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PERFORMANCE ANALYSIS FOR THE 1103 SYSTEM

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1. SUMMARY

The performance of the 1103 system was different than the performance of either the 1101 or the 1102 system. The best description of the 1103 system performance as evidenced in the photographic record can be found in the PEIR Report* on mission 1103, several sections of which are quoted below:

"THE PET JUDGED THE GENERAL IMAGE QUALITY OF MISSION 1103 AS FAIR, AND NOT AS GOOD AS MISSION 1102. THERE WAS A SIGNIFICANT VARIABILITY IN IMAGE QUALITY THAT WAS GREATER THAN NORMALLY ENCOUNTERED WITH A KH-4B SYSTEM. THIS VARIABILITY RANGES FROM RATHER GOOD TO POOR. THE PHOTOINTERPRETERS REPORTED THAT 'THE INTERPRETABILITY OF THE IMAGERY ON THIS MISSION IS CONSIDERED TO BE MORE VARIABLE THAN THE IMAGERY OBTAINED ON MISSIONS 1101 AND 1102. IN ADDITION THE IMAGERY OF THE FORWARD-LOOKING CAMERA RECORD IS SUPERIOR TO THAT OF THE AFT CAMERA IN ALMOST EVERY CASE. THE OVERALL MISSION INTERPRETABILITY IS RATED AS FAIR.' THE EXACT CAUSE OF THE VARIABILITY IS NOT CLEAR; MAJOR FACTORS, HOWEVER, APPEAR TO BE HAZE AND FOCUS. THIS MISSION WAS SEVERELY AFFECTED BY HAZE, BUT IT CANNOT BE POSITIVELY STATED THAT WEATHER WAS THE MAJOR CAUSE OF THE QUALITY VARIATION. THE GENERAL QUALITY OF THE AFT-LOOKING RECORD IS LESS THAN THAT OF THE FORWARD-LOOKING. IN GENERAL, THE AFT-LOOKING RECORD APPEARS TO HAVE SLIGHTLY SOFTER FOCUS. ALTHOUGH THERE IS SOME EVIDENCE OF BETTER AFT-LOOKING IMAGERY ON THE VERY FIRST PORTIONS OF THE MISSION, AFT-LOOKING IMAGERY COMPARABLE TO THAT OF THE EARLY PORTIONS IS NOT EVIDENCED LATER IN THE MISSION, EVEN WHEN FAVORABLE WEATHER CONDITIONS EXISTED. . . . .THERE IS EVIDENCE THAT AT LEAST A PORTION OF THE DEGRADATION IN OVERALL MISSION QUALITY IS DUE TO IMAGE SMEAR. THIS CONDITION IS APPARENT ON FRAMES WHERE THE MAXIMUM SLIT WIDTH WAS USED. FOCUS VARIABILITY APPEARS TO HAVE BEEN THE MAJOR CAUSE OF IMAGE DEGRADATION. HOWEVER, SEVERE HAZE, THERMAL GRADIENTS, FOCUS AND SMEAR OFTEN COMBINED TO PRODUCE IMAGERY POORER THAN THAT ATTRIBUTABLE TO FOCUS ALONE. ALSO, IN SOME CASES, THESE FACTORS APPEARED TO BE COMBINED IN SUCH A MANNER AS TO PRODUCE GOOD IMAGERY. THE ULTIMATE CAPABILITY OF THE MISSION 1103 CAMERA SYSTEM IS INDICATED BY THE RESOLUTION LEVEL

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AND FROM GROUND TARGETS. THE CORN* MOBILE TARGETS WERE THE BEST YET RECORDED, PRODUCING EIGHT FOOT GRD†, WHEREAS THE BEST FIXED TARGET PRODUCED SIX FEET GRD. THESE READINGS ARE INDICATIVE, HOWEVER, ONLY OF BEST PERFORMANCE AND NOT GENERAL PERFORMANCE."

The contractor's independent evaluation of the photographic record of mission 1103, conducted mainly on dupe positive materials, reached the following conclusions:

1. Image quality of the 1103 system for geographical areas known to have dry climates and low moisture content in the atmosphere (for example deserts) is obviously superior to the system image quality for areas with an appreciable amount of moisture in the atmosphere (haze but no cloud cover). The haze is quite obvious when examining the terrain camera (DISIC) photography and comparing the images of the FWD- and AFT-looking cameras of the same ground objects. The degradation in performance over the hazy areas should be attributed mainly to weather and atmospheric conditions. True indications of the system's potential performance can best be determined by evaluating the system's photography over deserts or geographic areas known to have dry climates. Conclusions can then be arrived at by combining these data with known anomalies in the system's operation during the mission.

2. The performance of the FWD-looking camera was better than that of the AFT-looking camera throughout the mission, but the difference in performance between the two cameras was very marked over areas where haze prevailed. Thus, the difference in performance over the hazy areas should be attributed mainly to the different filters that were utilized (a W-25 in the FWD-looking camera and a W-21 or SF-05 in the AFT-looking camera).

3. In the AFT-looking camera, the SF-05 filter was used extensively. This filter produces very low contrast imagery especially in the presence of haze. Twenty-one HPL‡ targets were assigned to the SF-05 filter; however, due to programmer limitations, 39 percent of the total photographic record of the AFT-looking camera was taken with the SF-05 filter, and, perhaps more significantly, approximately 67 percent of the HPL targets photographed by the AFT-looking camera were exposed through the SF-05 filter. It is the contractor's opinion that the AFT-looking camera's rating has been adversely affected by the extensive use of the SF-05 filter.

4. From the photographic record, it appears that the contrast of the AFT-looking camera would have been improved if a W-25 filter were used instead of the W-21 over areas covered with haze. Similarly, it seems that the performance of the FWD-looking camera would have been improved if a W-21 filter were used over desert areas. (It seems that the FWD-looking camera's photography was lacking in grey tones over desert areas.)

The following conclusions have been reached as described in the various sections of the report:

1. Section 2.1. The "apparent" air-to-vacuum focus shift was between 0.013 and 0.0135 inch. The focus uncertainty could be drastically reduced if a simulator with photographic capability was available in which the thermal and vacuum environment of the mission could be duplicated.

2. Section 2.2. The optimum focal position for the Petzval lenses of the 1100 series panoramic cameras is approximately 0.0005 inch further away from the field flattener than the

* Controlled Range Network.
† Ground resolved distance.
‡ High priority list.

focal position at which the low contrast (2:1) resolution of the lens reaches a peak. Experimentally, the optimum focal position of a lens can be determined by performing dynamic resolution versus focal position tests under various amounts of IMC mismatch between the panoramic camera and the target wheel. If these tests are performed in an ambient atmosphere (this is the present capability), an accurate correction must be made to the focal position for the air-to-vacuum focus shift.

3. Section 3.3. Seventy-five percent of the resolution predictions for the CORN targets correlate favorably with the actual readings.

4. Section 3.4.1. For the HPL targets, the average altitude of photography was 87.9 nm. Approximately 10 percent gain in scale could be achieved by reducing the average altitude of photography for these targets to 80 nm.

5. Section 3.4.2. The V/h programming errors seem to be within the allowable rms error of 1.5 percent. However, 22 percent of the frames checked had V/h errors larger than 1.5 percent, and it seems that it should be possible to reduce the V/h error to less than 1.5 percent for essentially all the frames of a mission.

6. Section 3.4.3. In this section, a study was carried out to determine possible ways of improving the resolution performance of the 1103 panoramic system with respect to the HPL targets. This study showed that a 19 percent improvement in resolution performance would have been achieved if the following conditions had prevailed:

a. Both lenses were focused to maximize tri-bar resolution.*
b. The average altitude of photography was 80 nm.
c. Type SO-230 or SO-205 film was used instead of Type 3404.

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* Both lenses were initially focused in ambient to maximize the low contrast resolution. Then the focus error was introduced by an apparent air-to-vacuum focus shift of about 0.0133 inch instead of the anticipated value of 0.014 inch.

2. ANALYSIS OF FOCUS PROBLEM

2.1 AIR-TO-VACUUM FOCUS SHIFT

Compared with mission 1102, mission 1103 was a disappointment. As mentioned in the PET Report, the main degrading factors of the performance of mission 1103 were thought to be severe haze conditions extended over large geographical areas and improper focusing of the panoramic cameras. Before the mission took place, the cameras had been dynamically focused optimally on the basis of the information available at that time. An air-to-vacuum focus shift of 0.014 inch had been assumed, and tri-bar resolution versus focal position curves had been obtained by photographic tests. The position of the film in each camera had been adjusted to coincide with the focal position which produced the maximum low contrast resolution. Another implied assumption was that the focal position which produces the maximum low contrast resolution also results in the best aerial photography for a specific lens. This assumption is true for a truly diffraction-limited lens, but ought to be investigated for any other lens design.

The factors that could produce focusing errors are:

1. Air-to-vacuum focus shift other than 0.014 inch
2. Vacuum film lift above focal plane rollers different than air film lift
3. Lens focus shift due to mission thermal environment
4. Optimum focal position of lens for aerial photography different than focal position of peak resolution.

The contractor's computer program which is utilized for predicting lens performance and characteristics indicates that the air-to-vacuum focus shift is 0.0141 inch for all Petzval lenses of the 1100 series. Visual experiments on the air-to-vacuum focus shift showed that the shift is 0.0140 to 0.0145 inch. Other static photographic resolution experiments (with UTB film and W-25 filters) showed that the air-to-vacuum focus shift is somewhere between 0.0128 and 0.0138 inch and apparently varies between lenses of the same generation. These same experiments also showed that the vacuum focal position of maximum resolution can be determined significantly more accurately than the respective focal position in air. This observation is in agreement with other investigations which showed that the refractive index of air is affected by temperature, barometric pressure, relative humidity, and CO_2 content. Therefore, while the vacuum peak focal position is only a characteristic of the lens, the air peak focal position is, in addition, a function of all the variables which affect the refractive index of air. The barometric pressure has the most significant effect on the air peak focal position (or equivalently the air focal length) of the lens. The focal length of the lens increases by 0.00047 inch when the barometric pressure increases 1 inch of mercury. On the other hand, a 10 °F temperature rise decreases the air focal length by 0.00029 inch. In addition, an increase in relative humidity of 50 percent increases the air focal length by

0.00018 inch. Note that the temperature effect discussed here is related to the air focal length only through the change it produces on the refractive index of air. This temperature effect should be clearly distinguished from other temperature effects (discussed below) on the lens itself which influence the behavior of the lens whether in vacuum or immersed in air.

