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# FACTORS THAT INFLUENCE
# THE QUALITY OF SATELLITE PHOTOGRAPHY

September 1973

Prepared by: R. J. Kohler

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## 1.0 INTRODUCTION

The factors that influence the quality of a photographic image produced by a satellite reconnaissance system are many. Not only are these factors numerous but often their interactions are complicated and difficult to analyze. It is the purpose of this report to discuss the major influences on image quality and, to the extent practical, illustrate how these factors relate to each other.

The discussion will include an analysis of the effect of launch time on image quality, the effect of the camera acquisition conditions on image quality, the influence of contrast on resolution and how these factors relate to image suitability from a photointerpreter point of view. Lastly, the effect of the duplication process on quality will be briefly discussed.

The report will not discuss the numerous camera design factors (focus, smear, thermal effects, etc.) that influence image quality since that is not its purpose. Indeed, given that the camera has no significant problems and is performing reasonably in accordance with its design, other factors are considerably more significant than the camera in determining the image quality the PI will see.

## 2.0 THE EFFECT OF LAUNCH TIME ON IMAGE QUALITY

This section treats a number of photographic quality parameters as they are affected by launch time. It does not consider problems such as time synchronization of the photographic vehicle with a meteorologic satellite, or vehicle thermodynamic problems. The discussion assumes all such problems are solvable. It does consider, however, the optimum launch times from a photographic viewpoint. In this regard, the section considers the following factors:

a. mitigation of the effects of spectral reflections

b. the avoidance of sun-camera geometry resulting in shadowless target acquisitions

c. optimization of shadow lengths for mensuration

d. the position of the terminator in terms of latitude.

e. the minimization of camera exposure change in the north latitude, descending pass portion of the orbit.

For most of the discussion, several assumptions were made concerning the orbit. The orbital inclination was assumed to be 96.3°. The launch time and the time of accessing 35°N latitude during a revolution are taken to be identical*. As such, most of the details are applicable to HEXAGON and GAMBIT CUBED if flown at this inclination. There is a summary chart, however, that illustrates the proper launch time for 110° inclinations, the current GAMBIT CUBED orbit. All times mentioned in the report are apparent solar times (true sun time). In addition, the discussion pertains to the northern latitudes only, because that is where the vast majority of intelligence photography is taken.

## 2.1 Spectral Reflections

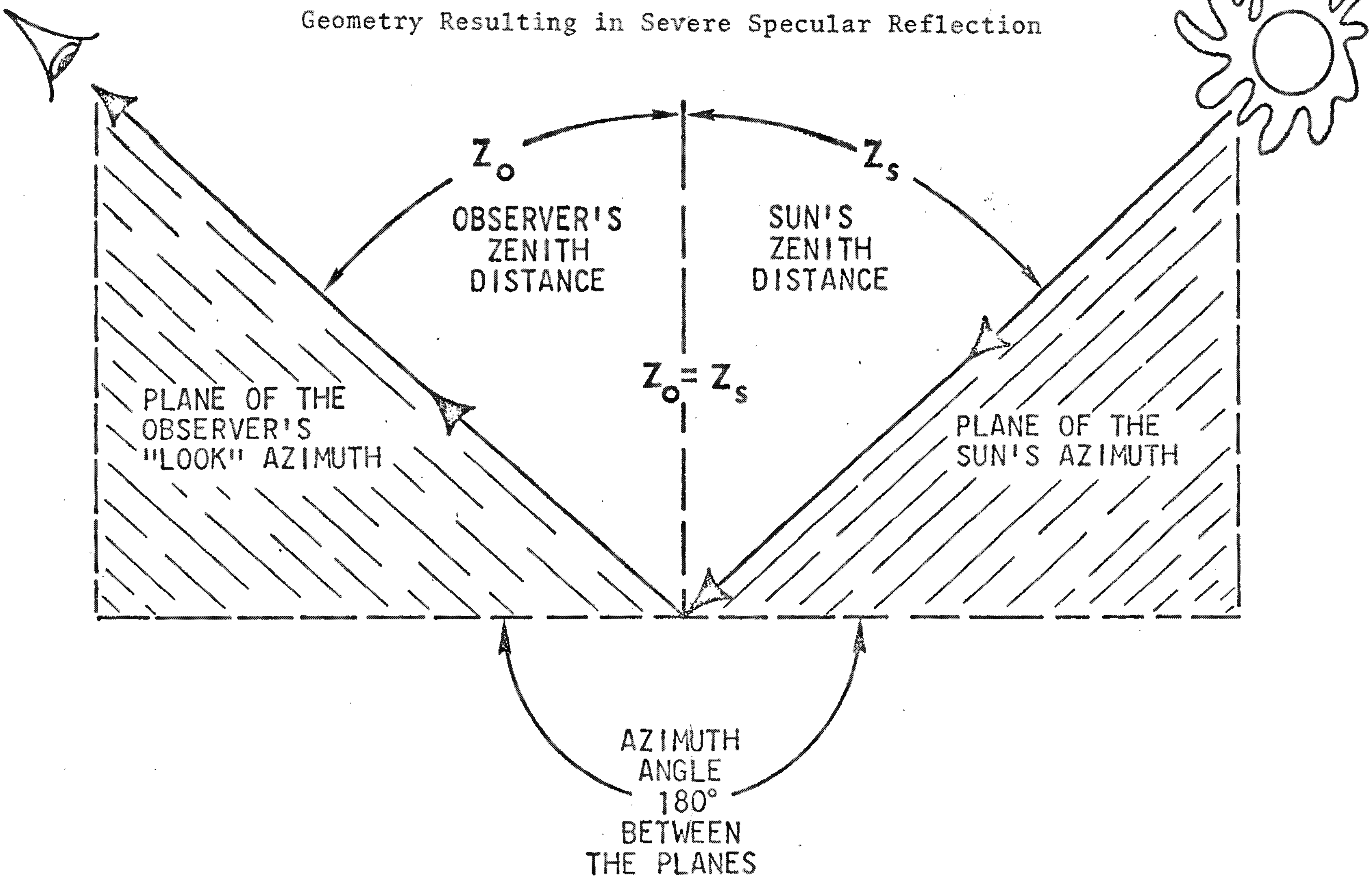
Specular reflections can occur when the acquisition conditions are near those illustrated in Figure 2-1. Specular reflections produce a severe blooming of the imagery and, when they occur, can severely impair the utility of the imagery for interpretation. Fortunately, whether or not a specular reflection will occur, given the acquisition conditions of Figure 2-1, is also dependent on the nature of the target. Water or wet soil, for example, always produce specular reflections.

During the period 23 March to 21 September, specular reflections can be a problem, particularly with regard to forward-looking acquisitions (descending pass). Figures 2-2 and 2-3 indicate the position in latitude and scan (roll) angle of the most intense specular reflections. Degradation usually extends approximately ±5° in latitude and ±7° in scan about the indicated values.

* That is, the launch times discussed herein are the true sun time at 35°N latitude at the time of launch and not the actual time at VAFB. This was done to avoid the problems of the difference between local time and true sun time, which is the important factor. This way of expressing launch time, however, does not deviate from the local time at VAFB by more than seven minutes.

FIGURE 2-1

Geometry Resulting in Severe Specular Reflection



LATITUDE AND SCAN ANGLE OF SPECULAR REFLECTIONS
AS FUNCTIONS OF TIME OF YEAR AND LAUNCH TIME

(Forward look, 10° pitch, descending pass)

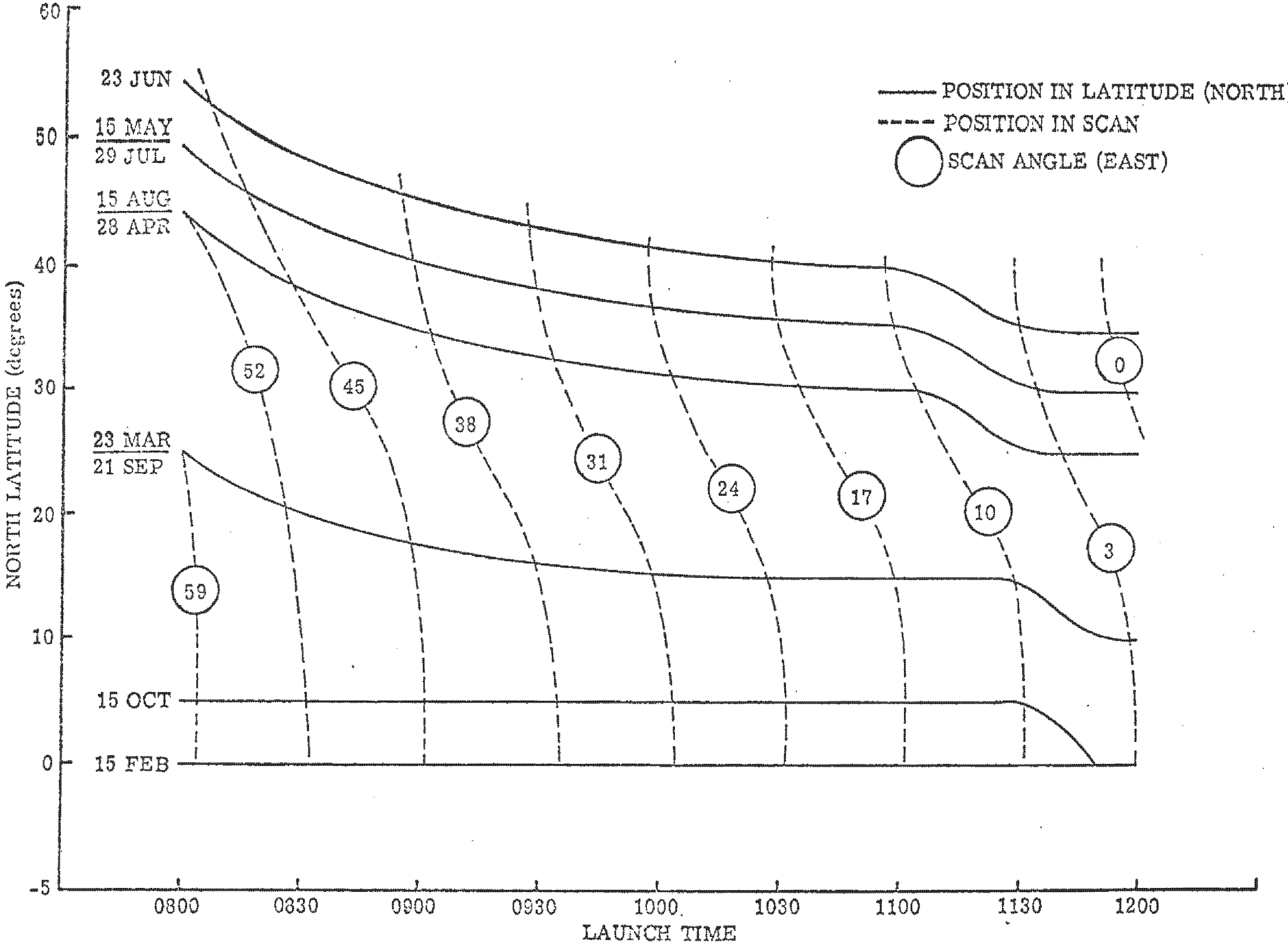
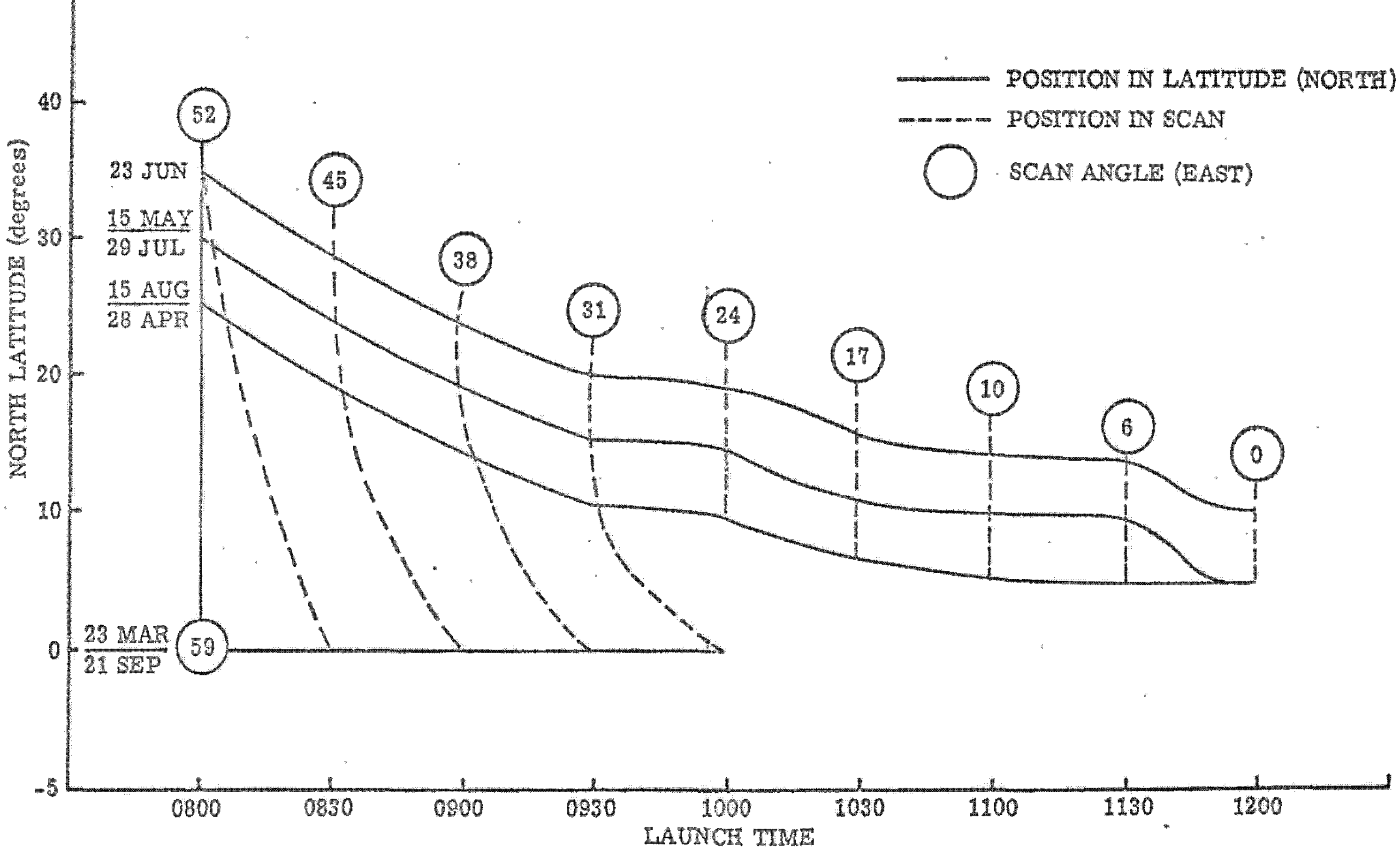


FIGURE 2-3

LATITUDE AND SCAN ANGLE OF SPECULAR REFLECTIONS
AS FUNCTIONS OF TIME OF YEAR AND LAUNCH TIME

(Aft look, 10° pitch, descending pass)



The position of the specular reflections in latitude is governed mainly by the solar declination and secondarily by launch time. The position in scan (or roll) is governed by launch time. Around the time of the summer solstice, a very early launch is desirable in that it locates the specular reflections far out in scan (roll) angle. Table 2-1 illustrates the launch times required to minimize the effects of specular reflection.

TABLE 2-1

Optimum Launch Times to Minimize

Specular Reflections

| Month | Time |
| --- | --- |
| September thru March | There is no problem during these months because the solar declination is minus. |
| April | 8:35 |
| May | 8:15 |
| June | 8:00 |
| July | 8:10 |
| August | 8:30 |

The criteria applied in this table are to put the majority of specular reflections below 20°N latitude and that above 20°N the specular reflection must fall at a scan (roll) angle of 45° or greater.

## 2.2 Shadowless Acquisitions

Associated geometrically with the problem of specular reflections is the problem of shadowless target acquisitions; that is to say, when the camera geometry is such that the optical axis has the same altitude and azimuth angles as the sun. This is illustrated in Figure 2-4. The result of such acquisitions is to produce imagery that has no shadows and, hence, greatly reduced contrast. Such imagery looks dimensionless and, in the worst cases, image detail is actually lost. In the latter case, stereo viewing can also be significantly impaired. The graphs (Figures 2-2 and 2-3) for the location of specular reflections hold equally well for this problem except that the geometry is reversed. To determine the position of shadowless geometry for the aft look, use the forward look graph and read the positive scan (roll) angle as being west instead of east. It follows from this discussion that if a launch time is selected which minimizes specular reflections, then the shadowless acquisition problem is reduced also.

Akin to the shadowless acquisition problem is that of taking pictures at very high solar altitudes, While geometrically the problem is not the same, the practical effect is. When the sun is at very high solar altitudes, there are, of course, no shadows; and again the image contrast is very poor.

## 2.3 Optimizing Shadows for Mensuration

The optimum solar altitude for shadow mensuration is 45°. As the solar altitude decreases from 45°, errors in measurement arise due to uncertainties regarding the elevation of the surface that the shadow is projected upon. Additionally, as the solar altitude decreases from 20°, the contrast between the shadow and the background is lowered substantially and the edges of the shadows become increasingly difficult to ascertain. As the solar altitude increases from 45°, errors in measurement arise due to the shortening dimension of the shadows.

Approaching the problem of optimum laumch time with regard to shadow mensuration, the question arises as to which latitudes are considered important. Three northern latitude groups are considered here:

a. 0-80° - this latitude range is considered to contain most targets of significant intelligence interest.

