CORONA [redacted]

[redacted]
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3 August 1970

MEMORANDUM FOR THE RECORD

SUBJECT: CRYSPER-C Performance Prediction Program (Mission 1111 Examples)

1.0 INTRODUCTION

This memorandum is intended to generally describe the CRYSPER-C computer program, to illustrate the potential applications of this program and to detail some of the plans for its validation.

2.0 BASICS OF THE PROGRAM

The CRYSPER series of computer programs have the basic intent of calculating and/or predicting the resolution performance of a satellite camera system in-orbit. There are currently two versions of CRYSPER, one for CORONA (CRYSPER-C) and one for [redacted]. The basic input to the program is targets (e.g. COMIREX targets), and the basic output is predicted ground resolved distance (GRD) for each camera per target access, the rev of access, time and scan angle.

Each program is fundamentally the same; however, this memo concentrates on CRYSPER-C. The major difference between the two programs is in the camera module. The CRYSPER-C program consists of three basic components: an orbital module, atmospheric/target reflectance module and a camera module.

The orbital module is basically the OSTAMOD computer program. It takes orbital elements, "flys" the mission and determines when targets are accessed (not considering weather), and where they are located on the frame relative to scan angle. The atmospheric (target brightness) module is the CRYSTAL BALL computer program. The CRYSTAL BALL program forms an important portion of the on-orbit prediction program as it attempts to account for very important image quality degrading factors. The basic inputs to the program are listed below. As can be seen from the list, most are input from OSTAMOD and some are manual inputs.

a. Spectral response of the system (i.e. transmission of optics, filter and film sensitivity)

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b. Haze level

c. Altitude in nautical miles

d. Launch date and time

e. Solar declination

f. Inclination

g. Look heading

h. Camera stereo offset

For these particular set of conditions (for each target accessed), the program will calculate the transmission and brightness of the atmosphere and the brightness and contrast of the target in the camera image plane. It takes into account actual exposure time. One must, however, put into the program information relative to the highlight and lowlight reflectance so the apparent contrasts can be calculated. Also, one has to assume a haze condition (e.g. clear, normal, heavy) and input this to the program. It does not "forecast" haze, nor at the moment is this statistical in nature. The data in the program on clear, normal and heavy haze (and its effect on contrast and brightness) has been experimentally verified over a period of three years with both aircraft and satellite [redacted] and CORONA) tests.

The camera module is essentially a model of the camera system from an image quality point of view. This part of CRYSPER-C (referred to as CASSANDRA) basically performs the following functions:

a. It estimates the image smear associated with any point on the panoramic format.

b. It simulates the degrading effects of linear image motion on modulation transfer with a sine function.

c. It modifies the lens MTF (the program uses measured MTF's) by the sine function corresponding to the predetermined image motion.

d. It adjusts the film emulsion threshold curve such that its combination with an MTF reflects the apparent contrast of a three-bar target incident at the camera. It receives this appropriate contrast from CRYSTAL BALL.

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e. It crosses the sine modified lens transfer function with the adjusted film threshold function to yield resolution in c/mm on the film.

f. It converts resolution in c/mm to ground resolved distance (GRD) in feet through precise scale considerations.

3.0 PROGRAM USES

It has been envisioned that this kind of on-orbit performance prediction program could be used for a number of tasks; namely,

a. Establish expected performance levels. Such a program can be used to evaluate as built vs. design performance. That is, the effect of errors greater than budget on real performance can be assessed. In this way, one could get a feel for the practical importance of a "lower" performance camera system.

b. Evaluate performance post-flight. Such a program can assist in evaluating performance post-flight. One of the most difficult tasks in a post-flight environment is to sort out how the camera performed vs. how it should have performed. Very often, a "poor" performing camera is doing the best it can, and the degradations are really other non-controllable factors such as sun angles, haze, etc.

c. Evaluate orbits. In the past, the major (and in many cases, the only) criteria for selecting orbits is maximizing coverage. While there often is no resolution requirement per se, various orbits will produce different GRD distributions. Knowing the GRD produced by various orbits during the orbit selection process may be a further aid in assessing which orbit is "best."

d. On-orbit target selection. One could conceive of using such programs to maximize the quality of photography on-orbit in a real time sense. While for systems like CORONA and [redacted] resolution is not the driving factor in decisions to take or not take (coverage requirements usually are), it is conceivable in certain circumstances that such a program may assist for special cases where resolution is important.

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4.0 COMMENTS

Before discussing the data attached to this memo, a few comments about the limitations of the program are in order. These comments fall into three general areas: haze, target reflectance and GRD estimates.

4.1 Haze

It is essential to understand that the program does not include a statistical model of haze. That is, it is not possible (at this time) to take into account the fact that haze level changes as a function of time of year, time of day, latitude and longitude, etc. While this aspect is being actively pursued, the work is not sufficiently along to include this in the program. There are, however, several haze levels which can be used but have to be manually set in; these are:

a. Very Clear - comparable to a Reileigh atmosphere.

b. Clear, U.S.A. - average clear haze over the U.S.A.

c. Average, U.S.A. (Clear, U.S.S.R.) - The average U.S.A. haze level has been determined empirically to be comparable to the average clear day in the U.S.S.R. and China.

d. Heavy, U.S.A. (Average, U.S.S.R.) - The heavy U.S.A. haze level has been determined empirically to be comparable to the average haze conditions in the U.S.S.R. and China.

e. Heavy, U.S.S.R. is a separate haze level. It appears that the typical worst haze condition in the U.S.S.R. is worse than that over the U.S.A.

f. Very heavy haze is a haze condition that is just before cloud formation. Could be thought of as similar to a condition where high cirrus clouds exist but can be "seen" through by the camera.

It is not the purpose here to discuss how these haze conditions were derived and measured. If the reader is interested, there are several reports that detail the work and verification program. In addition, it is believed that for many applications of this program (such as orbit select), the use of such average haze conditions is perfectly adequate. One does have the flexibility, for instance, of using average U.S.S.R. haze conditions over, say, the missile targets in the U.S.S.R. and clear haze over the Middle East.

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4.2 Target Reflectance

Another input that greatly affects the predicted GRD is the target reflectance(s). Two values are actually required, a lowlight and a highlight reflectance. One can readily see that as these values change, the apparent contrast will change and, hence, the GRD predicted will change. Our ultimate goal is to put in the program "typical" values of reflectance for each major COMIREX target category (e.g. missiles). A significant measurement program (Project Sunny) was undertaken to collect this data. Satellite photography of selected targets was measured for over two years, and a good data base now exists for inputing such information. However, it has not been input as of this date. In the main, performance estimates are made using a lowlight reflectance of 7% and a highlight reflectance of 33% as these are the reflectance values for the 51/51 mobile CORN resolution target. This has some advantages in that it provides consistency in the predictions, in a form that is understandable. That is, the resultant values are comparable to what one would expect if a CORN target were photographed. The GRD values that result, however, can be misleading since a 7-33% reflecting scene is relatively high contrast and, hence, the GRD estimate would be optimistic relative to an actual intelligence target that was of lower contrast. The 7-33% values are not fixed in the program, however, and others can be inserted to evaluate a specific problem. The use of 7-33% is probably not bad for many cases. Again, if one is interested in comparing orbits, the answers will be relatively the same regardless of the reflectance used as long as reasonable values are used. Later in this memo an example will be presented of how and why one might want to change the reflectance input, and what the impact on resolution is.

4.3 GRD Estimates

The last major question relative to any such model such as CRYSPER is the accuracy of the predictions. How accurate the numbers are cannot be assessed at this time. All that can be said is that they "look reasonable." That is, the predicted GRD values for CORONA are about what one would expect based on the past history of the J-3 camera. Also, as variables are changed (haze, target reflectance, etc.), the GRD estimates change in the right direction. It is virtually certain that the numbers are relatively correct. For certain applications, again, this kind of accuracy is probably acceptable. If one wants to know which orbit gives the best average performance, this program will (I believe) do that job. If, however, one wants to know if a given target will be photographed at eight feet or nine

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feet, this may be beyond the current accuracy of the program. This is not to degrade the program, but simply to put a caution on interpreting the "absoluteness" of the numbers. We simply have not had an opportunity to check predictions against, say, CORN targets. This is something we intend to do in the near future. Also, there is a limitation with the CORONA version of CRYSPER that we hope will not be in the [redacted] version, and that relates to focus. With CORONA, where focus ~~is~~ is always an uncertainty; the program assumes that focus is where we think (based on block testing) it is. However, history has shown that often we are wrong. What this would do, of course, is make the numbers optimistic by some constant amount. With [redacted] we should know much more precisely where focus is.

It should also be pointed out that the CRYSPER program does not take area coverage or cloud statistics into account. It simply attempts to address the question of on-orbit camera performance. It accesses every target input, given that it is within the camera's view. There appears to be no reason, at the moment, to attempt to consider either of these questions in such a program as they are out of the realm of engineering or technical camera performance.

5.0 PROGRAM TEST CASES

A number of test cases were run to demonstrate the potential of the CRYSPER-C program to assist in orbit selection. Mission 1111 was selected for demonstration because of the discussion that ensued relative to the optimum orbit for that mission. The study is broken into two parts:

a. Part I - Mission 1111 was intended as a "special" mission in that repeated coverage of the "missile belt" was desired to facilitate in searching for new SS-9 and SS-11 construction. To do this, it was considered necessary to fly an unusual inclination (60°) in order to provide daily access to the majority of these areas. As a result of this discussion, the question arose as to what was the best altitude for perigee. Consideration was given to two, 88 and 100 nm. There are, of course, many considerations in a selection such as this, the amount of total coverage being a very important one. The 88 nm perigee orbit was selected since intuitively everyone knew that resolution would be better. What was not known, however, was how much better (except for a feel based on simple altitude changes), and what the comparison was of performance at different locations of the world. This was of particular interest since the sync period of the two orbits (i.e. 88 and 100) were to remain the same. To do this, apogee for the

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88 nm perigee orbit had to be higher than for the 100 nm case; and, hence, some photography for the 88 nm perigee orbit can be expected to be the same or slightly worse than for the 100 nm case. To demonstrate what CRYSPER-C might have contributed to these discussions, GRD predictions were made for the following conditions:

Missile Areas — All 1A COMIREX targets (1434) were used. Predictions were made for both the 88 and 100 nm orbits for both the forward- and aft-looking cameras. In addition, predictions were made for both descending and ascending photography.

Middle East — A large sampling of Middle East targets (304) were used. Predictions were made for the same conditions as above.

b. Part II - This portion of the test was done subsequent to Part I as a result of discussions with SOC personnel relative to the results of Part I. It was done to evaluate: (1) what the performance would have been if a more normal orbit had been used, at two altitudes, 80 and 100 nm; and (2) what the effect of target reflectance is on the predicted GRD numbers. Two sets of predictions were made:

Normal Orbits — A series of predictions were made for an 80 and 100 nm perigee orbit, the 80 nm having an inclination of 81.5° and the 100 nm orbit having an inclination of 75°. These orbits were selected from past CORONA missions. Prediction for descending photography only was made over the same missile areas and Middle East targets as in Part I. As before, separate predictions for the forward- and aft-looking cameras were made.