It should be obvious that the inaccuracies of determining the air peak focus can be considerably reduced by experimentally determining the air peak focus in a well controlled atmosphere. Even so, the technique of focusing the panoramic cameras in air is inherently inaccurate when compared with the dynamic focusing of cameras in vacuum, because even if the air peak focus could be determined (in a controlled atmosphere) as accurately as the vacuum peak focus, a correction to the focal position which is equal to the air-to-vacuum focus shift must be made. In turn, the air-to-vacuum focus shift is not known accurately, and, at best, can be determined by performing static photographic experiments on the lens utilizing a vacuum chamber with the added capability to produce a well controlled atmosphere. Even with this chamber, the error in determining the air-to-vacuum focus shift is expected to be approximately 1.4 times larger than the error in the vacuum peak focal position. Therefore, one reaches the conclusion that the only accurate method is to focus the lenses in vacuum. In that respect, the dynamic vacuum focusing of a complete camera in a vacuum chamber with photographic capability is the most desirable method. A somewhat less accurate but more practical technique is to focus each lens statically in a small vacuum chamber and later make a small adjustment for the dynamic film lift above the focal plane rollers.

There is, of course, another technique for focusing the cameras—the old, relatively simple trial and error method. Each system's focus is adjusted on the basis of the focus settings of the previous systems and their apparent mission focus conditions as well as they can be deduced from examination of the original negatives. This technique, of course, is a last resort and obviously is no substitute for an accurate and dependable laboratory focusing technique.

There are some indications that the vacuum film lift is somewhat different than the dynamic film lift in air. However, accurate and reliable data on this problem are not presently available.

On the basis of the information presently available, the lens focus shift due to the thermal environment of the mission appears to be less than 0.0003 inch. An investigation is being conducted at the present time to analyze the effects on the lens performance of the day-to-night thermal gradients resulting from the orbital motion of the vehicle.

Following the 1103 mission, a group of photographic resolution tests (known as the DRT* chamber tests) were performed on the 1109 panoramic system utilizing a large vacuum chamber which was made available on a temporary basis. The results of the tests are described in Appendix E. One sequence of these tests showed an air-to-vacuum focus shift of 0.0133 inch for the AFT-looking camera (having a second generation lens) and a corresponding shift of 0.0146 inch for the FWD-looking camera (having a third generation lens). Since the 1103 cameras both carried second generation lenses, it was suspected that perhaps the air-to-vacuum focus shift for the 1103 system was 0.0133 inch rather than 0.014 inch which was the originally expected air-to-vacuum focus shift. In addition, it was found that if an air-to-vacuum focus shift of 0.014 inch was assumed, the CORN target predictions did not correlate well with the actual readings (see Sections 3.1 through 3.3). However, if the air-to-vacuum focus shift was assumed to be 0.0133 inch, a favorable correlation could be established between the CORN target predictions and the actual readings.

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*Dynamic resolution test (DRT).

Thus, it seems that the "apparent" air-to-vacuum focus shift for the 1103 system is 0.0133 inch. The term "apparent" includes not only the actual air-to-vacuum focus shift but also all the factors that affect the position of the film with respect to the lens peak focus.

2.2 OPTIMUM FOCUS FOR AERIAL PHOTOGRAPHY

The preceding section was centered about the problem of determining the mission peak focus position with respect to the film (essentially determining the position of the film on the dynamic resolution versus focus curve of the lens (see Figs. 3-1 through 3-4). Basically, this problem has been created by the inability to simulate the mission environment in the laboratory and to simultaneously perform photographic resolution tests. Now the attention of the reader is directed towards a different problem which has been successfully resolved. This problem is described below.

Suppose the position of the resolution versus focus curve can be accurately predicted before the mission takes place. Then one raises the question of how the film position should be adjusted with respect to the resolution versus focus curve in order to achieve optimum focus for the targets which are being photographed. If the targets of interest were tri-bar resolution targets, then obviously the film position should be adjusted to coincide with the expected position of the peak of the resolution versus focus curve. However, most real targets do not resemble tri-bar resolution targets.

Each specific target of interest has its own two-dimensional Fourier transform in which certain spatial frequencies will have larger amplitudes than others. If all possible targets are considered, it is to be expected that, on the average, all spatial frequencies will have approximately equal amounts of energy and therefore are of equal importance. In this case, for the average target, the best photography can be obtained by adjusting the focus of the lens so that the lens is the best possible approximation to the diffraction-limited lens of the same aperture and focal length. The diffraction-limited lens has no aberrations, and, when a plane wavefront of light enters the lens through the front element, it emerges through the last element as a purely spherical wavefront which converges on the point of optimum focus. On the other hand, a real lens has aberrations which produce distortions on the spherical wavefront. The root mean square (rms) deviation of the actual wavefront from the spherical wavefront is a measure of the quality of the lens. The rms wavefront distortion is expressed as a fraction of wavelength. The focal position at which the rms wavefront distortion reaches a minimum is the focal position at which the lens most closely approximates the diffraction-limited lens. Therefore, it was reasoned that for the average target, the best photography should be obtained by adjusting the film position so that it coincides with the focus position at which the rms wavefront distortion of the lens is minimum. Consequently, it became necessary to determine the relationship between the focal position which produced the maximum tri-bar resolution and the focal position which produces the minimum rms wavefront distortion. Thus, a theoretical investigation was conducted on a third generation lens with a W-25 filter and on a second generation lens with a W-21 filter. This investigation showed that for the third generation lens, the minimum rms wavefront distortion lies 0.0004 inch further away from the field flattener than the low contrast (2:1) resolution peak, while for the second generation lens, the corresponding displacement is 0.0005 inch. The results imply that the optimum focal position for general photography lies approximately 0.0005 inch beyond the low contrast resolution peak. The theoretical results have been confirmed by data collected on systems 1105 and 1109. (Explanations of these tests and interpretations of their results can be found in Appendices E and F.

In order to focus a camera for the minimum rms wavefront distortion, the usual resolution versus focus curve would be obtained and the film would be set at a position 0.0005 inch further away from the field flattener than the peak of the low contrast resolution versus focus curve.

However, since the determination of the peak of the resolution versus focus curve might be inaccurate, a more dependable technique requires performing dynamic resolution tests and varying the target wheel speed as well as the focus. At each focal position (increments of 0.0005 inch), a resolution versus image smear curve is obtained. The focal position which produces the maximum resolution curve for image smear larger than 2 to 3 microns lies within 0.00025 inch of the focal position which produces the minimum rms wavefront distortion. This technique had already been recommended in the 1101 performance report. In addition, the technique has been applied to the 1105 system, and the focusing recommendations for the 1105 system resulting from it coincide with the final focus settings of this system which were based on the performance of the 1104 system (assuming an air-to-vacuum focus shift of 0.0135 inch).

It has been known for a long time that tri-bar resolution data obtained at the contractor's laboratories display large fluctuations. These fluctuations are not due to equipment malfunctions but are a characteristic of and result from the statistical nature of the resolution data. Thus, individual resolution readings may be in error by a significant amount. In order to reduce the errors in the data, it has been customary, in the contractor's laboratories, to obtain at least five independent resolution readings under identical experimental conditions and average them, the result being a more accurate resolution number. Since the accuracy of the resolution data affects the accuracy with which a panoramic camera may be focused, it was decided to evaluate the accuracy of the resolution data and determine the most accurate technique of combining the resolution numbers. For this reason, a static photographic experiment was conducted utilizing a third generation lens and a W-25 filter. One hundred exposures were obtained on Type SO-380 film of a $\sqrt[6]{2}$ high contrast target and a $\sqrt[12]{2}$ low contrast target. Resolution readings were then obtained from the photographic images of the targets and their statistics were determined.

For the low contrast readings, the standard deviation of a single reading was computed to be approximately 20 lines per millimeter, while the mean was approximately 160 to 170 lines per millimeter. By averaging five readings, the standard deviation can be reduced to approximately 9 lines per millimeter. The average of 10 readings would have a standard deviation of approximately 6.5 lines per millimeter. However, the analysis of the statistics obtained from the experiment showed that if 10 independent resolution readings were available and five of them were averaged by eliminating the highest and four of the lowest readings, the resulting resolution number would have a standard deviation of approximately 3.5 lines per millimeter and would, of course, be larger than the average of the same 10 readings. Since most of the experimental conditions that cause the resolution reading fluctuations always reduce the resolution numbers, the higher average obtained by this new technique should be acceptable. In addition, for the purpose of focusing the panoramic cameras, whether the average resolution numbers are higher or lower is not important, but it is essential that the standard deviation of the averages obtained be as small as possible.

3. SYSTEM PERFORMANCE

3.1 CORN TARGET RESOLUTION

Each CORN target deployed consisted of the 51/51 tri-bar resolving power target, a Gray scale target, and a 100-foot edge target. These targets have already been described in the mission 1101 performance analysis report, so their description will not be repeated here. A more thorough explanation of these targets is also available in the CORN target manual.

Table 3-1 lists the geographic distribution of the CORN targets deployed. One was actually a fixed target (permanent installation). The first two columns labeled Pass and Frame uniquely identify the frame on which the image of a specific target display appears. The x and y coordinates listed in Table 3-1 pinpoint the position of the target image on the respective panoramic frame according to the universal grid system.

Table 3-1 — CORN Target Coverage

Pass	Frame	X, centimeters	Y, centermeters	Location
16	7 FWD	34	1	Edwards AFB, California, fixed
	13 AFT	42	2	target, 34°51′N, 117°45′W
16	14 FWD	45	1	Riverside, California, CORN target,
	21 AFT	30.5	1	33°50′N, 117°22′W
97	7 FWD	51	2	Napa, California, CORN target,
	13 AFT	24	4.5	38°22′N, 122°23′W
97	13 FWD	53	1	San Jose, California, CORN target,
	20 AFT	22	1	37°25′N, 122°11′W

The images of the CORN and the fixed target were examined by two observers who determined the corresponding ground resolved distances. The average readings are shown in Table 3-2. The readings were taken from the original negative. It is obvious that only a small number (four) of resolution targets were photographed in this mission. For the purpose of evaluating the system's performance, it would have been highly desirable to photograph more targets. It is understood that 13 CORN targets were deployed but only three were actually photographed.

For the targets of Table 3-2, the following information is pertinent if one tries to evaluate the system's performance utilizing the resolution readings:

1. FWD-looking camera, pass 16, frame 14. A W-12 filter was used to photograph this target instead of a W-25.
2. FWD-looking camera, pass 97, frame 7. The filter was being changed when this target was exposed.
3. FWD- looking camera, pass 97, frame 13. This target was also photographed with a W-12 filter.
4. AFT-looking camera, pass 16, frame 13. There is a possibility that this target might have been exposed while the slit was being changed.