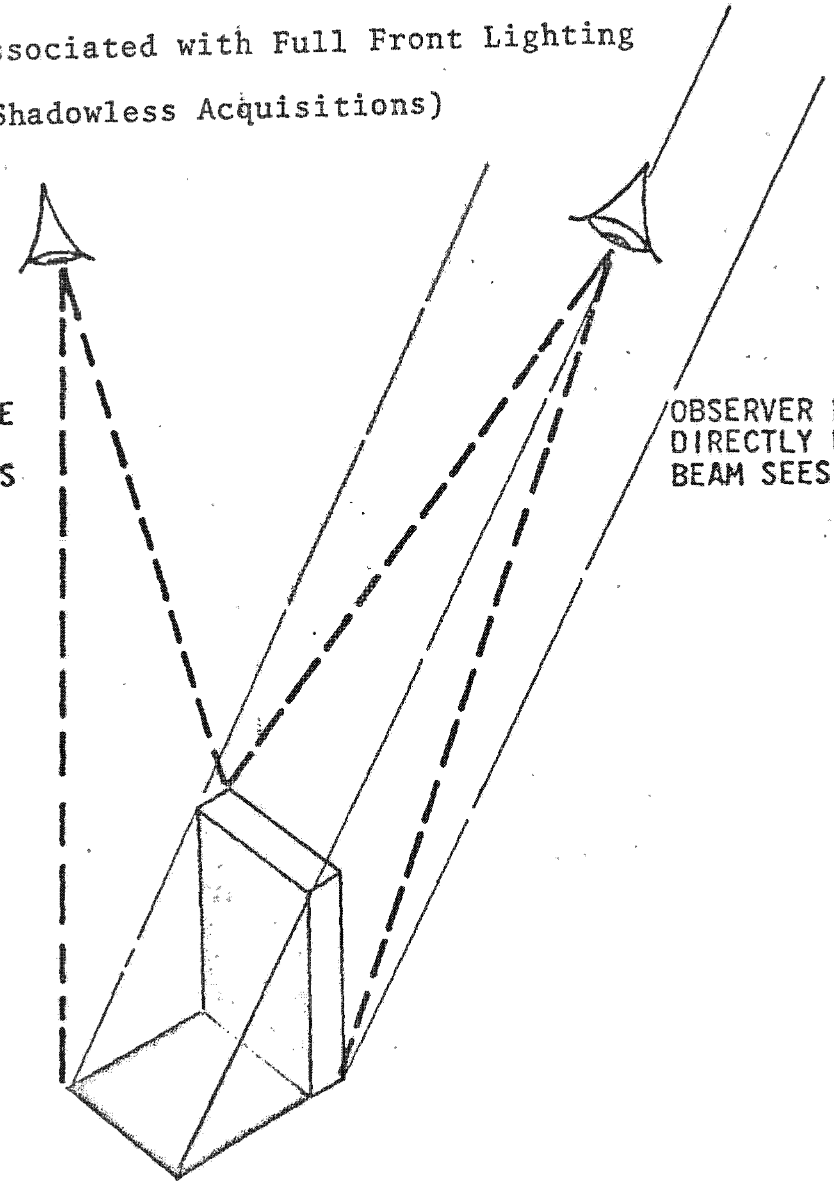
b. 20-60° - this latitude range is considered to contain the majority of important intelligence targets.

c. 50° - targets at latitudes ranging around this latitude are generally considered to be the most important.

FIGURE 2-4

Geometry Associated with Full Front Lighting

(Shadowless Acquisitions)



The solar altitudes were computed from each group for launch times between 0800 and 1200 local sun time for ten dates during the year. For groups a and b, the solar altitudes for every 10° of latitude were averaged. No weighting was given with regard to latitude, since the decrease in area with increasing north latitude is offset somewhat by the increase in the number of targets. For each date, a launch time was selected for which the deviation for 45° solar altitude was the least for all three groups, although some judgment was used to bias the least deviation in favor of the latitudes around 50°N. Figure 2-5 illustrates the optimum launch time versus date to optimize this factor. It should be noted that optimization of launch time to attain a solar altitude of approximately 45° at 50°N can only be made between approximately 21 March and 23 September due to the fact that the solar altitude simply does not get high enough in the winter. When the 45° optimization was impossible, the launch time was selected which resulted in the highest possible solar altitude for latitudes around 50°N.

## 2.4 Position in Latitude of the Terminator

It is desirable to launch the vehicle such that the terminator crossing is at the highest attainable north latitude, since 0° solar altitude represents a quality trade off point beneath which a higher speed film is required to record the highest possible ground resolution. This consideration is of particular importance around the time of the winter solstice, and it becomes insignificant between approximately 7 March and 6 October, when the highest latitude of the terminator is above the highest latitude attained with a 96.3° orbital inclination.

Figure 2-6 illustrates the launch times at various dates in the year which will result in the optimum positioning of the terminator with regard to latitude. The curve marked "highest latitude line" relates the date and attendant solar declination to the appropriate launch time. The 0800 launch time for a solar declination of -5.5° was set by judgment and is not the calculated value.

Due to various other factors discussed in the report, it is obvious that some of the very early launch times recommended on Figure 2-6 (i.e. 0830 on 1 March) are undesirable. However, any launch time between the "highest latitude line" and approximately noon would be acceptable since the reduction in latitude at which 0° solar altitude occurs for a later launch affects only the extremely high latitudes. This is due to the fact that

FIGURE 2-5

Optimum Launch Time to Maximize

Shadow Detail for Mensuration

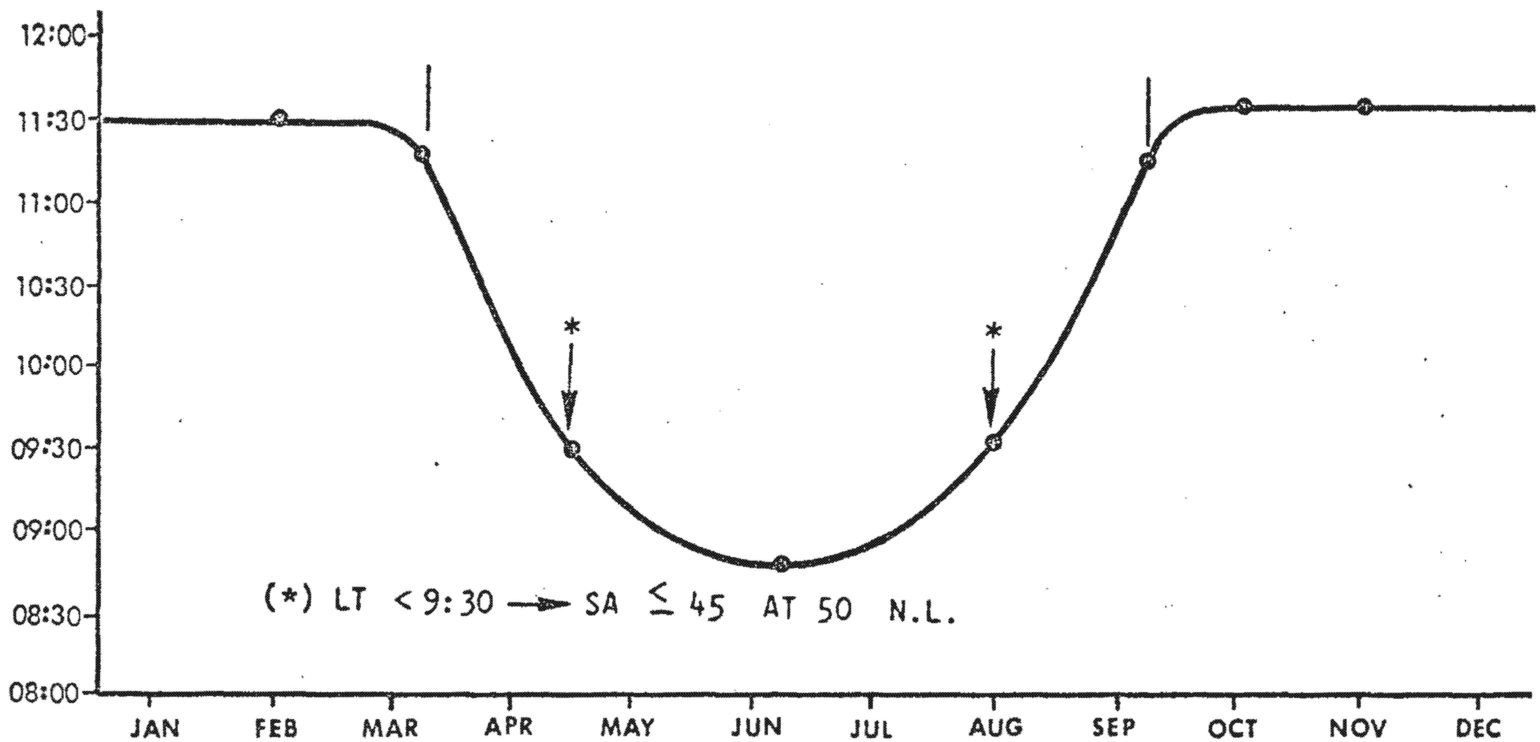





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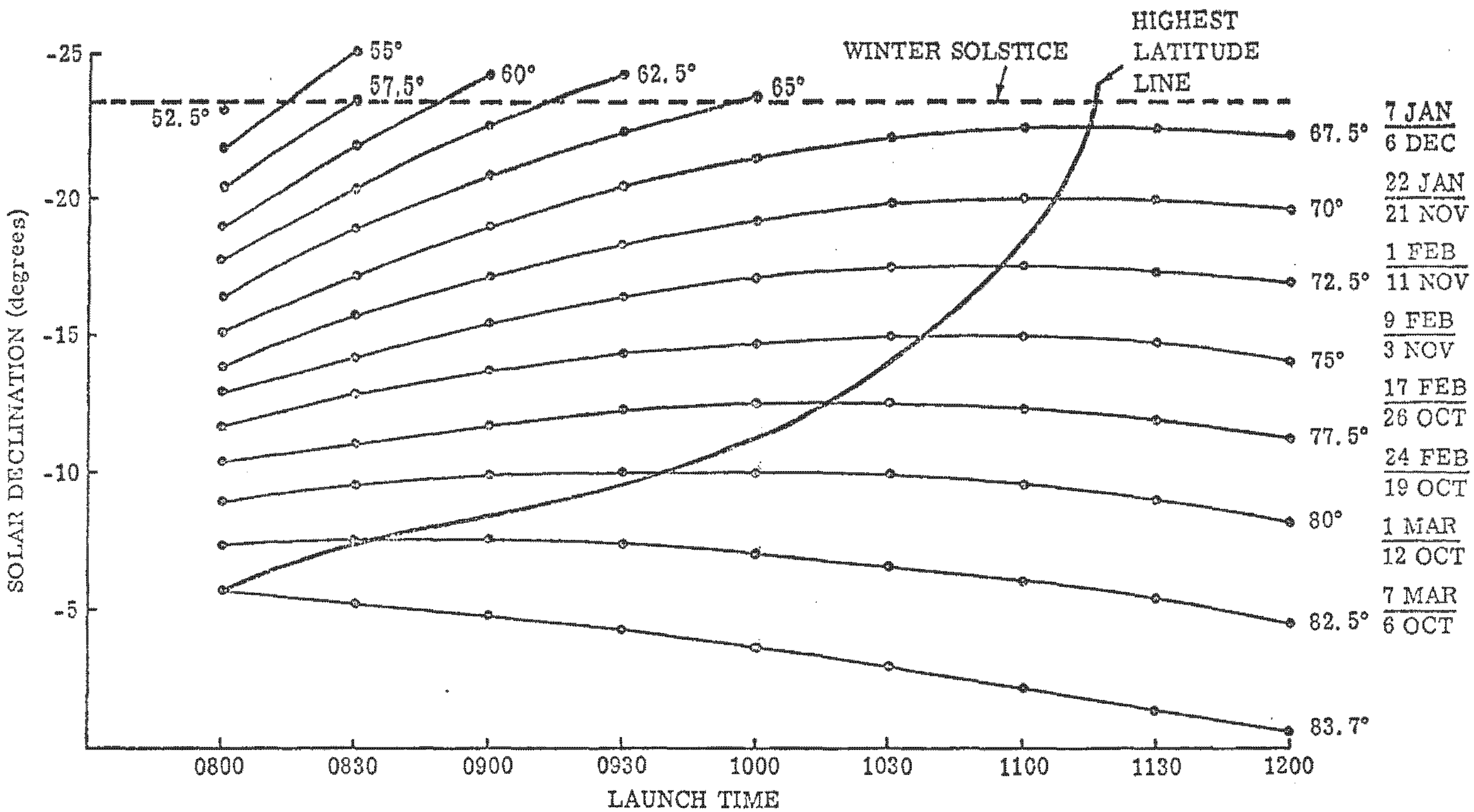
FIGURE 2-6

LATITUDE AT WHICH 0° SOLAR ALTITUDE OCCURS FOR 96.3° INCLINATION




NOTE: Curves are plotted values of latitude in degrees.

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CONTROL SYSTEMS JOINTLY

~~TOP SECRET~~ RUFF
HEXAGON GAMBIT

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proceeding north in latitude, the sun's hour angle is increasingly less of a factor in determining the solar altitude, the solar declination becoming the dictating influence.

## 2.5 Minimization of Required Camera Exposure Changes

An additional advantage is achieved by keeping the solar altitude close to some given value throughout the latitude range of interest. This advantage is that the variation in camera exposure time is held to a minimum. Thus, a fail-safe provision can be built in during mission planning. At the times of the summer and winter solstices, the launch times required to minimize camera exposure changes are essentially those required to obtain shadow record optimization and are illustrated in Figures 2-7 and 2-8. The latitude range of 0° to 80° is not considered at the time of the winter solstice since exposure compensation is impossible due to large negative values of solar altitude which occur at high north latitudes. At the times of the equinoxes, minimization of camera exposure change can be accomplished only at the expense of considerably lowering the average solar altitude. Figure 2-9 illustrates this dilemma. No great change in camera exposure range with variations in launch time is incurred, however, for the critical latitude range of 20°N to 60°N. The solar altitude required to maximize quality is discussed in Section 3.0. The exposure minimization factor is more important with HEXAGON than GAMBIT, because HEXAGON contains a fail-safe slit. That is, if the main slit and shutter mechanism fails, a mechanical device puts in one slit so that photography can still be taken. Minimizing the required exposure range will maximize the quality produced in this situation.

## 2.6 Summary

Several factors associated with the launch time of the mission can affect the quality of the resultant imagery produced. While the factors discussed are not necessarily of equal importance, they all yield essentially the same answer: launch late in the winter and early in the summer. The spring and fall are problem areas relative to the sun synchronous inclination because the solar declination is changing so rapidly that no single launch time is optimum. This is discussed in more detail below.

FIGURE 2-7

EXPOSURE CHANGE AS FUNCTION OF LAUNCH TIME
FOR SPECIFIED LATITUDE RANGES

(Summer Solstice)

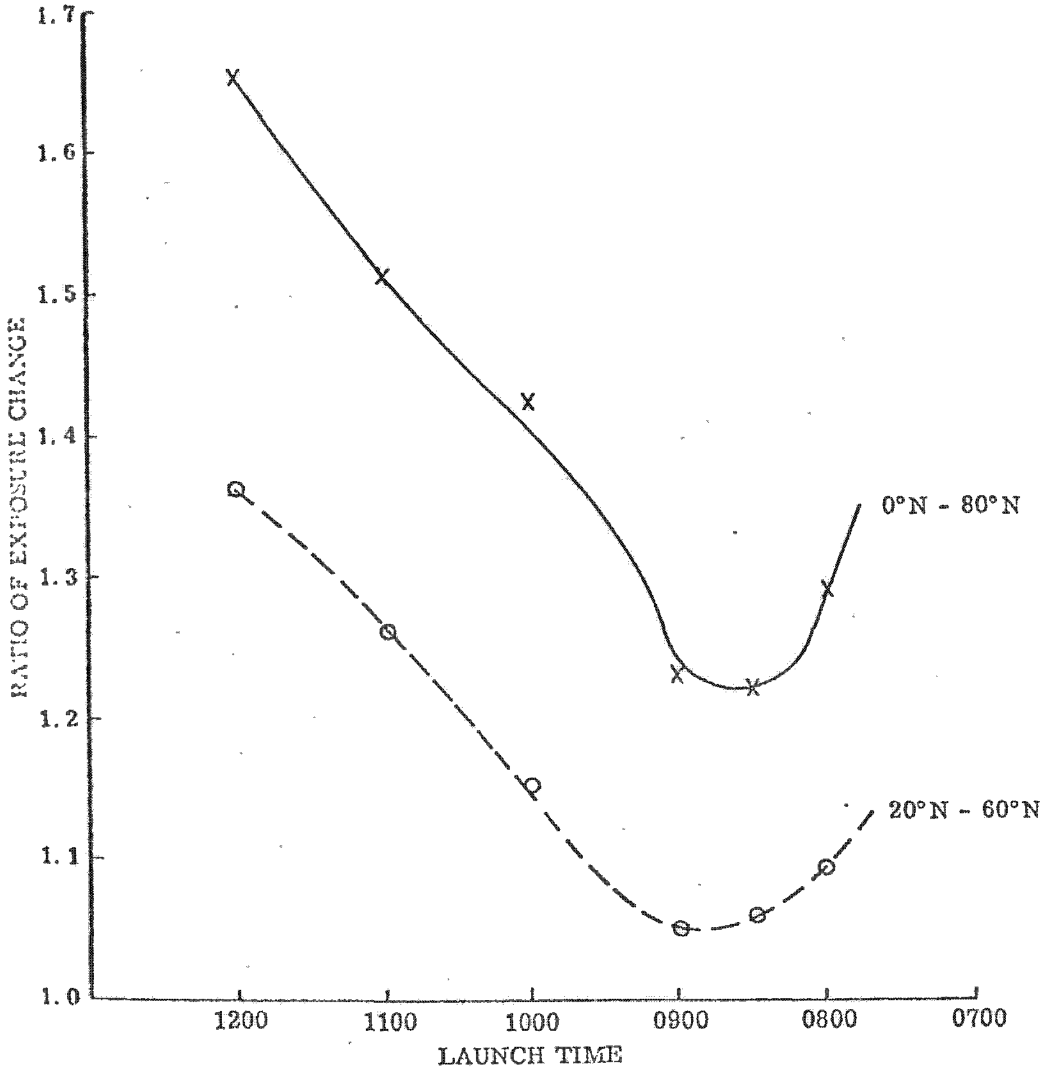


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FIGURE 2-8

EXPOSURE CHANGE AS FUNCTION OF LAUNCH TIME
FOR A SPECIFIED LATITUDE RANGE

(Winter Solstice)