Target Reflectance — It was assumed that some of the missile areas of interest would be under construction and that possibly dirt, earth scarring, and early construction was the prime "target." To evaluate this, a set of "low" reflectances of 5% and 12% were used. While these are probably not exactly the correct values, they do give a feel for the impact of target reflectances on the resultant GRD estimates. This analysis was done only for the 1A targets, descending photography for the 80 nm perigee case.

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6.0 TEST RESULTS

Before discussing the results, I want to emphasize three points:

a. Again, the "absoluteness" of the numbers cannot be proven. They are certainly in the right "ball park," but it cannot be proven at this time that they are absolutely correct.

b. Much of the interpretation of this data is subjective. That is, the significance of a given resolution improvement to the photo-interpreter cannot be proven by a computer. (Nor, often, can it be assessed by a PI.) I have given my own interpretation to the data, and the reader may differ with my conclusions. However, I have used the best judgment I can based on experience and history to assess what is significant and what is not.

c. The resolution of the CORONA camera has been a subject of some debate for a number of years. Some people who have reviewed the results herein have commented that "CORONA does not achieve five feet." On the average, it certainly does not. But there are a few predictions contained in this analysis which are in the five foot region. The purpose of this discussion is to point out that the J-3 camera, given a favorable orbit and a good performing camera, will take a few pictures at five feet. Table 1 shows the performance one would expect based on the camera design, at nadir, so it is not unreasonable to expect a few pictures with "very good" (for CORONA) resolution. It is remembered that the best CORN target (51/51 T-bar) that was recorded was on Mission 1104 where the resolution was slightly better than five feet. As the results are reviewed, it will also be noted that a large number of pictures are predicted at resolutions considerably larger than five feet.

6.1 Part I: Evaluation of the 60° Inclination Orbit, 88 vs. 100 nm Perigee

Tables 2 through 5 present the basic data employed in the study. These tables list simply the cumulative frequency distribution of targets, under the various conditions, as a function of resolution (GRD) cells. The selection of resolution cells (i.e. 6.0 to 6.5 feet) is purely arbitrary and is not intended to have any physical significance.

There are a number of ways to look at this data; and which is best is not, at this time, clear. Table 6 takes the data from

TABLE 1A

PREDICTED FWD CAMERA PERFORMANCE BASED ON DESIGN

80 nm, 2σ Values, 0-Degree Field,
2:1 Contrast, 3.64-Millisecond Exposure,
3404 Film, III Generation Lens with Wratten No. 25 Filter

CASE		ALONG TRACK			CROSS TRACK		
A.	2σ Best						
	Format position, degrees	0	15	30	0	15	30
	Image smear, microns	0.1	0.1	0.1	0.3	4.8	10.
	Resolution, lines per millimeter	180	180	180	180	136	85
	GRD, feet	4.8	4.9	5.5	4.6	6.5	13.
B.	Average						
	Format position, degrees	0	15	30	0	15	30
	Image smear, microns	1.6	1.6	1.5	2.7	7.3	12.
	Resolution, lines per millimeter	173	173	174	162	109	72
	GRD, feet	5.0	5.1	5.7	5.1	8.1	15.
C.	2σ Low						
	Format position, degrees	0	15	30	0	15	30
	Image smear, microns	4.9	4.8	4.3	5.4	9.8	15.
	Resolution, lines per millimeter	135	136	142	129	89	63
	GRD, feet	6.3	6.5	7.0	6.4	10.0	17.

TABLE 1B

PREDICTED AFT CAMERA PERFORMANCE BASED ON DESIGN

80 nm, 2 Values, 0-Degree Field,
2:1 Contrast, 2.44-Millisecond Exposure,
3404 Film, II Generation Lens with Wratten No. 21 Filter

CASE	ALONG TRACK			CROSS TRACK		
A. 2 Best						
Format position, degrees	0	15	30	0	15	30
Image smear, microns	0.1	0.1	0.1	0.2	3.2	6.9
Resolution, lines per millimeter	140	140	140	140	128	101
GRD, feet	6.1	6.3	7.1	5.9	6.9	10.9
B. Average						
Format position, degrees	0	15	30	0	15	30
Image smear, microns	1.1	1.1	1.0	1.8	4.9	8.5
Resolution, lines per millimeter	138	138	139	136	115	90
GRD, feet	6.2	6.4	7.1	6.1	7.7	12.2
C. 2 Low						
Format position, degrees	0	15	30	0	15	30
Image smear, microns	3.3	3.2	2.9	3.6	6.6	10.1
Resolution, lines per millimeter	127	128	130	125	103	81
GRD, feet	6.7	6.9	7.6	6.6	8.6	13.6

TABLE 2

MISSION 1111 - MISSILE AREAS
FWD-LOOKING CAMERA
GRD ESTIMATES FROM CRYSPER-C
CUMULATIVE FREQUENCY

Resolution (GRD - Ft)	Descending Photography 88 nm	Descending Photography 100 nm	Ascending Photography 88 nm	Ascending Photography 100 nm
5.0 - 5.5	10.2		2.8	
5.5 - 6.0	30.9	1.7	12.6	3.9
6.0 - 6.5	44.2	23.5	26.1	15.0
6.5 - 7.0	54.1	41.9	38.1	31.6
7.0 - 7.5	63.0	52.8	48.4	45.2
7.5 - 8.0	69.7	60.4	57.1	54.4
8.0 - 8.5	76.1	67.0	64.1	61.2
8.5 - 9.0	81.1	73.5	72.3	69.5
9.0 - 9.5	85.1	78.6	78.7	77.7
9.5 - 10.0	87.9	82.6	84.8	84.3
10.0 - 10.5	90.8	86.2	89.0	89.3
10.5 - 11.0	93.7	89.4	93.2	93.0
11.0 - 11.5	96.4	91.9	96.0	95.4
11.5 - 12.0	98.0	94.1	97.3	96.8
12.0 - 12.5	98.7	96.3	97.9	97.6
12.5 - 13.0	99.3	97.7	98.3	98.2
13.0 - 13.5	99.7	98.6	98.5	98.8
13.5 - 14.0	99.9	99.3	98.8	99.2
14.0 - 14.5	100	99.6	99.2	99.4
14.5 - 15.0		99.8	99.4	99.7
15.0 - 15.5		99.9	99.7	99.8
15.5 - 16.0			100	99.9
16.0 - 16.5				100
16.5 - 17.0				
17.0 to greater				
MEAN GRD	7.4 ft	8.1 ft	8.0 ft	8.2 ft

60° Inclination
5.25 Day Sync

TABLE 3

MISSION 1111 - MISSILE AREAS
AFT-LOOKING CAMERA
GRD ESTIMATES FROM CRYSPER-C
CUMULATIVE FREQUENCY

Resolution (GRD - Ft)	Descending Photography 88 nm	Descending Photography 100 nm	Ascending Photography 88 nm	Ascending Photography 100 nm
5.0 - 5.5				
5.5 - 6.0				
6.0 - 6.5	4.1		0.5	
6.5 - 7.0	23.4		6.2	0.1
7.0 - 7.5	35.1	6.3	17.1	5.6
7.5 - 8.0	46.1	24.0	28.7	16.9
8.0 - 8.5	57.1	34.9	40.4	29.2
8.5 - 9.0	69.0	45.7	53.2	40.5
9.0 - 9.5	81.0	56.6	66.2	54.4
9.5 - 10.0	89.8	66.6	75.1	66.2
10.0 - 10.5	93.4	76.3	82.4	72.2
10.5 - 11.0	95.3	86.9	89.8	83.3
11.0 - 11.5	96.4	93.1	93.4	90.5
11.5 - 12.0	97.5	95.8	95.9	94.1
12.0 - 12.5	98.6	97.6	97.5	96.3
12.5 - 13.0	100	98.3	99.2	98.1
13.0 - 13.5		99.1	99.8	99.2
13.5 - 14.0		99.8	100	99.8
14.0 - 14.5		100		99.9
14.5 - 15.0				100
15.0 - 15.5				
15.5 - 16.0				
16.0 - 16.5				
16.5 - 17.0				
17.0 to greater				
MEAN GRD	8.3 ft	9.3 ft	9.0 ft	9.5 ft

60° Inclination
5.25 Day Sync

TABLE 4

MISSION 1111 - MIDDLE EAST
FWD-LOOKING CAMERA
GRD ESTIMATES FROM CRYSPER-C
CUMULATIVE FREQUENCY

Resolution (GRD - Ft)	Descending Photography 88 nm	Descending Photography 100 nm	Ascending Photography 88 nm	Ascending Photography 100 nm
5.0 - 5.5	0.8	----		
5.5 - 6.0	9.5	0.7		
6.0 - 6.5	18.2	2.6		
6.5 - 7.0	25.8	14.0		
7.0 - 7.5	36.1	25.7	1.1	0.9
7.5 - 8.0	42.9	35.2	2.2	1.4
8.0 - 8.5	49.9	44.2	8.2	6.6
8.5 - 9.0	56.1	53.2	14.2	14.3
9.0 - 9.5	61.8	59.8	21.8	23.6
9.5 - 10.0	65.9	64.4	29.4	31.3
10.0 - 10.5	75.1	72.9	36.8	37.9
10.5 - 11.0	81.3	78.7	42.6	44.1
11.0 - 11.5	85.4	84.3	50.9	53.0
11.5 - 12.0	89.5	87.7	57.2	59.4
12.0 - 12.5	91.4	89.9	63.7	65.3
12.5 - 13.0	93.0	92.3	69.5	71.0
13.0 - 13.5	95.4	94.2	74.6	76.2
13.5 - 14.0	96.2	95.2	76.8	78.9
14.0 - 14.5	97.6	95.7	79.5	81.2
14.5 - 15.0	99.2	95.7	83.8	85.8
15.0 - 15.5	100.0	96.4	88.5	89.4
15.5 - 16.0		98.1	90.5	91.9
16.0 - 16.5		98.6	91.3	92.1
16.5 - 17.0		98.8	92.6	94.4
17.0 to greater		99.0 - 100	94.4 - 100	94.9 - 100
MEAN GRD	8.9 ft	9.4 ft	11.9 ft	11.9 ft