Table 3-2 — Resolution Target Readings, Average of Two Readers

Pass	Frame	Along Track GRD, feet	Cross Track GRD, feet	Target Apparent Contrast
16	7 FWD	9	8	Medium contrast, fixed target
		7	8	High contrast, fixed target
	13 AFT	9	9	Medium contrast, fixed target
		6	8	High contrast, fixed target
16	14 FWD	16	12	1.60:1 (heavy haze) (W-12 filter)
	21 AFT	16	16	1.36:1 (heavy haze)
97	7 FWD	7.5	12	1.73:1 (filter being changed)
	13 AFT	10	8	1.89:1
97	13 FWD	7	12	1.75:1 (W-12 filter)
	20 AFT	7.5	12	2.05:1

Initially, the purpose of photographing a few CORN targets with the W-12 filter was to compare the performance of the FWD-looking camera using a W-12 and a W-25 filter. The W-12 filter allows shorter exposure times than the W-25, but produces lower contrast photography. Low contrast affects all spatial frequencies, while image smear resulting from long exposure times affects the high spatial frequencies only. When the image smear is an appreciable degrading factor of image quality (usually for exposure times longer than 3 milliseconds), an improvement in image quality can be achieved by selecting a Wratten filter which would reduce the exposure time to just under 3 milliseconds. It should be made clear, however, that this is only a rough rule of thumb, because, unfortunately, the selection of the optimum filter is influenced not only by the exposure times that will be required to expose a specific target, but also by the type of lens used (second or third generation) and atmospheric (haze) conditions over the target. For example, if one wants to photograph a target shrouded by heavy haze, the best choice of filter for penetrating the haze would be a W-25 or even a W-29. However, a poor resolution performance should be anticipated because of the long exposure times associated with these filters. It should also be kept in mind that a filter like W-25 eliminates information present in a wavelength band which would have passed through a wider band filter. In other words, the narrow-band filters eliminate more information than the wide-band filters. In fact, for a target of peculiar color reflectances, a significant portion of the information associated with this target can perhaps be recovered by utilizing the SF-05 filter in one of the panoramic cameras and a W-21 or W-25 in the other camera.

As far as the W-12 versus W-25 filter test in the FWD-looking camera of system 1103 is concerned, the only information obtained is that the W-12 filter produces lower contrast photography than the W-25, a fact which was already known. It seems that this test had not been thoroughly evaluated before the mission took place, because the reduction in image smear achieved by the W-12 filter over the W-25 was not significant for the CORN targets of pass 97. Also, the CORN targets of pass 97 were apparently deployed close together and there was not enough time to change filters. On the other hand, this filter test eliminated the information that would have been obtained about the FWD-looking camera's performance with the W-25 filter. Since the CORN target readings are very important in evaluating and rating the panoramic systems, the CORN targets deployed in California or other areas which have consistently clear weather should be reserved for the primary filters. In addition, there is a need to perform special filter experiments. Obviously, the number of CORN targets deployed and photographed is inadequate.

3.2 DETERMINATION OF OPERATIONAL RESOLUTION

The method for determining the operational resolution is discussed more extensively in Section 3.2 of the 1101 performance analysis report.* This technique is described only briefly in the present section.

The dynamic camera resolution, image smear, and static lens-film resolution for any image point are related by the expression:

$$R_d = \frac{R_s}{\left[1 + (bR_s)^{E_1}\right]^{E_2}} \qquad (3.1)$$

where R_d = dynamic camera resolution
b = image smear
R_s = static lens-film resolution
E_1 and E_2 = experimentally determined exponents

Exponents E_1 and E_2 were determined from resolution versus image smear tests performed at the contractor's laboratory. Table 3-3 shows the exponents that were determined for the 1103 FWD- and AFT-looking cameras. The static resolution, R_s, at a specific point of the panoramic format is dependent on the performance of the Petzval lens at the corresponding field angle, the focus position occupied by the film, and the film characteristics. Thus, for all practical purposes,

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R_s varies over the panoramic format of a camera but is not a function of time (does not vary between successive frames). In fact, a contour map of R_s could be constructed over the panoramic format.

Table 3-3 — Mission 1103 Exponents

Aft			Forward	
E_1	E_2	Contrast	E_1	E_2
2.30	0.47	High	1.90	0.53
2.30	0.47	Low (2:1)	2.30	0.42

In the resolution predictions, the values of R_s are determined individually for each target. To accomplish this, the static resolution of the lens as a function of field angle and focal position (from laboratory data) are utilized. For a specific target image, its y coordinate immediately gives the field angle the image occupies. In order to determine the focus position the same target image occupies, it is necessary to review the film flatness tests which provide the relative focal position of the target image with respect to the center of format. Finally, the operational focal position at the center of the format can be obtained from the final dynamic resolution versus focus tests performed at the contractor's laboratory. The results of these tests have been plotted in Figs. 3-1 through 3-4. The anticipated focal position at the center of format during the mission is also shown in these figures. Having determined the field angle and focal position of a specific target, the associated R_s values are readily obtained.

The computation of image smear is also described in detail in Section 3.2 of the mission 1101 performance analysis report. Since it is not possible to compute the image smear exactly, a systematic image smear component, b_s, and a random component, b_r, are separately computed for each target image. Then, the total image smear, b_t, is determined by the equation

$$b_t = b_r + |b_s| \qquad (3.2)$$

Factor b_t is introduced into Equation (3.1) and utilized in the computation of the dynamic camera resolution, R_d. In turn, the ground resolved distance is related to R_d by a scale factor affected by vehicle altitude, camera focal length, and location on the panoramic format of the target image. The ground resolved distance which is computed in this fashion is a probabilistic quantity. Thus, the predicted ground resolved distance is not equal to the actual ground resolved distance. Instead, the predicted ground resolved distance implies that the probability that the actual ground resolved distance is smaller than the predicted value is between 64 and 84 percent. Therefore, the average predicted ground resolved distance is larger than the average actual ground resolved distance.

Resolution predictions were computed for the CORN targets of Table 3-1 and the HPL targets of Appendix A. For these targets, the SRV tape recorder summary was examined to determine if an abnormal number of jet firings took place, which would indicate possible vehicle disturbances and unusually high vehicle rates. For all of the targets mentioned above, the jet firing activity appeared normal.

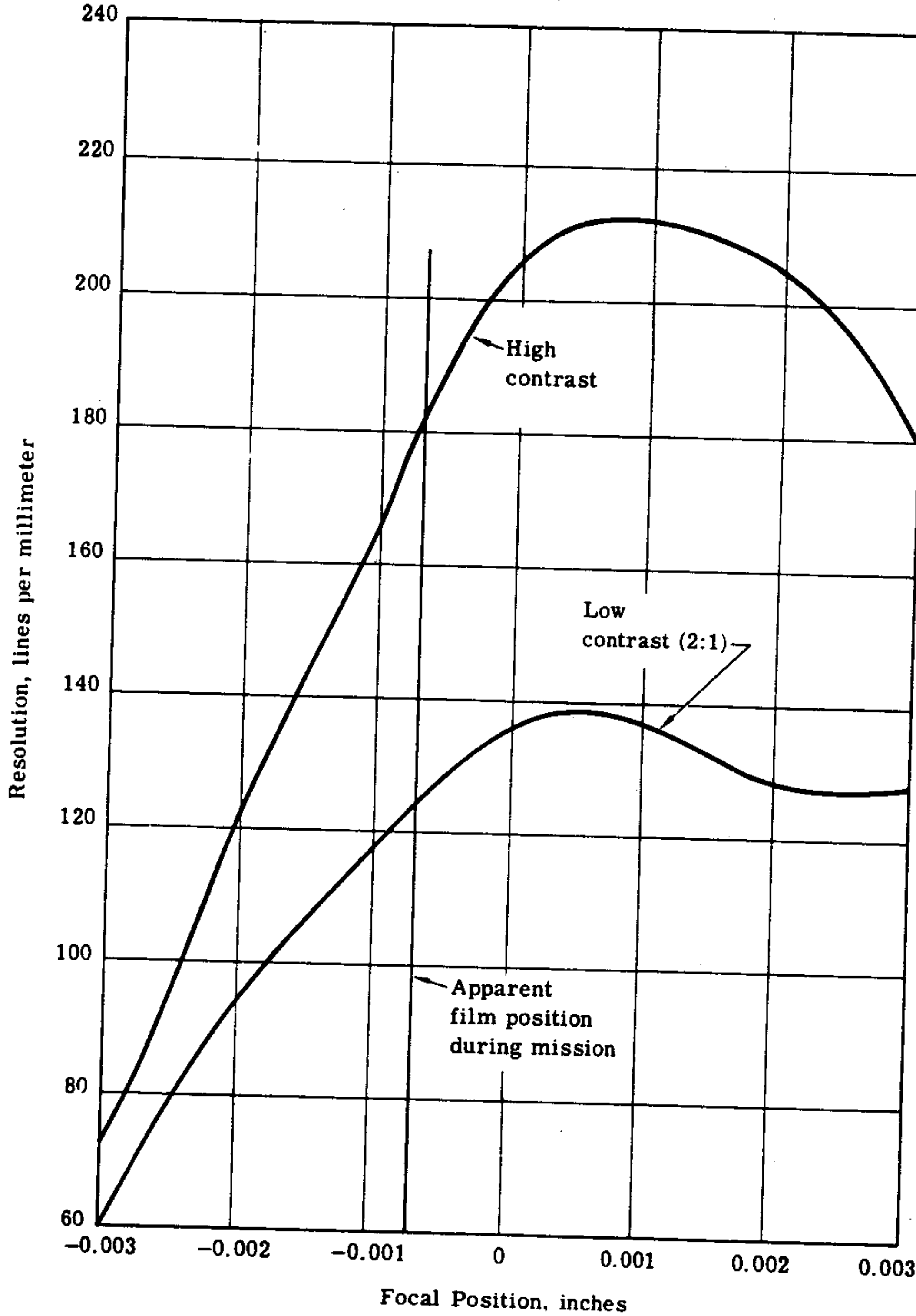


Fig. 3-1 — Dynamic resolution versus focus position, AFT-looking camera no. 306, along track

