delta} + \ln\left(\frac{1 + \sin\delta}{\cos\delta}\right)\right]$$

where

h = altitude



GE FORMAT CAMERA OVERLAP AND FOOTPRINT GEOMETRY

PANORAMIC CAMERA CONVERGENT STEREO FOOTPRINT GEOMETRY

COMBINED FOOTPRINT GEOMETRIES

FIGURE 17-44. Combination of imagery from frame and panoramic cameras.

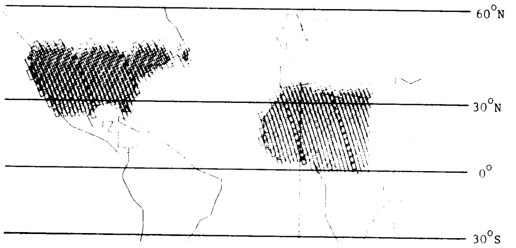


FIGURE 17-46. Coverage for 14-day mission.

t = effective ground tilt
θ = half field-angle in plane of tilt (intrack)
δ = half field-angle in plane perpendicular to plane of tilt (crosstrack)

This equation neglects planetary curvature but the error introduced by this assumption is less than 4% even in a ±60 degree-scan panoramic photograph (*see* footprint equations) and hence is negligible for virtually all practical cases.

For most systems the angular field of view of the lens is not sufficient to detect the curvature of the planet even from orbital altitudes. The one significant exception is a panoramic camera. In this case a suitable footprint equation including the effect of planetary curvature is obtained by assuming a cylindrical approximation to the planets surface. Referring to figures 17-47a and 17-47b, the footprint equations are as shown in figure 17-48. The error involved in neglecting curvature is given by:

$$\frac{\Delta X}{X} = \frac{h}{2R}\left(\frac{\sin\delta\cos\theta}{\cos\delta\cos\theta\cos t + \sin\theta\sin t}\right).$$

For a typical panoramic camera with $\theta = 0°$, $\delta = 60°$ and $t = 10°$ at an altitude of 150 nmi

$$\Delta X/X = 0.04.$$

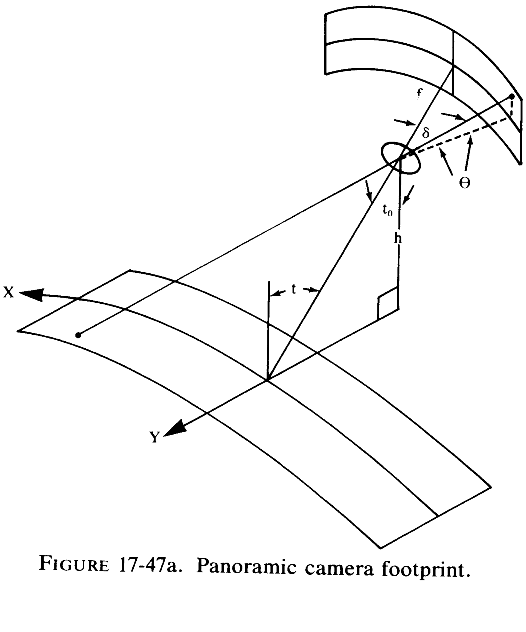


FIGURE 17-47a. Panoramic camera footprint.

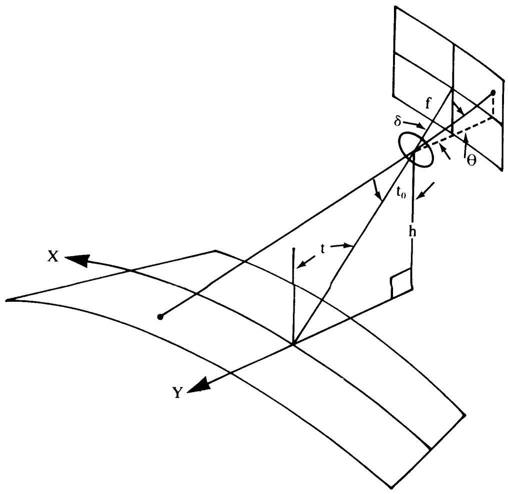


FIGURE 17-47b. Frame camera footprint.

A 4% error in a footprint calculation for a panoramic camera may be of interest but for a frame camera with a total field of view of 40° the resulting edge-of-footprint error, which would be approximately 0.8%, is negligible in most practical applications.

17.8.2.3 ESTIMATING EXPOSURE REQUIREMENTS

Exposure is defined as the quantity of light received by a photographic emulsion. It is the product of the rate at which light falls on the emulsion and the time during which the light is received. It is calculated by the equation

$$H = Et \qquad (17.175)$$

where

H = exposure (usually expressed in lux-seconds),
E = illuminance (usually in lux), and
t = time (usually in seconds).

The exposure required for high-altitude photography is dependent upon a number of factors.

