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ACQUISITION SUBSYSTEM ON-ORBIT PERFORMANCE PREDICTION

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ACQUISITION SUBSYSTEM ON-ORBIT PERFORMANCE PREDICTION

SEPTEMBER 1968

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MOL Systems Development

SECTION 1

INTRODUCTION

SECTION 1

INTRODUCTION

This report is written to summarize the present status of the Acquisition Subsystem On-Orbit Performance Prediction analysis. It is the second in a planned series of reports dealing with this subject. The first report (see reference 1) is recommended reading for those who wish to obtain a better understanding of the analytical techniques used for the prediction analysis.

It is important for the reader to recognize that the analytical predictions presented herein do not include the effects of all the presently defined factors which may influence alpha performance. However, recent customer and in-house interest in alpha performance has made necessary the need to document the present status of the effort. This report will discuss the major factors that influence ATS performance and will clearly indicate which effects are included in the overall performance prediction. It will also outline the work yet to be done in those areas where the analysis is not complete. Wherever possible, the probable effect of these factors will be discussed in order to give the reader a feeling for the sensitivity of overall performance to these factors.

System performance predictions presented herein are based on the resolving power criteria for specifying optical system performance. The standard U. S. Air Force (MIL-STD 150A) tri-bar target has been used as a basis for the analysis. This method of specifying resolution is of prime importance in that the significance of the results obtained are thoroughly understood throughout the photo-intelligence community. However, to avoid improper interpretation, it must be remembered that an ATS resolution number based on a tri-bar target is solely a measure of man's ability to resolve that specific geometric configuration. At the present time a correlation between specific object-of-interest resolution and tri-bar resolution has not been established.

This report concerns itself only with on-axis performance prediction. Table 1-1 contains a brief summary of the major uses of the ATS. Of these, activity detection is the only use where an accurate determination of ATS performance is required. This use, however, is where man may make his greatest contribution to mission effectiveness. Therefore, a complete understanding of the performance capabilities of man in this capacity is essential. Determining ATS performance in terms of tri-bar resolution is a major step towards answering the ultimate question, i.e., how effective is man in utilizing the ATS, thereby enhancing the primary photographic mission by detecting the presence of Essential Elements of Information (EEI) or of specific activity indicators which may indicate the presence of the EEI

The Air Force plans to use the results of the work presented herein in an attempt to correlate tri-bar resolution to recognition of specific objects of interest. Another possible direct application for the results of this work is in the sequencing of targets for the ATS. It is well to note that the analytical techniques developed for calculating ATS performance have considerably increased the accuracy of the predictions; however, resolution determination is inherently not a highly accurate tool. As an example, inaccuracies are introduced in specifying optical system performance with a Modulation Transfer Function (MTF) because phase relationships are ignored. Also, the visual threshold of the flight crew used in this study is based on the mean performance of the present 14 crewmen, so there exists a statistical variance about this mean. It is felt that the absolute accuracy of the performance estimates are within five percent, but that the relative accuracy between the various conditions may be considerably greater. For this reason, resolution numbers in terms of ft/cycle are given only to two significant figures.

Table 1-1. Uses of ATS

Enhancement of Primary Photographic Mission		
a. Cloud/Haze Detection	(16X)	
b. Activity Detection	(127X)	
Accurate Determination of Target Location		(63X)
Improvement in Main Optics Pointing Accuracy		(63X)
Backup for Visual Optics		
a. Target Centering	(63X)	
b. Rate Nulling	(127X)	

[redacted]

SECTION 2

SUMMARY

SECTION 2

SUMMARY

With a 3.0:1 contrast tri-bar target on the ground, and assuming a moderately hazy (average) atmosphere, a 20 Hz, 0.25 sec (0-Pk) line-of-sight jitter, and a sun elevation angle of 36 degrees, the dynamic on-axis ATS nadir resolution is predicted to be 2.6 feet. For a line-of-sight angle of 60 degrees, the dynamic resolution of the ATS is predicted to be 8.0 feet. The above information is depicted on Figure 2-1.

Furthermore, because of the shapes of the ATS and Main Optics performance curves in the very low contrast regions, together with the slopes of the visual and film threshold detectability curves, it may be possible that man will be able to detect low contrast targets that the Main-Optics will not be able to photograph.

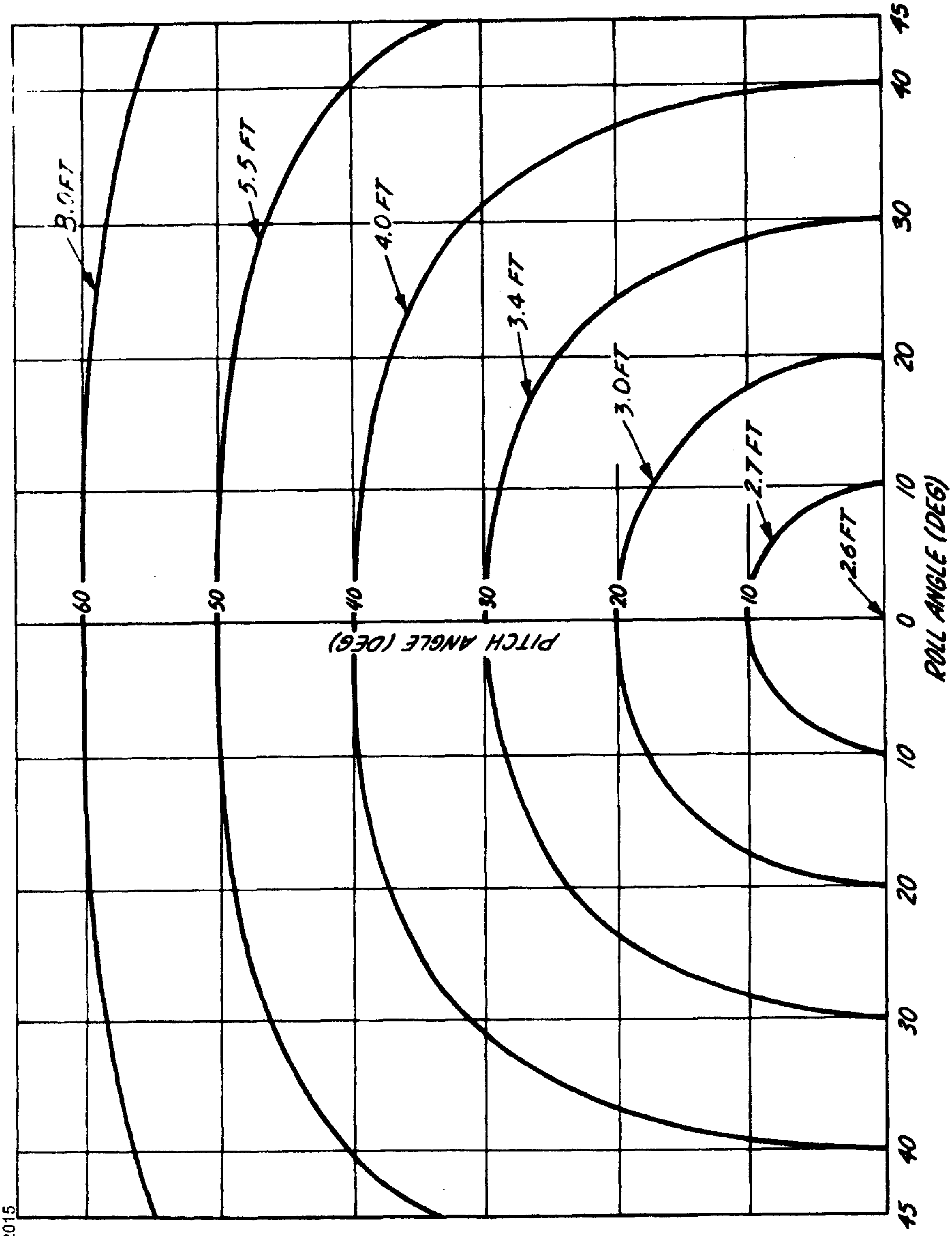

Figure 2-1. Average Day Tri-Bar Resolution in Forward Scan Field (Based on PAM Atmospheric Data and 3.0:1 Contrast Ratio (0.234/0.078) on Ground), Tri-Bar Chart Flat on Ground, ATS Magnification = 127X

SECTION 3

FACTORS INFLUENCING ATS PERFORMANCE

SECTION 3

FACTORS INFLUENCING ATS PERFORMANCE

3.1 BACKGROUND

Less than one year ago, a limited understanding existed concerning the validity of the analytical techniques and assumptions used to predict on-orbit ATS performance. Also, little consideration was given to the real world conditions under which the ATS will perform. For example, Acquisition Subsystem Performance Predictions were based on the intersection of a nominal telescope MTF curve with an arbitrarily selected visual threshold curve. As discussed in Reference 1, the direct intersection of an MTF curve and a visual threshold curve is not valid. Also, the visual threshold curve selected to make the original performance predictions was based on an extrapolation of experimental results obtained by O. Schade (References 2 and 3).

The analyses were undertaken for the on-orbit conditions that had been selected by the customer to specify Alpha performance requirements: 2 to 1 contrast at the input aperture, 530 ft-L scene brightness, 80 nm orbit, nadir LOS, etc. Jitter effects were incorporated using the technique employed to predict the degradation caused by smear in a photo-optical system.

3.2 FACTORS PRESENTLY BEING CONSIDERED

To overcome the deficiencies in the original performance and analysis, several factors which influence ATS on-orbit performance have been identified and categorized according to their influence on:

a. Visual performance of man in the MOL on-orbit environment.

b. System performance of the ATS hardware. (This includes telescope optical performance, control system performance, thermal degradation, structural vibration, etc.)

c. Scene characteristics at the input aperture of the system.

The factors influencing performance in each of these areas will be discussed in some detail below. However, it is well to reiterate that there are several factors for which the required analysis and/or experimental measurements have not been completed, and therefore, are not included in the overall performance prediction of Section 4. As these data become available their effect on Alpha performance will be factored into the analysis.

3.2.1 VISUAL PERFORMANCE OF MAN

The performance of man in resolving the tri-bar target, both under static conditions and in the presence of sinusoidal jitter, has been investigated in considerable detail. An experiment was conducted to determine man's performance in this area. A report is being prepared to cover the apparatus and procedures used in the experiment, the data reduction techniques employed, and the results obtained. A brief discussion and summary of the results as they apply to performance prediction are included here.