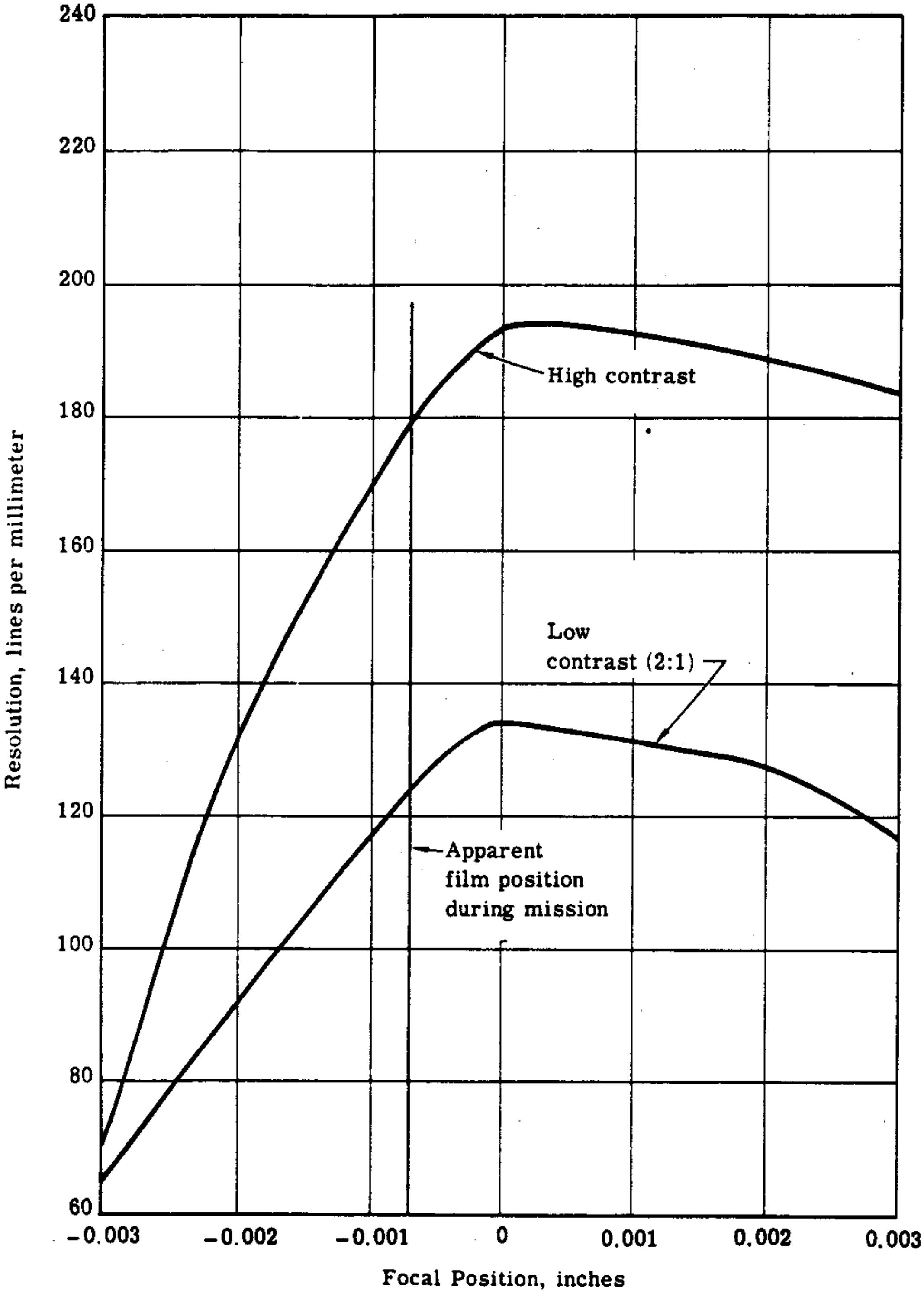


Fig. 3-2 — Dynamic resolution versus focus position, AFT-looking camera no. 306, cross track

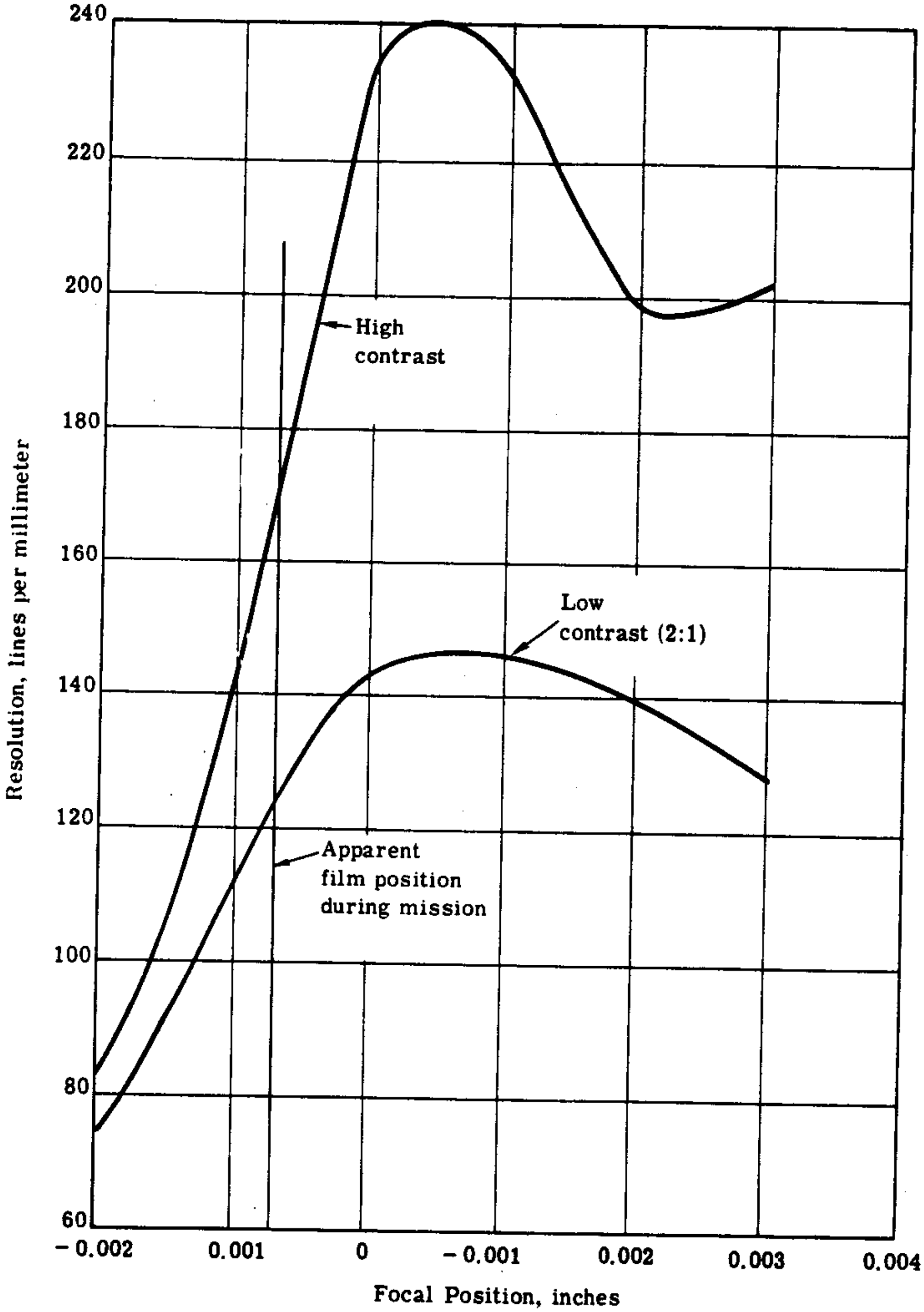


Fig. 3-3 — Dynamic resolution versus focus position, FWD-looking camera no. 307, along track

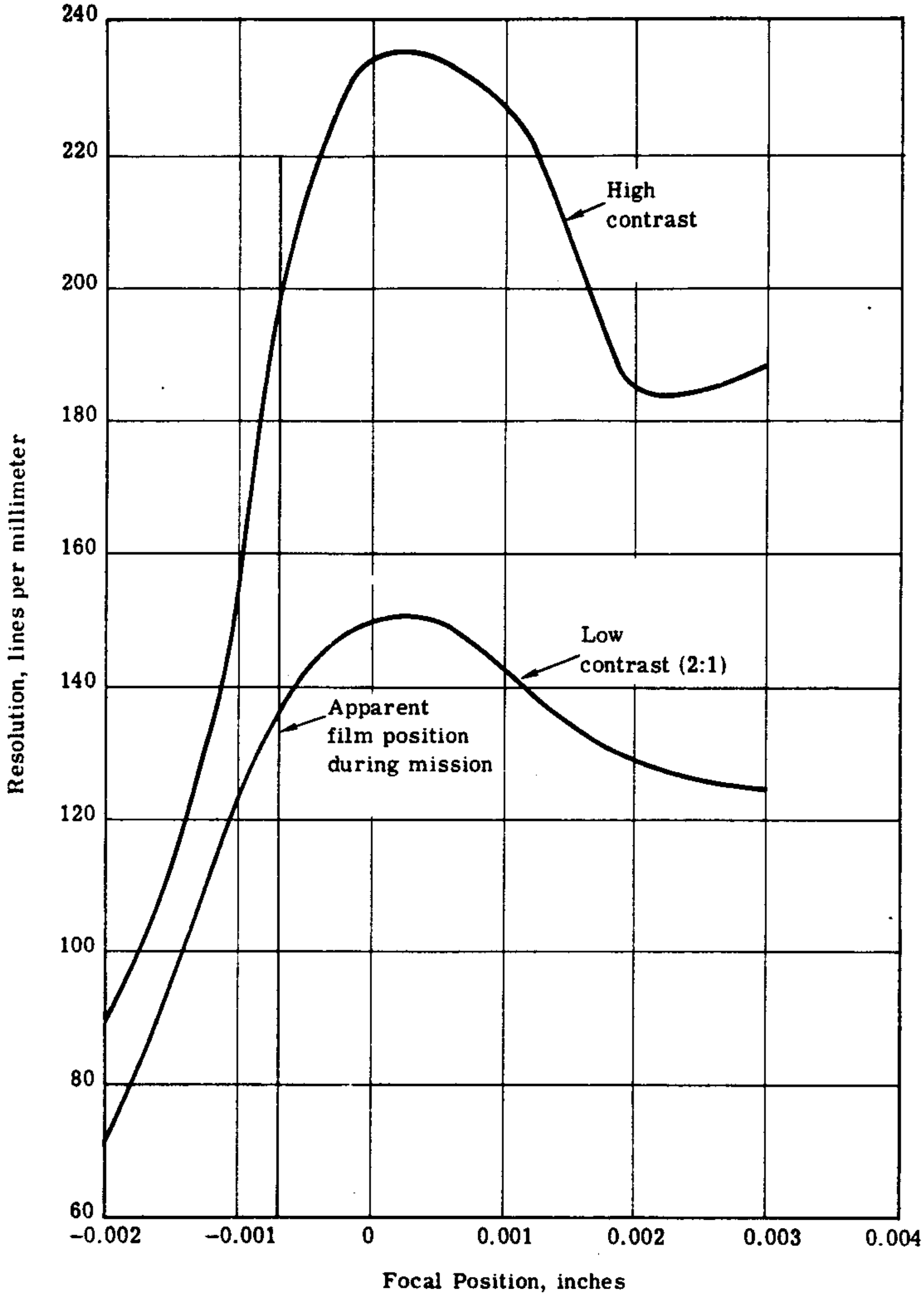


Fig. 3-4 — Dynamic resolution versus focus position, FWD-looking camera no. 307, cross track

3.3 COMPARISON OF CORN TARGET AND PREDICTED RESOLUTIONS

A fair comparison between a CORN target reading and the corresponding predicted ground resolved distance cannot be conducted without a knowledge of the apparent contrast of the target at the lens aperture. Resolution predictions have been computed for very high contrast and low contrast (2:1) tri-bar targets. On the ground, the contrast of the CORN targets is a nominal 4.7:1. The fixed targets are usually of higher contrast, approximately 10:1, but their real contrasts at the lens aperture are unknown, and depend on how well the targets are maintained.