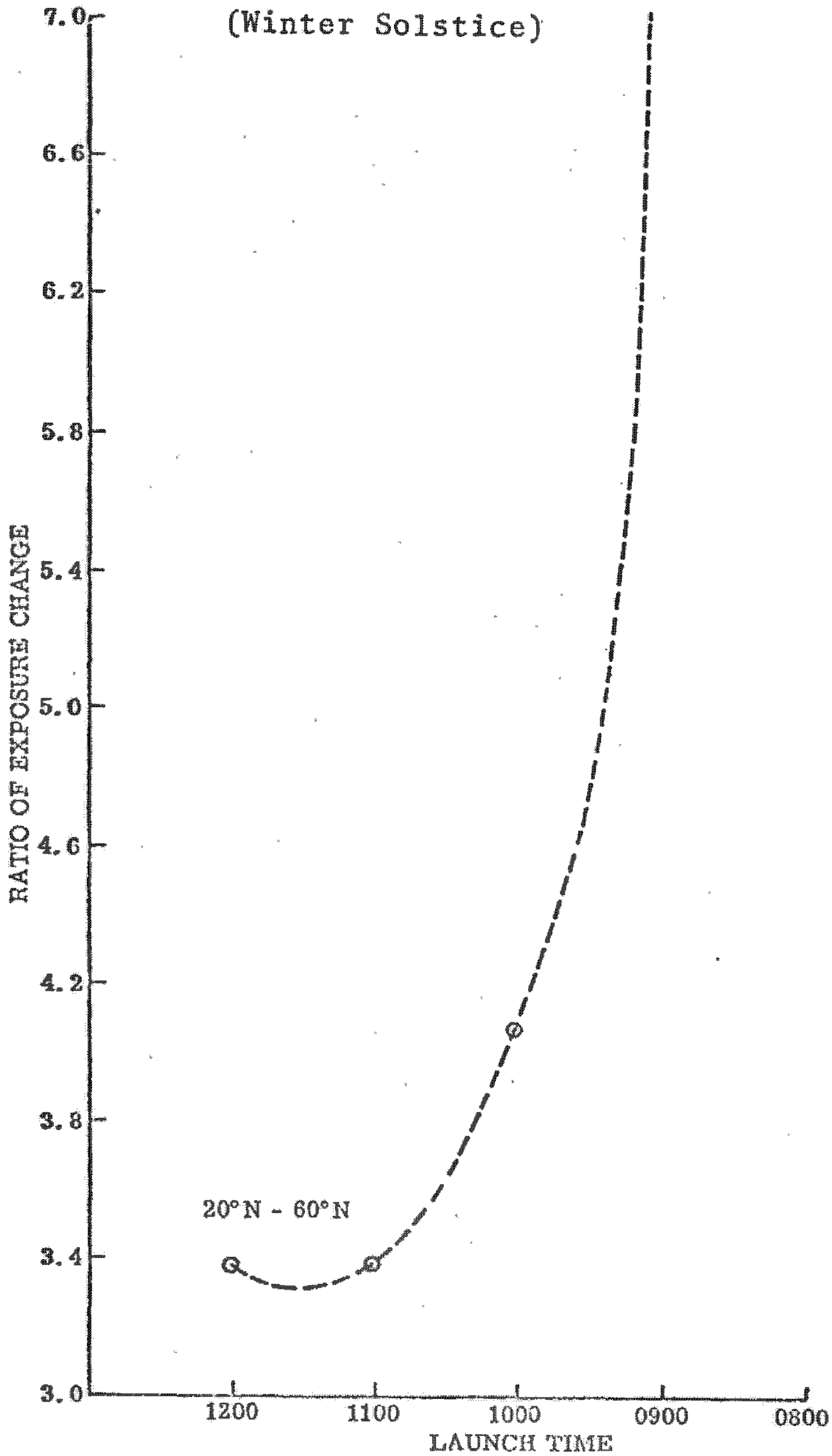
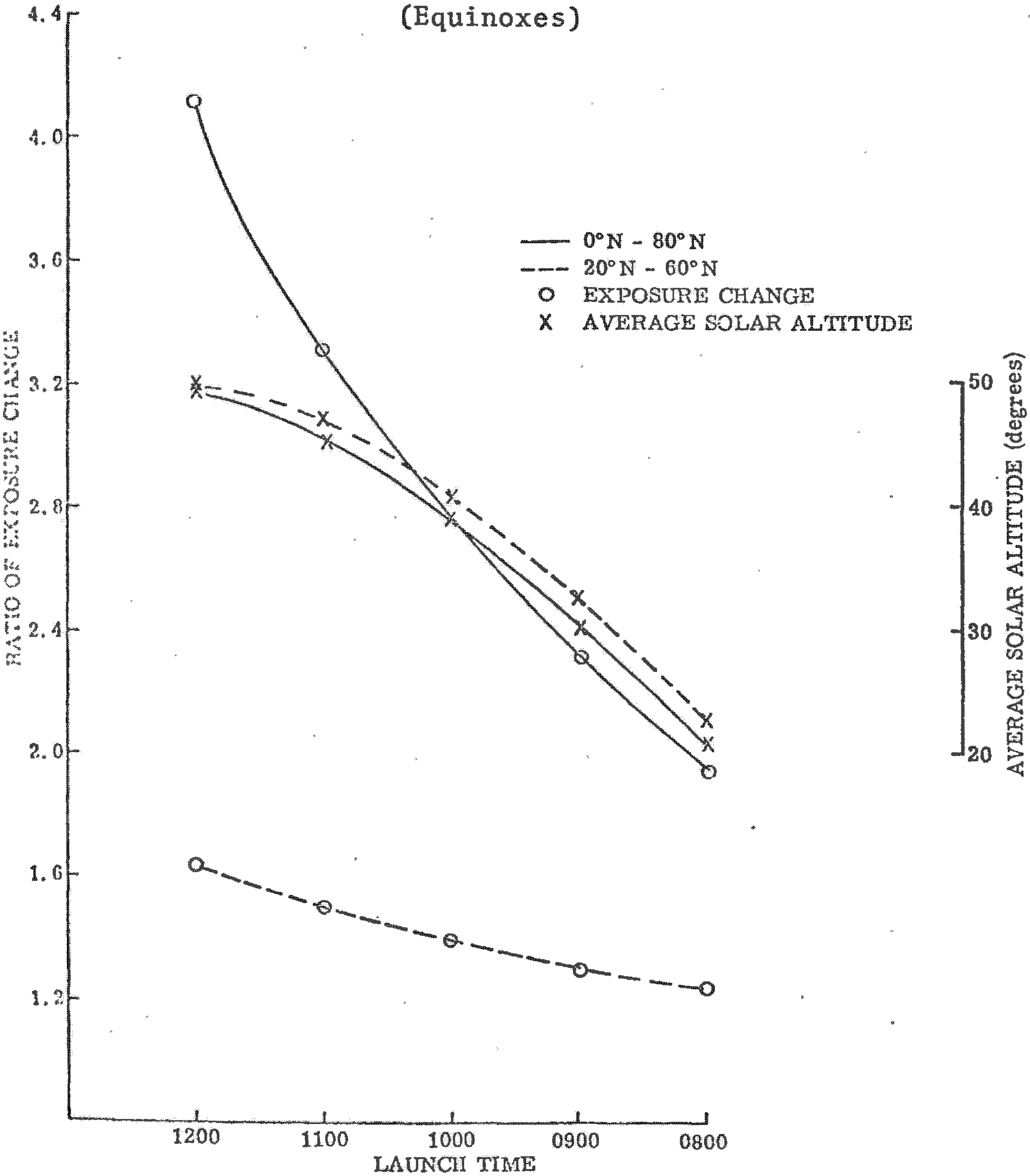


FIGURE 2-9

EXPOSURE CHANGE AS FUNCTION OF LAUNCH TIME
FOR SPECIFIED LATITUDE RANGES

(Equinoxes)



The optimum launch times, then, to maximize photographic image quality are shown in Tables 2-2 and 2-3 for the two inclinations currently employed. These tables list one other factor not discussed above, and that is the launch time required to produce a solar altitude of 30° at 50°N latitude. As will be discussed in Section 3.0, a solar altitude of 30° is sufficient to maximize camera performance. The times in Tables 2-2 and 2-3 are the minimum launch times. Times later than those indicated (except for the winter months) will produce higher solar altitudes at 50°N latitude.

As was mentioned above, the spring and fall are difficult to optimize for sun synchronous inclinations. This can be solved, however, by employing non-sun-synchronous orbits. Figure 2-10 illustrates two specific inclinations that could be employed to provide optimum acquisition conditions in the spring (92.9°) and fall (99.9°). These inclinations are superimposed on top of the shadow mensuration curve because it is generally representative of all the factors considered.

## 3.0 THE INTERACTION OF THE CAMERA AND THE ACQUISITION CONDITIONS

The previous section discussed the effects of launch time on quality, irrespective of the performance level of the camera itself. Later it will be shown that much of the conclusions possible from the previous discussion can be practically implemented. There are, however, other factors that need to be considered in the process of understanding the image quality to be achieved with any given system at any given point in time. This section attempts to bring together some of the key factors as they apply to the GAMBIT and HEXAGON systems; namely,

a. exposure time and smear

b. contrast

c. haze and time of year

d. target illumination and target reflectance

TABLE 2-2

Optimum Launch Times for Best Image Quality

(96.3° Inclination)

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHADOW MENSURATION | 11:30 | 11:30 | 11:20 | 10:05 | 9:10 | 8:45 | 8:55 | 9:30 | 10:35 | 11:30 | 11:30 | 11:30 |
| SPECULAR REFLECTION/FRONT LIGHTING | NP | NP | NP | 8:35 | 8:15 | 8:00 | 8:10 | 8:30 | NP | NP | NP | NP |
| HIGHEST LATITUDE LINE | 11:15 | 10:25 | ← | | | NO PROBLEM | | | → | 9:35 | 11:05 | 11:15 |
| MINIMUM EXPOSURE CHANGE (20° TO 60° N.L.) | 11:30 | 11:30 | 11:00 | 9:45 | 8:30 | 9:00 | 8:30 | 8:00 | 10:30 | 11:30 | 11:30 | 11:30 |
| MIN. RESOLUTION CHANGE FOR HEXAGON (50° N.L.) | ≥11:45 | 11:45 | 9:30 | 8:15 | 7:30 | 7:06 | 7:12 | 7:54 | 9:00 | 11:06 | 11:45 | 11:45 |
| MIN. RESOLUTION CHANGE FOR GAMBIT (50° N.L.) | ≥11:45 | 9:45 | 8:09 | 7:09 | 6:24 | 6:06 | 6:12 | 6:48 | 7:45 | 9:00 | 11:00 | 11:45 |

NOTES: A. (NP) No problem

B. Min. resolution change times are the times required to maintain a solar altitude of 30° at 50°N latitude. These times are only accurate for March through October. During November-February the time is that required to produce the highest possible solar altitude at 50°N latitude.

TABLE 2-3

Optimum Launch Times for Best Image Quality

(GAMBIT at 110° Inclination)

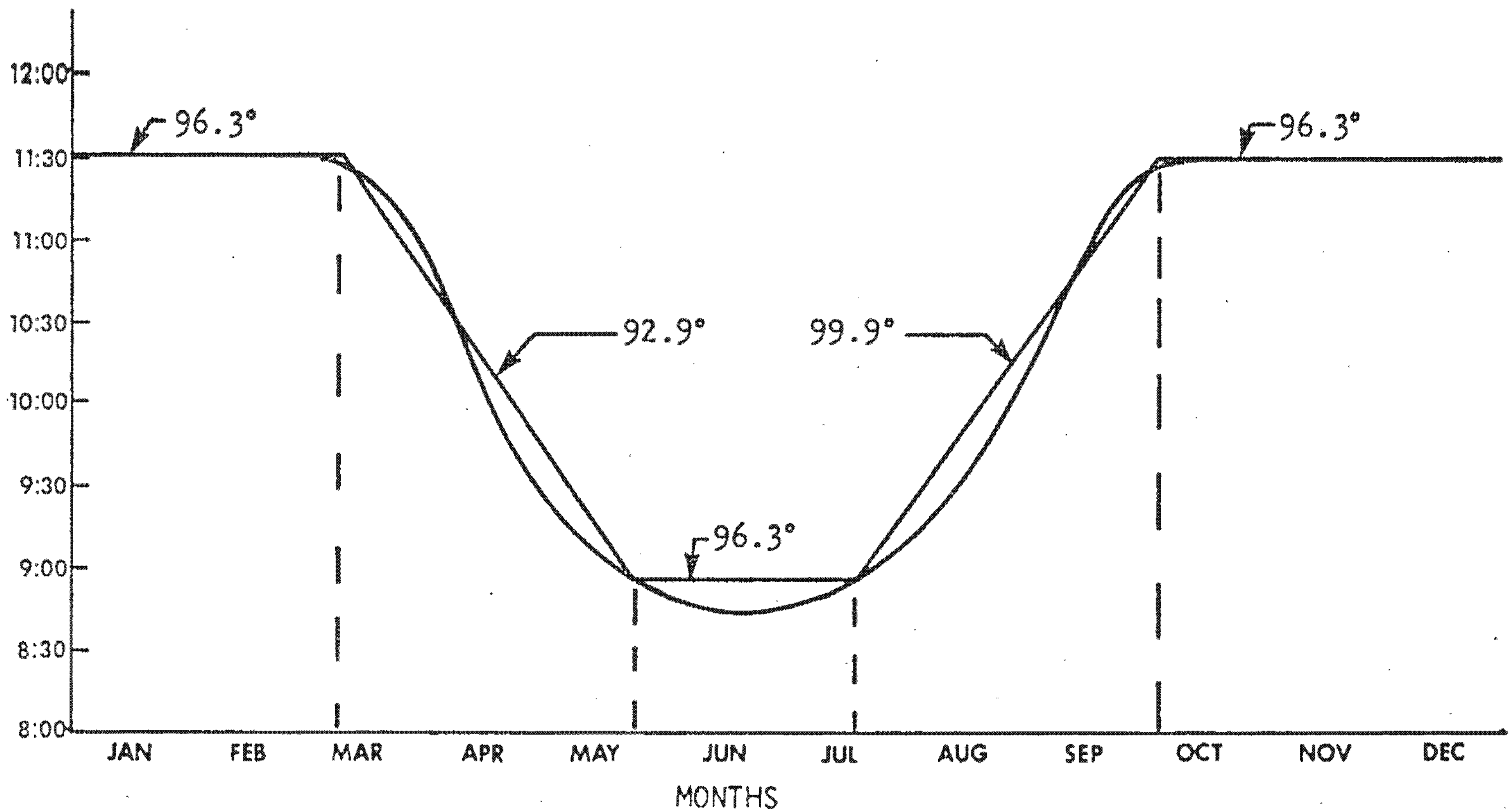
| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHADOW MENSURATION | 11:30 | 11:30 | 11:30 | 10:40 | 8:45 | 8:30 | 8:35 | 9:30 | 11:15 | 11:30 | 11:30 | 11:30 |
| SPECULAR REFLECTION/FRONT LIGHTING | NP | NP | NP | 9:05 | 8:15 | 8:15 | 8:20 | 9:05 | NP | NP | NP | NP |
| HIGHEST LATITUDE LINE | 9:40 | 9:30 | ← | | | NO PROBLEM | | | | → | 9:10 | 9:45 |
| MINIMUM EXPOSURE CHANGE (20° TO 60° N.L.) | 12:00 | 12:00 | 12:00 | 9:45 | 9:30 | 10:00 | 9:30 | 9:00 | 10:45 | 12:00 | 12:00 | 12:00 |
| MIN. RESOLUTION ≥ CHANGE FOR GAMBIT (50° N.L.) | 12:00 | 12:00 | 9:00 | 7:45 | 7:00 | 6:30 | 6:45 | 7:25 | 8:25 | 10:00 | 12:00 | 12:00 |

NOTES: A. (NP) No problem.

B. Min. resolution change times are the times required to maintain a solar altitude of 30° at 50°N latitude. These times are only accurate between March and October. During November-February the time is that required to produce the highest possible solar altitude at 50°N latitude.

FIGURE 2-10

Example of Orbit Inclinations to Optimize Image Quality



## 3.1 GAMBIT CUBED

### 3.1.1 Exposure Time and Smear

All satellite camera systems produce smear of one kind or another. Image motion compensation (IMC) can only easily compensate for smear perfectly at zero degree field and on a line along the major axis of film travel. The amount of smear in a picture, however, is primarily a function of the exposure time, the longer the exposure time the greater the smear. The exposure time required is, of course, a function of the solar altitude and the resultant brightness of the scene in question. Figure 3-1 shows the typical exposure time required for GAMBIT CUBED as a function of solar altitude. This graph illustrates that exposure time does not change very much above a solar altitude of 20-30°. The mean smear that would be expected, then, as a function of solar altitude is shown in Figure 3-2. This figure is for the worst direction (cross-track) smear. In any event, the graph shows that at solar altitudes above about 20° the smear can be expected to be less than two microns 50% of the time.

### 3.1.2 Camera Performance

The effect of the required exposure time and the resultant smear on the resolution produced can be computed. Figure 3-3 illustrates the mean expected GRD for GAMBIT CUBED as a function of solar altitude for nadir and 30° roll angle. Here the effects of the smear are clearly seen. Below solar altitudes of 20°, the resolution drops off drastically. In the case of nadir, the GRD goes from [redacted] at 20° solar altitude to a GRD of [redacted] at 5° solar altitude. This is a loss in GRD of 65%, due solely to the increasing smear resultant from the longer exposure times. At higher solar altitudes, however, the reverse situation is true. While, as the solar altitude increases the resolution also increases, the change is not nearly so dramatic. While 20° solar altitude produces a mean GRD at nadir of [redacted] going to 50° solar altitude only improves this figure to [redacted], an improvement in GRD of only 7%. Clearly, from a pure camera performance point of view, as long as the acquisition solar altitude is 20° or greater, there will be no significant change in resolution. As shown in Figure 3-3, these conclusions are applicable to a 30° roll angle as well.