The objectives of the experiment were to:

a. Determine the static visual threshold for the MOL flight crew using tri-bar targets.

b. Evaluate the degradation in resolution caused by single frequency sinusoidal jitter.

c. Determine the influence of variations in scene brightness on resolution.

d. Investigate the sensitivity of the eye to jitter amplitude as a function of jitter frequency.

Figure 3-1 is a comparison of the visual thresholds obtained from the experiment and thresholds derived from published experiment data. This curve shows that:

a. Utilizing the visual threshold derived from the work of O. H. Schade produces extremely conservative predictions of ATS performance.

b. The visual threshold based on an experiment conducted by Campbell produces less conservative results than the Schade threshold. The experiment by Campbell was conducted using a very similar experimental technique to that of Schade.

[redacted]

Figure 3-1. Comparison of Visual Thresholds

c. The visual threshold obtained from the experiment using ordinary observers (employees) with 20/20 vision correlates very clearly with the results obtained using the published results of Lowry-DePalma (Reference 4).

d. The static visual threshold for the flight crew produces better results than do the equivalent threshold for the ordinary observer. This appears to be reasonable in that the nominal visual acuity for the flight crew is on the order of 20/15 as compared to a normal 20/20 for the Itek observers.

Figures 3-2, 3-3, and 3-4 represent the crewman visual threshold under static conditions and in the presence of 20 cycle per second jitter at 1/4 and 1/2 arc seconds (0-P) amplitude, respectively. Also shown on these curves are the ± 1 sigma standard deviations about the mean. These standard deviation curves are derived from the variations of the individual data points from the mean of all the points. Figure 3-5 shows the degradation of resolution due to variance in scene brightness from 180 to 30 ft lamberts as a function of contrast. The effect of brightness has not yet been factored into the present analysis. The visual threshold curve for 180 ft lamberts was used in the analysis.

It was noted during the experiment that fatigue had a large effect on man's ability to resolve a tri-bar target in the presence of jitter. The experiment procedures and apparatus minimized the effect of fatigue on performance, therefore, the performance prediction contained herein do not consider fatigue effects.

3.2.2 ATS HARDWARE PERFORMANCE

There are several factors that should be considered in determining the overall effect of hardware on the performance of the system. These major areas are: optical performance, control system performance, structural vibration, contamination and thermal distortion. These major areas are now discussed.

3.2.2.1 Optical Performance

The Acquisition Telescope optical performance is dependent upon the prescription, the manufacturing and alignment errors, and the effects of the on-orbit environment. There are also some secondary considerations which affect performance such as vignetting at the

[redacted]

Figure 3-2. Static Flight Crew Visual Threshold

[redacted]

Figure 3-3. Dynamic Flight Crew Visual Threshold 0.25 sec

[redacted]

Figure 3-4. Dynamic Flight Crew Visual Threshold 0.5 sec (Revised Data)

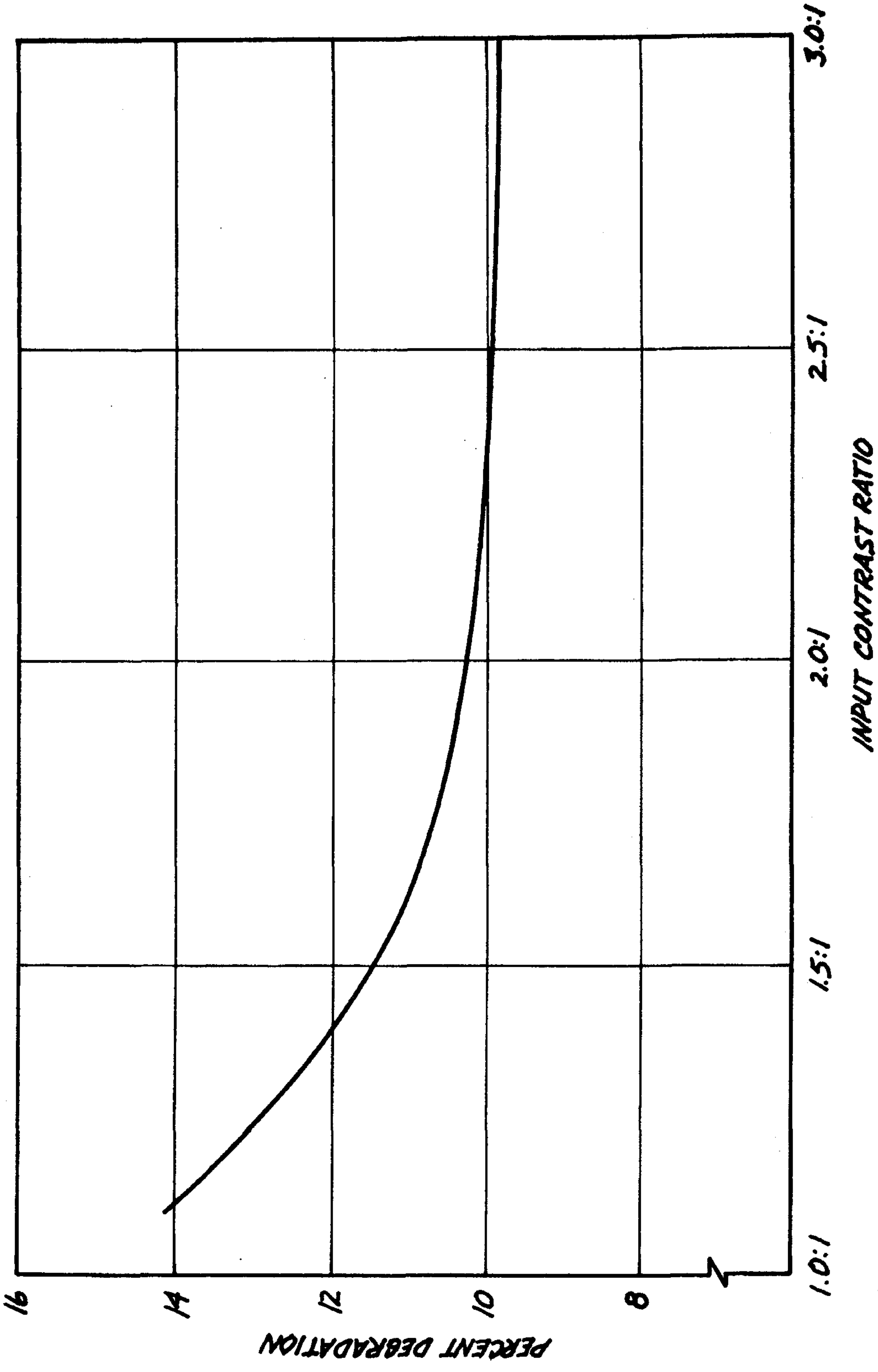

Figure 3-5. Percent Degradation in Static ATS Performance Due to Variations in Scene Brightness from 180 ft/lamberts to 30 ft/lamberts

high forward line-of-sight angles, scattering of light within the tube, etc. Predictions of the MTF to date have been based upon ray trace analysis performed by both GE and Itek Corporation.

Figure 3-6 is a chart which shows the results of this analysis. Curves 1 and 2 are the prescription physical frequency responses (MTF) calculated by GE and Itek, respectively. Curve 3 is the Itek nominal system performance estimate presented in their September 1967 PDR report (Reference 5) which they use for predicting system performance. Curve 4 is a GE worst-case tolerance buildup performance estimate based on previously described curves. The probability of designing and building the acquisition telescope to meet the performance described by this curve is considered to be relatively high. Therefore this curve was used in the present analysis.

Figure 3-7 represents optical quality factors (OQF) resulting from the ITEK nominal system performance estimate and the GE nominal performance estimate.

It should be noted that relatively large changes in the MTF OQF will not appreciably change the performance of the telescope (based on a 2 to 1 contrast input). For example, changing the OQF to 60 percent from its present value of 40 percent would improve resolution (for 2 to 1 contrast target) by only 0.2 foot. Decreasing the OQF to 20 percent from 40 percent would degrade system performance by 0.5 foot. The relative sensitivity of system performance to changes in the MTF OQF at the 2 to 1 input contrast is due to the slopes of these two curves.

Under low contrast input conditions (< 2:1) the changes in the system resolution become considerably greater. This will be discussed in greater detail in Section 4.

3.2.2.2 Control System Performance

In addition to the introduction by the control system of position and rate errors which would result in off-axis viewing (not considered in this analysis) and smear, respectively, the