On the other hand, during the photographic mission, the contrast of all ground objects including resolution targets is reduced by the atmosphere. The loss in contrast is affected by weather conditions as well as by solar elevation and azimuth. In Section 3.1 of the 1101 performance analysis report, the relationships between contrast and modulation are described. In the same section, a method for determining the apparent CORN target contrast at the lens aperture is also described. This method requires that microdensitometer traces be obtained on the original negative of the edge target which is part of the CORN target display. The fixed target displays have no edge targets. Thus, for the fixed targets, the apparent target contrast or modulation cannot be computed.

For mission 1103, the edge targets of the CORN target displays were traced with a microdensitometer by the Air Force Special Projects Production Facility. From these traces it was possible to compute the apparent tri-bar target contrasts shown in Tables 3-2 and 3-4.

Table 3-4 — CORN Target Readings and Predictions*

Pass	Frame	Along Track		Cross Track		Apparent Contrast
		Average Reading, feet	Predicted GRD, feet	Average Reading, feet	Predicted GRD, feet	
AFT-Looking Camera						
16	13	9	7.8	9	7.1	<2:1
16	21	12-16	7.7	12-16	7.7	1.36:1
97	13	10	6.9	8	7.5	1.89:1
97	20	7.5	7.1	8-12	7.9	2.05:1
FWD-Looking Camera						
16	7	9	8.6	8	6.9	1.73:1
97	7	7.5	7.0	8-12	7.2	1.73:1

* Predictions are for low contrast (2:1) targets.

Table 3-4 provides a means of comparing the CORN target readings with the predicted ground resolved distances. The column identified as Average Reading has entries which are the corresponding average readings taken from Table 3-2, except that some readings have been replaced by two numbers separated by a dashed line. This was deemed necessary because the CORN target display has only three panels for GRD's larger than 8 feet. These panels correspond to the following GRD's—8 feet, 12 feet, and 16 feet. Hence, whenever the reading is 12 feet, the actual GRD is somewhere between 8 and 12 feet. The predicted ground resolved distances are low contrast (2:1) values. No predictions were made for CORN targets photographed by the FWD-looking camera with the W-12 filter, because the required laboratory data for this filter do not exist.

Examination of Table 3-4 shows that 75 percent of the predicted ground resolved distances correlate well with the average target readings when the apparent contrasts of the targets are taken into account.

3.4 EVALUATION OF SYSTEM OPERATION

While the other sections of this report attempt to establish the performance level of the 1103 system, this section is devoted to methods and techniques which could have improved and optimized the 1103 system's performance. Hopefully, this kind of evaluation will provide valuable information for the optimization of subsequent systems.

3.4.1 Altitude of Photography

For the CORN and HPL targets for which resolution predictions were computed, the average altitude of photography turned out to be 87.9 nm. It should be obvious that the average ground resolved distance and the scale of the photography could be reduced almost 10 percent by photographing the HPL targets from an average altitude of 80 nm. Fig. 3-5 shows the altitude distribution of the HPL targets. Each point in this distribution represents one or more targets. Two targets photographed on revolutions no. 203 and 218 are not shown in Fig. 3-5. The HPL targets fall into the following categories according to their respective altitudes of photography:

1. Three targets between 95 and 100 nm
2. Six targets between 90 and 95 nm
3. Twenty targets between 85 and 90 nm
4. Seven targets between 82 and 85 nm.

Fig. 3-5 shows that the altitude of photography for the HPL targets is somewhat reduced as the mission progresses. The average geographic latitude for the HPL's is approximately 50 °N, with a standard deviation of approximately 7 degrees. However, for mission 1103, the perigee of the orbit was maintained throughout the mission at latitudes between 17 °N and 50 °N, and the altitude at perigee was not allowed to be reduced below 83.7 nm. Thus, it seems that the HPL targets for mission 1103 could have been photographed at an average altitude of 80 nm by maintaining the orbit perigee at approximately 50 °N and by reducing the perigee altitude to approximately 79.5 nm.

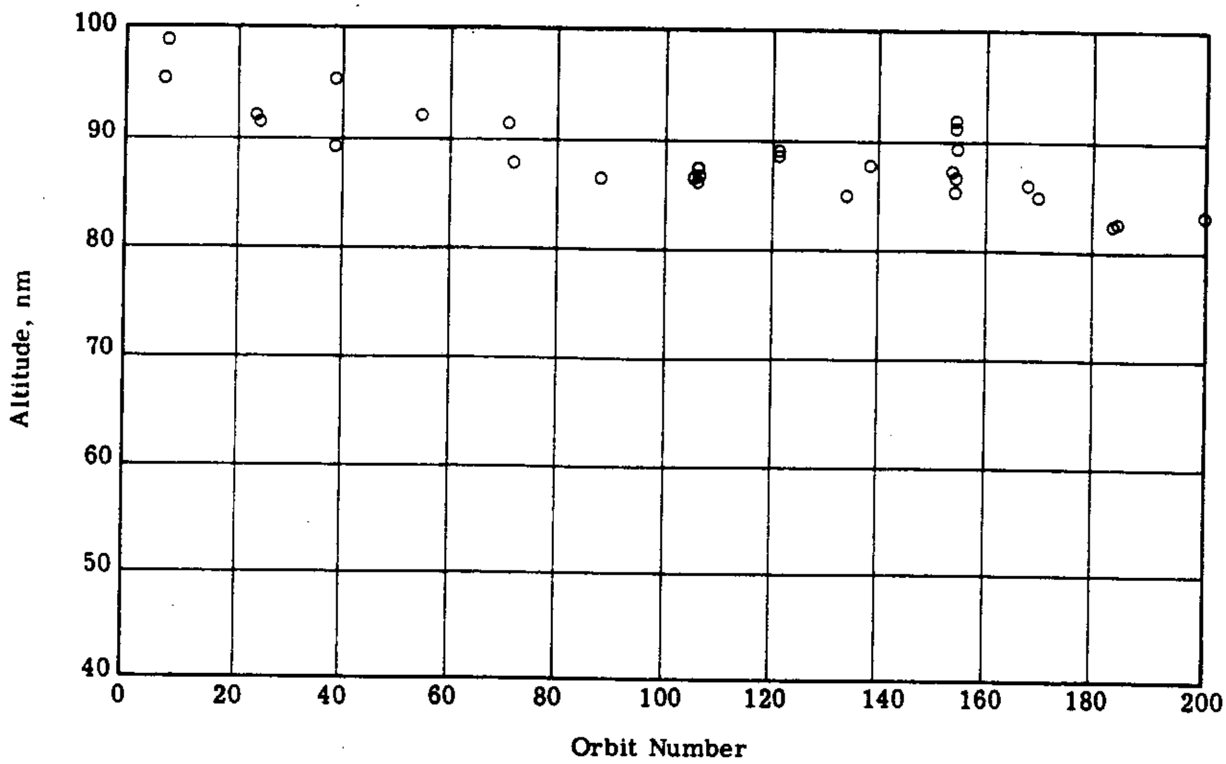


Fig. 3-5 — Altitude distribution of HPL targets

3.4.2. V/h Errors

The FMC rates of the panoramic cameras were checked against the required V/h rates computed from ephemeris data. This was done for 107 frames from both the FWD- and AFT-looking cameras. Of these, 72 frames contained the HPL targets. It was found that in pass 184, both cameras were running approximately 36.7 percent too slow, a gross error which was attributed to the V/h programmer. Since both cameras appeared to be running very closely at the same speed throughout the mission, it was considered that the major error between the FMC and V/h rates should be attributed to the V/h programmer. Excluding two targets from pass 184, the average percentage error for the remaining 105 frames turned out to be +0.11 percent, while the standard deviation from this mean was 1.31 percent. It appears that the performance of the V/h programmer has been improved and is within the requirement of 1.41 percent. However, 12 frames had a percentage error between 1.5 and 2.0 percent, 7 frames had a percentage error between 2.0 and 3.0 percent, and 3 frames had a percentage error between 3.0 and 4.6 percent. Thus, approximately 22 percent of the frames checked had an appreciable (larger than 1.5 percent) V/h error. On the other hand, 78 percent of the frames checked had a V/h error of less than 1.5 percent. Therefore, it appears that it should be possible to reduce the V/h error to less than 1.5 percent for essentially all the frames of a mission.

3.4.3 Ultimate Resolution Performance

Ways by which the performance of the 1103 panoramic cameras could have been optimized will now be considered. All possibilities that were considered fall under one of the following categories:

1. Reduction of image smear
2. Reduction of altitude of photography
3. Improvement of lens focusing techniques.

Various steps which would have improved the 1103 system performance with various degrees of success have been listed in Table 3-5. In Table 3-6, the average expected ground resolved distances for the cases described in Table 3-5 have been entered. In Table 3-6, an attempt has been made to use identical values for all parameters which should be invariant between any two cases. This is essential in order to make a valid comparison. At the same time, data from mission 1103 have been used in order to make the comparison directly applicable to this mission. The data utilized were obtained by averaging the respective data from the CORN and HPL targets. Thus, average image smear, average static lens resolutions, and average scale factors were determined for the CORN and HPL targets.

