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PERFORMANCE ANALYSIS FOR THE 1105 SYSTEM

APRIL 1969

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PERFORMANCE ANALYSIS FOR THE 1105 SYSTEM

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1. INTRODUCTION

Mission 1105 was the first mission of the 1100 series to utilize a full load of SO-380 film (ultrathin base film having the same emulsion as the familiar 3404 film). Mission 1105 followed mission 1104, which is considered to be the best mission to date of the 1100 series from the point [redacted]aphic quality (see the Performance Analysis for the 1104 System, [redacted]

According to the findings of the Performance Evaluation Team (PET), the average image quality of the 1105 mission was not as good as the average image quality of mission 1104, because there is a larger variability in image quality of mission 1105. Visual examination of CORN target images, as well as images of other targets on the original negative, confirms this observation. The variability in image quality manifests itself as areas of sharp images interspersed over the panoramic format with areas of fuzzy images or images obviously degraded by image smear. Stated in another way, the image quality of mission 1105 was not consistent, indicating that the performance of the complete photographic system (cameras, film, and vehicle) was not controlled throughout the panoramic format to the same high level displayed during the 1104 mission.

However, despite the variability in image quality that was observed, it appears that mission 1105 was one of the better missions with regard to the first priority targets. Table 1-1 shows the statistics of the photointerpreter ratings assigned to the first priority targets for missions 1104 and 1105. It is not entirely clear what the reasons are for the apparent discrepancy between the visual evaluation conducted by the PET and the photointerpreter ratings. It is possible that the photointerpreter ratings were influenced by weather and increased coverage (50 percent higher than 3404) provided by the SO-380 film. However, the most important factor appears to be the magnification utilized for evaluating the photography. A portion of the variability in image quality which is obvious under a magnification of 60× will not be apparent when the magnification is reduced to 20×.

Table 1-1 — Statistics of Photointerpreter Ratings

Mission	Poor	Fair	Good
1104	14.9%	61.7%	23.4%
1105	13.6%	40.9%	45.5%

The variability in image quality observed in the photography of mission 1105 has probably reduced the information capacity per linear foot of film. However, if the photography of a mission is normally evaluated under a magnification of less than 40×, then it is expected that the loss in information retrieved from the photography per linear foot of film be smaller than the loss in information capacity.

There are many similarities between the panoramic cameras utilized in missions 1104 and 1105, the most important being the similarity between the corresponding lenses and the focusing adjustments of the lenses. On the other hand, the major difference between the two missions is the type of film utilized (3404 for 1104 and SO-380 for 1105), and a minor difference is the static takeup spool tension (46 ounces for 1104 and 36 ounces for 1105).

It seems, though not conclusively, that the panoramic cameras in mission 1105 were unable to control the flatness and motions of the SO-380 film over the panoramic format to the degree that was required for consistently high image quality. One need not know the mechanical details of the camera operation to understand the basic interaction of physical forces that affect the film flatness. The following elementary description of the physical forces should be sufficient.

1. The film is controlled by tension only and it is supposed to occupy, during exposure, a predetermined focal surface. There are no other controlling forces applied by the camera normal to the film.
2. A flatness error exists whenever the film occupies, during exposure, a focal surface other than the predetermined one.
3. A flatness error amounts to an out-of-focus condition with the focus shift being equal to the displacement of the surface occupied by the film from the predetermined focal surface.
4. The film is displaced from the focal surface by disturbing forces normal to the focal surface.
5. Some of the disturbing forces are due to the camera operation (tracking and film scanning during exposure) and the rest are inherent in the film.
6. The disturbing forces are minimized by preflight adjustments in the laboratory.
7. The film is displaced from the focal surface by the disturbing forces until an equilibrium is reached between the disturbing forces and the compensating forces.
8. The compensating forces are the tension applied by the camera plus other forces inherent in the film.

Note that the forces inherent in the film have been separated into disturbing and compensating forces rather than grouping them together into a net force. This separation is important because it helps explain the fundamental difference between the 3404 and SO-380 films. The disturbing forces arise primarily in the emulsion while the compensating forces are due to the base of the film. The base of the film is a very stable and strong material. On the other hand, the emulsion is sensitive to humidity and undergoes dimensional changes depending on the amount of moisture it contains. However, the emulsion is attached to the base which in turn resists any dimensional changes. Large forces are developed between the emulsion and the base and an equilibrium is reached, where some dimensional changes occur, though considerably smaller than the dimensional changes which would have taken place if the emulsion were free to expand or contract.