60° Inclination
5.25 Day Sync

TABLE 5

MISSION 1111 - MIDDLE EAST
AFT-LOOKING CAMERA
GRD ESTIMATES FROM CRYSPER-C
CUMULATIVE FREQUENCY

Resolution (GRD - Ft)	Descending Photography 88 nm	Descending Photography 100 nm	Ascending Photography 88 nm	Ascending Photography 100 nm
5.0 - 5.5				
5.5 - 6.0				
6.0 - 6.5	1.1			
6.5 - 7.0	6.8			
7.0 - 7.5	16.6	2.7		
7.5 - 8.0	29.3	9.0		
8.0 - 8.5	35.5	23.8		
8.5 - 9.0	43.4	31.3	0.7	0.2
9.0 - 9.5	60.7	38.6	6.0	4.1
9.5 - 10.0	69.4	47.8	10.7	9.3
10.0 - 10.5	77.0	62.9	15.4	14.5
10.5 - 11.0	82.4	73.4	23.5	21.8
11.0 - 11.5	89.4	83.4	27.1	26.1
11.5 - 12.0	93.5	88.5	32.2	31.1
12.0 - 12.5	95.9	92.4	39.8	39.5
12.5 - 13.0	98.3	95.3	45.4	45.9
13.0 - 13.5	99.7	97.0	56.6	55.9
13.5 - 14.0	100	98.0	61.7	61.4
14.0 - 14.5		98.5	65.7	65.7
14.5 - 15.0		99.7	72.9	73.9
15.0 - 15.5			84.5	85.3
15.5 - 16.0			87.4	88.5
16.0 - 16.5			92.3	92.4
16.5 - 17.0			92.7	93.5
17.0 to greater		100	93.6 - 100	93.7 - 100
MEAN GRD	9.2 ft	10.1 ft	13.4 ft	13.3 ft

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Tables 2 through 5 and summarizes it into more "gross" resolution bins. This table lists the absolute percentage of targets predicted to be in one of four resolution categories. It also lists the mean resolution predicted. If one believed this arbitrary breakdown, he would say that not a great deal was achieved in lowering the altitude. For example, evaluating the missile areas:

a. For descending photography, 69.7% is expected to be better than eight feet (on the forward-looking camera) for the 88 nm case vs. 60.4% for the 100 nm case. Not a significant difference. The same kind of minimal difference is demonstrated in the ascending photography.

b. For the aft-looking camera, the difference in the two altitudes (over the missile area) is more significant, being better for the 88 nm orbit by about a factor of two (over the 100 nm orbit).

c. From this table, it would appear that the lower orbit has done more in the Middle East than for the missile areas. Again, looking at descending photography (aft-looking camera), the 88 nm case predicts 29.3% of the targets better than eight feet vice only 9% for the 100 nm case, an improvement of about three times.

Tables 7 and 8 present the data in a slightly different form. They are an attempt to assess what advantages have been gained, between the two orbits, from the standpoint of the best photography that can be expected. Table 7 looks at the percentage of targets that can be expected to be better than seven feet and Table 8 at the percentage of targets expected to be better than six feet. Now one can see what the lower altitude is really buying is an improvement in the amount of "best" photography. From Table 7 one can see that for most cases studied there is a significant difference in the amount of photography better than seven feet for the 88 nm case vice the 100 nm case. Table 8 is even more demonstrative, showing that for the missile areas (descending, forward-looking camera) fully 30% of the targets are predicted to be better than six feet (for the 88 nm perigee) versus 1.7% (for the 100 nm perigee).

Tables 6 through 8, however, can be misleading in that they rely on arbitrary resolution "bins" to enable drawing conclusions. These bins have no physical significance (such as ability of PI to detect or identify objects) and the structure of these bins could be incorrect.

TABLE 6

MISSION 1111

GRD ESTIMATES FROM CRYSPER-C

PERCENTAGE OF TARGETS VS. RESOLUTION

DESCENDING PHOTOGRAPHY

	MIDDLE EAST				"MISSILE" AREAS			
	FWD		AFT		FWD		AFT	
GRD (Ft)	88	100	88	100	88	100	88	100
5.0 - 8.0	42.9	35.2	29.3	9.0	69.7	60.4	46.1	24.0
8.0 - 10.0	23.0	29.2	40.1	38.8	18.2	22.2	43.7	42.6
10.0 - 15.0	33.3	31.3	30.6	51.9	12.1	17.2	10.2	33.4
15.0 - 20.0	0.8	4.3	0.0	0.3	0.0	0.2	0.0	0.0
MEAN GRD (Ft)	8.9	9.4	9.2	10.1	7.4	8.1	8.3	9.3

ASCENDING PHOTOGRAPHY

	MIDDLE EAST				"MISSILE" AREAS			
	FWD		AFT		FWD		AFT	
GRD (Ft)	88	100	88	100	88	100	88	100
5.0 - 8.0	2.2	1.4	0.0	0.0	57.1	54.4	28.7	16.9
8.0 - 10.0	27.2	29.9	10.7	9.3	27.7	29.9	46.4	49.3
10.0 - 15.0	54.4	54.5	62.2	64.6	9.6	15.4	24.9	33.8
15.0 - 20.0	16.2	14.2	27.1	26.1	5.6	0.3	0.0	0.0
MEAN GRD (Ft)	11.9	13.3	13.4	13.3	8.0	8.2	9.0	9.5

60° Inclination
5.25 Day Sync

TABLE 7

MISSION 1111

GRD ESTIMATES FROM CRYSPER-C

PERCENTAGE OF TARGETS BETTER THAN 7 FEET

	88 nm Perigee		100 nm Perigee	
	FWD*	AFT*	FWD*	AFT*
MIDDLE-EAST DESCENDING	25.8	6.8	14.0	0
MIDDLE-EAST ASCENDING	0	0	0	0
MISSILE AREAS DESCENDING	54.1	23.4	41.9	0
MISSILE AREAS ASCENDING	38.1	6.2	31.6	0.1

* FWD or AFT Looking Camera

TABLE 8

MISSION 1111

GRD ESTIMATES FROM CRYSPER-C

PERCENTAGE OF TARGETS BETTER THAN 6 FEET

	83 nm Perigee		100 nm Perigee	
	FWD*	AFT*	FWD*	AFT*
MIDDLE EAST DESCENDING	9.5	0	0.7	0
MIDDLE EAST ASCENDING	0	0	0	0
MISSILE AREAS DESCENDING	30.9	0	1.7	0
MISSILE AREAS ASCENDING	12.6	0	3.9	0

* FWD or AFT Looking Camera

SUBJECT: CRYSPER-C Performance Prediction Program (Mission 1111 Examples)

Probably a more meaningful way to look at the data is to actually assess frequency plots generated from Tables 2 through 5. Figures 1 through 9 present this data in slightly truncated form for convenience, Figures 1 through 4 being for the missile areas and Figures 5 through 8 for the Middle East. Evaluation of these figures allow, in my estimation, the following conclusions:

a. The aft-looking camera produces, under all conditions, poorer photography than the forward. This was expected because of lower optical performance (second vs. third generation lens).

b. For descending photography over the missile areas, the 88 nm perigee orbit produces better photography than the 100 nm case. The improvement on both the forward- and aft-looking cameras is about one foot, although the improvement on the aft is more uniform. In my view, this improvement is significant to the PI's and will result in more missile targets being rated good than would have been the case with the 100 nm orbit.

c. For ascending photography over the missile areas, there is also an improvement for the 88 nm orbit, but not as dramatic as the descending case, being on the order of 0.5 feet. In my view, this improvement is marginal. In this case, the aft-looking camera probably benefited slightly more than the forward.

d. For descending photography over the Middle East, again the lower orbit has helped. I judge that the 88 nm case would produce significantly better photography than the 100 nm case. Again, the aft-looking camera has benefited slightly more than the forward.

e. For ascending photography over the Middle East, the lower orbit has not helped at all, the resolution distribution for the two being virtually identical. This one would expect since the orbits are very nearly crossing at this latitude due to maintaining identical periods. Further, ascending photography over the Middle East will be rather poor (approximately 12 feet at best) and may well be not good enough to consider taking unless there is a very high priority target or requirement. In any event, one should not expect too much out of this photography.

The overall conclusion I draw then is that if the primary requirement was to see missiles as best as can be done (with CORONA), the 88 nm orbit was a better selection and probably significantly so. Whether it was the "best" orbit, from a camera performance point of view, is another issue.