Case H shows the optimum performance level of which the 1103 system was capable. For this case, the following assumptions have been made:

1. Both lenses have been focused to maximize tri-bar resolution.
2. The average altitude of photography is 80 nm.
3. Type SO-230 or SO-205 film has replaced Type 3404.

A comparison of cases H and A in Table 3-6 shows that case H represents a 19 percent improvement in performance over case A, approximately 10 percent of which can be attributed to the reduction in the altitude of photography to 80 nm. More significantly, the operational requirements imposed by case H (the three assumptions discussed above) should be well within the realm of possibility.

Table 3-5 — List of System Configurations

Case	Description
A	Actual mission 1103 configuration
B	Identical to A except the average altitude of photography reduced to 80 nm
C	Identical to A except the cameras focused for maximum resolution
D	Identical to C except the average altitude of photography reduced to 80 nm
E	Identical to A except that Type 3404 film replaced by Type SO-205 or SO-230
F	Identical to E except that the average altitude of photogaphy reduced to 80 nm
G	Identical to C except that Type 3404 film replaced by Type SO-205 or SO-230
H	Identical to G except the average altitude of photogaphy reduced to 80 nm

Table 3-6 — Comparative Chart of Average System Performance, Low Contrast GRD

Case	FWD-Looking Camera		AFT-Looking Camera	
	Along Track GRD, feet	Cross Track GRD, feet	Along Track GRD, feet	Cross Track GRD, feet
A	8.0	8.1	7.6	8.5
B	7.3	7.4	6.9	7.8
C	7.5	7.7	7.4	8.4
D	6.8	7.0	6.8	7.6
E	7.7	7.3	7.4	7.8
F	7.0	6.7	6.8	7.1
G	7.1	6.8	7.3	7.6
H (Goal)	6.5	6.2	6.6	6.9

4. A-TAKEUP EXPERIMENT

4.1 GENERAL

The purpose of this experiment was to measure three image quality parameters as a means of detecting changes in the original negative imaging characteristics accrued during mission environment. Measurements of (1) resolution as a function of contrast, (2) granularity as a function of density, and (3) modulation transfer as a function of spatial frequency were made on both mission-recovered Type 3404 samples and two different Type 3404 control samples.

The payload sample (identified as "A-takeup") was an initial length of film (3404-401) removed from the A-takeup cassette of the 1103-1 recovered capsule. Proximate control (identified as "Preflight") was a sample of 3404-401 taken from the odd serial number 1103 supply cassette just before installation into the capsule. Ultimate control (identified as "Control") was a sample of film (3404-406) taken from the film contractor's refrigerator master supply.

A possible weakness of this experiment is the fact that this "A-takeup" film was run through the camera on the pad before lift-off under ambient ground conditions. Because the film is somewhat protected on the core by subsequent film convolutions, it is questionable whether this film has experienced the full impact of the 1103 mission environment. However, it is the best method available for this type of study, being one step more refined than an analysis of material having no environmental history at all.

Replicate exposures of tri-bar resolution targets (at selective contrasts). uniform patches (at selective luminance levels), and straight edges (at a single contrast) were made by the processing contractor on each of the three experimental samples. These exposures were all made at one given time in a microscope objective camera arrangement with a simulated daylight source modified by a W-23A filter. The samples were then processed along with the mission film. Measurements and analyses were carried out by this contractor. Fig. 4-1 displays the structure of the experiment in summary form.

Results indicate that the Type 3404 film flown in the 1103-1 mission underwent no appreciable change in imaging characteristics. Comparison with the similar experiments performed on the 1102 and 1101 missions reveals some inconsistencies in the data which will require at least one other similar experiment to resolve.

4.2 RESOLUTION AS A FUNCTION OF CONTRAST

Standard $\sqrt[6]{2}$ tri-bar resolution targets of six different contrasts were imaged onto the three Type 3404 film samples in sets of three replications at each of 11 exposure levels. Each recorded target was read individually by three different readers. The consequent sets of nine values for the condition of best exposure were statistically analyzed for mean and 95 percent confidence limits, and the results are shown in Table 4-1. All calculations were executed in logarithmic

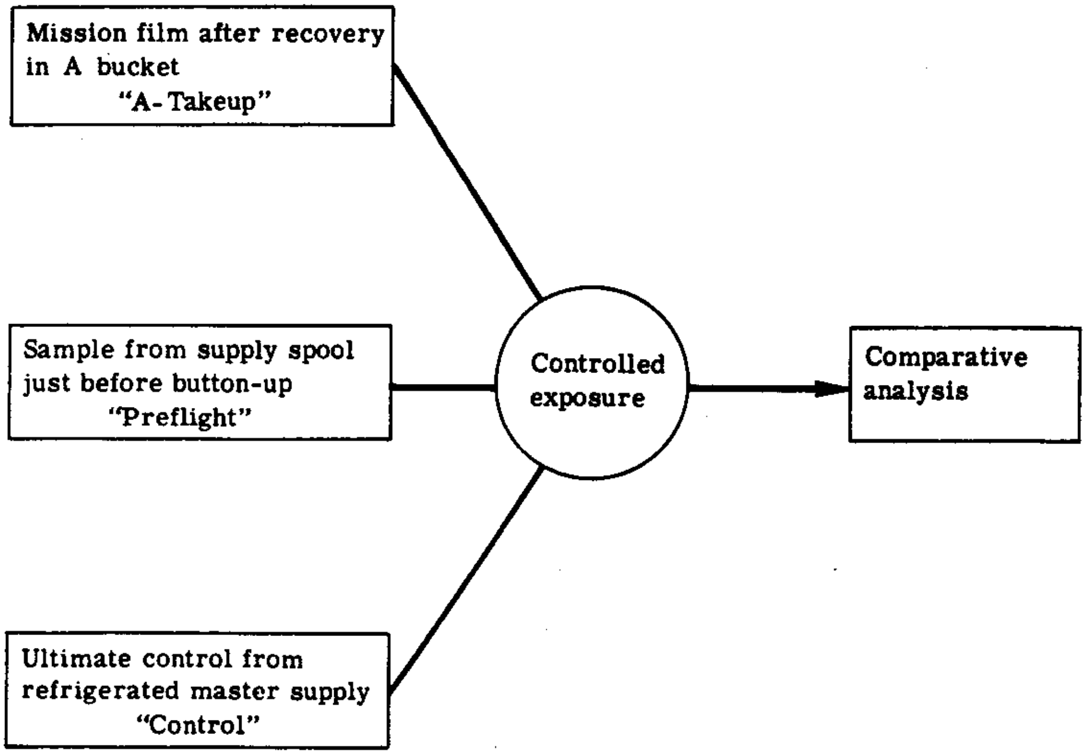


Fig. 4-1 — Structure of the A-takeup experiment

terms in order to properly weight the resolution target element progressions (in lines per millimeter) as a geometric function.

The data so reduced are presented graphically in Fig. 4-2 (a to c). Mean and 95 percent confidence limits are plotted for each of the three film conditions. For each set of data, an average curve is fitted to show the functional dependency of recorded target resolution on object target modulation. All of these curves are contained within the confidence limits associated with each of the three film conditions. Since the difference between the derived averages for these curves lies within the spread defined by experimental error, it is indicative that the 1103 A-takeup film underwent no appreciable change in imaging characteristics due to the mission environment. For ease in comparison, the curves for the test condition and the two control conditions are replotted together in Fig. 4-2(d).

Comparison of this 1103 data with that generated for the preceding two J-3 missions is shown in Fig. 4-3. Analysis of raw data bears out what these curves illustrate. There is an appreciable difference in resolution as a function of contrast for each of the three A-takeup experiments. For the most part, the 1101 curve oscillates between the 1102 and 1103 curves. At the same time, the clear-cut distinction between 1102 and 1103 is evident. It is interesting to note, however, that both of these sets of curves display a tendency to level off at a threshold value of 0.035 modulation.

Table 4-1 — Results of 1103 Resolution Data Reduction

Filter	Identification	Target Contrast	Target Modulation	Average Resolution, lines per millimeter	95 Percent Confidence Limits	
					Low	High
78 + 23A	Control (3404-406)	1.08:1	0.0384	33	26	41
78 + 23A	Control (3404-406)	1.15:1	0.0698	121	106	138
78 + 23A	Control (3404-406)	1.26:1	0.1150	164	149	181
78 + 23A	Control (3404-406)	1.70:1	0.2592	261	235	289
78 + 23A	Control (3404-406)	2.63:1	0.4490	378	378	420
78 + 23A	Control (3404-406)	5.14:1	0.6743	435	404	468
78 + 23A	Preflight (3404-401)	1.08:1	0.0384	37	33	42
78 + 23A	Preflight (3404-401)	1.15:1	0.0698	106	92	122
78 + 23A	Preflight (3404-401)	1.26:1	0.1150	147	130	165
78 + 23A	Preflight (3404-401)	1.70:1	0.2592	218	195	244
78 + 23A	Preflight (3404-401)	2.63:1	0.4490	368	336	403
78 + 23A	Preflight (3404-401)	5.14:1	0.6743	429	380	485
78 + 23A	A-takeup (3404-401)	1.08:1	0.0384	41	35	48
78 + 23A	A-takeup (3404-401)	1.15:1	0.0698	111	106	115
78 + 23A	A-takeup (3404-401)	1.26:1	0.1150	145	131	160
78 + 23A	A-takeup (3404-401)	1.70:1	0.2592	241	225	259
78 + 23A	A-takeup (3404-401)	2.63:1	0.4490	363	345	383
78 + 23A	A-takeup (3404-401)	5.14:1	0.6743	403	370	438