FIGURE 3-1

# TYPICAL EXPOSURE VS. SOLAR ALTITUDE CURVE FOR GAMBIT CUBED

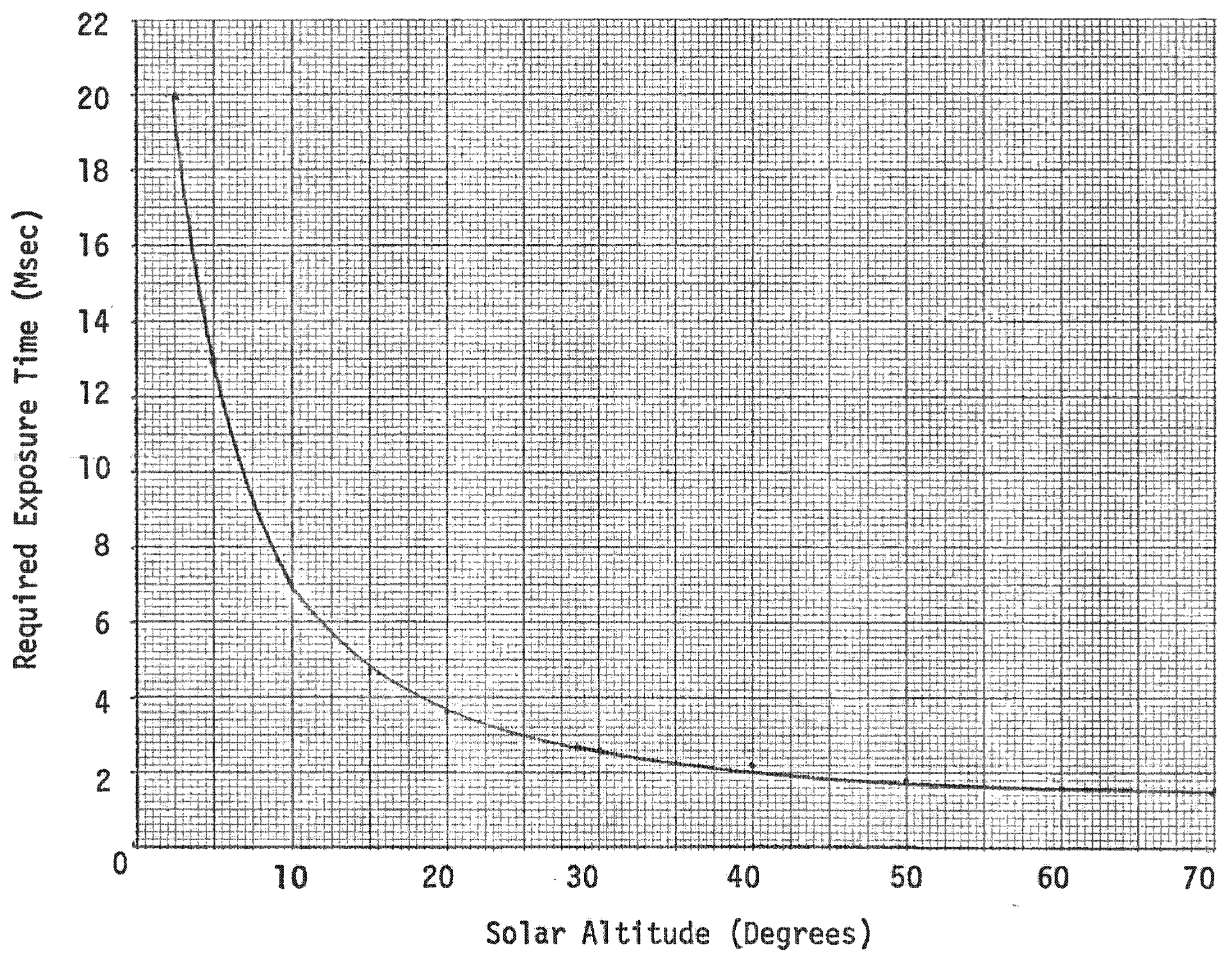


FIGURE 3-2

GAMBIT CUBED ESTIMATED MEAN SMEAR

FOR 4342 AND UP

(SMEAR RATE = 117 MICRO-RADS/SEC)

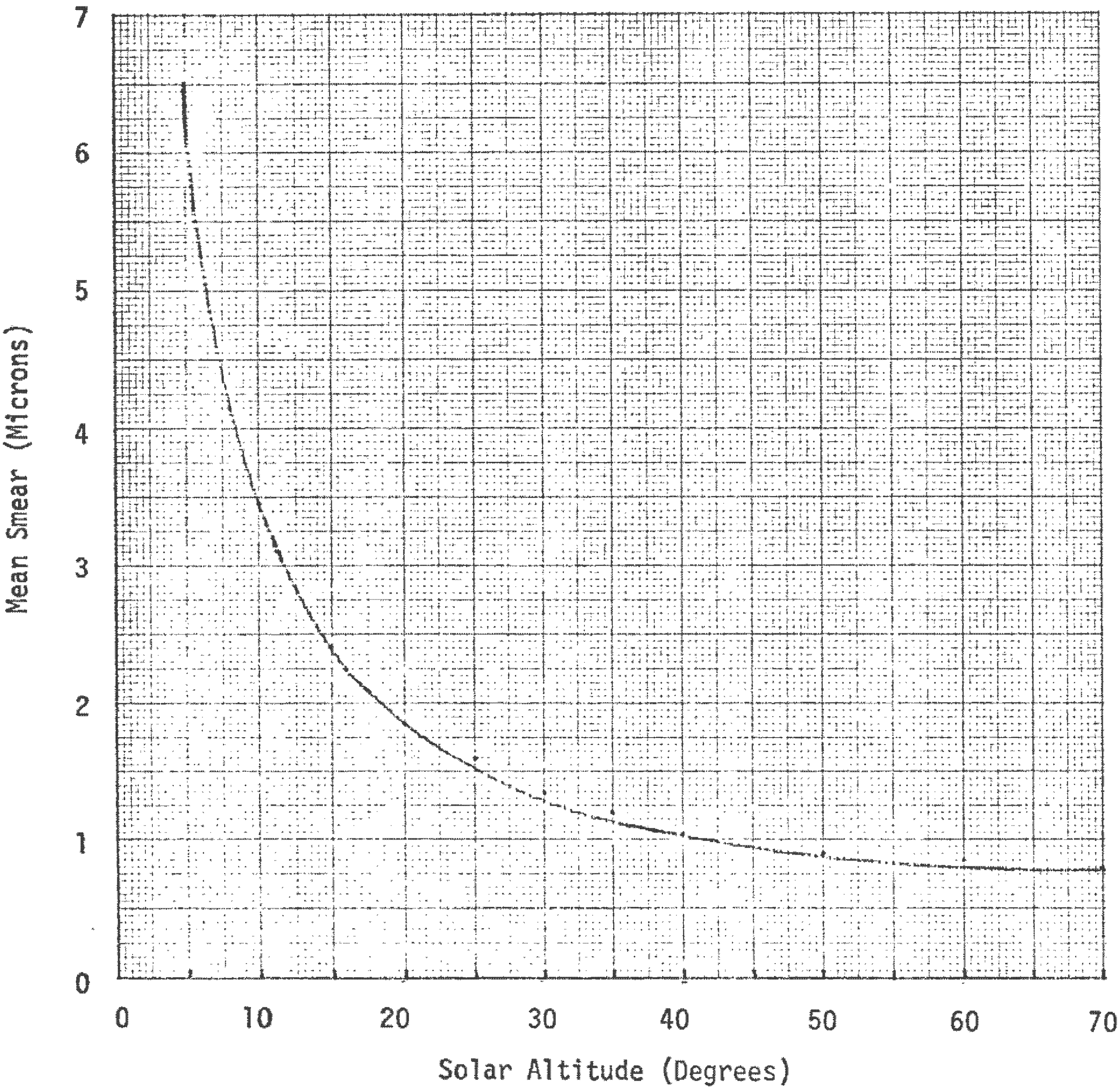


FIGURE 3-3

## MEAN EXPECTED GAMBIT CUBED GROUND RESOLVED DISTANCE (GRD) FOR CONSTANT 2:1 CONTRAST

(OQF = 0.82, 73 NM ALTITUDE)

### 3.1.3 The Impact of Contrast on Achieved Resolution

The previous section (3.1.2) discussed the impact of smear on achieved camera resolution. Figure 3-3 was plotted for a constant contrast value of 2:1. This is appropriate since the analysis was aimed at evaluating only the effects of smear, optics and roll angle on photographic image quality. However, when attempting to evaluate performance to be expected in a real sense (i.e. ground resolution of intelligence targets), the contrast must be considered. Real intelligence targets (as seen by the camera) are usually not 2:1 in contrast. In addition, because the camera angle to the sun (CATS) angle is changing as a function of solar altitude, the amount of haze back scatter changes; and, hence, the contrast of a given target will change as a function of solar altitude as well. As will be discussed in more detail later, haze is also a function of time of year, the summer time being worse (haziest) and the winter time best (clearest).

Figures 3-4 and 3-5, then, present the mean expected GRD for GAMBIT CUBED as a function of solar altitude for typical intelligence targets. For reference, the constant 2:1 contrast performance estimates are included on the graphs. Figures 3-4 and 3-5 illustrate the following:

a. Whereas the 2:1 contrast plot indicates a best GRD of [redacted] the typical intelligence target plot shows a best that can practically be expected at nadir of [redacted]

b. Both Figures 3-4 and 3-5 illustrate that (for the same solar altitude) December produces better GRD's than June. This is to be expected because of the clearer weather conditions. It does not consider, however, the impact of more pictures being acquired at lower solar altitudes in December. This will be discussed later. Nor does it consider that prevailing snow and weather may obscure significant amounts of the ground scene in December.

c. Whereas Figure 3-3 illustrated that above 20° solar altitude no significant improvements in performance could be expected, Figures 3-4 and 3-5 do not totally agree. Since contrast and smear are both influencing the results presented in Figures 3-4 and 3-5, it should be expected that slightly different conclusions would be

FIGURE 3-4

# MEAN EXPECTED GAMBIT CUBED GROUND RESOLVED DISTANCE (GRD) FOR TYPICAL INTELLIGENCE TARGETS

(73 NM ALTITUDE)

FIGURE 3-5

# MEAN EXPECTED GAMBIT CUBED
# GROUND RESOLVED DISTANCE (GRD)
# FOR TYPICAL INTELLIGENCE TARGETS

(73 NM ALTITUDE)

reached. For nadir in either June or December, the 20° solar altitude is still acceptable. For 30° roll, however, the ground resolution of typical intelligence targets is dropping off more sharply with solar altitude than it does for the 2:1 contrast case. In the 30° roll case, a solar altitude of 25-30° is needed before no significant change in resolution is noted.

The above discussion considered, however, only the average seasonal haze conditions that exist for the two months as a function of solar altitude. In any event, it can be seen for Figures 3-4 and 3-5 that the average GRD produced by the GAMBIT CUBED camera (for typical intelligence targets) can vary from a best of [redacted] to a low of nearly 20 inches, depending solely on the time of year, roll angle and solar altitude.

Haze tends to be akin to exposure time in its effect. That is, there is a range of relatively clear haze conditions that do not change performance very much. However, as haze gets worse than average, performance drops off more rapidly.

Figure 3-6 illustrates the point. This figure presents the mean GRD that would be expected for GAMBIT CUBED under a variety of haze conditions, two solar altitudes, nadir and 30° roll. There are several interesting observations that can be made from the graph:

a. As noted above, as the haze levels get better (clearer) than average, there is no significant improvement in GRD, with the possible exception of the 30° roll case at 10° solar altitude.

b. The significant losses in resolution occur as the haze condition worsens from the average level. In addition, whereas a GRD of [redacted] is predicted at nadir (30° solar altitude) for the average haze conditions, under very heavy haze, this is reduced to a best of [redacted] For the 30° roll, 10° solar altitude case, the GRD of [redacted] under average haze conditions decreases to 17.5 inches for the very heavy haze condition.

c. The important observation, however, is that as the acquisition conditions worsen (i.e. lower solar altitude, higher roll angle, etc.), the effect of haze on contrast becomes increasingly severe; and, hence, the

FIGURE 3-6

# GAMBIT CUBED RESOLUTION FOR VARIOUS CONDITIONS OF SOLAR ALTITUDE, CONTRAST AND ROLL ANGLE

resultant ground resolution becomes increasingly degraded.

## 3.2 HEXAGON

The factors that influence the image quality of the HEXAGON camera are very similar to those that influence that of the GAMBIT CUBED camera. These effects are discussed in the following paragraphs.

### 3.2.1 Exposure Time and Smear

The influence of the smear produced by the HEXAGON camera is much the same as that with the GAMBIT CUBED. HEXAGON, however, because it is a panoramic camera the optics of which rotate about its major axis, must move the film (in the cross-track direction) much faster* than need GAMBIT CUBED. This results in a slightly larger smear budget for HEXAGON**. While the budgeted smear rates for HEXAGON are nominally twice those of GAMBIT CUBED, it can stand more smear since it has a faster lens (f/3.5 for HEXAGON vs. f/4.0 for GAMBIT) and hence can employ shorter exposure times. The nominal required exposure times for HEXAGON (for both filters) are shown in Figure 3-7. Figure 3-8, then, shows the mean smear that is expected with HEXAGON as a function of solar altitude. In this case, the expected smear does not get below two microns until approximately 25° solar altitude.

### 3.2.2 Camera Performance

As was done for GAMBIT CUBED, the effect of the required exposure time and the resultant smear can be computed. Figure 3-9 illustrates the mean expected GRD for HEXAGON as a function of solar altitude for nadir and 45° of scan. Again, the effects of smear are clearly seen. Below a solar altitude of 20°, the resolution drops off rapidly. In the case of nadir, the GRD

*Up to a maximum of 204 in/sec.

**The HEXAGON mean expected smear spec is .05 in/sec both in-track and cross-track. This equates to 1.3 microns/msec. The comparable rate for GAMBIT is 0.52 microns/msec.

FIGURE 3-7

# TYPICAL HEXAGON EXPOSURE TIME VERSUS SOLAR ALTITUDE

(89.3 NM ALTITUDE)

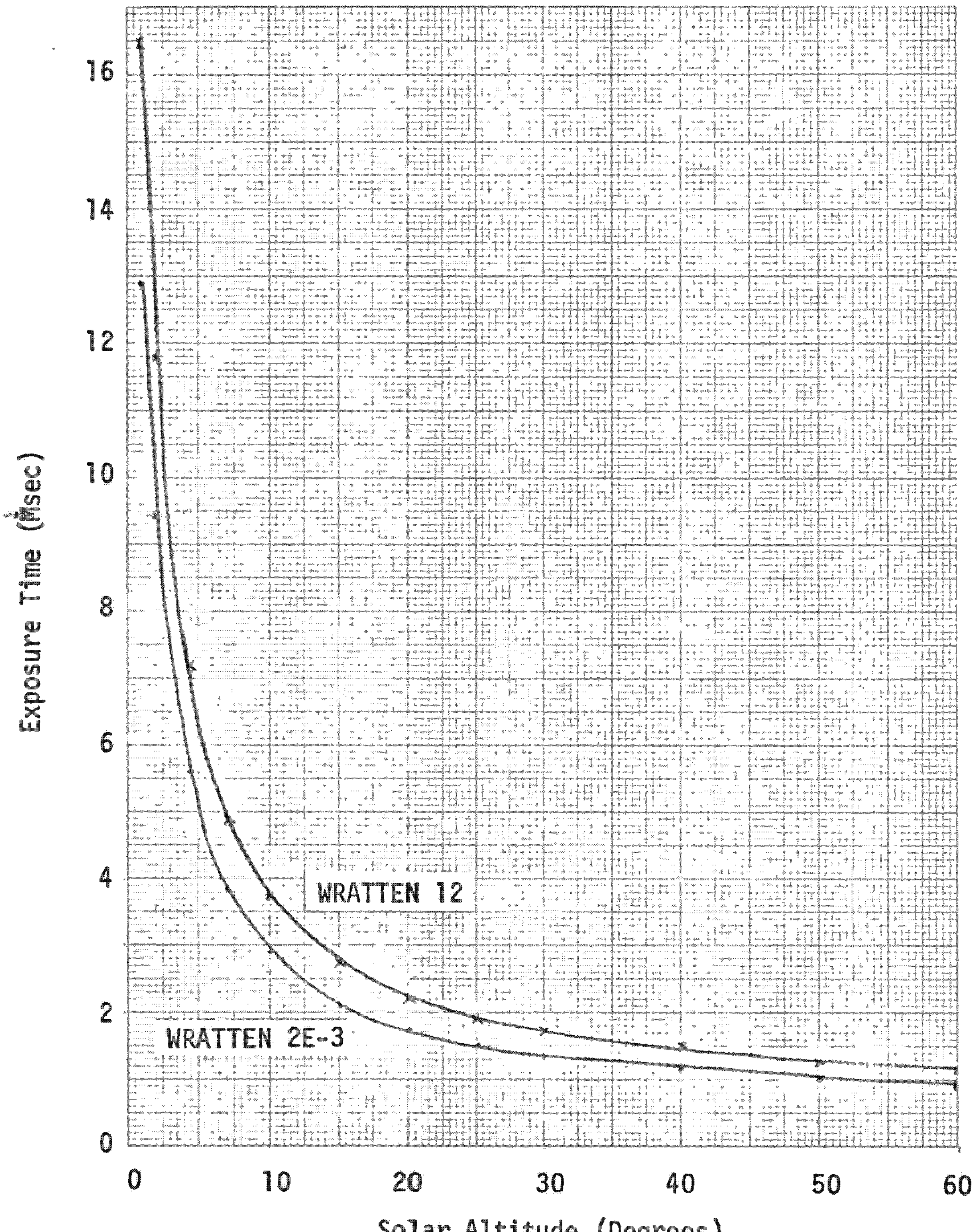


FIGURE 3-8

# TYPICAL HEXAGON SMEAR VERSUS SOLAR ALTITUDE

(89.3 NM ALTITUDE)