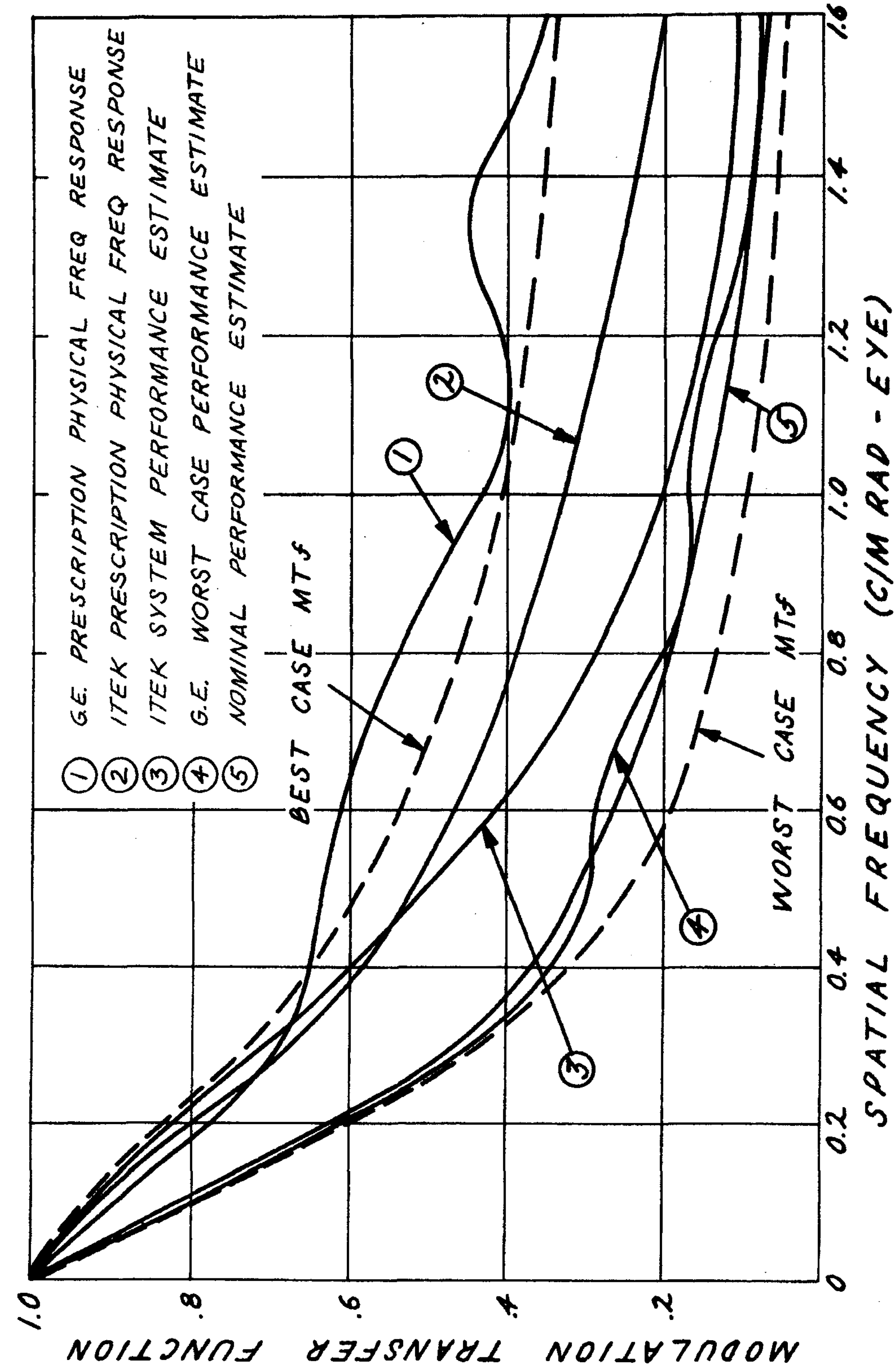

Figure 3-6. ATS's Transfer Function Envelope under Static Conditions

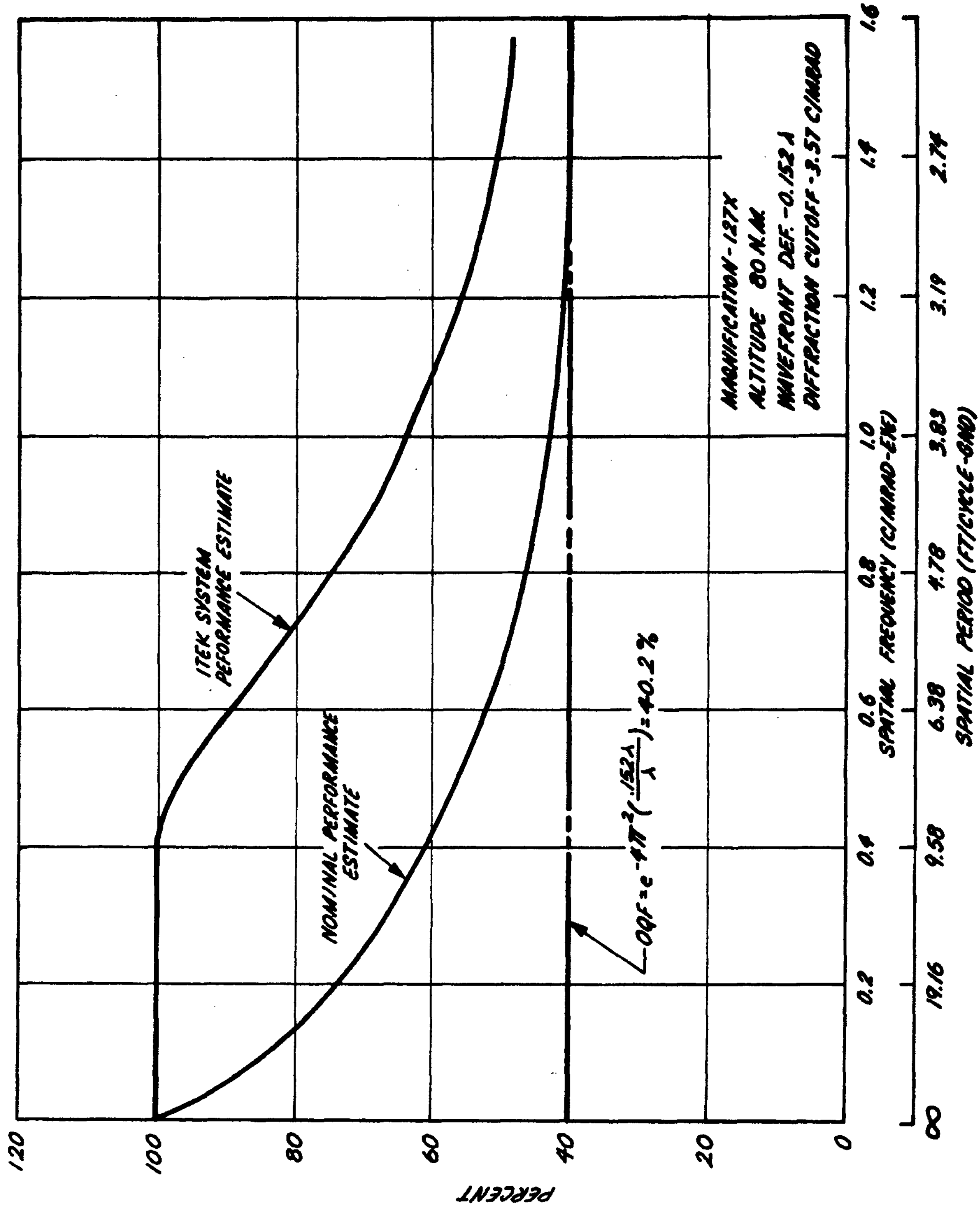

Figure 3-7. Optical Quality Factor - ATS

control system will also introduce low amplitude random vibration (jitter). Normally, the rate error can be nulled by the crewman; jitter, being random in nature, cannot be negated.

The noise sources producing control system jitter are:

Bearing Noise — This is the largest contributor.

Input Noise - Electro-magnetic interference (EMI).

Electronic Noise - Power amplifier, pre-amplifier.

Torquer Noise, Gyro Noise, D-A Noise.

In order to see the effect of jitter on resolution, consider single-frequency, sinusoidal motion of the LOS. If this motion is at a small enough amplitude and low enough frequency, the eye and brain will be able to follow it; under these conditions there will be no loss in resolution. If the frequency is increased above approximately 1.0 Hz, the eye is not able to completely track the LOS and the object begins to become smeared. If the frequency of the motion were time-varying, the eye and brain would not be able to track as well as with single frequency motion; thus jitter, which in practice is random in nature, could be a significant source of resolution degradation. Above approximately 20 Hz, smear becomes independent of frequency; the peak amplitude determines resolution.

This analysis takes into account single frequency jitter at amplitudes (0-P) of 0.25 sec and 0.50 sec. No data on the effect of random jitter on resolution is available at this time. An experiment to determine random jitter effects is being planned for implementation in late 1968 or early 1969.

3.2.2.3 Structural Vibration

Data is presently being obtained to determine the amplitude and frequency of the LOS due to structural vibrations caused by such sources as ACTS jet firing, main optics mirror slew, sliding mask slew, camera operation, etc. These data are being obtained using a vibration model developed by GE. This performance prediction analysis does not take into account structural vibration effects. These effects will be included in a subsequent issue of this report.

3.2.2.4 Contamination

A possible large contributor to resolution degradation is contamination. The two major sources of contamination are exhaust products of the ACTS propellants (various hydrocarbons formed from the combustion of N_2O_4 and hydrazine) and the waste products from the life-support system. No data is now available concerning the level of contamination on the ATS.

At this time little is known concerning the effects, if any, of contamination on the ATS. The possible effects include change in reflectivity of the mirrors, change in transmittance of the window, or perhaps evan a change of the system MTF.

Contamination effects are not considered in this performance prediction analysis.

3.2.2.5 Thermal Effects

Wavefront deformation, resulting in decreased resolution, can occur if the optical elements are subjected to a thermal gradient.

Data is presently being analyzed to determine the extent of this deformation. Preliminary indications are that the thermal gradients are sufficiently large enough to cause a degradation of resolution. When more data is available, they will be factored into the performance prediction analysis.

3.2.3 SCENE CHARACTERISTICS AT SYSTEM INPUT APERTURE

If there were no atmosphere between the ground target and the orbiting vehicle, the intrinsic contrast of the target would not be attenuated when viewed from orbit. Since there is an atmosphere, its effect on apparent contrast and brightness (and therefore on resolution) must be determined.

On-orbit brightness and contrast is a function of the following:

a. Relative positions of the Sun, observer, and target.

b. Altitude.

c. Target characteristics.

d. Observing sensor characteristics.

e. Eye sensitivity.

f. Solar flux.

g. Atmosphere scattering characteristics.

The on-orbit brightness and contrast determined in this performance analysis was obtained using the Photometric Atmosphere Model (PAM) (Reference 6) using a tri-bar target of reflectances 0.234 and 0.078 giving an intrinsic contrast of 3.0:1. PAM corresponds to an atmosphere that is considered "moderately" hazy by EK standards.

SECTION 4

PERFORMANCE ANALYSIS

SECTION 4
PERFORMANCE ANALYSIS

4.1 ORIGINAL PERFORMANCE PREDICTION

As has been previously discussed, the original performance predictions were based on the intersection of a nominal MTF (Modulation Transfer Function) with a Schade (derived) visual threshold curve. Figure 4-1 shows that the intersection of the static and dynamic ATS performance curves with the Schade threshold indicates a system resolution of 3.3 and 3.6 ft, respectively. For a tri-bar target flat on the ground and a constant on-orbit contrast of 2:1 (no atmosphere contrast degradation as a function of LOS angle) the static and dynamic resolution as a function of LOS angle is shown in Figure 4-2.

Based on this original prediction of ATS performance as a function of LOS angle, one can easily see that considering the contrast degradation properties of the real world atmosphere would make the apparent on-orbit performance considerably degraded, probably in the order of 8-9 feet at 40 degrees and in excess of 20 feet at 60 degrees.

Figure 3-3 shows the intersection of the system performance curve for 2:1 and 1.3:1 contrast input. Drawing a family of these system performance curves over the region between 5:1 and 1.1:1 allows the generation of a curve which describes the performance of the system based on optical system and observer performance. This curve can then be extended to represent system resolution as a function of LOS angle. This scale factor is directly proportional to the percent change in LOS distance from the vehicle to the ground as the LOS angle varies. This assumes that there is no degradation in resolution caused by change of aspect angle WRT the plane of the ground. This is considered separately.