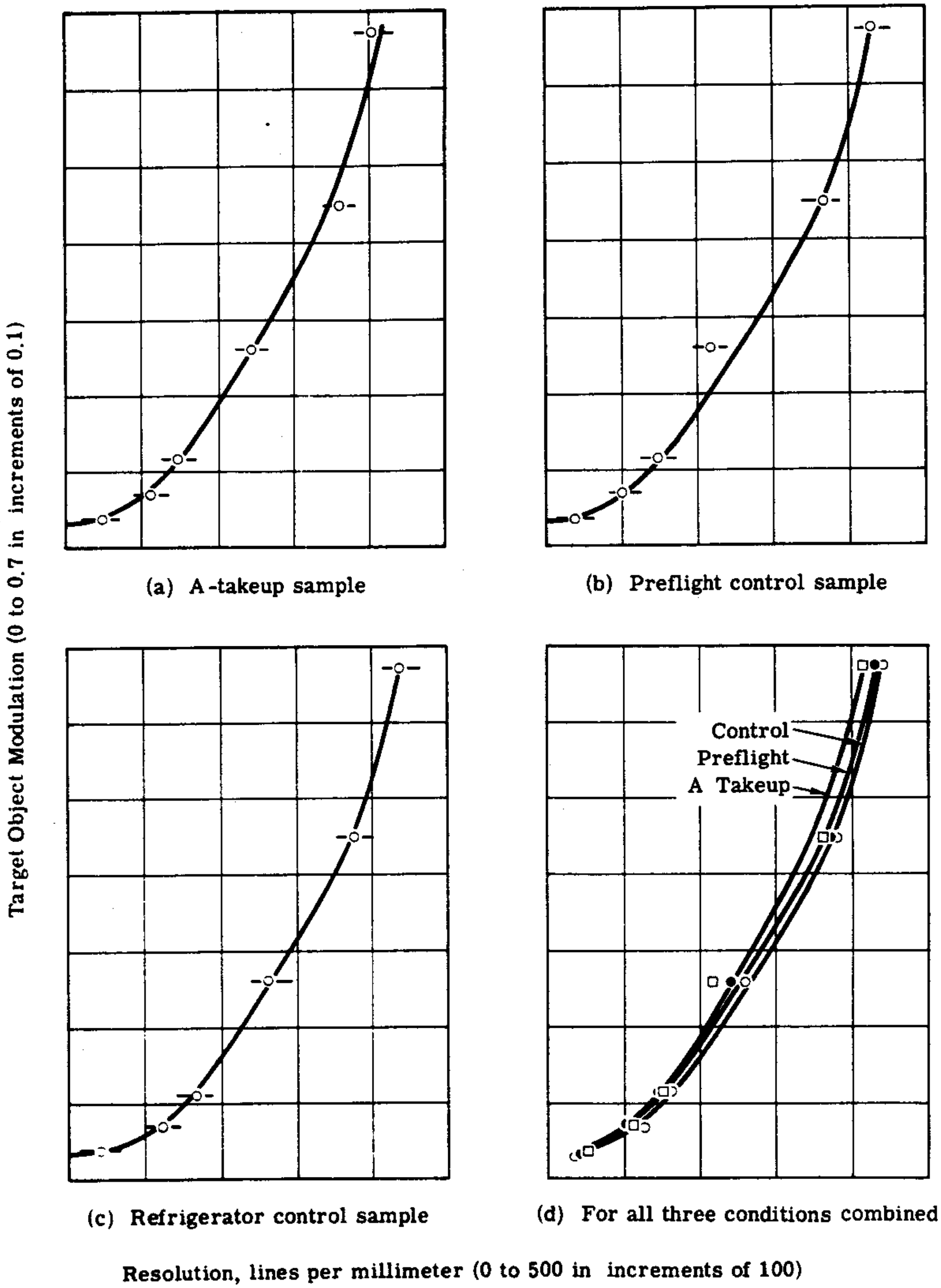


Fig. 4-2 — Target object modulation versus recorded target resolution for mission 1103 (horizontal bars represent real data contained within 95-percent confidence limits)

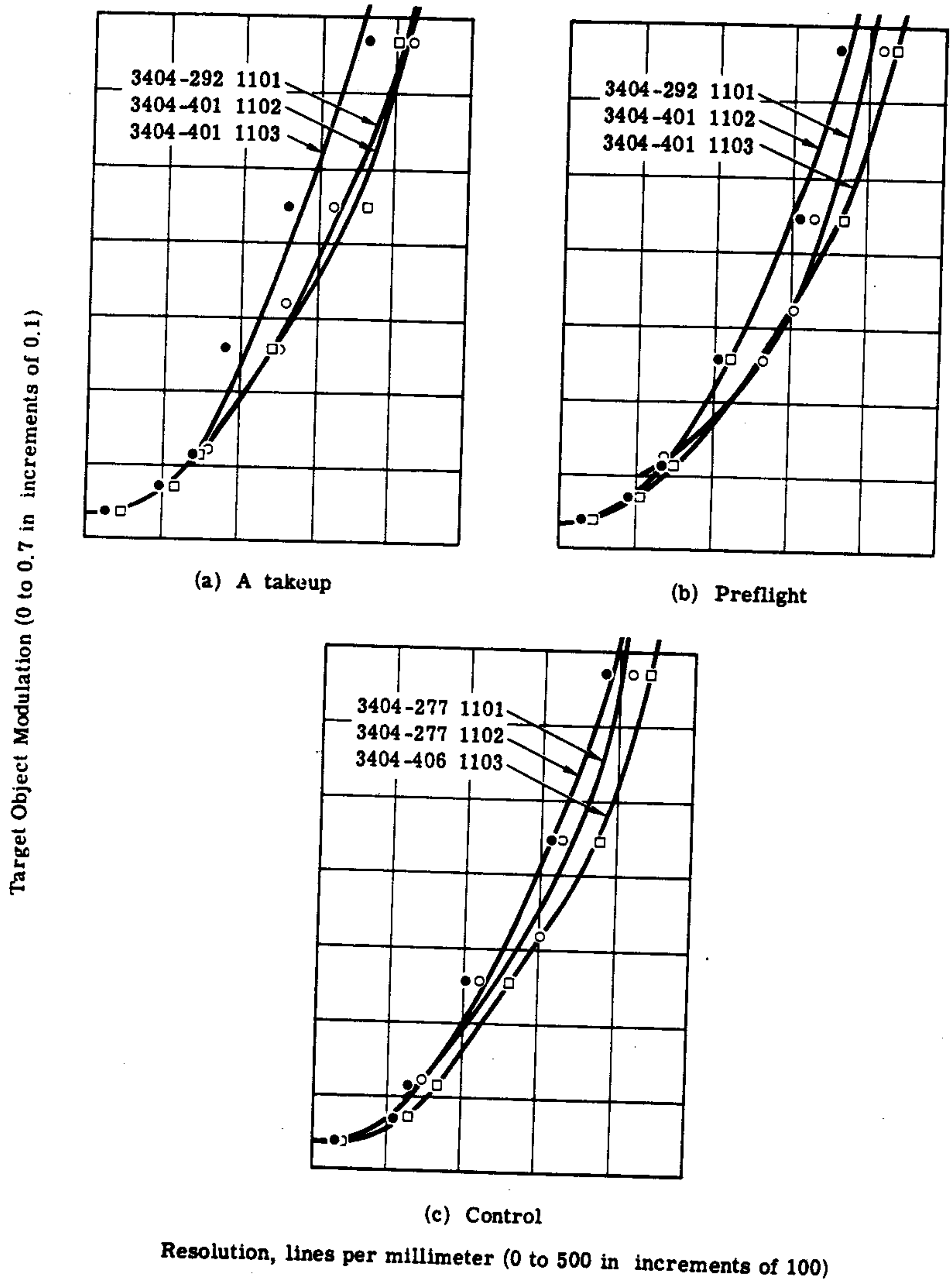
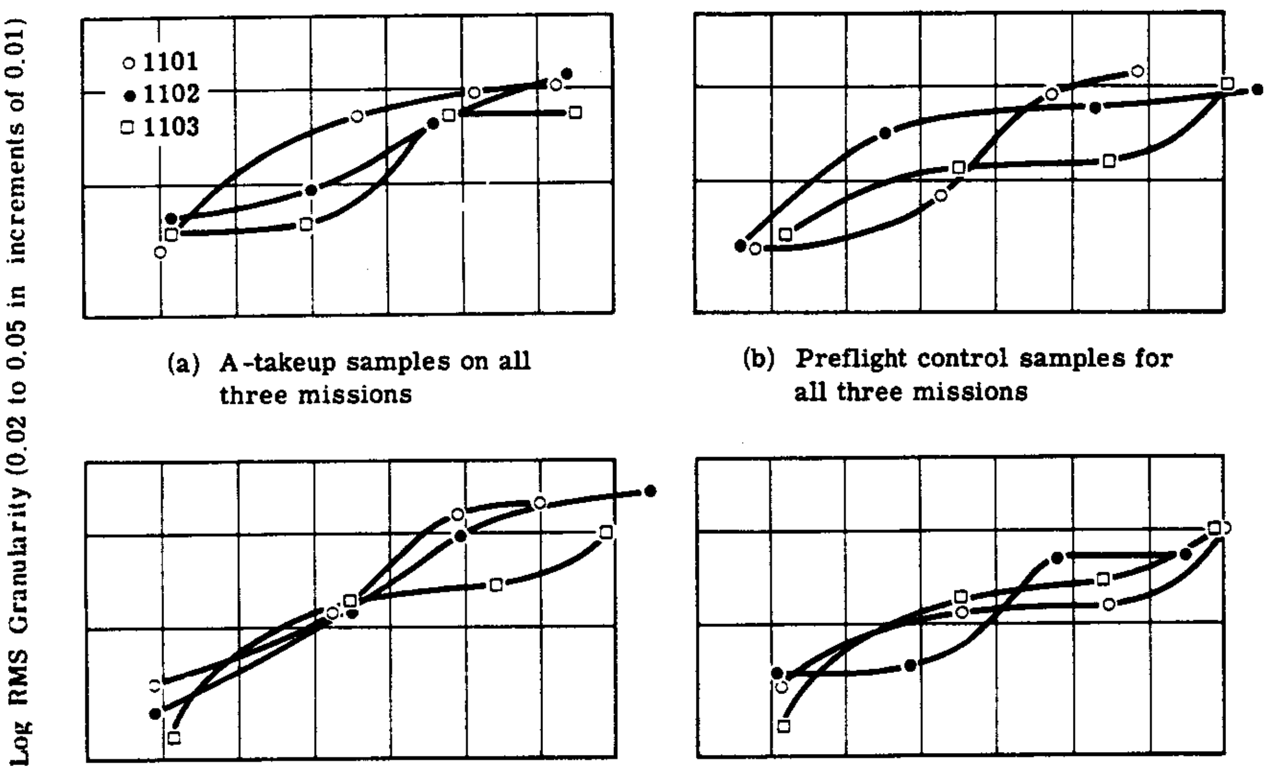


Fig. 4-3 — Resolution as a function of contrast for each of the three film conditions on each of the three J-3 mission A-takeup experiments

4.3 GRANULARITY AS A FUNCTION OF DENSITY

Values of rms granularity were determined at four density levels for each of the three film conditions. The resultant data are plotted in Fig. 4-4, representing granularity as a function of density. Interpolated values of rms granularity at 1.0 gross density level are listed in Table 4-2 to comply with a comparison standard. The fact that these comparison values are nearly identical (0.031—0.033) suggests that there has been no alteration in the imaging characteristics of the 3404 emulsion due to the orbital environment. At the same time, the spread in the limited number of experimental data points producing anomalies in the projected curve shapes for the different missions indicates that the number of density levels sampled is insufficient to characterize the functional relationship between granularity and density in a smooth way.