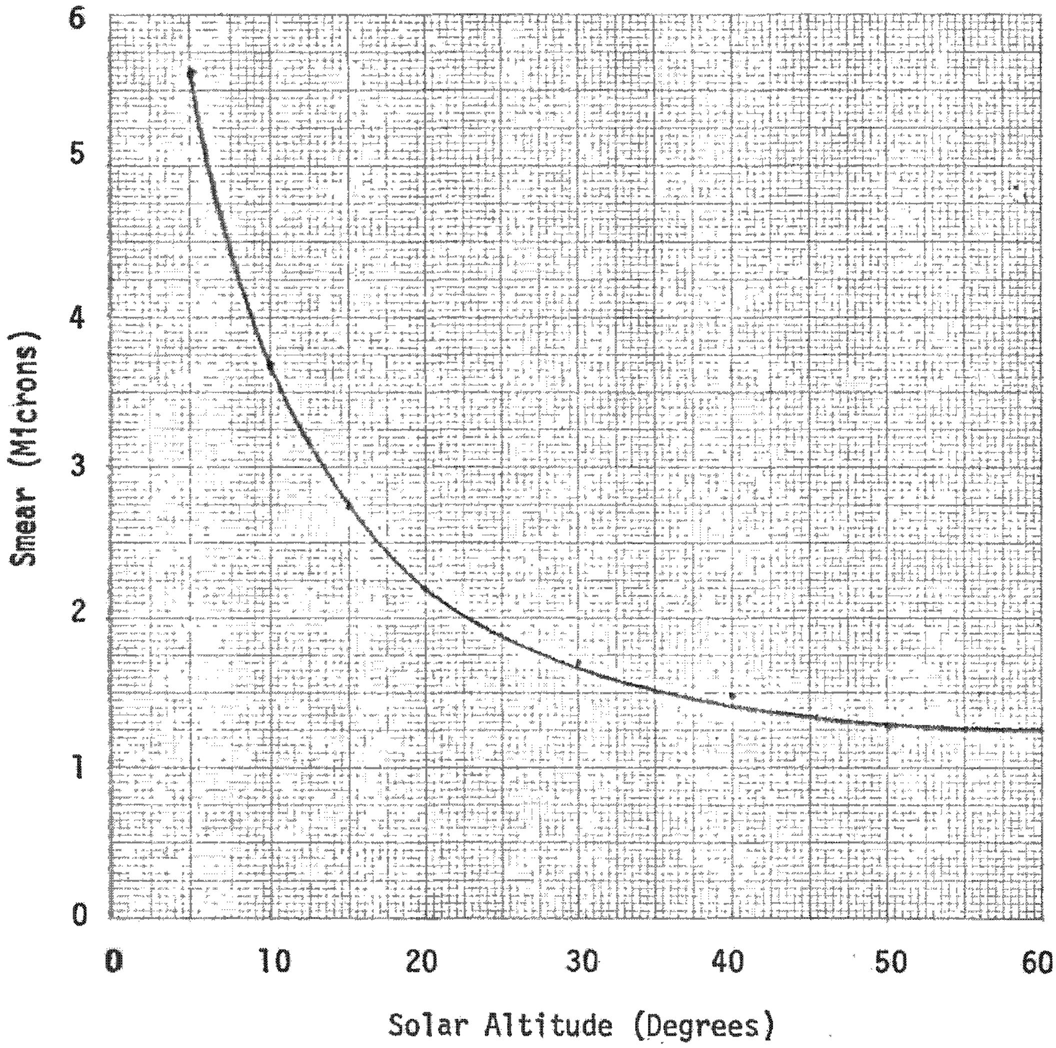
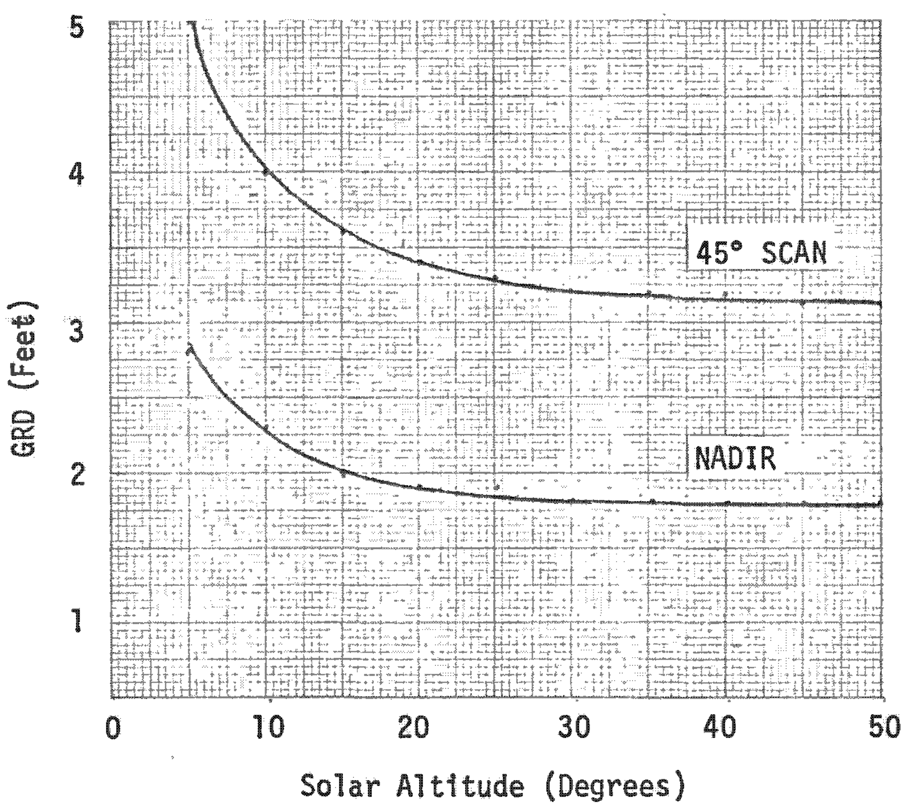


FIGURE 3-9

MEAN EXPECTED HEXAGON
GROUND RESOLVED DISTANCE (GRD)
FOR CONSTANT 2:1 CONTRAST

(89.3 NM ALTITUDE)



goes from 1.9 feet at 20° solar altitude to a GRD of 2.8 feet at 5° solar altitude, a loss in resolution of 50%. At high solar altitudes, however, the reverse is true. While the solar altitude increases, there is almost no change in predicted mean GRD, going from 1.9 feet at 20° solar altitude to 1.8 feet at 50° solar altitude. These observations are generally applicable to the 45° scan angle case, except the solar altitude of no significant improvement appears to be about 30°.

### 3.2.3 The Impact of Contrast on Resolution

As with the GAMBIT discussion, the previous section (3.2.2) was limited to evaluating the effects of sun angle, exposure time, smear and scan angle on quality. HEXAGON performance as well is affected by contrast effects; and when considering the GRD to be produced for real intelligence targets at various times, the contrast effects must be considered. As pointed out in Section 3.1.3, real intelligence targets are not usually of 2:1 contrast (at the camera aperture), and haze effects (and hence contrast) change as a function of solar altitude and time of year.

Figures 3-10 and 3-11 present the mean expected GRD for HEXAGON, as a function of solar altitude, for typical intelligence targets instead of the constant 2:1 contrast discussed above. The following observations can be made:

a. Whereas the 2:1 contrast plot indicates a best GRD of 1.8 feet, the typical intelligence target plot (3-10) shows a best of 2.9 feet for the same solar altitude condition (30°). The 45° scan angle comparisons are 3.2 feet (2:1 contrast) vs. 4.9 feet (15 December plot) for the typical intelligence target. These comparisons are also for 30° solar altitude.

b. Again, both Figures 3-10 and 3-11 predict better GRD's for the same solar altitude in December than in June. As with GAMBIT CUBED, this is due to the better haze conditions, and hence contrast, in December versus June.

c. Figures 3-10 and 3-11 show performance improving more dramatically above 30° solar altitude than did Figure 3-9. This is particularly true for the 45° scan angle case.

FIGURE 3-10

MEAN EXPECTED HEXAGON
GROUND RESOLVED DISTANCE (GRD)
FOR TYPICAL INTELLIGENCE TARGETS

(89.3 NM ALTITUDE)

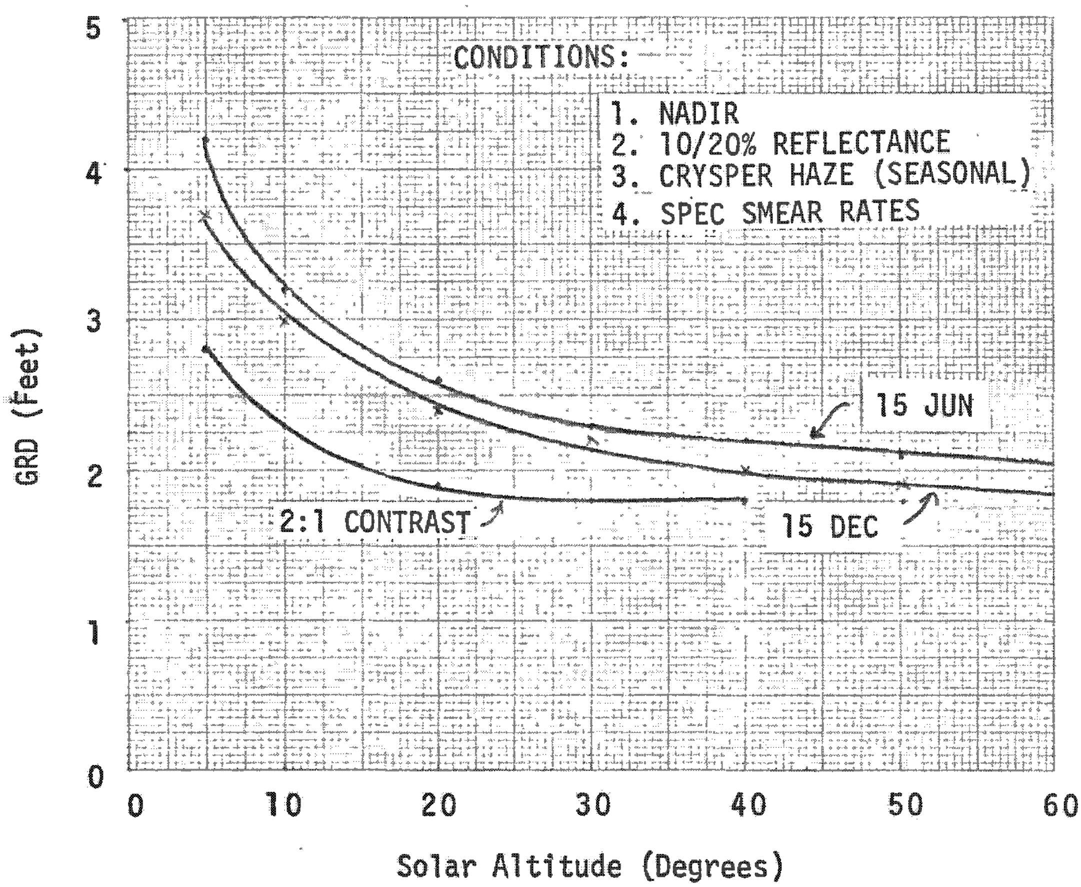
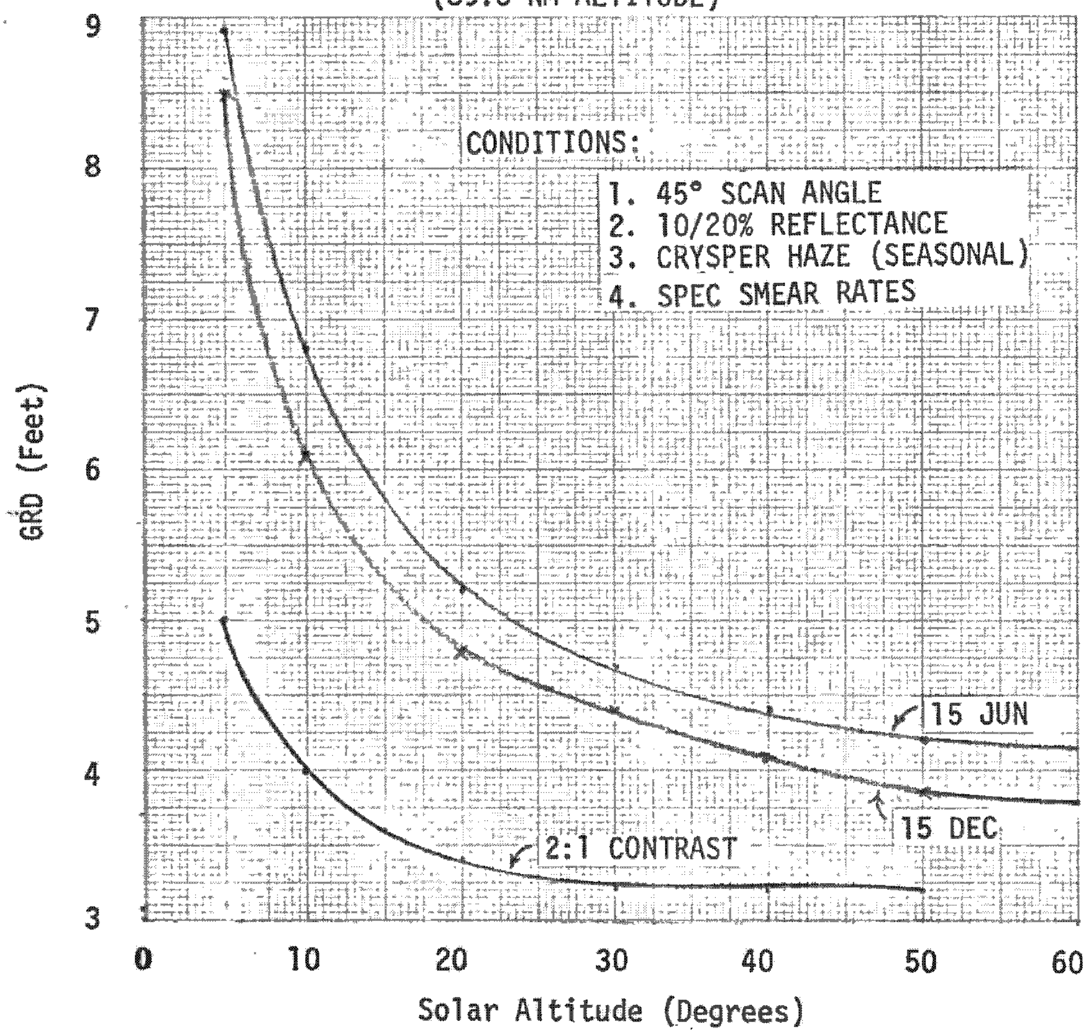


FIGURE 3-11

# MEAN EXPECTED HEXAGON GROUND RESOLVED DISTANCE (GRD) FOR TYPICAL INTELLIGENCE TARGETS

(89.3 NM ALTITUDE)



As before, the above discussion relative to the effects of contrast considers only the "typical" intelligence target and average seasonal haze conditions. The influence of different specific targets will be discussed later. The effects of other than average haze are shown on Figure 3-12*. This figure illustrates, as well, that average-to-clear haze conditions do not affect resolution that significantly. As haze conditions worsen, however, the effect on resolution becomes more severe, the severity increasing in its effect with lower sun angle and higher scan angle.

## 3.3 Effect of Target Type, Illumination and Time of Year

The previous sections (3.1 and 3.2) discussed image quality in a somewhat theoretical sense since they were based on analysis using models of camera performance and the atmosphere. In these previous discussions, it was assumed that the target was a horizontal one, on a horizontal plane and illuminated by daylight. Real intelligence targets are often not horizontal in nature nor are they necessarily illuminated by daylight. This section attempts to discuss in more detail the effects on photographic image quality of the target itself, its illumination conditions and the time of year the picture is taken.