It is felt that dividing by the cosine of the angle that the LOS vector makes with the normal to the Earth's surface at the point of intersection is overly harsh due to the three dimensional characteristic of the real world.

Considering the real world and the orientation of the Standard USAF tri-bar, the worst case degradation was found to occur when the projection of the LOS formed a 45 degree angle with both sets of bars in the group. Figure 4-3a represents the degradation factor (that applies to nadir resolution) as a function of LOS for a target oriented perpendicular to the LOS. Figure 4-3b is an additional factor to account for the target laying flat on the ground oriented so that the bars form a 45 degree angle with the horizontal projection of the LOS. Both factors were used in this analysis.

4.2 COMBINATION OF FACTORS INFLUENCING ATS PERFORMANCE

In Section 3, the many factors influencing system resolution were enumerated. In this section the method of combining these factors to arrive at the ATS performance is described. The performance curves of the ATS as a function of input modulation were obtained by convolving the MTF of the ATS with the input scene. The procedure is explained in Reference 1. The intersection of the performance curve for a particular input aperture modulation with the dynamic flight crew visual threshold curve gives the ATS dynamic resolution for that modulation.

Figure 3-3 shows intersections of these curves for contrasts of 2.0:1 and 1.3:1 (modulation = 0.333 and 0.130, respectively). The jitter amplitude of Figure 3-3 is 0.25 $\widehat{\text{sec}}$ (O-P); the jitter frequency is 20 cps; the LOS angle is 0 degrees.

Figure 3-4 differs from Figure 3-3 in that the jitter amplitude is 0.50 $\widehat{\text{sec}}$.

Thus, it is possible to generate a curve of resolution vs contrast ratio for the 0 degrees LOS case. This is shown as the top curve of Figure 4-4.

In order to generate resolution vs contrast ratio curves for LOS angles other than 0 degrees, the data of Figure 4-3 was applied. The result of applying the factor (both curves of Figure 4-3) of resolution degradation as a function of LOS angle is shown as the family of curves of Figure 4-4. Figure 4-4 describes the relation between ATS dynamic resolution. LOS,

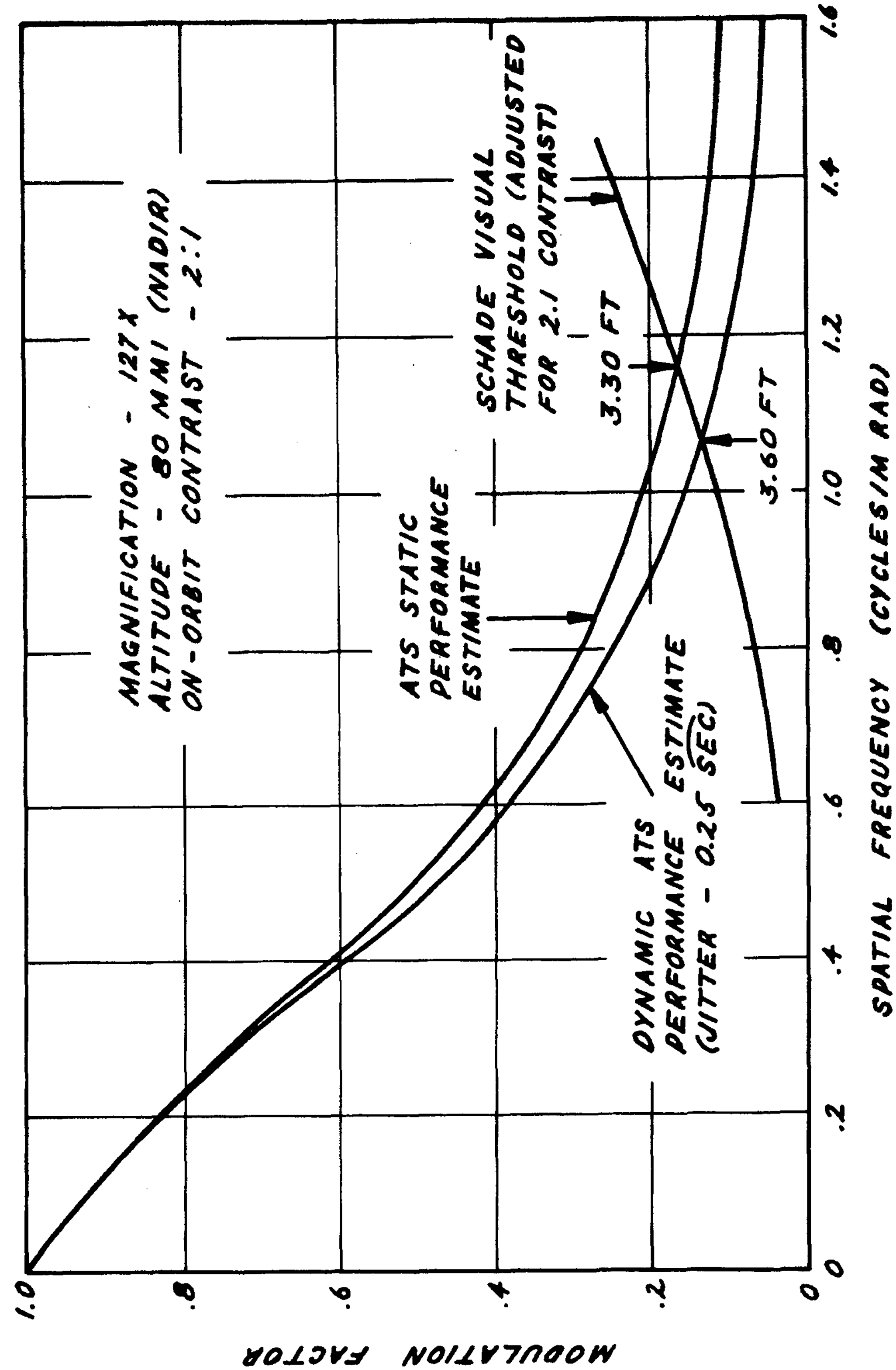

Figure 4-1. Original ATS Static and Dynamic Performance Prediction

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and contrast ratio. Thus, Figure 4-4 in conjunction with Figures 4-5 and 4-6 allow the generation of Figure 2-1; ATS dynamic resolution as a function of roll and pitch angle.