FIGURE 1

MISSILE AREAS

CRYSPER-C Predicted GRD

FWD-looking Camera Descending Photography

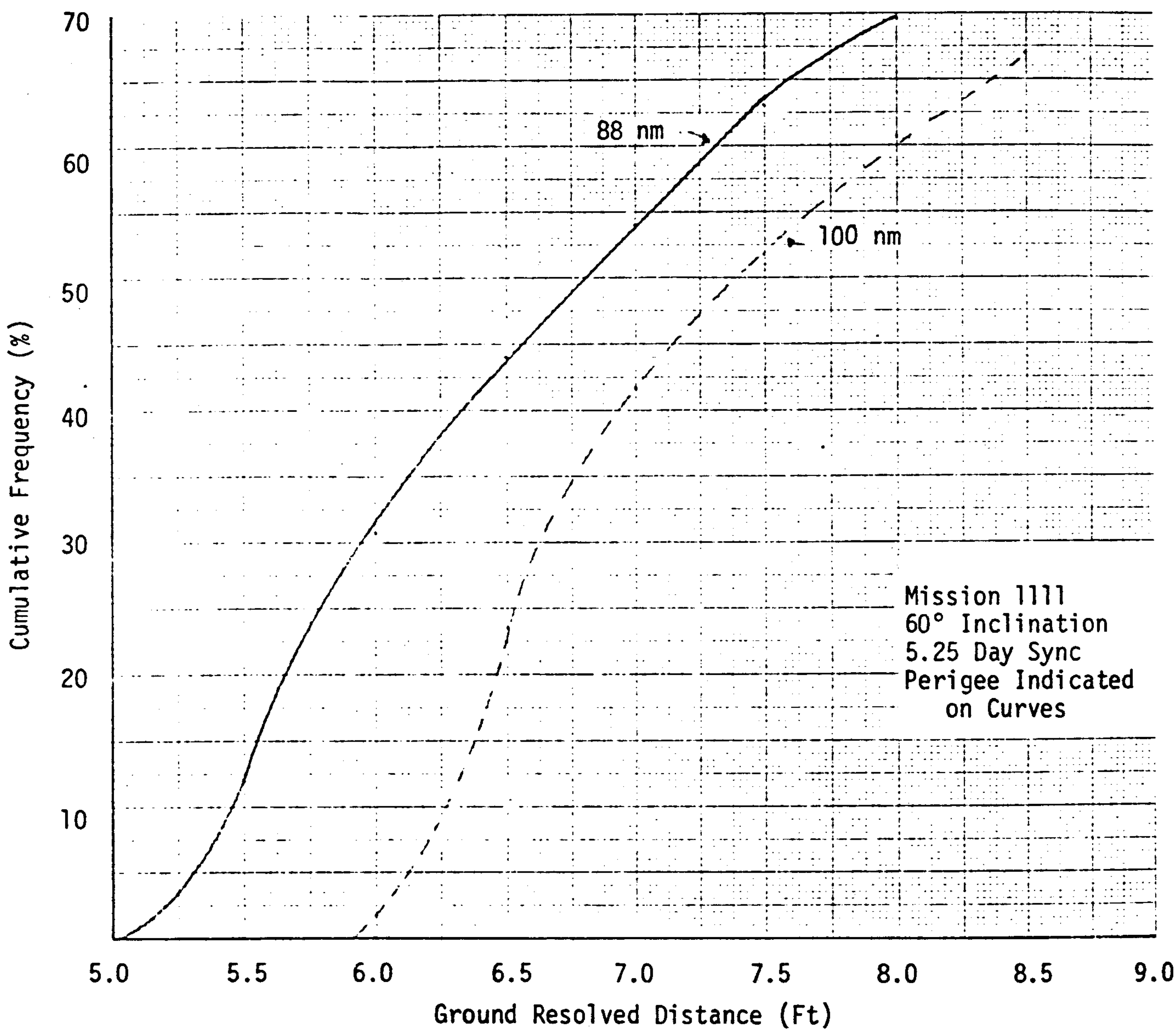


FIGURE 2

MISSILE AREAS

CRYSPER-C Predicted GRD

AFT-Looking Camera Descending Photography

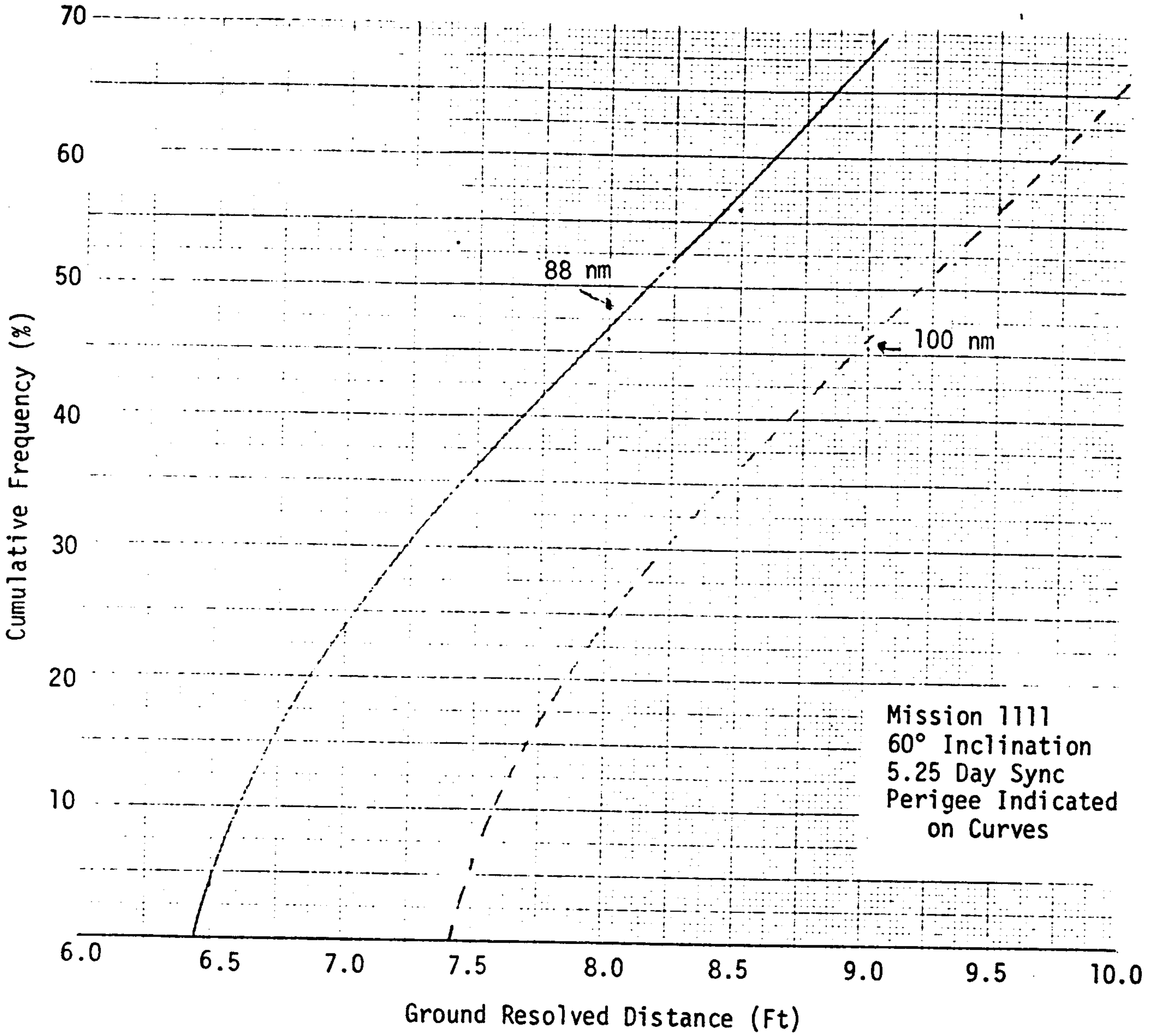


FIGURE 3

MISSILE AREAS

CRYSPER-C Predicted GRD

FWD-Looking Camera Ascending Photography

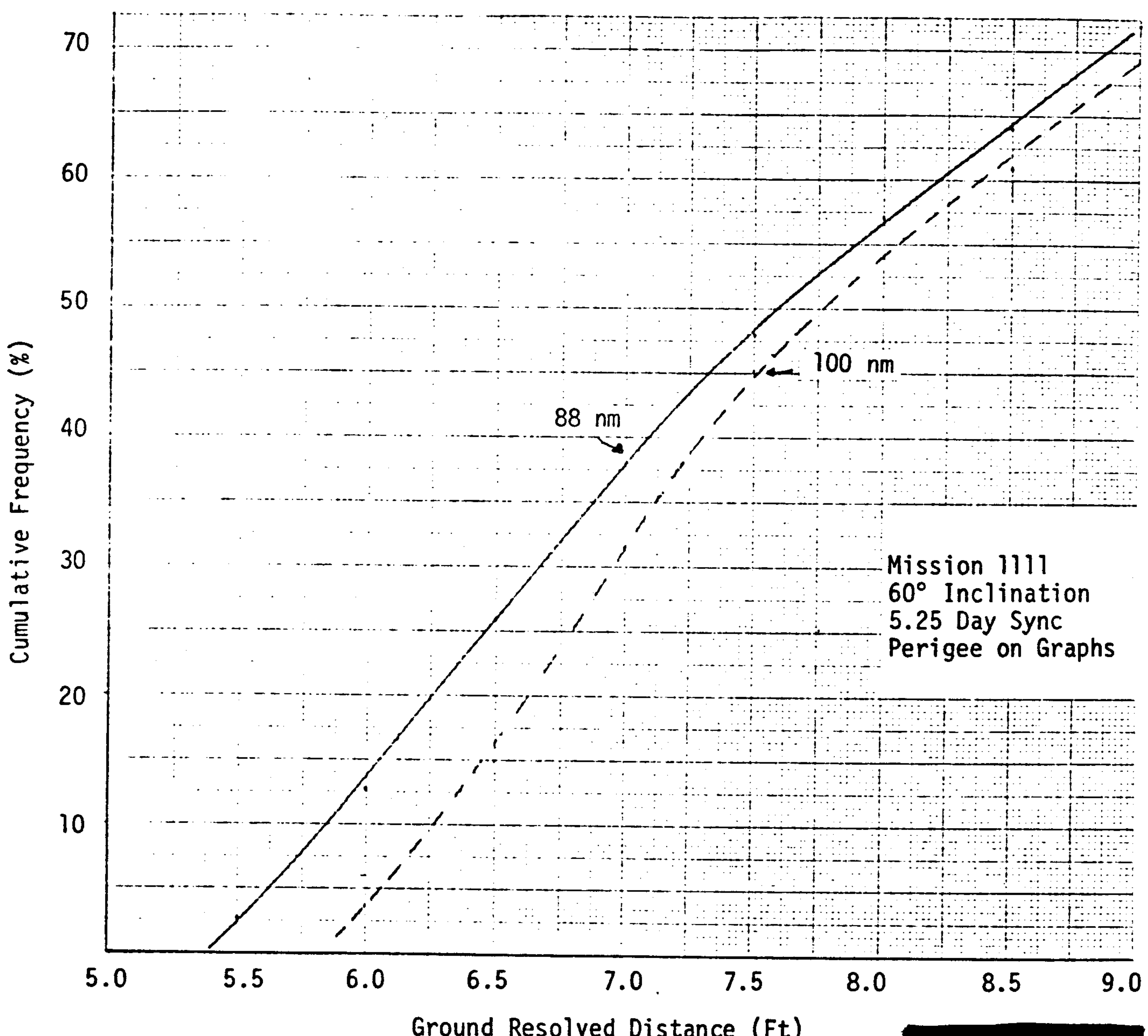


FIGURE 4

MISSILE AREAS

CRYSPER-C Predicted GRD
AFT-Looking Camera Ascending Photography

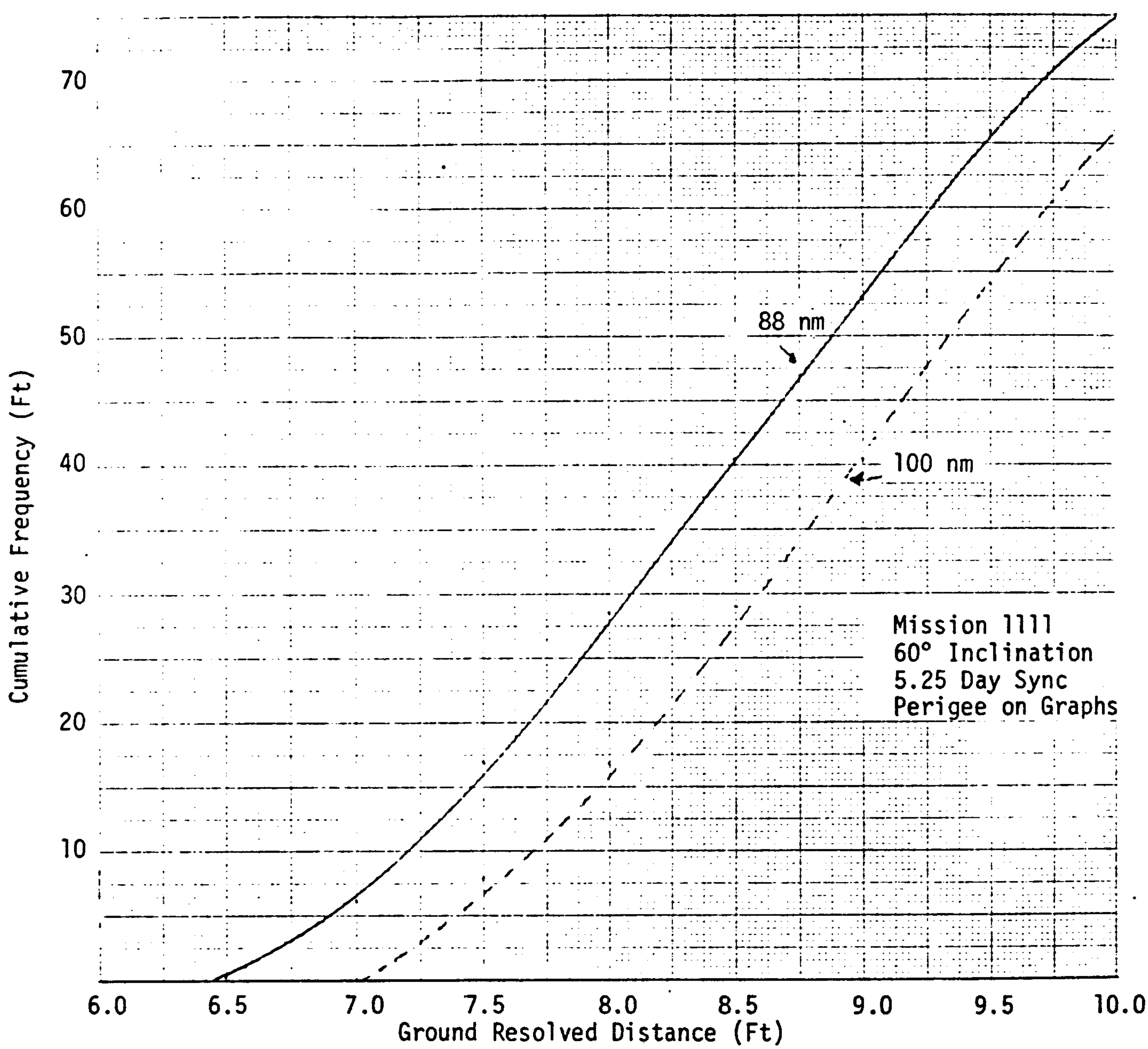


FIGURE 5

MIDDLE EAST TARGETS

CRYSPER-C Predicted GRD

FWD-Looking Camera Descending Photography

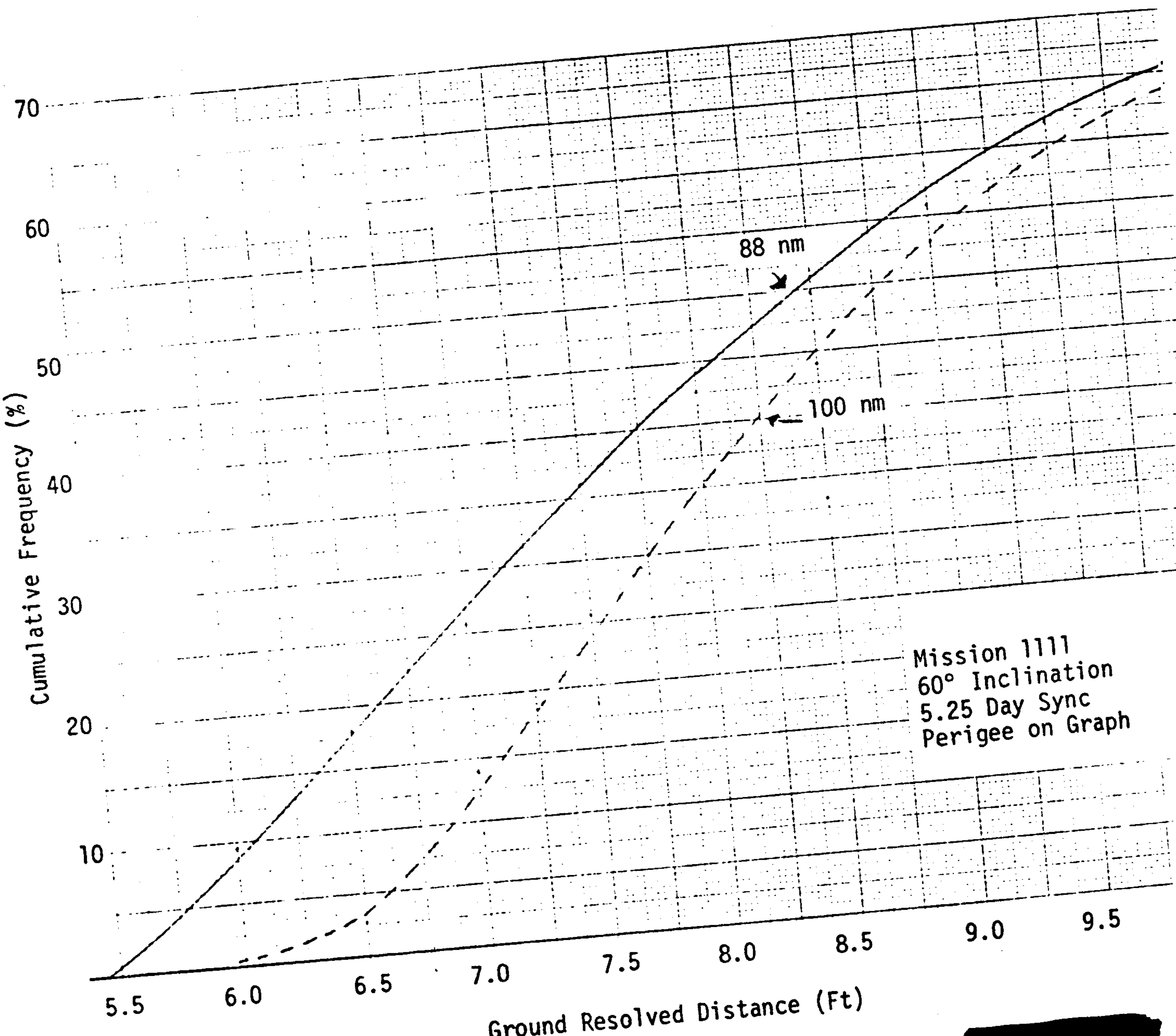


FIGURE 6

MIDDLE EAST TARGETS

CRYSPER-C Predicted GRD
AFT-Looking Camera Descending Photography

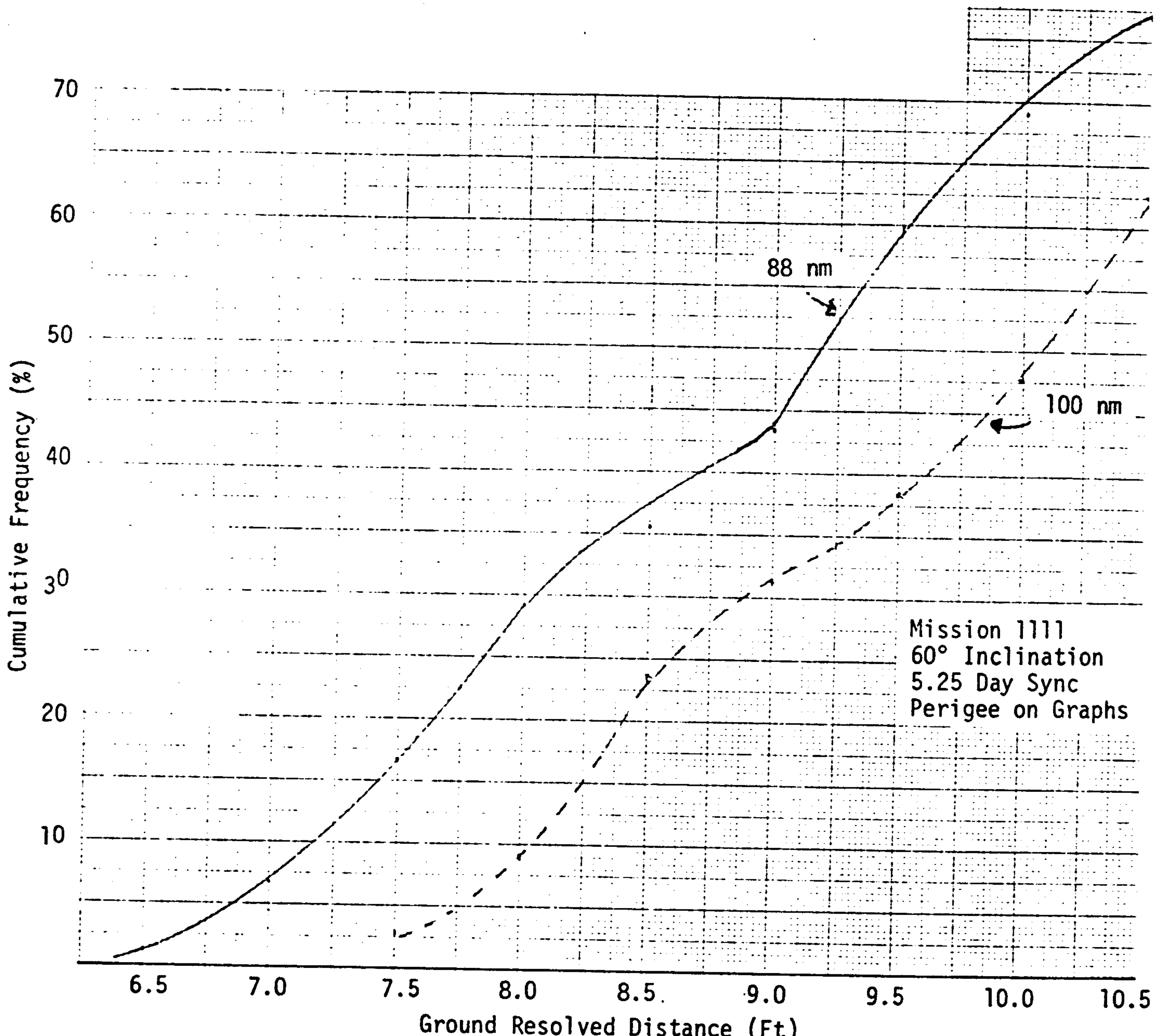


FIGURE 7

MIDDLE EAST TARGETS

CRYSPER-C Predicted GRD
FWD-Looking Camera Ascending Photography

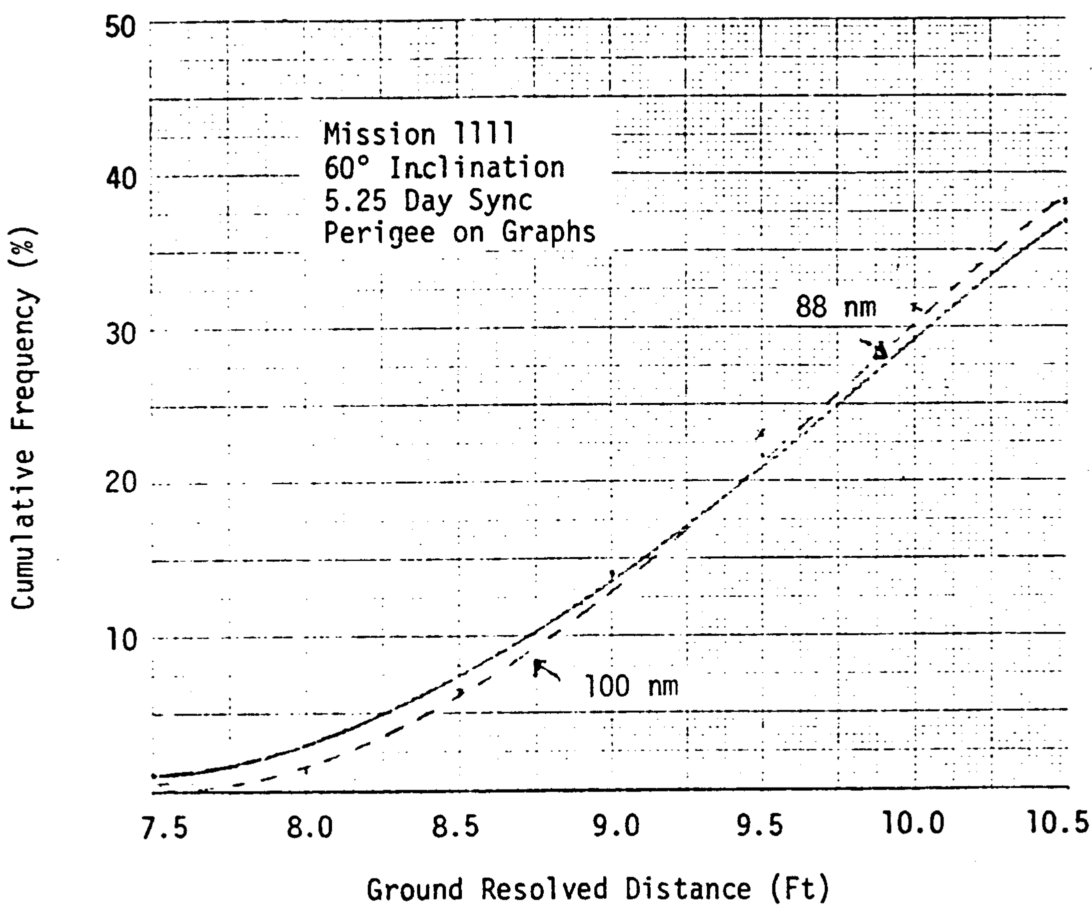
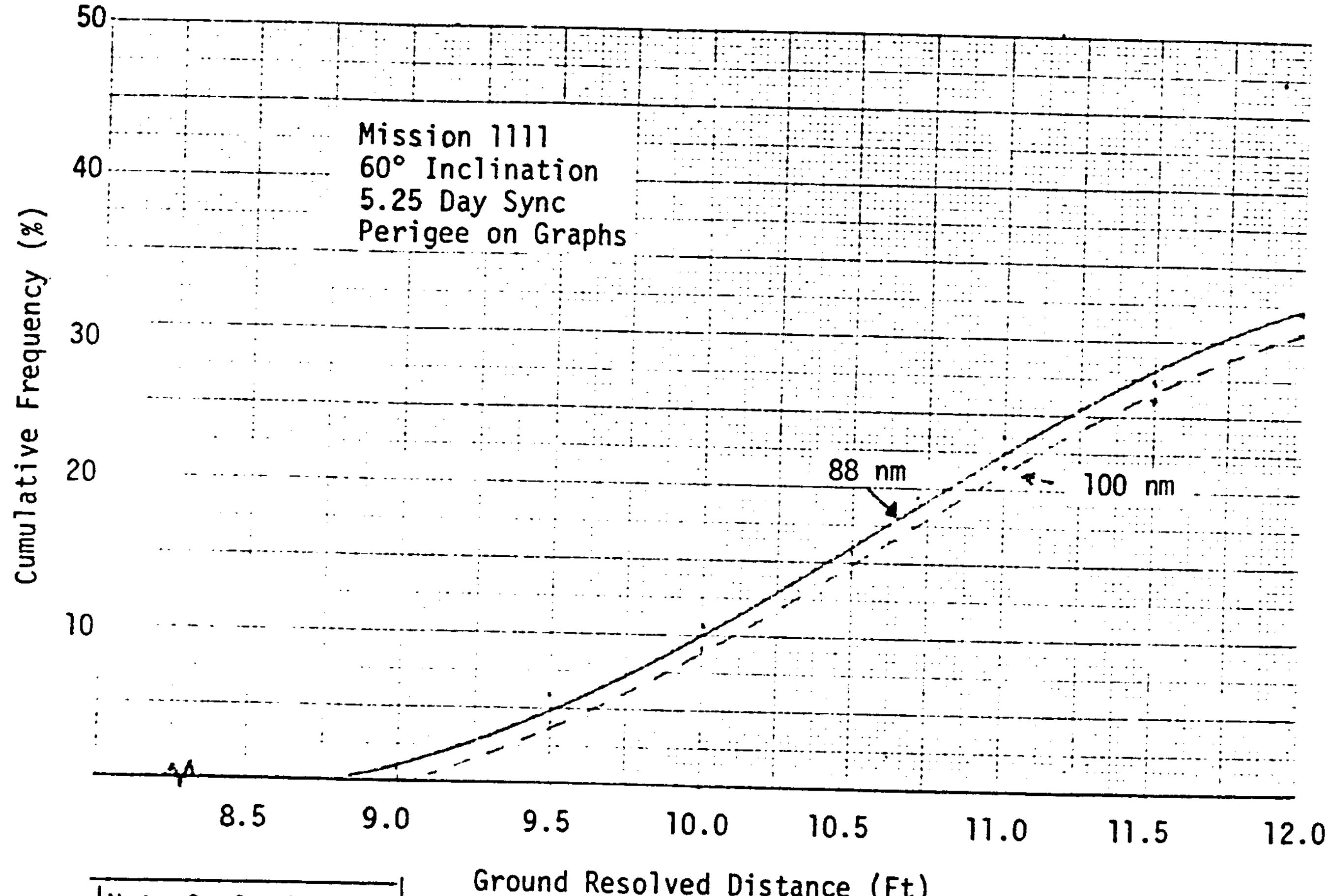


FIGURE 8

MIDDLE EAST TARGETS

CRYSPER-C Predicted GRD
AFT-Looking Camera Ascending Photography



Note Scale Change (GRD) Relative to Other Graphs

SUBJECT: CRYSPER-C Performance Prediction Program (Mission 1111 Examples)

6.2 Part II - Evaluation of the Predicted Performance of Mission 1111 for Other Orbits

This aspect of the analysis was aimed at evaluating two questions:

a. What kind of GRD would other orbits have produced, and

b. What effect does target reflectance have on predicted GRD?

For convenience purposes, the ephemeris from two past missions was employed for this aspect of the study. The two other orbits studied were:

a. From Mission 1106, 80 nm perigee, 81.5° inclination.