### 3.3.1 Target Type and Illumination

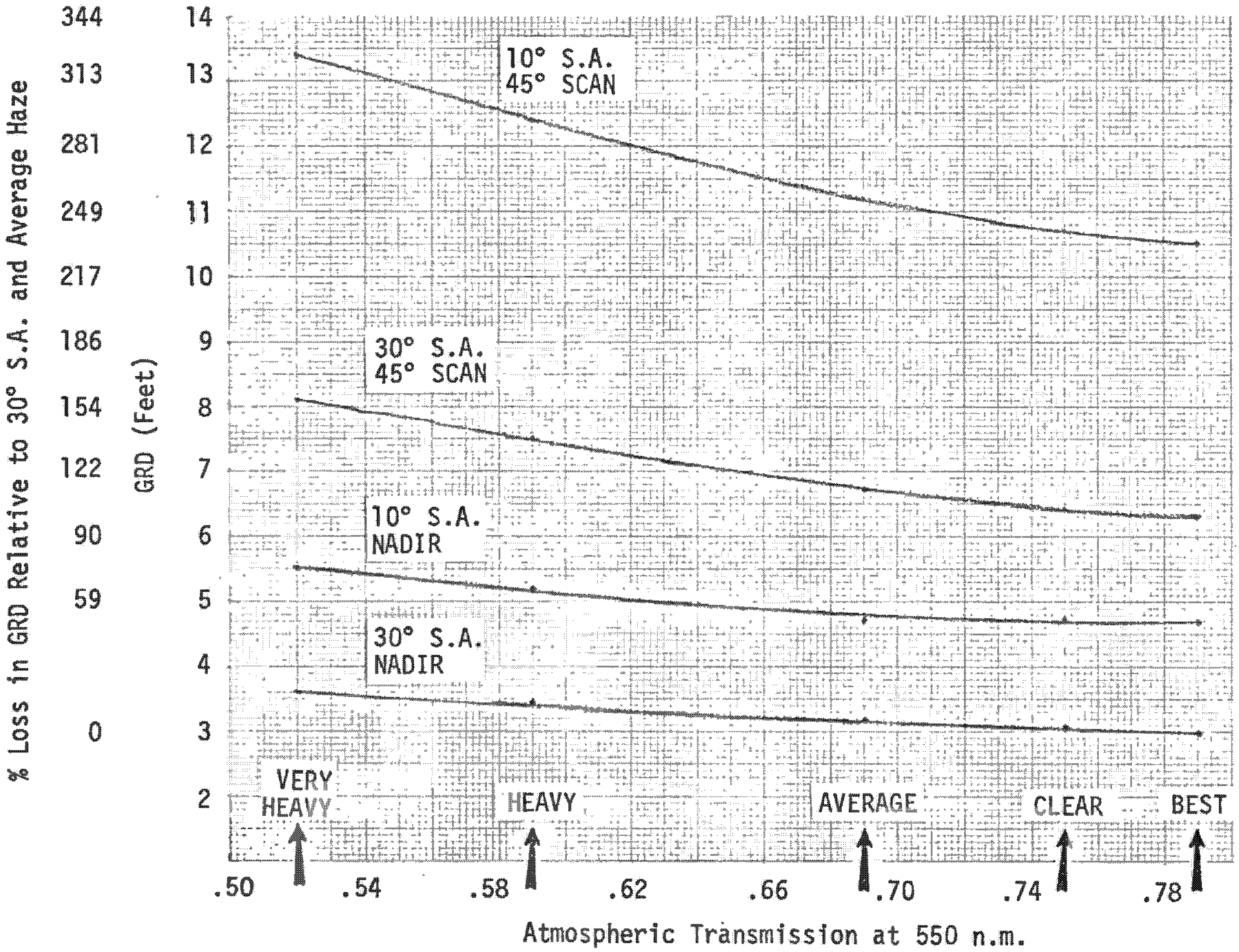
There are numerous combinations of camera/target/sun (CATS) angle and target illumination that will cause variations in the amount of energy at the image plane. Even if the spectral reflectance of the target is identical under all conditions of illumination, the effective contrast at the image plane differs in each situation. For example, a target of interest might be found in shadow, in partial shadow; or the target could be a vertical object that is front-lighted or back-lighted. It is the purpose of this section to give the reader insight as to how relative GRD may vary when a single target having a maximum and minimum reflectance of 33 and 7 percent

*It should be noted that the GRD values in Figure 3-12 are two sigma low estimates. The previous plots presented the mean expected GRD.

FIGURE 3-12

# HEXAGON RESOLUTION FOR VARIOUS CONDITIONS OF SOLAR ALTITUDE, CONTRAST AND SCAN ANGLE TWO SIGMA LOW VALUES

(89.3 NM ALTITUDE)




NOTES:

1. 10/20% REFLECTANCE
2. CRYSPER HAZE (AS INDICATED)
3. 1206 SMEAR RATES

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respectively (a CORN tri-bar target) is illuminated under various conditions and is acquired from various scan (roll) angles.

Figure 3-13* gives relative GRD as a function of scan angle for a June 23 acquisition using a forward-looking camera (at 10° pitch) to photograph various targets under a variety of combinations of illumination and target orientation. The relative GRD values include only the effect of atmospheric haze, target illumination and target orientation. Effects of slant range and other geometric considerations are excluded.

In Figure 3-13, the greatest loss in relative GRD occurs when the target is either horizontal or vertical but under shadow conditions. The case for a vertical target in shadow improves, however, when acquired in December. This is the result of a lesser effect of haze combined with look angle conditions and illumination conditions which are improved in the December acquisition for vertical targets. Figure 3-14 shows the results of the prediction of GRD for a December 23 acquisition. The characteristic U-shaped curve is found on every illumination and object orientation condition.

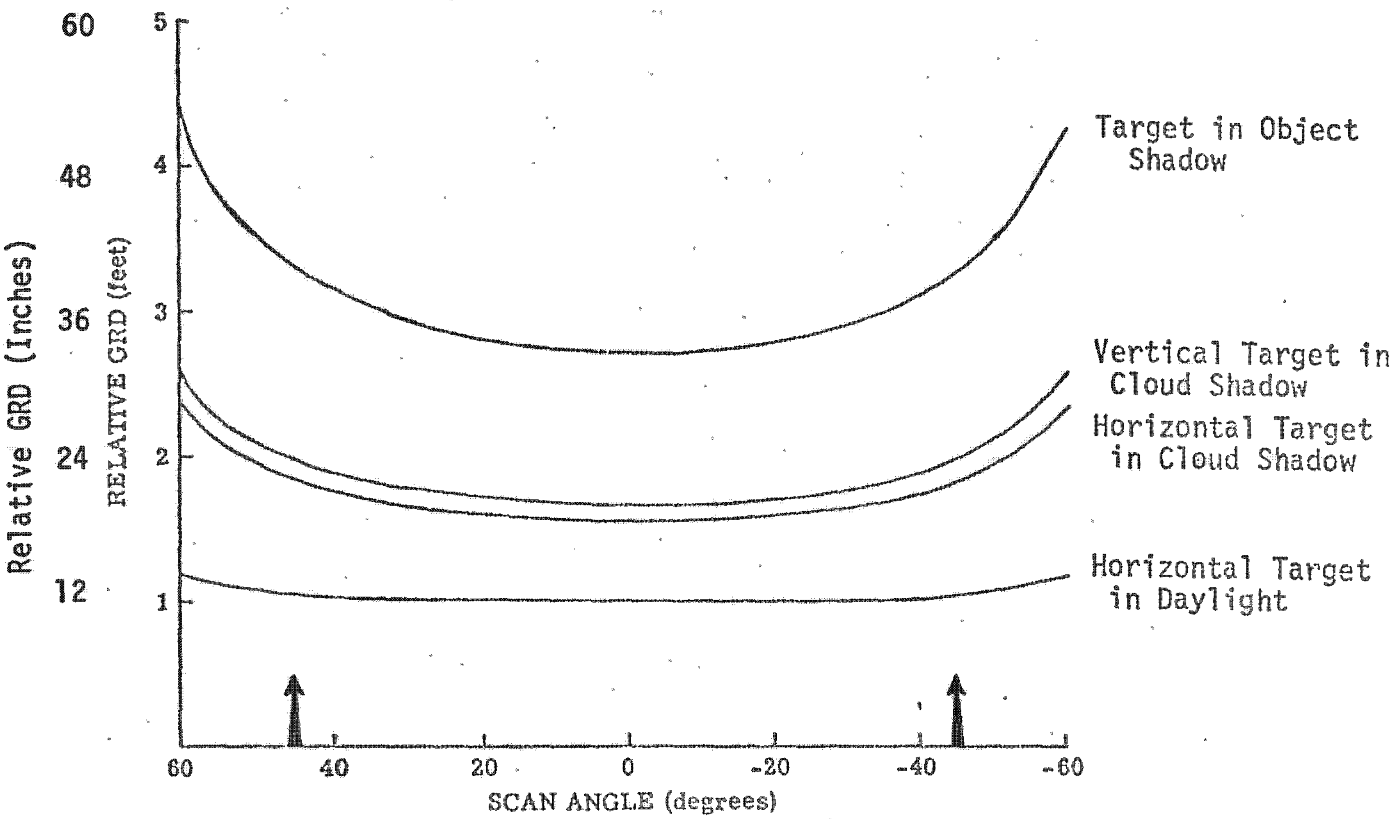
The two figures illustrate the very significant influence the illumination conditions have on the resultant GRD, irrespective of the performance level of the camera itself. In the summer, the GRD produced at nadir for a specific horizontal target can vary by a factor of nearly one foot (say 2.5 feet to 3.5 feet) based strictly on whether or not the target is illuminated by daylight or is in cloud shadow. This observation most likely has more practical consequences with the GAMBIT system since it is more target-oriented than is HEXAGON.

For the same set of conditions (nadir, horizontal object), the GAMBIT GRD also will vary by nearly one foot (say 12 inches to 24 inches) based solely on whether or not the object is in daylight or cloud shadow. If the target is in object shadow (equipment in shadow of building, for example), then the losses at nadir are on the order of two feet. That is, for a GAMBIT CUBED system operating at a nominal 12-inch

*The calculations that resulted in Figures 3-13 and 3-14 were done specifically for HEXAGON. They are reasonably close to what will happen for a GAMBIT CUBED forward look, however, and hence are applicable to that camera as well.

FIGURE 3-13

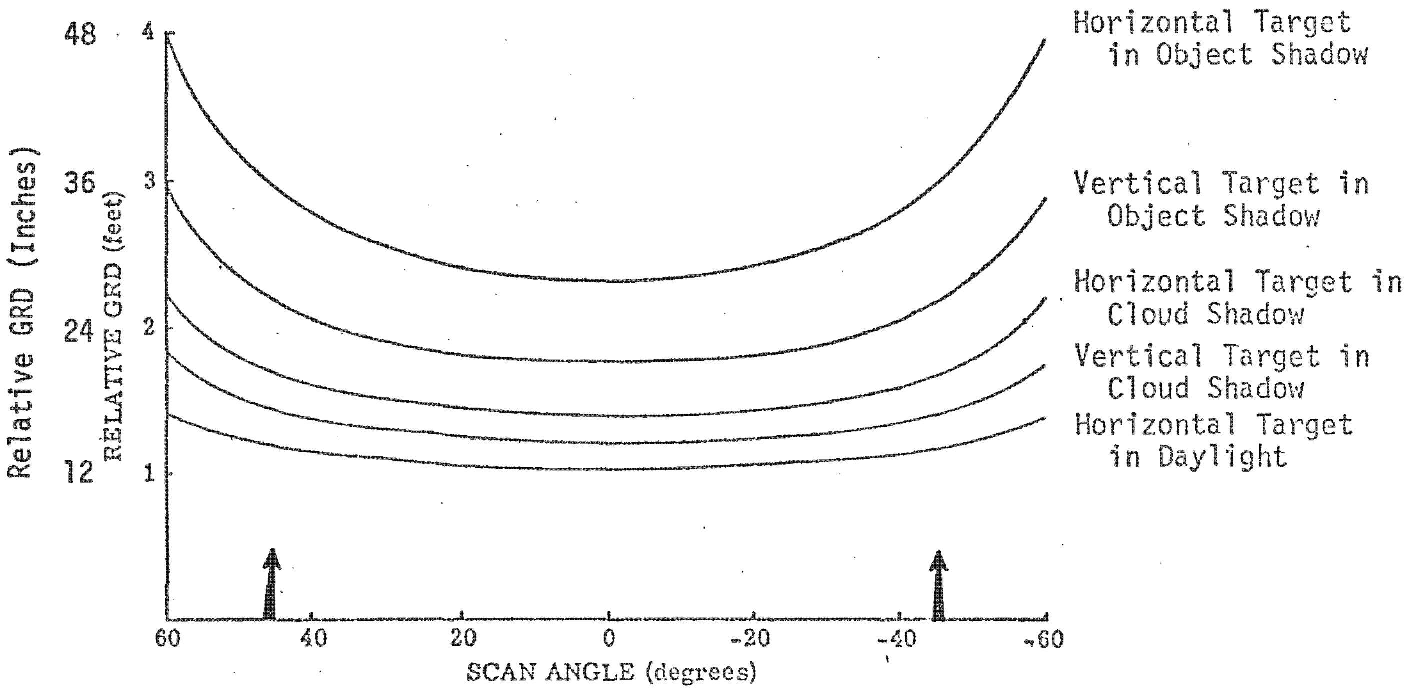
RELATIVE GRD FOR VARIOUS TYPES OF TARGET ILLUMINATION FOR SUMMER ACQUISITION




NOTE: Solar Altitude = 63°
Arrows indicate GAMBIT CUBED cut-off

FIGURE 3-14

RELATIVE GRD FOR VARIOUS TYPES OF TARGET ILLUMINATION FOR WINTER ACQUISITION




NOTE: Solar Altitude = 17°
Arrows indicate GAMBIT CUBED cut-off

level, the real GRD for this condition produced would be 36 inches (three feet) due strictly to the illumination conditions.

The above discussion considered horizontal and vertical targets of a given constant set of reflectances (33% and 7%). As such, Figures 3-13 and 3-14 present the effect on GRD of two variables only, illumination and target orientation (i.e. horizontal or vertical). Each target, however, has its own unique set of reflectances (contrasts) that will also influence the ground resolution produced. Over the years, data has been collected that allows assigning a general set of highlight and lowlight reflectances to classes of intelligence targets. These reflectances can be used to predict the GRD of specific classes of targets with a program such as CRYSPER. Figure 3-15 illustrates the GRD's that could be expected for three classes of intelligence targets: ICBM's (COMIREX Class 1A), Military Installations (COMIREX 7A) and Surface-to-Air Missiles (COMIREX Class 1I).

The difference in mean expected GRD between the three classes of targets is obvious from the graph. The difference in GRD's is due solely to the different reflectance nature of the targets. If five feet GRD is used as an arbitrary definition of an acceptable picture, ICBM complexes can be (on the average) satisfactorily acquired out to scan angles of 45°, while military installations can only be satisfactorily acquired within approximately $\pm 35°$; and SAM's can only be satisfactorily acquired within approximately $\pm 25°$.

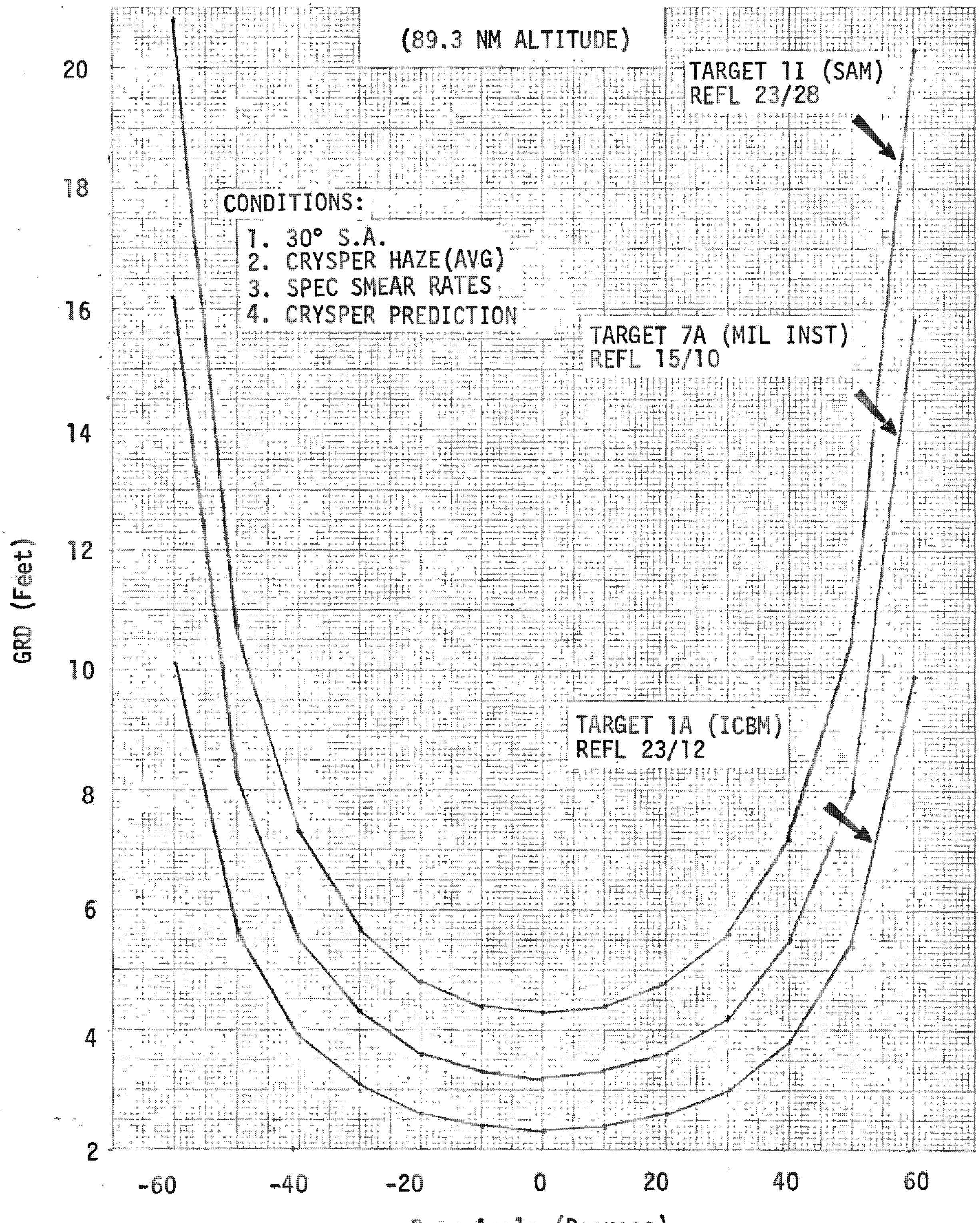
### 3.3.2 Contrast and Time of Year

The discussions presented in Sections 3-1 and 3-2 alluded to the fact that, for a constant solar altitude, photographic image quality is better in December than June and stated that this was due to better (clearer) haze conditions. This is a difficult problem to evaluate accurately because the modeling of haze is extremely difficult. The problem is further complicated by the fact that there is no known way to measure, describe or otherwise report on haze conditions in a way that is meaningful to the satellite photography case. Therefore, data on haze and its statistics must be inferred.