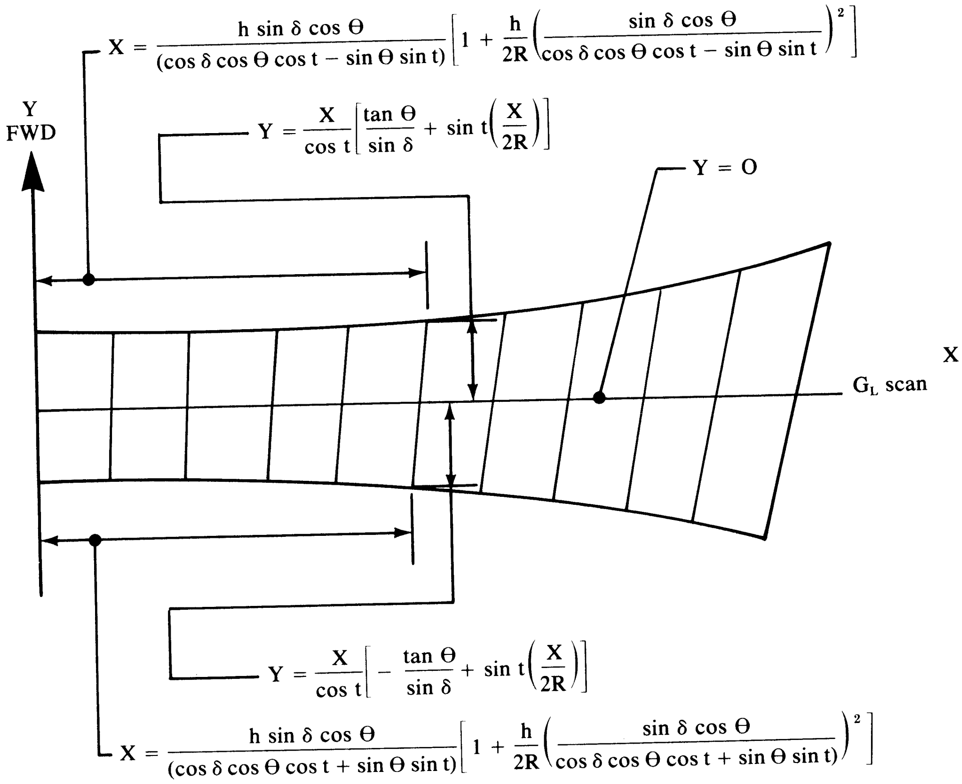
1. The apparent brightness of the scene to be photographed (surface luminance and atmospheric effects).
2. The efficiency of the camera system to gather and transmit light.
3. The response of the recording medium (film) to the light reaching it.

Of the above three factors, the apparent scene brightness is the most difficult value to ascertain due to the many variables involved. The guidelines which follow will result in fairly accurate computations, but may have to be modified slightly if unusual conditions are encountered.

These factors and their interrelationships are explored in the following.

17.8.2.3.1 SURFACE LUMINANCE

The amount of light reflected from a surface, *i.e.*, luminance, is dependent on three factors.



NOTE: R = Earth Radius (3440 n.m.)
for $\delta = 0$

$$Y = \begin{cases} \dfrac{h \sin\Theta}{\cos t \cos(t + \Theta)} \\ -\dfrac{h \sin\Theta}{\cos t \cos(t - \Theta)} \end{cases}$$

FIGURE 17-48. Footprint calculations considering planetary curvature.

1. The amount of light incident on the surface, *i.e.*, illuminace.
2. The spectral reflectance of the surface.
3. The reflection characteristics of the surface.

17.8.2.3.2 ILLUMINANCE

Illuminance, or illumination, is defined as the luminous flux incident on a surface per unit area. It is generally measured in terms of meter-candles (lux) or foot-candles, the latter being equal to 1 lumen per square foot.

The values of solar altitude versus geographic position, time of year and time of day are depicted in figures 17-49 through 17-56. The optimum solar altitude for high altitude earth-photography is 45°.

17.8.2.3.3 SPECTRAL REFLECTANCE

The spectral reflectance of the surface material is dependent primarily on its composition.

The spectral range of the most commonly used black and white panchromatic aerial films is from 360 to 720 nm. The blue cutoff is determined by the glass in the camera since optical glasses do not pass radiation below 360 nm. The red cutoff is determined by the spectral sensitivity of the aerial film. Many aerial films are not sensitive beyond 720 nm.

Over this spectral range, the distribution of radiant energy incident on the earth on a clear day closely approximates that of a blackbody temperature of 6,000°K. In figure 17-57, the blackbody curve for a 6,000°K radiator is plotted together with the relative solar distribution curve outside the atmosphere. Over the visible spectrum, the color temperature of the solar distribution is between 5,600 and 5,800°K. When the predominantly blue skylight from a clear sky (color temperature ranging from 10,000 to 60,000°K, depending on weather conditions and angle from zenith) is added to the sunlight, the color temperature increases to around 6,000°K.

These data become important for computing exposure for photography over narrow spectral