b. From Mission 1107 Test Case,* 100 nm perigee, 75° inclination, perigee located at approximately 25° N. latitude.

For both cases, only descending photography was studied. It also should be noted that only the orbit ephemeris was used from these missions. That is, these are still Mission 1111 simulations in that the launch dates and camera data employed were those of Mission 1111 and not 1106 or 1107.

6.2.1 Different Orbits

The major purpose of this study was to evaluate if different orbits may have improved image quality (GRD) over the missile targets. The basic data is shown in Tables 9 and 10. However, the data is easier to understand if one views Table 11 and Figures 9 and 10. Table 11 simply compares the percentage of targets expected in gross (and again arbitrary) GRD bins. Table 11 dramatically demonstrates the difference in resolution resulting from the 80 and 100 nm cases studied, this difference being on the order of 30%.

Figures 9 and 10 then compare the GRD vs. frequency distribution for all the orbits studied for the missile targets.

*This was not actually the 1107 orbit but one of the orbits generated during the orbit select process for that mission.

TABLE 9

Mission 1111 - 80 nm, 81.5° Incl. Orbit

GRD Estimates From CRYSPER-C

Cumulative Frequency

(Descending Photography Only)

Resolution (GRD - Ft)	Missile Targets		Middle East	
	FWD	AFT	FWD	AFT
4.0 - 4.5	0		4.2	
4.5 - 5.0	4.3		28.8	
5.0 - 5.5	25.5		47.1	12.5
5.5 - 6.0	41.4		68.8	26.7
6.0 - 6.5	52.6	13.3	79.2	47.5
6.5 - 7.0	63.7	29.2	84.2	68.8
7.0 - 7.5	72.1	44.4	88.3	91.3
7.5 - 8.0	81.2	55.9	92.9	96.7
8.0 - 8.5	87.2	66.3	96.3	99.6
8.5 - 9.0	90.6	78.2	97.9	100
9.0 - 9.5	92.6	88.9	99.6	