One way to make this inference is by evaluating the brightness range recorded on the film of several urban/industrial

FIGURE 3-15

# HEXAGON GROUND RESOLVED DISTANCE (GRD) VERSUS SCAN ANGLE FOR SPECIFIC TARGET CATEGORIES



scenes as a function of time of year. Figure 3-16 illustrates such data collected from both HEXAGON and GAMBIT CUBED photography. From this data, it can be stated that the summer time is generally the worst from a contrast point of view; and from that it can be inferred that haze is the predominant factor. Clearly, however, as one departs from the summer, the apparent contrast is rising rapidly.

## 3.4 The Relationships between Photographic Image Quality and PI Suitability

The previous discussions attempted to point out the numerous factors that both individually and in combination can dramatically influence the quality of the final photographic image. The real questions are: Are these truly reflected in the imagery and do they really affect the photointerpreter's ability to interpret the photography? This section attempts to deal with these questions. It should be noted, however, that the discussion will be more complete for HEXAGON than GAMBIT CUBED since there are more analytical tools available with HEXAGON with which to conduct such an analysis.

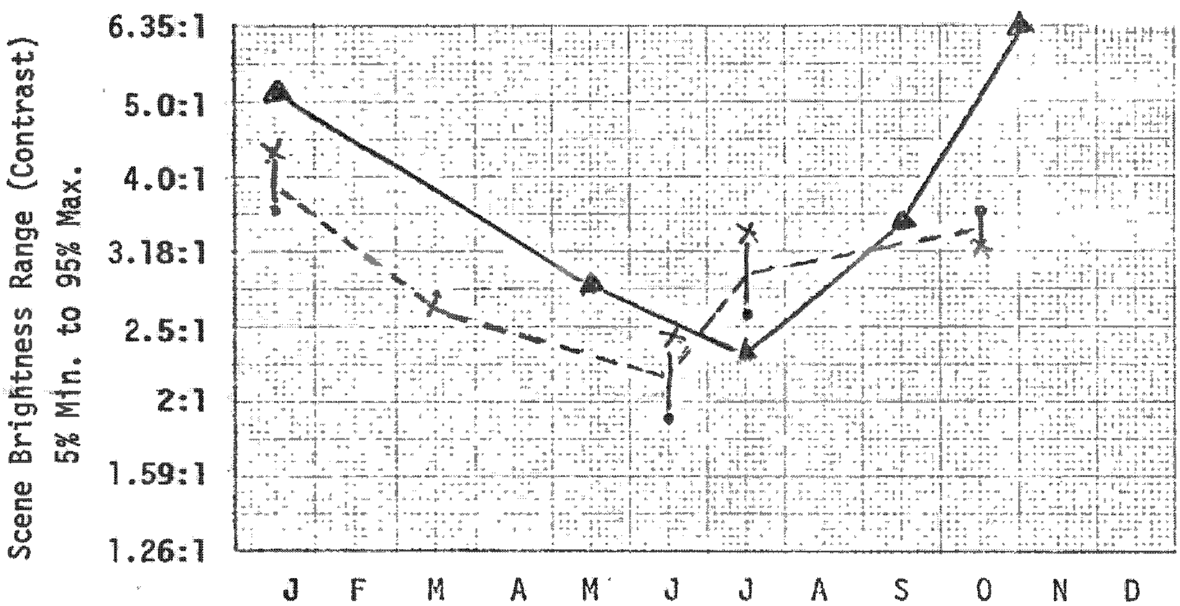
### 3.4.1 GAMBIT CUBED

#### 3.4.1.1 Exposure Time

From the Section 3.1.1 discussion, it could be concluded that overall image quality should not vary significantly (due to camera performance) if the solar altitude is maintained above 20-25°. This observation can be practically demonstrated by comparing the results of four recent GAMBIT CUBED missions. Mission 4337 was launched on 21 December 1972. The acquisitions on this mission were at an average solar altitude of 26°. Of the targets read out by the PI's, 39% were rated good. This percentage compares favorably with Missions 4336 (39% good), 4334 (32% good) and 4332 (36% good), even though the average acquisition solar altitudes on the later missions were 44°, 44° and 40° respectively. In addition, if solar altitude was the dominating factor, one would expect summertime missions to produce (on the average) the highest percentage of targets rated fair or better. Such is not the case, as is discussed in Section 3.4.1.2.

FIGURE 3-16

# SCENE BRIGHTNESS RANGE DATA FOR URBAN/INDUSTRIAL SCENES FOR 1200- AND 4300-SERIES MISSIONS




--- 1200-SERIES CAMERA

x Forward-looking
· Aft-looking

▲ 4300-SERIES CAMERA

NOTE: This data should not be inferred as representing the average apparent contrast of intelligence targets. It is collected by raster scanning (with a microdensitometer) urban/industrial scenes. 2000 data points are collected per area. These are collected into a histogram and the 5% min. and 95% max. values are used as the definition of the scene brightness range. As such, these contrast values are higher than the brightness range of contiguous areas or of a typical target.

### 3.4.1.2 Time of Year

The discussion in both Sections 3.1 and 3.3.2 allow the conclusion that, other factors being equal, image quality will vary as a function of time of year due to the varying effects of haze. Those discussions noted that haze tends to be worse in the summer time and best (clearest) in the winter. If this is so, this should be reflected in the photointerpreter ratings. Taking all the 4300-series missions to date and evaluating the percentage of targets rated fair or better by the photointerpreters provides the following data:

| Season | % Targets Rated Fair or Better* |
|---|---|
| Fall (Sep-Oct) | 79 |
| Winter (Nov-Feb) | 76 |
| Summer (Jun-Aug) | 71 |
| Spring (Mar-May) | 70 |

The above data bears out the general observations made. Fall missions produce the highest percentage of targets rated fair or better by the PI's. In addition, fall missions have resulted in the largest percentage and most frequent occurrence of targets rated excellent by the photointerpreters. Mission 4333 (launched 23 October 1971) had 6% of its targets rated excellent by the PI's. Only seven other missions had excellent ratings as high as 3%; and of these, only one was a summer mission (4332, 12 August 1971). Considering all factors, however, these observations should be expected. Not only is the contrast data favorable in the fall, but the sun angles are still reasonably high, so that acquisition solar altitudes in excess of 20-30° are easy to maintain for most targets of interest. It is somewhat surprising that the winter missions performed so well in that longer exposure times are required, but again the winter should produce the clearest (best contrast) acquisitions. It is interesting to note that the mission that produced

*Approximately 100,000 photointerpreter ratings of intelligence targets is included in this data base so that differences noted are most likely significant.

the highest number of target rated good (60%) was 4310. 4310 was launched on 5 December 1967. The mission that produced the second highest percentage of targets rated good (54%) was 4308. 4308 was a fall mission, being launched on 19 September 1967. The important observation from this discussion, however, is that solar altitude and exposure time are not the dominant factors in considering the image quality that will be produced by a satellite camera.

### 3.4.1.3 Target Dependency

Section 3.3.2 indicated that ground resolution should be dependent on the nature of the target itself. That is, each target has its own unique set of reflectances, and these will affect the contrast and the ultimate ground resolution. This factor is hard to evaluate since most targets acquired are not rated by the PI's, making it difficult to collect accurate statistical data. However, two COMIREX target categories, missiles and air installations, do have sufficient numbers of targets rated to allow comparisons. Based on the target reflectance data in CRYSPER, the mean contrast of air installations (on the ground) is approximately 1.8:1. Similarly, the mean contrast for missile and missile-related targets is approximately 1.6:1. If the nature of the target is important, then, on the average, air installations should receive a higher percent of targets rated good than missiles due simply to the higher inherent contrast of the targets. Indeed, this is the case. For all the targets rated in these two categories on Missions 4332 through 4337, 55% were rated good on air installations versus only 31% for missile categories.*

## 3.4.2 HEXAGON

### 3.4.2.1 Exposure Time and Smear

The question of the effect of exposure time and smear on quality can be addressed directly on HEXAGON from the visual edge match (VEM) data. Indeed, it is possible to evaluate

*It is certain that contrast is not the only factor that causes this difference in % targets rated good between the two categories. Many missile targets are mandatories; that is, they are taken at every opportunity and thereby are more likely to be taken under poor acquisition conditions. The data is generally consistent with what would be expected, however, if target contrast is a contributory factor.

each mission camera in terms of the resolution (in c/mm) produced in the film plane on operationally acquired photography and ignore the effects of haze, contrast, etc.* The data for the first five missions is summarized in Table 3-1, where the missions are listed in order of decreasing camera performance.

TABLE 3-1

HEXAGON Mission Resolving Power Data from VEM

(Values in c/mm)

| Mission | Dates Launch | Dates Completion | Mean Resolving Power |
|---|---|---|---|
| 1202 | 20 Jan 72 | 28 Feb 72 | 170 |
| 1201 | 15 Jun 71 | 16 Jul 71 | 156 |
| 1205 | 9 Mar 73 | 11 May 73 | 155 |
| 1203 | 7 Jul 72 | 2 Sep 72 | 137 |
| 1204 | 10 Oct 72 | 17 Dec 72 | 135 |

The table illustrates that the best mission, from a camera performance point of view, was 1202, a winter mission. This occurred in spite of the fact that this mission required longer exposure times than any other. The worst mission, from a resolving power point of view, was 1204. Yet, as later discussion will show, in most respects, this was the best HEXAGON mission to date.

### 3.4.2.2 Achieved Mission Performance

It is not possible to evaluate HEXAGON performance as a function of time of year (as was done with GAMBIT CUBED) because there have been a far fewer number of missions and

*VEM resolution values are for a constant 2:1 contrast and are not affected by the specific contrast of the scene.

the statistics would be shakey at best. It is possible, however, with the CRYSPER Program and knowledge of the acquisition conditions, to evaluate the five missions to date and arrive at conclusions about the factors that influence PI suitability. It is also possible to illustrate how these factors are in agreement with previous discussions.

With HEXAGON, the vehicle altitude, amount of photography at high scan angles and contrast are all important factors in determining how the PI will rate the imagery. These factors cannot be considered alone but must be considered together. The following discussion illustrates this point.

Table 3-2 presents a summary of the "all weather" photointerpreter ratings for the OAK and OAK Supplement targets.

TABLE 3-2

Summary of All Weather PI Suitability Ratings

(Percent)

| Rating Category | 1201 | 1202 | 1203 | 1204 | 1205 |
|---|---|---|---|---|---|
| Excellent | 1.0 | 0.5 | 0.4 | 0 | 0 |
| Good | 22.4 | 22.9 | 14.8 | 23.5 | 15.0 |
| Fair | 47.7 | 48.4 | 56.7 | 52.1 | 58.6 |
| Poor | 28.9 | 28.2 | 28.1 | 24.4 | 26.4 |

From this table, one would conclude that 1201, 1202 and 1204 were all of about the same quality, with 1204 having a slight advantage. By this rating, 1203 was the worst system.

Altitude could also be used as a criteria in evaluation of mission performance. The nominal acquisition altitudes for these missions is noted below.

| Mission | Altitude (nm) |
|---|---|
| 1201 | 103 |
| 1202 | 84 |
| 1203 | 100 |
| 1204 | 91 |
| 1205 | 86 |

Based solely on altitude, one would expect 1202 and 1205 to be clearly superior to the other missions. From Table 3-2, this is obviously not the case, particularly in the instance of 1205.

Evaluating the amount of high scan angle photography does not totally answer the question either. The amount of area covered at high scan angles on the several missions is noted below.

| Mission | % Area Covered Beyond 30° Scan | % Area Covered Beyond 45° Scan |
|---|---|---|
| 1201 | 50.1 | 10.5 |
| 1202 | 62.9 | 34.8 |
| 1203 | 57.2 | 30.3 |
| 1204 | 40.8 | 3.9 |
| 1205 | 44.7 | 11.5 |

Based on this data, 1202 looks by far the worst mission, and 1205 the best. ?
4

While the amount of photography at high scan angles is not the only consideration in assessing the general performance, it is a very important factor. In detailed studies conducted on both 1201 and 1203, it was found that the vast majority of targets rated poor for interpretation were acquired at high scan angles. On 1201, 54% of the targets rated poor were acquired beyond ±45° of scan and 80% beyond ±30° of scan. On 1203, 40%

of the targets rated poor were acquired beyond ±45° of scan and 85% beyond ±30° of scan.

To try and illustrate the confusion that only looking at one factor produces, Table 3-3 lists the missions from best to worst based on the several factors discussed above.

TABLE 3-3

Mission Ranking, Best to Worst, for Several Factors

| Ranking | Camera Resolution | PI Ratings | Mean Acquisition Altitude | Min. Area at High Scan Angles |
|---|---|---|---|---|
| 1 | 1202 | 1204 | 1202 | 1204 |
| 2 | 1201 | 1202 | 1205 | 1201 |
| 3 | 1205 | 1201 | 1204 | 1205 |
| 4 | 1203 | 1205 | 1203 | 1203 |
| 5 | 1204 | 1203 | 1201 | 1202 |

The CRYSPER Program combines all these factors in its prediction of the GRD for any given location on the film format. It is possible, using CRYSPER, to estimate the overall mean area weighted* GRD produced by a mission. If all these variables are properly treated, then, the GAWA obtained for the mission should have some relationship to overall quality from a PI suitability point of view. The basic process employed and the results obtained are discussed below.

Major axis VEM profiles are used to calibrate the CRYSPER Program. That is, 2:1 contrast resolution predictions are made with CRYSPER and then compared to actual VEM data. The actual average of the combined VEM data from all scan angles and scan modes is used. The differences between the actual and predicted VEM are computed and applied to the CRYSPER

*Referred to as the Grand Area Weighted Average (GAWA) resolution.

predictions for the "average" intelligence target.* The final data used for the GAWA computations combines forward and aft camera resolving power data. The GRD predictions, then, are for the average intelligence target and are based on ground reflectances of 10% and 20%. In most cases, the seasonal haze model is used. There has been, however, one exception to this. The GAWA is computed based on the total cloud-free area coverage as a function of scan sector. The GAWA computations for the past five missions are presented in Table 3-4 for the "average" intelligence targets.

TABLE 3-4

Area Weighted GRD Summary

for Typical Intelligence Targets

(Values in feet)

| | Scan Sector (Degrees) | | | |
|---|---|---|---|---|
| Mission | 45-60 | 30-60 | ±30 | GAWA |
| 1201 | 10.5 | 6.5 | 3.6 | 5.0[1] |
| 1202 | 8.0 | 6.3 | 3.1 | 5.1[2] |
| 1203 | 12.4 | 9.3 | 3.7 | 6.9 |
| 1204 | 11.8 | 5.9 | 3.3 | 4.4 |
| 1205 | 13.5 | 8.6 | 4.3 | 6.2[3] |

NOTES: [1]Based on 120° scan mode only.
[2]Based on the forward camera only.
[3]Based on heavy haze model.

*In effect, this is a calibration of the camera model portion of the CRYSPER Program.

The relationship of GAWA to PI suitability ratings is shown in Figures 3-17 and 3-18. Figure 3-17 gives the average intelligence target GAWA for each mission versus the percent of all weather targets rated good. The figure shows that there is a reasonable relationship between overall mission performance as reflected in the GAWA computation and PI suitability. The importance of contrast is further highlighted by comparing GAWA computations for constant 2:1 contrast*. This can be done by simply employing the VEM data, converting it to GRD and making the same area weighted computation. This data is shown in Table 3-5.

TABLE 3-5

Area Weighted GRD Summary for 2:1 Contrast

(Values in feet)

| | Scan Sector (Degrees) | | | |
|---|---|---|---|---|
| Mission | 45-60 | 30-60 | ±30 | GAWA |
| 1201 | 6.5 | 4.6 | 3.0 | 3.8[1] |
| 1202 | 5.8 | 4.5 | 2.1 | 3.7[2] |
| 1203 | 8.6 | 6.6 | 3.0 | 5.1 |
| 1204 | 9.0 | 4.0 | 2.8 | 3.6 |
| 1205 | 6.0 | 4.1 | 2.3 | 3.1 |

NOTES: [1]Based on 120° scan mode only.
[2]Based on the forward camera only.

*That is, the CRYSPER computations are, on the average, more reflective of the quality from a PI point of view than is the VEM. This is to be expected since the CRYSPER Program employs a haze model and considers fundamental illumination considerations. VEM is calibrated to a constant 2:1 contrast and hence ignores these variables. This is highly desirable for camera performance assessment but not for PI-related factors.

FIGURE 3-17

## GRAND AREA WEIGHTED AVERAGE (GAWA) RESOLUTION VERSUS OAK TARGETS RATED GOOD UNDER ALL WEATHER CONDITIONS

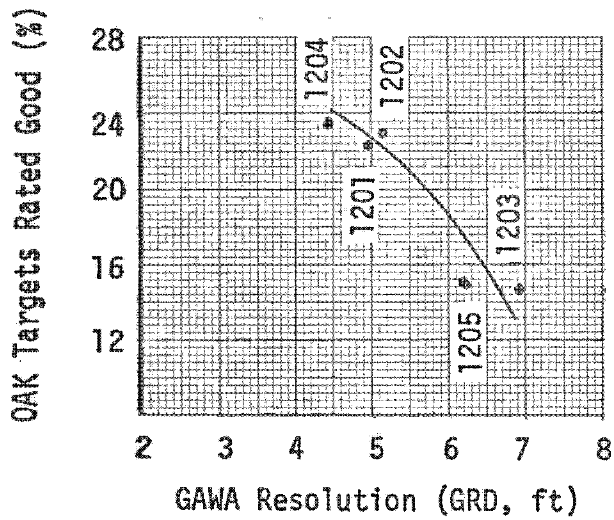
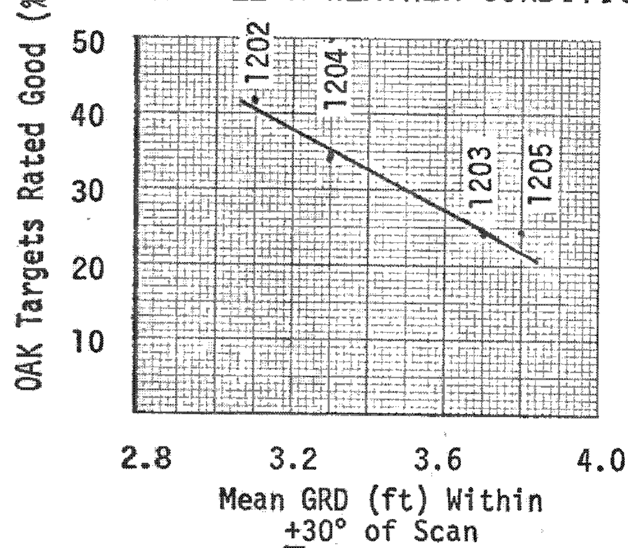



FIGURE 3-18

## MEAN GRD (FT) WITHIN ±30° OF SCAN VERSUS OAK TARGETS RATED GOOD UNDER CLEAR WEATHER CONDITIONS



Based on the GAWA data from Table 3-5, 1203 would be expected to be worst. This agrees with the Table 3-4 observation, but that is the extent of the agreement. The constant 2:1 contrast data would say that 1205 was the best mission, whereas the data in Table 3-4 shows this mission to have produced the second worst GAWA; and the PI rating data shows it to have been the worst mission.