The presence of large opposing forces in the emulsion and the base result in bending moments, because the emulsion and the base are two separate layers and the film has a tendency to curl (a sort of bimetallic action). The film manufacturer has solved this problem by actually sandwiching the base between two layers of similar physical properties. One of these layers is the emulsion; the other is a gelatin layer similar to the emulsion but without the silver halide crystals. Thus, as long as the moisture content is uniform over the film area and identical on both sides, the film tends to remain flat or, in other words, its intrinsic curling forces are minimized. During a mission though, the moisture content along the width of the film is expected to vary because the film is rolled into a large spool and the edges of the film dry out much faster than the center. This nonuniform moisture content, discussed in Section 3.2 of this report, is expected to produce film buckling or curling. The corresponding curling forces must be counteracted by compensating forces from the film base and the camera tension in order to achieve a predetermined level of flatness during exposure.

The resistance of the film base to incremental bending moments (curling forces) depends on the modulus of elasticity of the base material and the thickness of the base layer. A small piece of film should deflect under the influence of a small bending moment by a distance inversely proportional to the third power of the thickness. Since SO-380 and 3404 differ only by the base thickness (1.5 mils for SO-380 and 2.5 mils for 3404) one would expect SO-380 to be about 4.6 · weaker than 3404 in resisting bending moments. Therefore, one reaches the conclusion that while the curling forces are approximately the same for both SO-380 and 3404 films, the ability of the SO-380 film to oppose the curling forces is reduced considerably (compared to 3404) and the burden of maintaining the film flat during exposure is left almost entirely to the camera.

The camera controls the film flatness (counteracts the curling forces) by applying tension to the film. The tension required to reduce the film displacement (or flatness error) to a specified value for a given bending moment is approximately proportional to the bending moment and inversely proportional to the film displacement allowed. This is a very significant relationship because for any finite bending moment as the allowed displacement approaches zero, the required tension must approach infinity (clearly a physical impossibility). In reality, a maximum tension limit exists in the panoramic cameras because as tension is increased, various film tracking problems appear. One then should try to answer the following important questions:

1. Is the maximum tension available in the 1100 series panoramic cameras sufficient to control the film flatness of SO-380 film to the specified levels for 3404 film?
2. What can be done to reduce the curling or disturbing forces affecting the film?

The first question cannot be answered without obtaining data on camera tensions and the magnitude of curling forces experienced by the film. As far as system CR-5 is concerned though, it would appear that there was not enough tension to control the film flatness.

The second question can be answered conclusively only through experimental evidence, but an attempt has been made in this report to point out what seem to be the most promising avenues of approach.

2. PREDICTED PERFORMANCE

The performance of the CR-5 system raises a question of paramount importance with respect to the utilization of the UTB (SO-380) film in other missions following mission 1105:

> Was the performance of the CR-5 system typical of a KH-4B system utilizing UTB film or was the performance affected by anomalies in the CR-5 system not likely to occur in other systems?

There were no anomalies in the CR-5 system that the contractor is aware of. The lower tension of the CR-5 system (discussed in Section 4) cannot be considered an anomaly. The system was tested and accepted under the lower tension and no loss in performance was anticipated.

If one could show that the performance of the CR-5 system during the mission was equal to its performance in the laboratory, then one could be sure that, indeed, there were no anomalies. Unfortunately, no simulated aerial photography was taken in the laboratory so there is no way to visually compare the actual mission photography to preflight samples. The acceptance testing of a system is limited to dynamic resolution tests and film flatness tests. The dynamic resolution tests for system CR-5 showed a resolution performance very similar to that of system CR-4. Also, the CR-5 system was focused by the same technique utilized for focusing the CR-4 system.

The film flatness tests on system CR-5 with UTB film under ambient conditions showed a different behavior than the behavior observed on system CR-4 with 3404 film:

1. The variability in film flatness between successive frames increased.
2. The sensitivity of film flatness to adjustments in the camera (including tension) as well as to individual spools of film increased.