9.5 - 10.0	94.4	94.8	100	
10.0 - 10.5	96.1	98.5		
10.5 - 11.0	97.9	99.8		
11.0 - 11.5	99.5	100		
11.5 - 12.0	100			
MEAN GRD	6.8	7.9	5.8	6.5

TABLE 10

Mission 1111 - 100 nm, 75° Incl. Orbit

GRD Estimates From CRYSPER-C
Cumulative Frequency
(Descending Photography Only)

(GRD - Ft)	Missile Targets		Middle East	
	FWD	AFT	FWD	AFT
5.0 - 5.5				
5.5 - 6.0				
6.0 - 6.5			3.4	
6.5 - 7.0	5.3		12.8	4.4
7.0 - 7.5	21.5		29.4	23.3
7.5 - 8.0	33.1	5.9	39.5	30.4
8.0 - 8.5	41.9	14.0	46.3	34.8
8.5 - 9.0	50.6	21.3	50.0	38.5
9.0 - 9.5	57.4	30.7	55.7	43.9
9.5 - 10.0	63.4	39.6	63.5	51.7
10.0 - 10.5	67.9	48.7	67.9	64.2
10.5 - 11.0	72.6	57.0	73.3	82.1
11.0 - 11.5	77.4	64.6	76.7	88.5
11.5 - 12.0	82.3	77.1	80.1	91.2
12.0 - 12.5	85.7	87.3	85.1	95.3
12.5 - 13.0	88.4	91.5	87.2	95.9
13.0 - 13.5	89.7	94.2	89.5	98.0
13.5 - 14.0	91.0	97.1	91.2	98.6
14.0 - 14.5	92.3	99.1	93.2	99.7
14.5 - 15.0	93.3	99.9	95.3	100
15.0 & greater	94.7 - 100	100	96.6 - 100	
MEAN GRD	9.8	10.6	9.6	9.5

TABLE 11

Mission 1111 Test Case

GRD Estimates From CRYSPER-C

Percentage of Targets vs.
Resolution "Normal" Orbits

(Descending Photography Only)

	Middle East				"Missile" Areas			
	FWD		AFT		FWD		AFT	
GRD (Ft)	80*	100**	80*	100**	80*	100**	80*	100**
4.0 - 5.0	28.8	0	0	0	4.3	0	0	0
5.0 - 8.0	64.1	39.5	26.7	30.4	76.9	33.1	55.9	5.9
8.0 - 10.0	7.1	24.0	70.0	21.3	13.2	30.3	28.9	33.7
10.0 - 15.0	0	31.8	3.3	48.3	5.6	29.9	5.2	60.3
15.0 - 20.0	0	4.7	0	0	0	6.7	0	0.1
MEAN GRD (Ft)	5.8	9.6	6.5	9.5	6.7	9.7	7.9	10.6

1. *81.5° Incl., **75° Inclination.
2. 80 and 100 indicate orbit perigee.
3. All Middle East was run with clear weather.
4. All "Missile" Areas were run with Average U.S.S.R. Haze
5. First Bucket only.