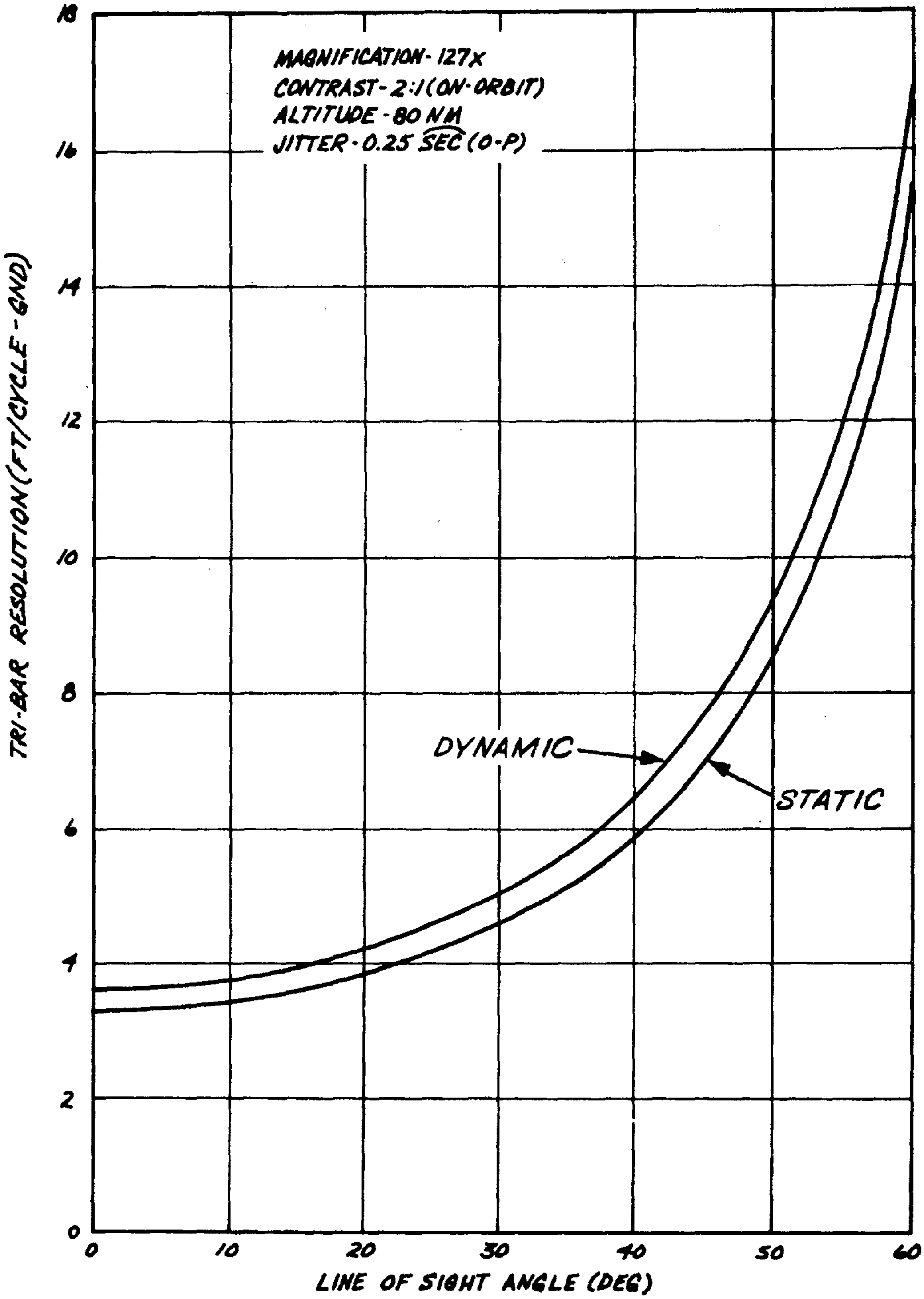


Figure 4-2. Original ATS On-Orbit Resolution vs LOS Angle

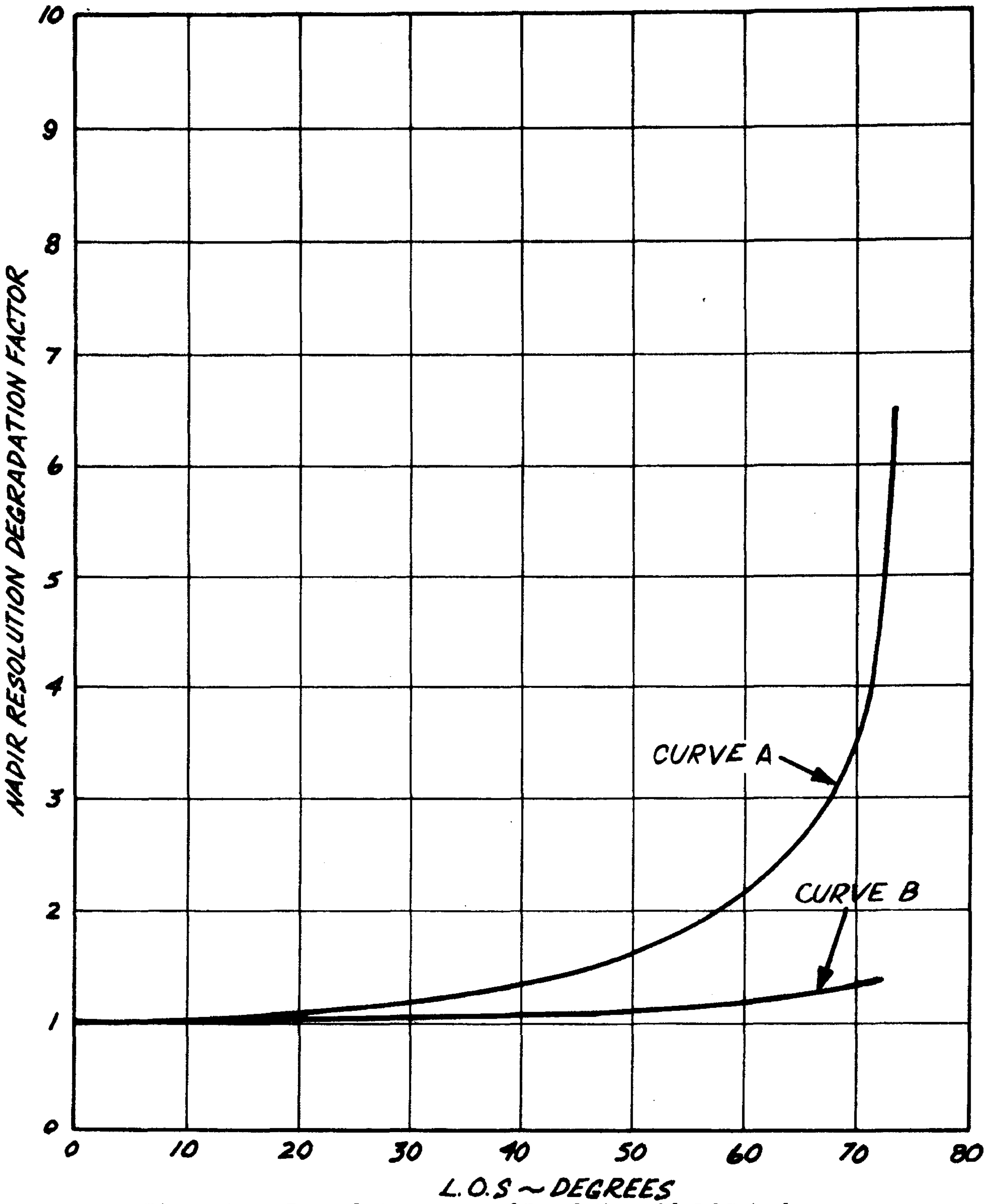


Figure 4-3. Degradation Factor of Resolution with LOS Angle

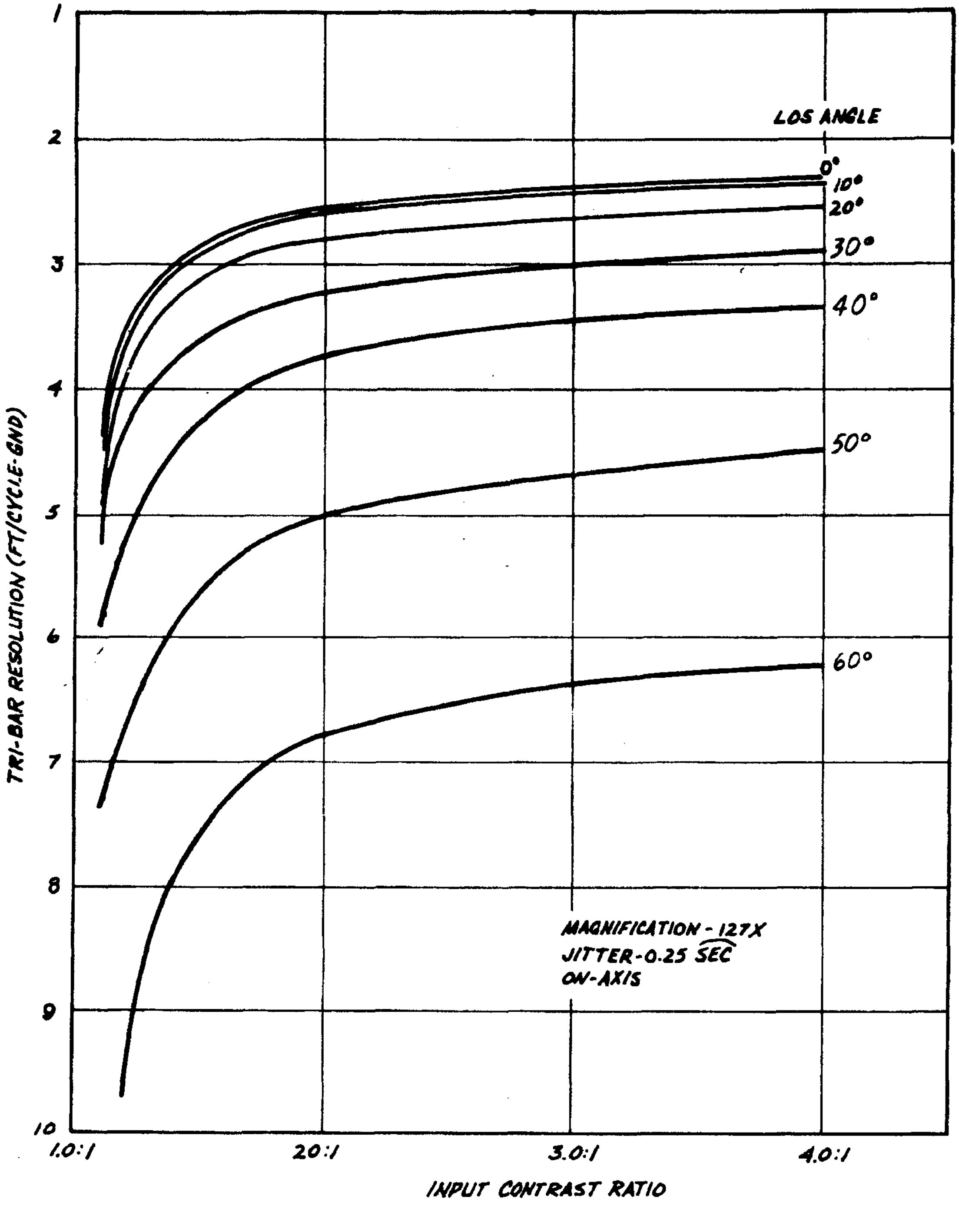
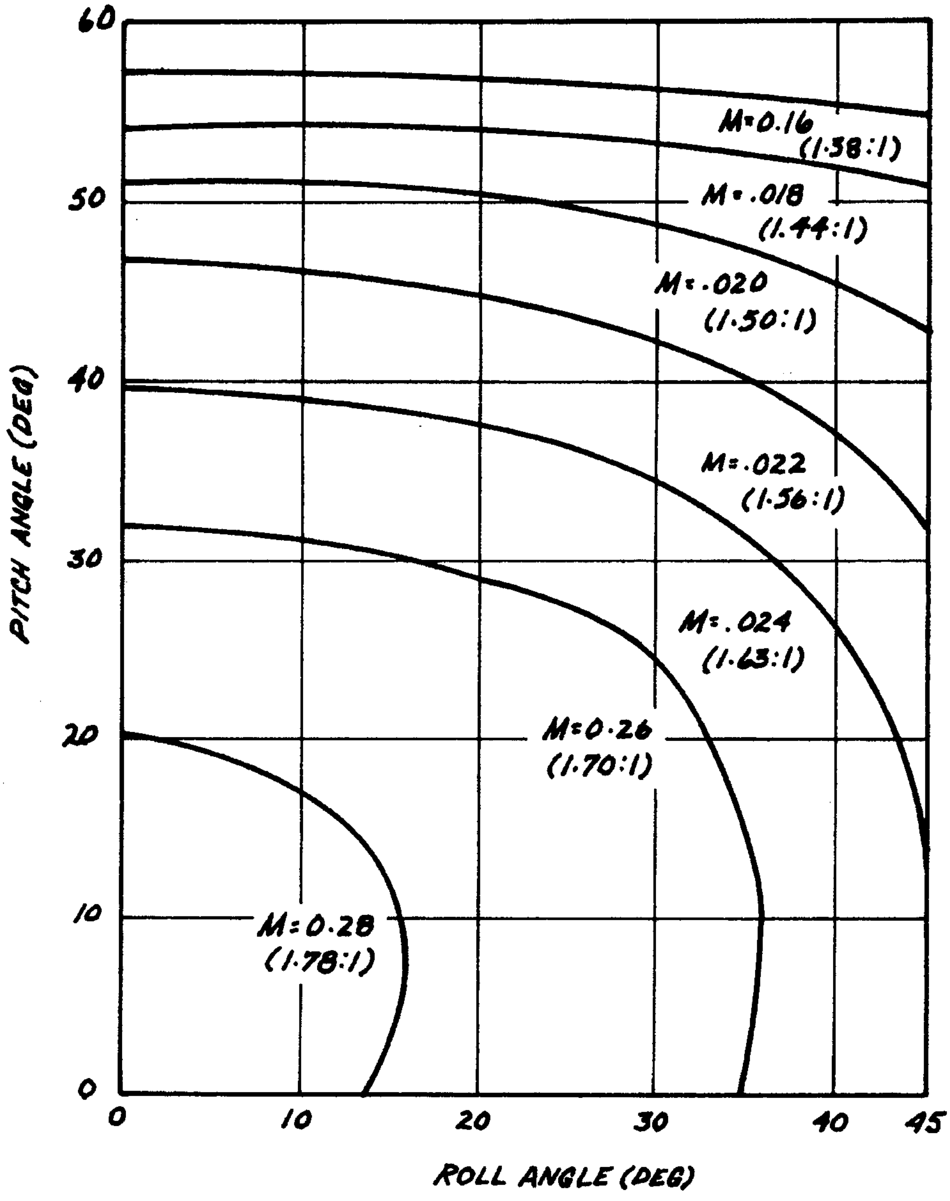


Figure 4-4. ATS Resolution Dynamic vs Input Contrast Ratio as a Function of LOS



$$M = \frac{B_{MAX} - B_{MIN}}{B_{MAX} + B_{MIN}}$$

Figure 4-5. Modulation as a Function of Pitch and Roll Angles (Based on PAM Atmospheric Model and 3:1 Contrast Ratio Flat on Ground)

It is now possible to determine resolution as a function of contrast ratio for any LOS angle. What remains to be done is to determine what is the functional relationship between LOS angle and contrast ratio with respect to real world parameters.