The aperture size, 12 microns, was used because it was considered to be more in keeping with the viewing magnification to be used on the system product. To convert reported rms values thus determined to figures comparable to those obtained with a 24-micron aperture size, divide the values by 2 in conformance with Selwyn's Law.*



(a) A-takeup samples on all three missions

(b) Preflight control samples for all three missions

(c) Ultimate control samples for all three missions

(d) Three samples of mission 1103 alone

Density (0.2 to 1.6 in increments of 0.2)

Fig. 4-4 — Granularity as a function of density

*Selwyn's Law states that granularity varies inversely proportional to the square root of the scanning aperture.

Table 4-2 — RMS Granularity at 1.0 Gross Density

Condition	1101	1102	1103
Control	0.036	0.035	0.033
Preflight	0.034	0.037	0.031
A-takeup	0.038	0.033	0.032

Aperture size	12 ± 1 micron
Data point spacing	Approximately 10-percent diameter overlap
Number of density patches per strip	4
Number of scans per density patch	5
Number of data points per scan	500

The rms granularity values were computed for each of 60 scans using bad data elimination and detrending techniques. A pooled estimate of the variance and rms value was calculated for each patch.

The granularity versus density curves in Fig. 4-4 for all three missions portray a general increase in rms value with increasing density. There is no tendency in these data for one mission experiment to be consistently different from the rest. The random intermixture of data points from each mission suggests that the variations are due to experimental error rather than any systematic symptom. Comparison between film conditions and between missions is made on the basis of rms granularity at 1.0 gross density as standard practice. Comparison between missions shows that the 1103 data indicates slightly lower granularity than the 1102 and 1101 data. Comparison between mission 1103 film conditions reveals that there has been no change in granularity in the payload film from the two control films.

4.4 MODULATION TRANSFER AS A FUNCTION OF SPATIAL FREQUENCY

4.4.1 Results

Modulation transfer functions for each of the two Type 3404 film control conditions and the one mission condition were computed from microdensitometric traces of low contrast edges exposed onto all of the film samples after completion of the 1103-1 mission. Comparisons have been made with the MTF's derived from the 1102-1 and 1101-1 A-takeup experiments. Results indicate that:

1. There is no significant difference in the A-takeup MTF from the two control MTF's.
2. The data variation in replicate determinations is about the same degree for the A-takeup as well as the two control MTF's.
3. All of the 1103 MTF's are about the same as the 1102 MTF's.
4. All of the 1101 MTF's are significantly higher than both the 1102 and 1103 MTF's.

4.4.2 Detailed Analysis

Each of the three film samples received a step tablet exposure and three replicate exposures to a low contrast edge in the Kodak Microscope Camera at one period of time and under the same instrumental conditions. Lenses employed in the camera were a Zeiss 0.65 NA planapochromat 25× objective with a Zeiss Komplan 8× eyepiece for an overall reduction of −189×. The nine edges so produced exhibit nonsymmetrical properties and are generally characterized by approximately an 0.8 specular density difference. Edge spread varies in a 2:1 range, from 13 microns at best to 25 microns at worst, as shown in Fig. 4-5. Since there is no patterned relationship between edge spread and film condition, we know that there is no weighting of edge acuity to any particular test sample.

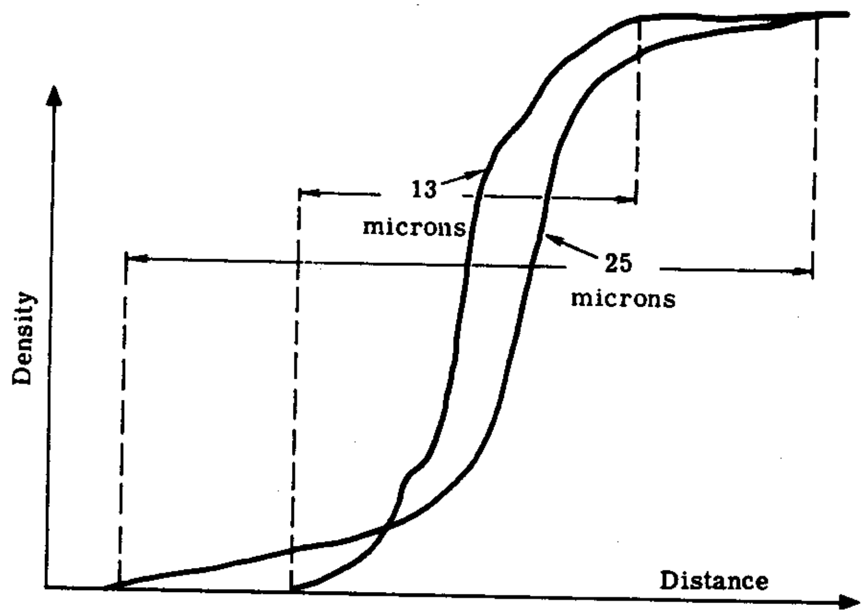
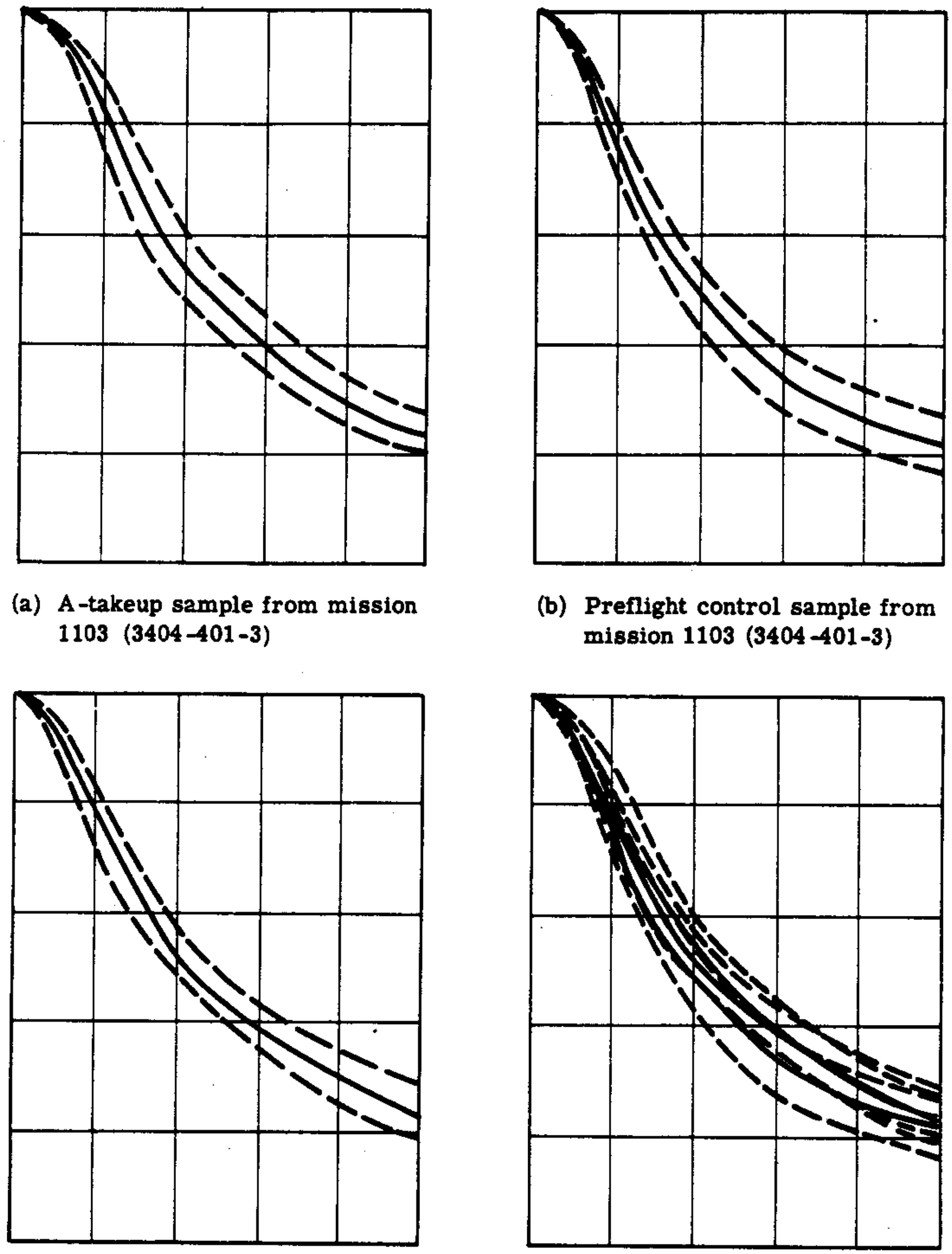


Fig. 4-5 — Comparison of the sharpest and broadest smoothed edges (All of the nine edges constituting the base data for this MTF analysis are contained within these limits.)

Each of the nine edges was traced on an Intectron microdensitometer with a 30- × 0.6-micron slit at five contiguous positions. Stepped densities from the calibrated wedge were also recorded. For each edge, the five microdensitometric traces were superimposed, matched with regard to density scale, shifted on the distance scale to achieve alignment of the linear portion of the traces, and then hand-smoothed onto an overlay. These averaged edge traces were then sampled at 0.25-micron increments to produce a 100-point data base for each curve. The step tablet exposure density values were data processed to produce the appropriate relative exposure base, and this information was loaded into the MTF computer program together with the edge data.

The computer MTF plots of Fourier calculated MTF's become noisy and, therefore, unreliable at very high frequencies, so the analysis is restricted to the 0-to-200-cycle-per-millimeter frequency domain. Experimental variation in the data is reflected in minor fluctuations and cross-over points. Envelopes were drawn to encompass these experimental fluctuations and a mean curve was drawn between them.

The mean curve, together with smoothed envelopes for each of the three test conditions, are reproduced in Fig. 4-6. Two points are evident: (1) the displacements in the means are contained within the degree of experimental variation, and (2) the three replicate MTF determinations have about the same degree of variation for all three test conditions.



Modulation Transfer (0 to 1.0 in increments of 0.2)

(a) A-takeup sample from mission 1103 (3404-401-3)

(b) Preflight control sample from mission 1103 (3404-401-3)

(c) Current process control sample (3404-277)

(d) Superimposition of the three conditions

Spatial Frequency, cycles per millimeter (0 to 200 in increments of 40)

Fig. 4-6 — Average MTF's (solid lines) for each of the three test conditions with respective experimental variation (dashed lines)