FIGURE 9

COMPARISON OF ORBITS AND CAMERA GRD

FWD-LOOKING CAMERA

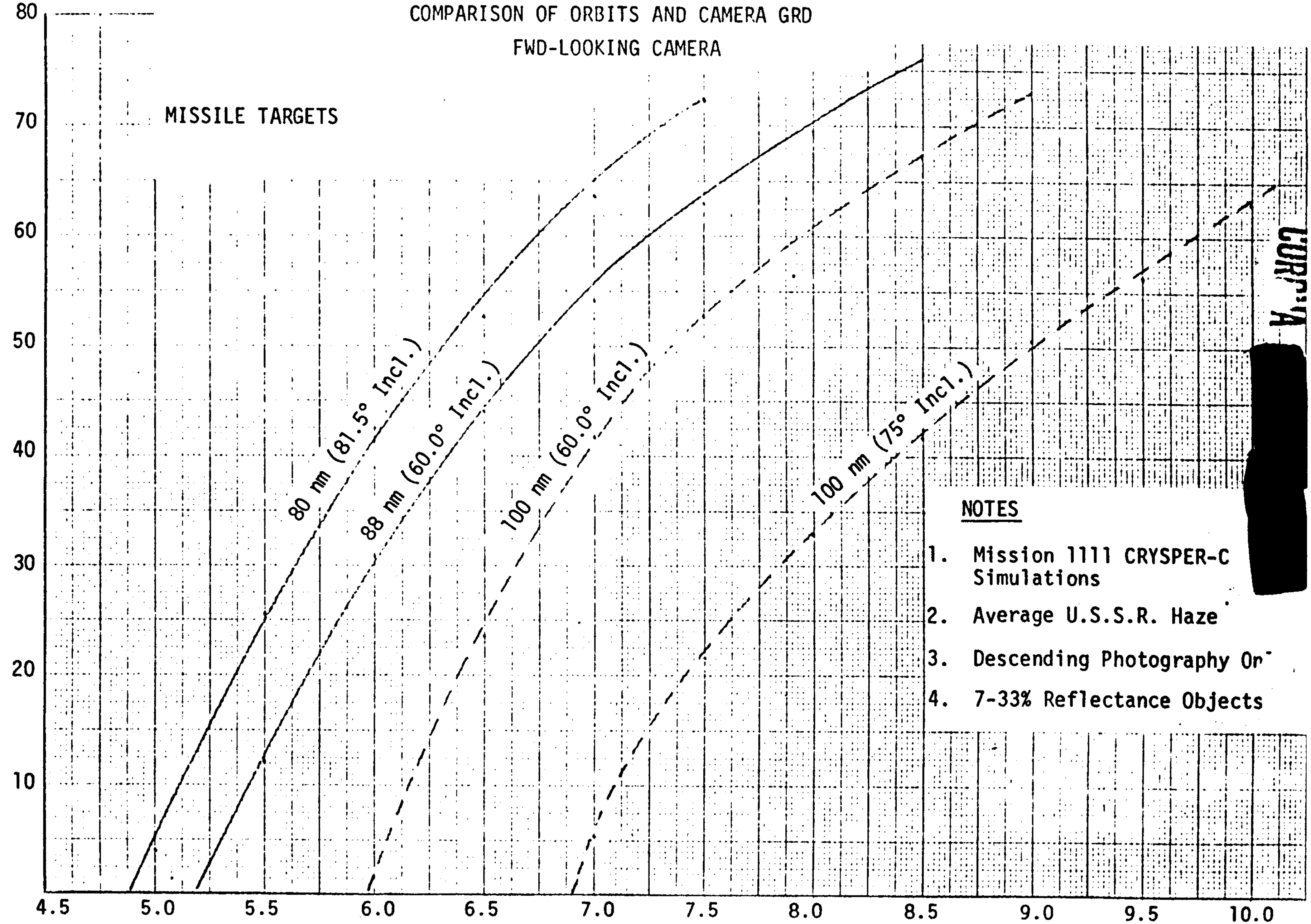
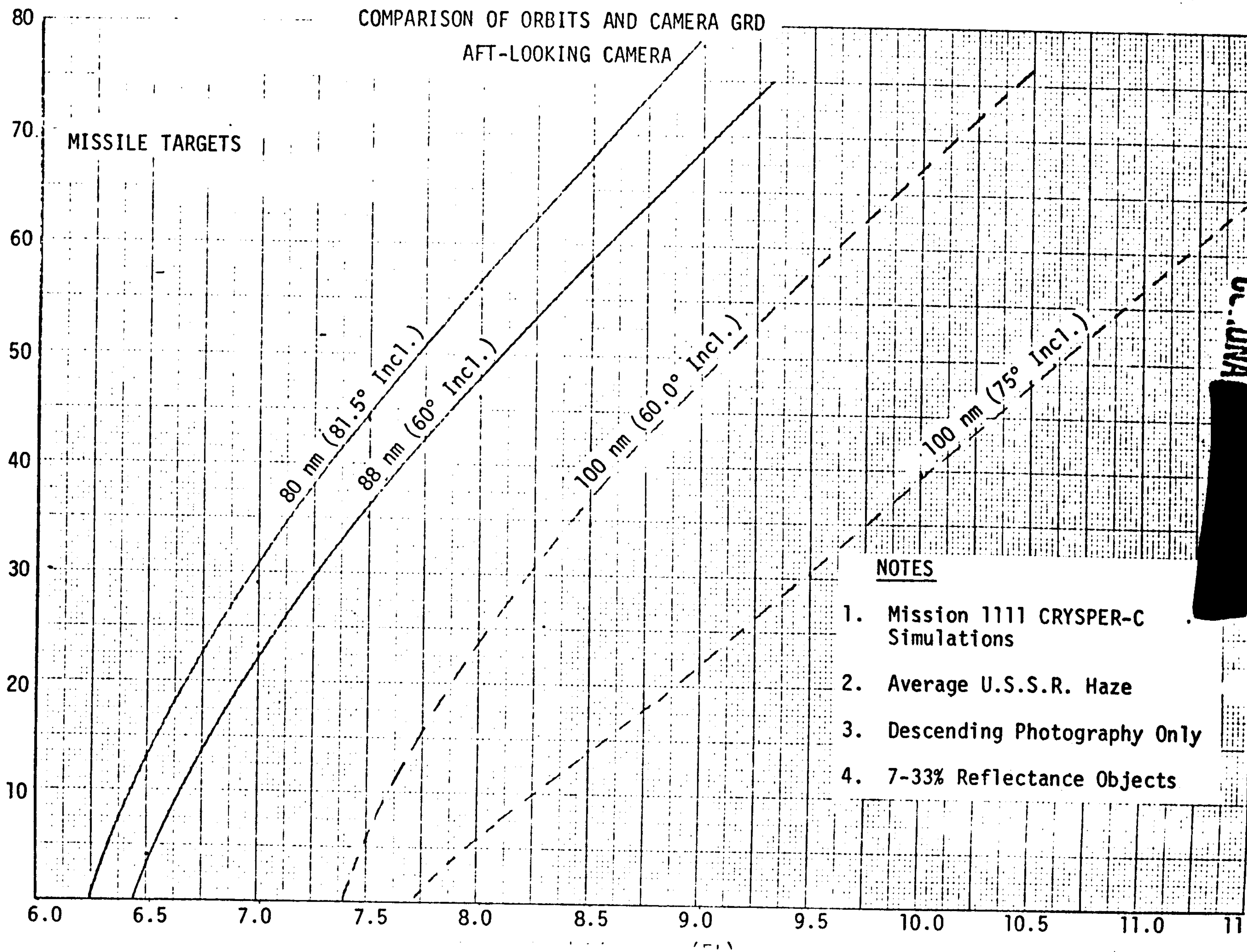


FIGURE 10

COMPARISON OF ORBITS AND CAMERA GRD

AFT-LOOKING CAMERA



NOTES

1. Mission 1111 CRYSPER-C Simulations
2. Average U.S.S.R. Haze
3. Descending Photography Only
4. 7-33% Reflectance Objects

SUBJECT: CRYSPER-C Performance Prediction Program (Mission 1111 Examples)

It is rapidly seen that if one is primarily interested in resolution, then the 80 nm (81.5° Inclination) orbit is best. There are, of course, other considerations in such an orbit select, "access" and "looks" being usually the most important. While CRYSPER does not include weather probabilities, it does provide a feel for this aspect of the problem by providing the total possible looks for each orbit. Table 12 provides this information for the orbits studied. While the 80 nm case provides the best resolution, the 88 nm (60° Inclination) case provides nearly 2.5 times more total possible target looks (3,467 vs. 1,645). Given the vast difference in looks, the 60° inclination (88 nm perigee) resolution loss is probably acceptable.

Another point should be made. The 75° inclination orbit looks significantly worse, at 100 nm, than the 60° orbit. The difference is due to the fact that perigee is located at a significantly different place than the 60° inclination orbit and it would not be expected to be optimized for the missile targets.

6.2.2 A Note

A final note relative to this study. This was not an attempt to really study how to optimize GRD for a mission like 1111. The orbits selected above for evaluation were chosen more or less at random to see how orbits used on past missions would have changed the resolution distribution. Also, the Middle East targets GRD cannot be directly compared between the 60° inclination cases and the other cases since the haze level was changed between runs. The original intent of the study was simply to evaluate the 88 vs. 100 nm (60° inclination) orbits to see gross differences in resolution distributions. For this, haze level was kept constant (Average U.S.S.R.). However, in the last study, the Middle East predictions were done with clear haze (more realistic for that area of the world). This means that the Middle East GRD prediction for the 60° inclination cases are pessimistic.

6.2.3 Effect of Target Reflectance on Resolution

One simple test was run to demonstrate the effect of target reflectance on predicted GRD. For this test, it was assumed that for missiles under construction the object contrast would be lower than the 7-33% CORN target contrast, and probably

TABLE 12

COMPARISON OF TOTAL ACCESSES
POSSIBLE WITH DIFFERENT ORBITS

Mission 1111 Simulations
Missile Targets Only

Inclination	Perigee (nm)	Ascending/Descending	Accesses
81.5°	80	D	1,645
60.0°	88	D	3,467
60.0°	88	A	4,202
75.0°	100	D	2,186
60.0°	100	D	4,025
60.0°	100	A	4,413

1. Total targets in deck was 1,434.
2. Does not include cloud statistics.
3. First bucket only.

a lower reflectance level if one is looking for earth scarring, etc. Arbitrarily, it was decided to evaluate the predicted GRD for 5 and 12% reflecting objects vice the 7 and 33%. This choice is probably not bad, however, as the 5 and 12% reflectance are very nearly comparable to the mean lowlight and mean reflectances of all targets measured in Project Sunny. The main results of this study are shown in Table 13 and Figure 11. It is readily seen that reflectance has a highly significant effect on predicted resolution, the 5 and 12% reflecting objects producing approximately 30% lower resolution values than the 7 and 33%. This is logically correct in that the 5/12% case is both lower contrast and lower brightness than the 7/33% case. Lower contrast by itself produces lower resolution. Further, however, the lower brightness objects are more significantly affected by haze (a DC contributor) than are high brightness (reflectance) objects.