The real world parameters are introduced by means of the Photometric Atmospheric Model (PAM) (Reference 6). PAM calculates contrast ratio (~ modulation) as a function of the following:

a. Relative position of the Sun, observer, and target.

b. Altitude

c. Target reflectances

d. Characteristics of observing sensor.

e. Eye sensitivity.

f. Solar flux.

g. Scattering characterisitcs of the atmosphere.

On Orbit brightness and contrast factors

For this performance prediction, a Sun angle (elevation angle) of 36 degrees was assumed together with ground tri-bar target reflectances of 0.234 and 0.078. This choice of reflectances result in a ground (intrinsic) contrast ratio of 3:1 (modulation = 0.50) and an average reflectance of 0.156. The target was assumed to be flat on the ground for all cases. A detailed explanation of the PAM is given in the Appendix.

Figure 4-5 shows a map of constant modulation contours as a function of roll and pitch angle. Figure 4-5 was obtained from PAM output data.

Figure 4-6 gives the LOS angle as a function of pitch and roll angle.

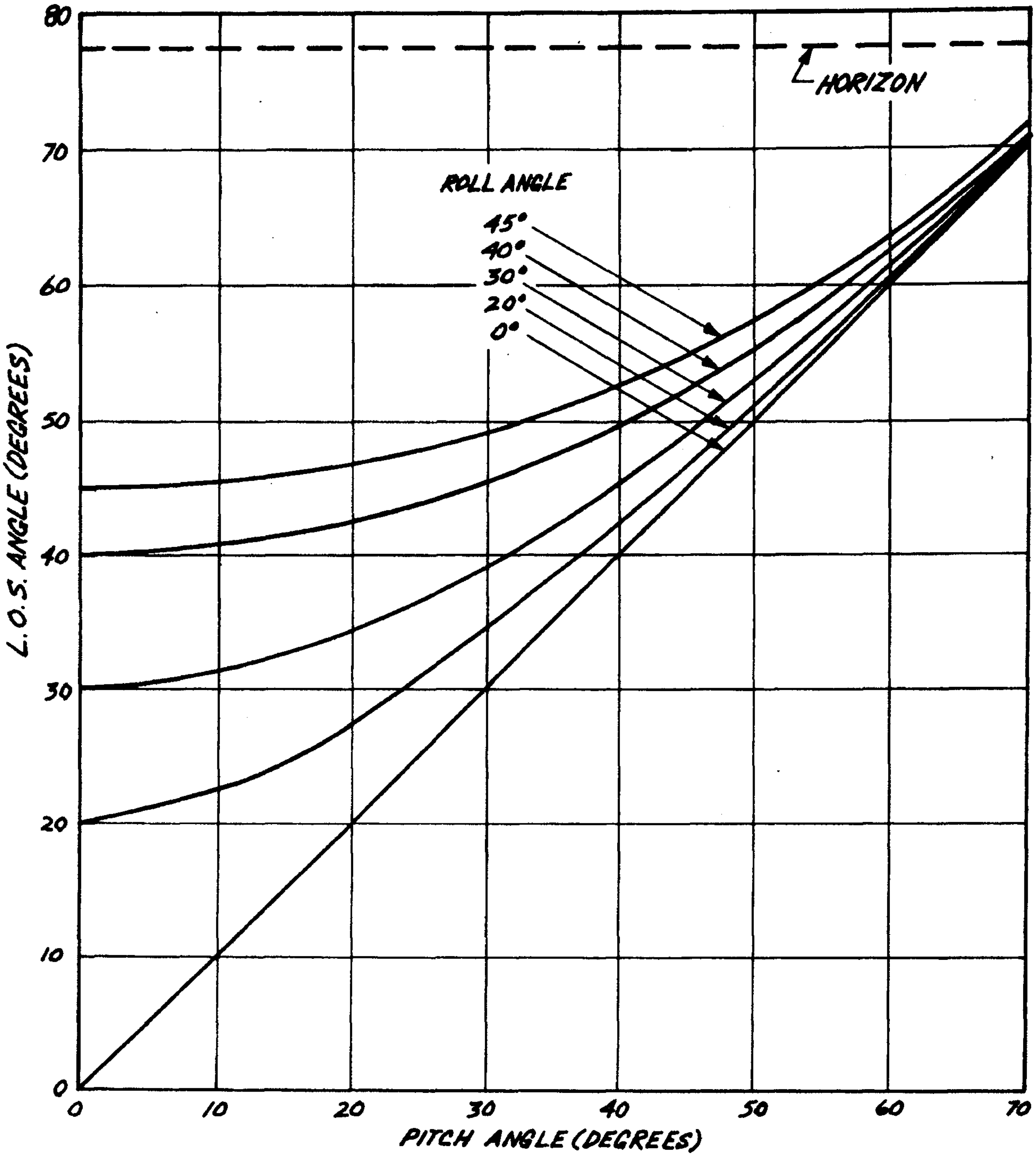


Figure 4-6. LOS Angle as a Function of Pitch and Roll Angles

Figure 4-5 together with Figure 4-6 allows the generation of Figure 4-7, on-orbit contrast ratio vs LOS angle. The parameters involved in this curve are given in paragraph 4.3.

Figure 4-7 together with Figure 4-4 produce the desired result; average day tri-bar resolution in the forward scan field. This is Figure 2-1.

Figure 4-8, the percent of useable forward scan field as a function of resolution for target recognition describes the cumulative percent of the forward field that yields resolution better than the value of the abscissa.

4.3 ATS PERFORMANCE PREDICTION

Using the methods described in paragraph 4.2 it was possible to obtain Figure 2-1, the Average Day Tri-Bar Resolution in the Forward Scan Field. Nominal values were chosen for the pertinent parameters involved: the tri-bar reflectances were 0.234 and 0.078 (3.0:1 at the ground; the target was flat on the ground and always oriented 45 degrees to the horizontal projection of LOS; the sun elevation angle was 36 degrees, a yearly average over the latitudes of interest; the nadir altitude was 80 nm; the other pertinent data used in the PAM program is described in the Appendix; the crew visual threshold for 0.25 $\widehat{\sec}$ (O-PK) and 20 Hz jitter was used with the ATS performance curves obtained from curve 5 of Figure 3-6.

The dynamic nadir on-axis resolution (roll angle = 0, pitch angle = 0) was found to be 2.6 ft. This represents a significant change from the original prediction of 3.6 ft. At 60 degree pitch angle, 0 degree roll angle, the resolution has degraded to 8.0 ft; based on the original performance prediction one would have anticipated a value in excess of 20 ft at a 60 degree angle.

Figure 4-8 indicates than on-axis resolution for 50 percent of the forward scan field is better than 4.4 ft, resolution for 70 percent of the field is better than 6.1 ft.