Table 3-6, then, provides a ranking of HEXAGON mission performance based on the GAWA computations. Table 3-6, in addition to Figure 3-17, illustrates that there is good agreement between the mission rankings based on the GAWA and the mission rankings based on the photointerpreter ratings. Key comments relative to the mission ranking are included.

The all weather PI rated target GAWA comparison will, of course, have more scatter in the data due to the fact that CRYSPER can only estimate the haze based on statistics. This often will not correlate with the real acquisition situation. To minimize this variable, it is useful to compare the percent targets rated good in clear weather and acquired within ±30° of scan with the mean GRD estimate within ±30° of scan. The summary of these clear suitability ratings is given in Table 3-7. The percent goods is plotted against the mean GRD, as estimated from CRYSPER, for within ±30° of scan.

TABLE 3-7

Summary of PI Suitability Ratings from

Stereo, Clear and Complete Coverage of OAK Targets

(Percent)

| Rating Category | 1202 | 1203 | 1204 | 1205 |
|---|---|---|---|---|
| Excellent | 0.3 | 0 | 0 | 0 |
| Good | 41.9 | 23.5 | 34.7 | 24.1 |
| Fair | 44.8 | 64.7 | 60.9 | 65.3 |
| Poor | 13.0 | 11.8 | 4.4 | 10.6 |

TABLE 3-6

Summary of HEXAGON Mission Performance

| Rank | Mission | GAWA (ft) | % Targets Rated Good | Average Acquisition Altitude (nm) | Comments |
|---|---|---|---|---|---|
| 1 | 1204 | 4.4 | 23.5 | 91 | Reasonable altitude; small % of photography at high scan angles; fall/winter mission. |
| 2 | 1201 | 5.0 | 22.4 | 103 | High altitude, reasonable amount of photography at high scan angles. |
| 3 | 1202 | 5.1 | 22.9 | 84 | Good altitude; however, large amount of photography at high scan angles. |
| 4 | 1205 | 6.2 | 15.0 | 100 | High altitude; reasonable amount of photography at high scan angles; very poor haze conditions dominated this mission. |
| 5 | 1203 | 6.9 | 14.8 | 86 | Good altitude; however, large amounts of high scan angle photography. |

Since these targets were all rated clear by the interpreters, only the seasonal haze model was used in the average GRD computation. The plot of the average GRD within ±30° of scan and the percent goods from Table 3-7 is given in Figure 3-18.

Figure 3-18 allows some interesting observations*. The sensitivity of the percent goods to small changes in GRD is somewhat surprising. Changes of a fraction of a foot GRD result in significant changes in the percent targets rated good. The GRD that produced the highest percentage of targets rated good (42%) was 3.1 feet. A mean GRD of 3.7 feet produced only 29% of the targets being rated good. What this indicates is that the ability of the HEXAGON system to produce "good" photography from a PI point of view is very sensitive to any factor which produces relatively small changes in GRD. This is not surprising considering the resolution range HEXAGON produces within ±30° of scan; namely, 2.5 to 5 feet depending on the altitude. This is a critical resolution range for many order of battle targets, and it is not surprising to find that relatively small decreases in GRD affect the interpreters' ability to perform these kinds (i.e. OB) readouts.

A separate but related study reported on in the 1204 PFA report (TCS-363502-73, 6 April 1973) illustrated that of all the targets rated good by the interpreters, 50% had (based on CRYSPER predictions) a GRD of 3.0 feet or better. This points out that small increases in altitude, for example, can be expected to affect the percent of targets rated good by the interpreters. Indeed, Figure 3-18 could be related to altitude as well. This is done below:

| Mission | % Clear Targets Rated Good | Nominal Acquisition Altitude (nm) |
|---|---|---|
| 1202 | 42 | 84 |
| 1204 | 34 | 91 |
| 1203 | 24 | 100 |
| 1205 | 24 | 86 |

*It should be noted that 1201 is not included on Figure 3-18 because the PI rating data was not collected in this manner and is, therefore, not available.

Only 1205 does not fit the pattern, but it was severely affected by haze.

### 3.4.2.3 Effect of Specular Reflections and Shadowless Acquisitions on Quality

This report started with a discussion of the effect of launch time on quality. In that discussion, it was pointed out that specular reflections and shadowless acquisitions were by-products of improper launch time that could cause image degradation. Mission 1206 was so launched. The effect of these problems on image quality was addressed by the Post-Flight Analysis Team in their preliminary report on the quality of 1206-1. The applicable portions of this report are quoted below.

> *The late launch time of Mission 1206 caused specular reflections and full front lighting (shadowless acquisitions) to occur at nadir and between 40-30° north latitude on this mission segment. The PFA conducted a preliminary investigation of the effect of this phenomenon. The validity of the pre-mission predictions was easily established. Numerous examples of specular reflections on the forward camera were found within the latitude bands indicated at nadir. In addition, several cases of bloomed highlights were found outside the latitude bands indicated above at nadir. This is to be expected. The problem of specular reflections is not as severe as the problem of shadowless acquisitions because the occurrence of speculars is largely dependent on the nature of the target and not solely on the illumination geometry of the acquisition. Shadowless acquisitions are target independent and occur, with varying degrees of severity, at nadir on every frame within the latitude band noted above. The full front lighting problem is the reverse of the specular reflection problem and hence affects the aft camera. The effect on photography is to produce poor quality imagery as there is a severe loss in contrast due to the lack of any shadows in the scene. Several ops evaluated by the PFA (both domestic and denied area) exhibited shadowless target conditions and the attendant poor quality under the predicted latitude and scan angle constraints. The effect is most severe within approximately ±3° of nadir. Under magnification, the imagery looks very flat and dimensionless. In addition, edges cannot be readily determined due to the lack of edge contrast enhancement provided by shadows. In the most severe cases, detail is totally lost on the aft camera imagery.*

*This problem is most severe with imagery that already has poor target contrast such as desert scenes. The PFA recommends that:*

*a. For those acquisitions where maximum image quality is desired, the conditions noted in ref A should be avoided.*

*b. Summer time missions should be launched early (approximately 0900 hours).*

The effects of full front lighting are best shown with pictures. Figure 3-19 illustrates a typical case of front-lighting in an urban area. The aft camera imagery can be seen to be extremely flat and dimensionless. The lack of shadows gives the picture an almost "bombed out" appearance. The specular reflection off the river on the forward camera photograph can also be noted. Figure 3-20 illustrates a more severe case of front lighting. In this example, considerable detail has actually been lost. In comparing the portions of the aft camera photography, highlighted by the arrows, with the forward camera photography, it can be seen that significant details are missing in the aft camera photograph due to the complete lack of shadows. Figure 3-20 illustrates the effect of shadowless acquisition on an actual intelligence target. Mission 1206 was launched such that the specular reflection/shadowless acquisition problems occurred near nadir and started at about 40°N latitude. As such, approximately 20% of the 1206-1 acquisitions were affected by these related problems.

## 3.5 Summary

These discussions illustrate that certain fundamental conditions control the quality that will be achieved by a satellite photoreconnaissance camera. Scan or roll angle obviously produce losses due simply to the geometry involved. The image gets smaller as the scan (roll) angle increases. Smear also influences quality up to a point. There is a minimum solar altitude that produces sufficient illumination and, as a result, short enough exposure times. Further reductions in exposure time (while necessary to properly expose the image) are not significant from an image quality point of view. In fact, as solar altitude becomes very high (70-90°), image quality will start to decrease due to the loss of contrast that results from the ever-decreasing shadows.

Insert
Figures 3-19 & 3-20
(pages 60-61)
here

Contrast must also be considered as a function of solar altitude because it also affects performance. In general, the lower the solar altitude, the worse the contrast. Again, there is some solar altitude where this problem stabilizes. Considering all these factors, it can be concluded that the image quality produced by a satellite camera will not, on the average, change significantly if the solar altitude is 30° or higher. Increasingly significant losses in quality can be expected as the solar altitude decreases below 30°. Camera-induced losses, however, start to become a problem below solar altitudes of 20°.

Overall, contrast is also a function of time of year because the haze conditions vary during the year. The data clearly indicates that, on the average, the atmospheric conditions are clearest during the fall/winter seasons and worst during the spring/summer seasons.

The nature of the target itself and its illumination are also significant contributors to the quality of the final image. Changes in the illumination of the target can change the GRD produced by a foot or more. The target also has a unique inherent contrast, and resolution is a function of contrast. In considering the quality that will be produced from a photograph of any given target, or class or targets, the nature of the target and the acquisition conditions to be employed must be carefully considered, particularly if the best possible quality is desired. This is an area for which the community has only the most basic and limited understanding and one that deserves considerably more attention.

Most significant, however, the majority of these observations and analyses are reflected in the PI suitability ratings. The importance of time of year (and clarity of the photography) are reflected in the fact that on GAMBIT missions the highest percent of targets rated fair or better occurred on the fall missions. Winter missions, despite the longer exposure times, rated second best when evaluated in this manner. Analysis of HEXAGON missions illustrates that it is possible to combine all the camera/acquisition factors into a model that provides GRD predictions that, on the average, correlate with the PI suitability ratings.

## 4.0 EFFECTS OF THE REPRODUCTION PROCESS

This discussion would not be complete without at least highlighting the major influences on the quality of imagery due to the reproduction process. The photointerpreters receive and, in nearly all cases, use duplicate copies made from the original negative. The quality of the imagery viewed by the interpreters is dependent on how well the "dupes" reproduce the original. This section is not intended to be a treatise on the subject but is intended to highlight the key areas that affect image quality. They are two: tone transfer and image quality transfer.

### 4.1 Tone Transfer

The ground scene is made up of an array of brightnesses (luminances). These are, of course, modified in the imaging process, but they end up as an array of densities on the original negative. The purpose of the reproduction process is to capture those densities and reproduce them as another set of densities on the dupe positive that will be most meaningful to the interpreter. If the reproduction of densities (referred to as tone transfer) is not done properly, information can be actually lost or impaired on the PI's copy. Unfortunately, this is not an infrequent occurrence.

There are a number of problems in reproduction that must be dealt with, the most fundamental one being how to reproduce the densities of the original. Because of all the factors discussed in the previous sections, scenes vary dramatically in their contrast. This means that one seldom wants to reproduce the densities on the original with the same (1:1) relationship on the duplicate. For example, a very low contrast (low density range) scene should be reproduced to enhance (expand) the contrast. Conversely, a very high contrast scene may have such an extreme density range on the original negative that all the densities can not be recorded on the dupe film being used. In this case, two duplicates may be required to provide all the tonal information. If the PI only uses one of these, he will not be seeing all the information recorded on the original negative. Needless to say, the more copies required to reproduce all the information inherent in the original negative, the more complicated the PI's task becomes.

The fact remains, however, that no one reproduction process is completely satisfactory for all the pictures taken, and other processes are necessary to attempt to reproduce as much photography as possible under the optimum conditions.

An example of such specialized printing is useful in understanding the problems. On Mission 1205, there were a total of 556printing parts. Of these, a total of 31.7 required multiple printing. That is, the original negative density range was too great on these to be returned within the desired limits on a single "medium" copy. Therefore, two or three prints (at different print levels) were necessary to reproduce all the information. In addition, 57 printing parts were reproduced at higher than normal contrast for the benefit of low contrast areas on the original negative. It should be noted that considerably more photography benefited from high contrast printing, and these were delivered in addition to the normal copies. The above printing parts are those where the entire part benefited, and hence only the high contrast copy was delivered.

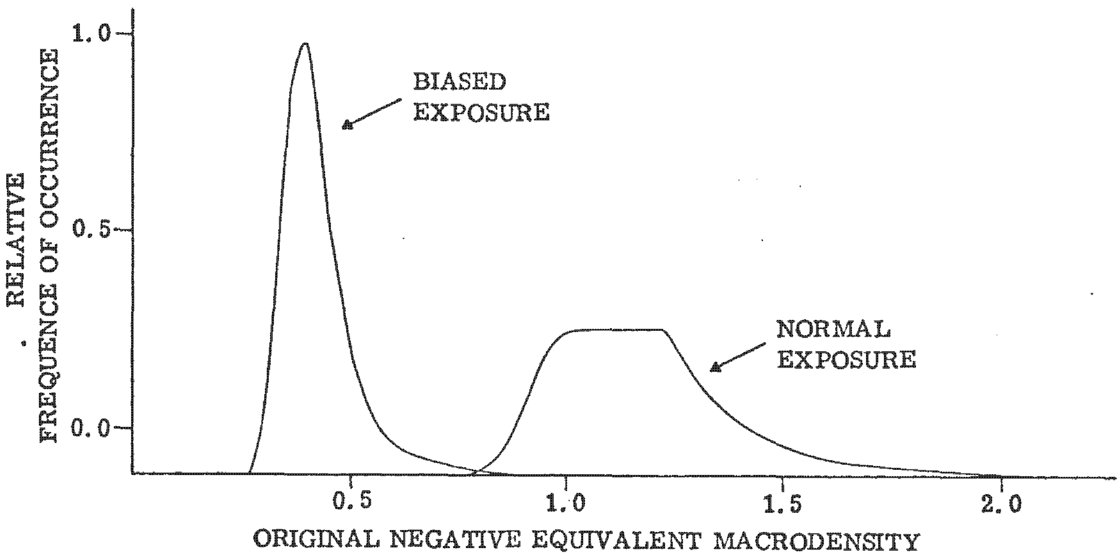
Special copies of specific targets are also required to maximize the tone transfer of the target only. On 1205, 96 such reproductions were made. The number of such reproductions on GAMBIT CUBED is usually higher.

The problem of reproducing mission photography accurately is decidedly more difficult on spring missions. On spring missions, there tends to be a significant number of areas with partial snow cover. That is, wide areas of the Soviet Union contain snow in the country and no snow or dirty snow in the target areas. This not only causes an exposure problem but a reproduction problem as well. For example, if you expose for the snow, the target area ends up under-exposed, and target detail can be harmed. If one exposes for the target area, the snow scene will be overexposed and searching could be impaired. This problem is compounded when attempting to reproduce this imagery because no matter how such a scene is exposed, the contrast is very high.

Figure 4-1 illustrates what happens to an urban scene when it is given the snow bias (for exposure compensation) when there is no snow in the city. This can occur either if snow is predicted in the scene but is not there or if snow is in the surrounding area but not in the city. From the graph, it is clear that the density range of the improperly exposed

FIGURE 4-1

Density Distribution of Urban Areas




area is greatly reduced over that of the properly exposed one. In this case, information will definitely be lost.

The real extent of the problem is shown in Figure 4-2. This figure illustrates the density range that exists on a frame of original negative for an industrial area with no snow and the surrounding area with snow. In this case, a compromise in exposure was given in the attempt to optimize both areas as best could be done. The density range still is very high, and at least two duplicates are necessary to capture all the information on this original negative.

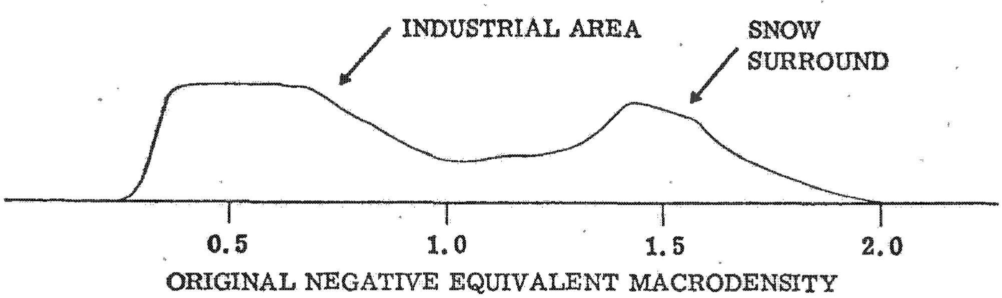
## 4.2 Resolution Transfer

The second major detrimental effect of the reproduction process is the loss of resolution that can occur. As the

FIGURE 4-2

Density Distribution of Industrial Target

Area with Snow Surround




inherent resolving power of the camera gets higher, it is more difficult to reproduce all the resolution. For example, for HEXAGON missions to date, Table 4-1 illustrates the typical resolution losses from original negative to dupe positive.

TABLE 4-1

Resolution Losses in Reproduction

| ON Resolution (c/mm) | 2nd Gen. D.P. Resolution Loss (%) | 3rd Gen. D.P. Resolution Loss (%) |
|---|---|---|
| 100 | 5 | 10 |
| 120 | 8 | 17 |
| 160 | 16 | 20 |
| 240 | 20 | 30 |

The third generation copies, as would be expected, produce the worst resolution loss. These are used with HEXAGON for the target complex duplicates for a number of customers. A nominal performance level with GAMBIT CUBED is on the order of 120-140 c/mm. For HEXAGON, the nominal performance level is on the order of 150 to 170 c/mm. At its best, however, HEXAGON performance will exceed 200 c/mm. Therefore, this problem of losses in quality due to duplication are more severe with HEXAGON than with GAMBIT.