Figure 11 is even more interesting in that (for the orbit studied) the aft-looking camera is more significantly degraded than the forward. This is most certainly due to a more significant effect of haze on the aft-looking instrument. Section 7.0 comments further on target reflectance.

7.0 COMMENTS ON TARGET REFLECTANCE

It has been mentioned throughout this memo that, in the main, these predictions were done using a lowlight reflectance of 7% and a highlight reflectance of 33%. There is no physical justification for these values other than that they correspond to the CORN 51/51 mobile T-bar resolution targets; and, hence, the predicted resolutions are comparable to what one would have seen if a CORN target were in the scene. The reflectance values (as has been demonstrated) significantly affect the resolution predicted, and real targets have different reflectances and different contrasts. To be truly meaningful (i.e. in that one tries to predict the resolution that the PI will see on his target), the program should use actual target reflectance data.

A good portion of the data required is now available. Throughout Project Sunny (Target Brightness Study), specific target types were examined against various backgrounds. In many cases, targets of a particular type were observed against different backgrounds, at the same target site. This is mentioned to point out that you cannot always generalize about a target/background combination of a particular site. Knowledge of the nature and location of the site should, perhaps, suggest

TABLE 13

MISSION 1111 TEST CASE

GRD ESTIMATES FROM CRYSPER-C

EFFECT OF TARGET REFLECTANCE ON RESOLUTION

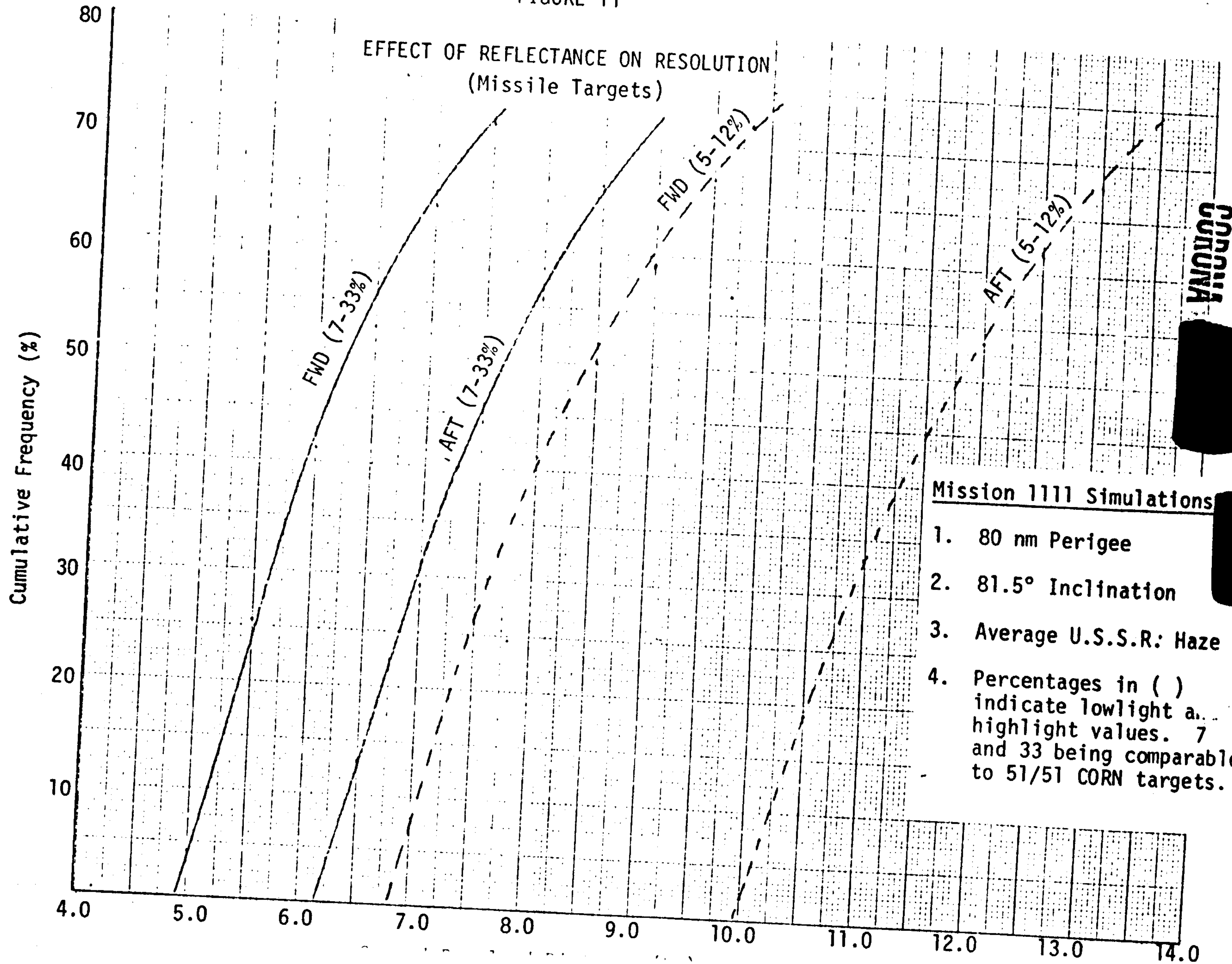
"Normal" Orbit
Descending Photography
(Missile Areas)

GRD (Ft)	FWD 5-12	FWD 7-33	AFT 5-12	AFT 7-33
4.0 - 5.0	0	4.3	0	0
5.0 - 8.0	41.2	76.9	0	55.9
8.0 - 10.0	25.7	13.2	2.2	28.9
10.0 - 15.0	26.2	5.6	90.8	5.2
15.0 - 20.0	0.1	0	7.0	0
MEAN GRD (Ft)	9.0	6.7	12.2	7.9

1. 80 nm Perigee.
2. 5-12, 7-33 Indicate Lowlight (5 and 7) and Highlight (12 and 33) Percent Reflectances.
3. All Runs with Average U.S.S.R. Haze.
4. First Bucket Only.

FIGURE 11

EFFECT OF REFLECTANCE ON RESOLUTION
(Missile Targets)



the backgrounds available and, in conjunction with the Project Sunny reflectance data, will allow real contrasts to be used and, hence, more meaningful resolution predictions.

Table 14 illustrates the data available to date. This table is slightly confusing and needs to be interpreted carefully. It gives the mean reflectances of target/background combinations for a variety of target types and backgrounds measured in Project Sunny. The numbers in parentheses represent the mean measured reflectance of that target type while the mean reflectance of the combinations (i.e. target and background) can be found at the intersection of the appropriate row (target) and column (background).

It can be noted from the table that no specific backgrounds have been identified for the first four target types. For each of these targets, the reflectance measurements were obtained for the mean target/background combination since the background was considered an integral part of it. The object and background reflectance values have been backed out using the average measured contrast. The background reflectances for these targets are rather low when compared with the identified background materials, but it must be remembered that in these areas of many objects in close proximity (i.e. an urban-industrial complex), there is much object shadow present.

From Table 14, then, one can see that the mean reflectance of launch pads is 22%. If their background were early vegetation (a reflectance of 16%), then these would probably be the proper reflectances to use in CRYSPER-C for the missile target study.

This has not been done since it is still uncertain exactly what set of reflectances should be used. As one can see, the different backgrounds (for launch pads) have significantly different reflectances, and each set would produce different predicted GRD values. Until this can be sorted out, the effective CORN target predictions are probably the most understandable.

It should be noted that all the Project Sunny data collected also allows determination of "average" reflectance data. That is, the low, mean and high useful reflectance values for all targets/backgrounds, etc. The average low reflectance is 3%; the mean, 12% and the average highlight reflectance is 32%.

TABLE 14

MEASURED REFLECTANCE DATA FOR VARIOUS TARGET TYPES

Specific Target Types \ Background		Early Vegetation (11)	Late Vegetation (13)	Dirt (13)	Asphalt (20)	Concrete (26)	Sand (29)
Army Barracks	(7)[1]	Average Target Reflectance = 9%			Average B'kgd Reflectance = 5%		
Ships	(9)[1]	Average Target Reflectance = 11%			Average B'kgd Reflectance = 7%		
Complexes	(10)[1]	Average Target Reflectance = 12%			Average B'kgd Reflectance = 8%		
Hydroelectric Plants	(10)[1]	Average Target Reflectance = 12%			Average B'kgd Reflectance = 8%		
Vehicles	(10)	11	12	12	14	16	17
Stockpiles	(12)	12	13	13	16	18	19
Tanks	(17)	14	15	15	19	21	23
Conveyor	(20)	15	16	16	20	23	24
Launch Pads	(22)	16	17	17	21	24	25
Silo Doors	(24)	16	18	18	22	25	26
Planes (Painted)	(29)	18	20	20	24	28	29
Buildings (pre-fab barracks, etc.)	(32)	19	21	21	25	29	31
Planes (Unpainted)	(44)	22	24	24	30	34	36

[1]Reflectance value represents the mean of the target/background combination.

SUBJECT: CRYSPER-C Performance Prediction Program (Mission 1111 Examples)

8.0 VALIDATION

Validation of this kind of program will probably take some period of time. We have, however, several specific efforts underway:

a. The simplest validation technique is to predict GRD values of CORN targets during a mission and then compare with actual readings. This will be done on Mission 1111 and others. The difficulty here, of course, is that the sample size is very small.

b. Compare the statistics of individual resolution prediction with subsequent PI quality ratings (i.e. good, fair, poor). It should be expected that there would be, on the average, some correlation between predicted GRD and PI quality ratings. The difficulty here is that very often a PI quality rating has no relationship to resolution but is strictly related to how well the picture answered his requirement.

c. Lastly, we will attempt in the PET meetings to subjectively evaluate the quality of the photography vice the CRYSPER prediction to see if, in a general sense, the performance of the camera was as CRYSPER predicted. If it was not, it is possible that CRYSPER can be further employed to assess why. For example, if focus seems to be the problem, amounts of defocus can be put into CRYSPER to see how much defocus produces what kind of resolution loss.

Work will continue with CRYSPER to try and refine it and get as good a feel as we can on its accuracy. I believe, however, that it is currently good enough to be used for many applications, particularly for orbit select studies where the quality of photography returned is of interest.

[redacted]

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