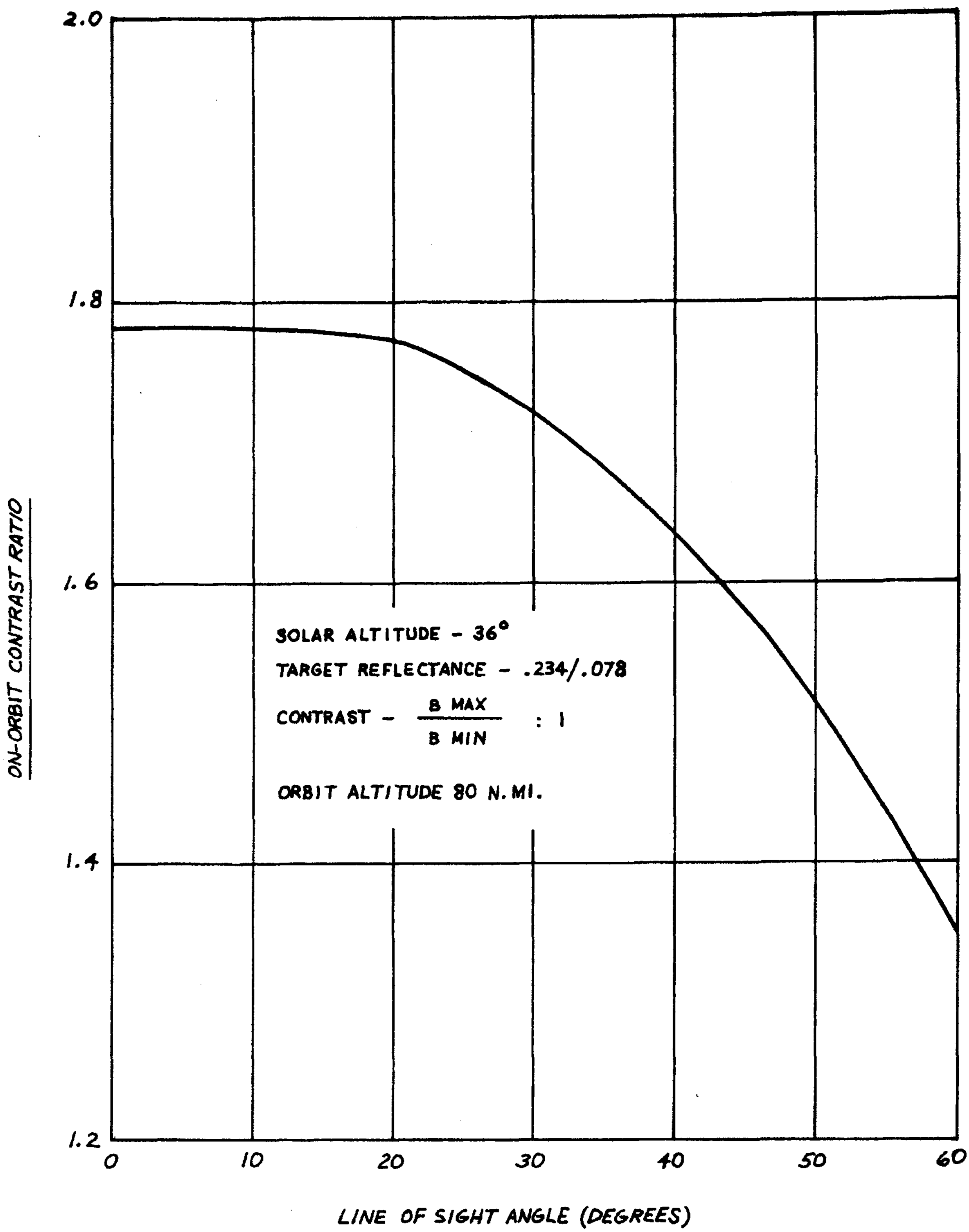


Figure 4-7. On-Orbit Contrast Ratio Based on PAM Atmospheric Data

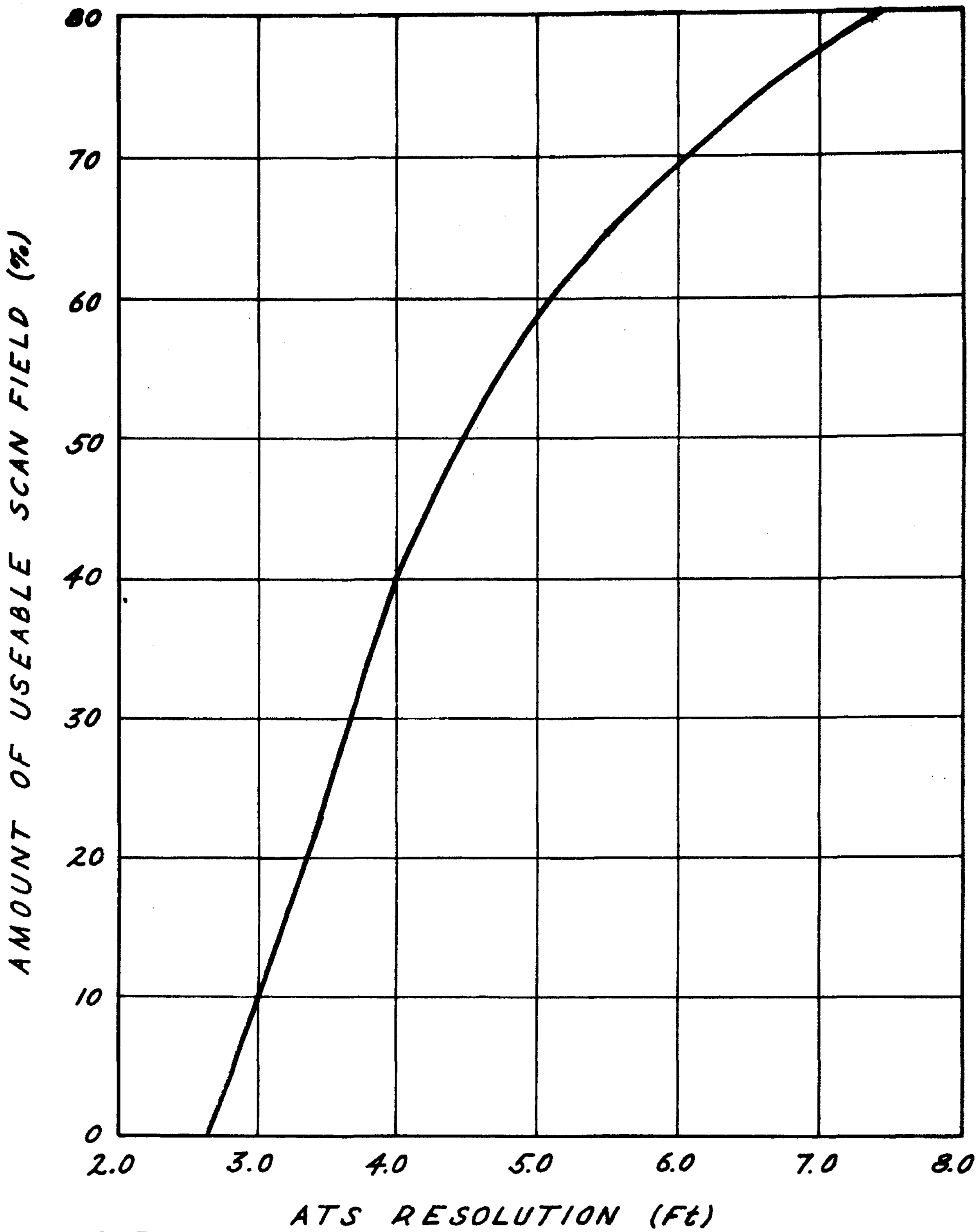


Figure 4-8. Percent of Useable Forward Scan Field as a Function of Resolution at 127X

4.4 MAN'S IMPACT

Figure 4-9 is a plot of normalized resolution for both the ATS and the Main Optics as a function of input contrast ratio. Both performance curves have been normalized to intersect at the 2:1 input contrast. The flatness of the curves show that the man-ATS system performance is much less sensitive to input contrast than is the Main Optics. This may, in part, be due to the fact that the Main Optics may have been optimized for a 2:1 contrast at the expense of performance at lower contrasts. However, a primary factor is the shape of man's visual threshold curve. The shape of the threshold curve is steep in the region where the 2:1 performance curve for the ATS and Main Optics intersect their respective thresholds for the eye and for film. Figure 4-10 illustrates this fact. It is a plot of modulation as a function of normalized spatial frequency for both the Main Optics and the ATS. They have been normalized so that the intersections of the system performance curves and the threshold curves both occur at the same normalized spatial frequency.

Figures 4-9 and 4-10 indicate that man's ability to resolve low-modulation level targets with the ATS is possibly greater than that of the Main Optics/Camera.

For relatively large objects which exhibit low on-orbit contrast ($\approx 1.1{:}1$) man may, under certain conditions, be able to detect their presence, whereas a Main Optics photograph of the same object might not reveal their presence.

It must be understood that this section (Section 4) is very preliminary and much further investigation should be undertaken to prove its validity.

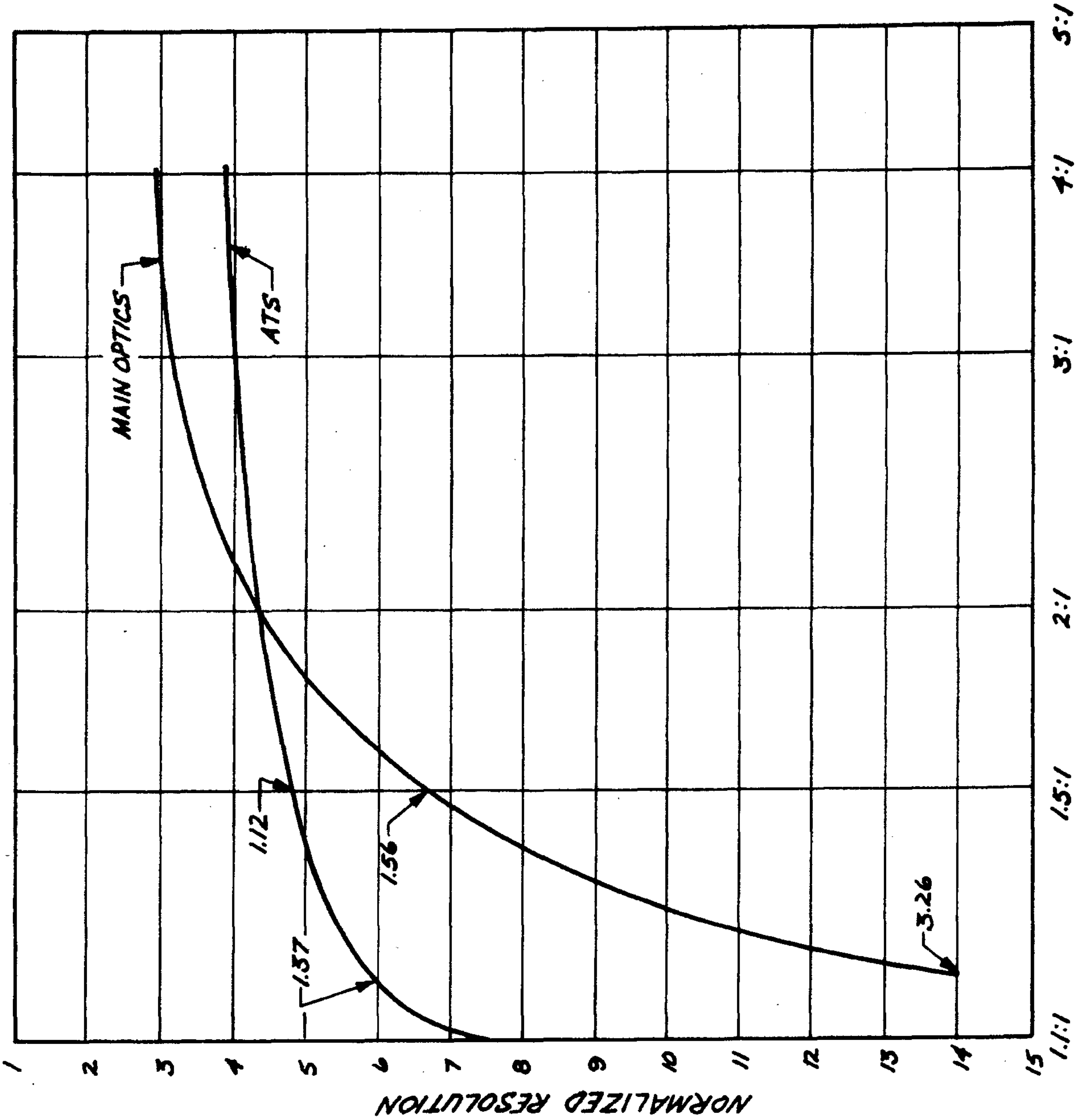


Figure 4-9. Relation Between Ground Resolution and Scene Contrast

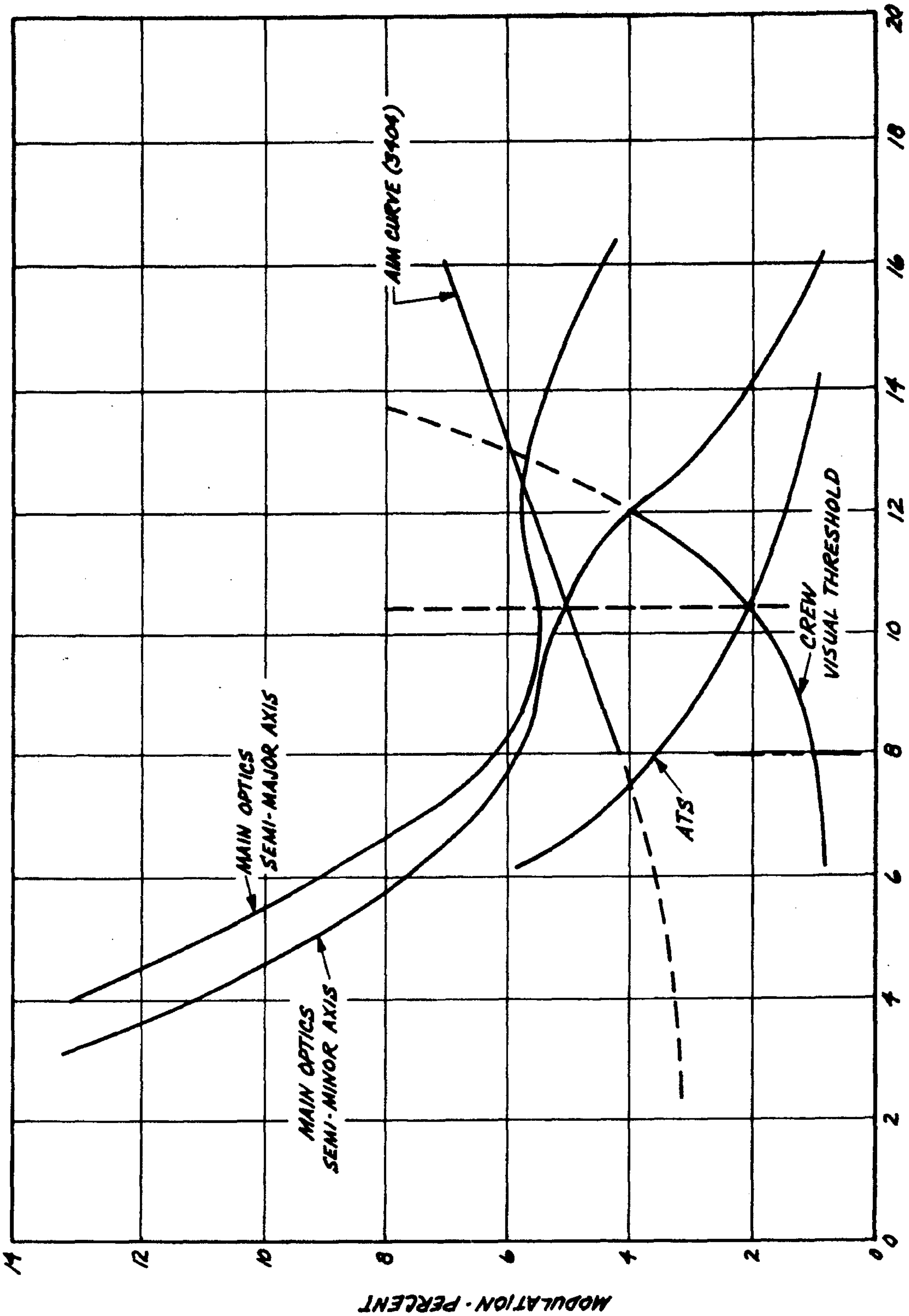


Figure 4-10. On-Axis System Performance 2:1 Contrast Ratio

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The major conclusion to be reached from this study is that the on-axis dynamic tri-bar resolution is far greater than originally anticipated. This is due primarily to the use of new experimental visual threshold data that differed greatly from that originally available. Though the resolution of 2.6 ft at nadir looks very satisfying, it must be remembered that many factors were not taken into account. These are: random jitter, structural vibration, contamination, thermal gradients and non-average haze.

A secondary conclusion is that for very low contrast (1.1:1) the man-ATS may detect targets that the Main Optics/Camera cannot resolve.

It is recommended that the following areas be investigated: non-nominal haze conditions; random jitter effects on visual thresholds; man's ability to enhance mission through observation of low contrast conditions; performance prediction based on real world statistics of target location, sun elevation and target contrasts; off-axis performance; contamination effects; thermal gradient effects; structural vibration effects.

It is further recommended that a stronger interface be established between performance prediction and simulation oriented contractor and customer personnel. Also, it is highly desirable that a regular working group be established including General Electric, Eastman Kodak, Itek, Air Force, Aerospace and the Intelligence Community in order to exchange information and solve problems.

SECTION 6

REFERENCES

SECTION 6

REFERENCES

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4. Journal of the Optical Society of America, Volume 52, March 1962, Page 325 by DePalma, J. J. and Lowry, E. M.

5. Acquisition Optics Subsystem PDR, ITEK Corporation dated 25 September 1967.

6. Photometric Atmospheric Model (PAM) by James Pierson.

APPENDIX

ATMOSPHERIC EFFECTS

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ATMOSPHERIC EFFECTS

The degradation in resolution of a tri-bar chart caused by atmospheric effects was determined through use of the Photometric Atmospheric Model (PAM) computer program. PAM calculates on-orbit brightness and modulation as a function of the following:

a. Relative positions of sun, observer and target.

b. Altitude.

c. Target characteristics (reflectances of light and dark bars of tri-bar).

d. Characteristics of observing sensor, such as wave length dependence of optics.

e. Wave length response of the eye.

f. Solar flux.

g. Scattering characteristics of atmosphere.

PAM corresponds to an atmosphere that is considered moderately hazy by EK Standards.

In PAM, the target is assumed to be a lambert diffuser specified by a pair of reflectances (PAM's calculations do not take into account the background in which this pair is submerged). In this study, the reflectance values were $a_1 = 0.234$ and $a_2 = 0.078$. These values are assumed to be independent of wave length. Thus, the ground contrast was $a_1/a_2 = 3:1$. The average reflectance was $\frac{a_1 + a_2}{2} = 0.156$

Table A-1 gives the values of transmittances as a function of wave length (λ) used in the program for the human eye and for the ATS optics. The transmittance values for the ATS optics are based on extrapolated and interpolated data from values furnished by ITEK.

Table A-2 gives the solar flux values relevant for light incident on the top of the atmosphere.

PAM is basically an empirical scattering model and allows for aerosol scattering and molecular scattering. The zenith angle of the Sun, A_1, and the nadir angle of observation, A_2 (the angle between the nadir and the target as viewed from the orbiting vehicle), determines relevant optical depths for light attenuation in the upward and downward directions. The apparent brightness seen by the observer may be considered to be composed of two parts:

1. Indirect or scattered light (haze).
2. Directly transmitted light which has been attenuated by its double traverse of the atmosphere. The direct light is proportional to the reflectance, a_1 of the target. Thus, B (apparent) = B (indirect) + aB (direct) where B (apparent) is the on-orbit brightness. B (direct) is calculated by:

$$B\ (\text{direct}) = \Sigma_\lambda \left[T_{3(\lambda)}\ T_{2(\lambda)}\ F_{(\lambda)}\ T_{1(\lambda)}\ \text{COS}\ (A_1) + F_{(\lambda)}\ S_{(\lambda)}\ V_\lambda \right]$$

where

λ	=	wave length values from Tables A-1 or A-2.
$T_{3(\lambda)}$	=	optical transmittance of sensor (Table A-1).
$T_{2(\lambda)}$	=	attenuation of light on its outward traverse of the atmosphere.
$F_{(\lambda)}$	=	solar flux (Table A-2).
$T_{1(\lambda)}$	=	attenuation of light during its inward traverse of the atmosphere.
$S_{(\lambda)}$	=	a function depending on λ and A_1 (zenith angle) governing the amount of flux incident on the ground due to light which has been scattered.
$V_{(\lambda)}$	=	visual sensitivity.

Table A-1. Transmittance

λ (Microns)	Visual Sensitivity V_2	Sensor Optical Transmittance $T_{3\lambda}$
0.40	0.0012	0.0564
0.45	0.0422	0.1926
0.50	0.3766	0.2947
0.55	0.9516	0.3374
0.60	0.6384	0.3286
0.65	0.1280	0.2898
0.70	0.0065	0.2510
0.75	0.0002	0.2124
0.80	0.0	0.1834

Table A-2. Solar Flux

λ Microns	Solar Flux (watts/m^2 - A^o) F_λ
0.40	0.1310
0.45	0.2090
0.50	0.2000
0.55	0.1930
0.60	0.1810
0.65	0.1620
0.70	0.1440
0.75	0.1270
0.80	0.1127

B (indirect) is a complicated function depending primarily on the scattering angle A_3 ($\cos A_3 = \cos A_1 \cos A_3 + \sin A_2 \cos \psi$ where ψ = azimuth angle), and the wave length dependence of aerosol and molecular scattering.

Since we are dealing with a tri-bar chart which has two reflectances a_1 and a_2, we define the apparent contrast above the atmosphere as B_1/B_2

where

B_1 = B (indirect) + a_1 B (direct)

B_2 = B (indirect) + a_2 (B direct)

$a_1 > a_2$

The apparent target modulation is defined as $M = (B_1 - B_2)/(B_1 + B_2)$; the average brightness, B_{AV} is defined as $(B_1 + B_2)/2$. An example is now given.

Assume a Sun elevation angle of 36 degrees (A_1 = 54 degrees), with the target at nadir (roll angle = pitch angle = 0 degrees). For these parameters B (indirect) is computed to be 119.29 ft lamberts and B (direct) = 998.74 ft lamberts. In this study $a_1 = 0.234$ and $a_2 = 0.078$. Therefore, $a_1/a_2 = \frac{0.234}{0.078} = 3.0{:}1$ = intrinsic contrast.

Then, $B_1 = 119.29 + 0.234\ (998.74)$, $B_1 = 352.995$ ft lamberts.
$B_2 = 119.29 + (0.078)\ (998.74) = 197.192$ ft lamberts.
The apparent contrast = 352.995/197.192 = 1.79:1.
The apparent scene modulation is 352.995 - 197.192/352.995 + 197.192 = 0.283 = M.

The average Sun elevation angle over the latitudes of interest (based on a yearly average) is 36 degrees. Figure 4-5 shows modulation and contrast ratio as a function of roll and pitch angle for the values of the parameters described in the above example. Figure 4-6 gives the line-of-sight (LOS) as a function of roll and pitch angle.