Both the variability and sensitivity which are undesirable seem to increase further in vacuum. This behavior of the film flatness can be explained by the model described in Section 1, and further insight can be gained by reading Sections 3 and 4. Due to the increased variability and sensitivity, it was decided to perform film flatness tests on the CR-5 system in the HIVOS* chamber. If these tests showed that the film flatness was acceptable despite the increased variability and sensitivity, then the system could be qualified for a mission. A large number of frames containing film flatness information was obtained in HIVOS from the CR-5 system. The film flatness data is reduced from each frame by a tedious and time-consuming measurement technique. Therefore, only a small number of the frames obtained were reduced. The contractor examined the reduced frames and decided that the film flatness was acceptable assuming that the frames reduced represented a typical sample of all the frames obtained.

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*High vacuum orbital simulator (HIVOS).

If one could predict the system resolution performance for mission 1105 from laboratory data, then one would be certain that no anomalies appeared during the mission. However, the converse statement is not true. In other words, if the system resolution performance could not be predicted, there is no certainty that there was an anomaly, because all the effects of the mission environment on the system performance cannot be simulated in the laboratory.

Resolution predictions were computed for system CR-5 utilizing film flatness data from the HIVOS tests and the resolution prediction computer program developed during the performance evaluation study conducted by the contractor for missions 1101 through 1104. Instead of making GRD* predictions for individual first priority targets, it was considered to be more important to indicate the expected GRD performance of the cameras over the panoramic format. For that reason, the mission ephemeris data utilized in these predictions was average for the first priority targets. Figs. 2-1 through 2-3 show the expected GRD distribution over the panoramic format for average film flatness conditions. In Figs. 2-1 through 2-3, GRD predictions were computed for a limited number of points of the panoramic format because the corresponding film flatness information was limited. Figs. 2-4 and 2-5 also show similar GRD distributions over the format. These distributions are more complete because predictions have been made for more points of the format. However, the film flatness data has been obtained from a single frame. In order to compare the system CR-5 predicted performance to that of system CR-4, similar GRD distributions have also been prepared for system CR-4 and are shown in Figs. 2-6 and 2-7.

Comparing the GRD data between the various figures, one reaches the following conclusions:

1. Figs. 2-1 and 2-4 correlate with each other.
2. Figs. 2-2, 2-3, and 2-5 correlate with each other.
3. For Figs. 2-4 and 2-5, the film flatness data appears to be better than average because the GRD numbers over the format seem to be smaller than the corresponding numbers in Figs. 2-1, 2-2, and 2-3.
4. The average GRD values for systems CR-4 and CR-5 are:

	AFT		FWD	
System	Along Track	Cross Track	Along Track	Cross Track
CR-4	8.6	9.2	7.0	10.8
CR-5	9.3	10.0	6.2	7.2

This comparison of average GRD values suggests that if system CR-5 had performed as anticipated from the better HIVOS flatness tests, the performance of its FWD camera should have been superior to the performance of the FWD camera of system CR-4. In general, the film flatness tests conducted in HIVOS suggest that the average performance of system CR-5 should have been comparable to the performance of system CR-4.

Resolution predictions were also computed for the CORN targets. Tables 2-1 and 2-2 contain the predicted GRD values and the average readings that two contractor photointerpreters obtained from dupe positive materials. It is evident in Tables 2-1 and 2-2 that the resolution performance

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*Ground Resolved Distance.

of system CR-5 was degraded in comparison to the performance anticipated from laboratory data. Therefore, there is a very strong indication that during mission 1105 the film flatness deteriorated and cannot be described by the HIVOS tests.

The possibility that the film flatness characteristics of a panoramic camera could change drastically without changing any of the camera's adjustments seems at first highly improbable. However, in the laboratory it has been repeatedly observed that the film flatness displays an extreme sensitivity to the spools of film being utilized. In other words, many times a flatness (or AGT) test was run with one spool of film and the results showed the film flatness to remain well within the tolerance levels. When the test was repeated with another spool of film, the flatness would become entirely unacceptable. This is a strong indication that the film humidity content and the film's physical properties have a profound affect on the ability of a panoramic camera to maintain the film flatness within the desired tolerances.

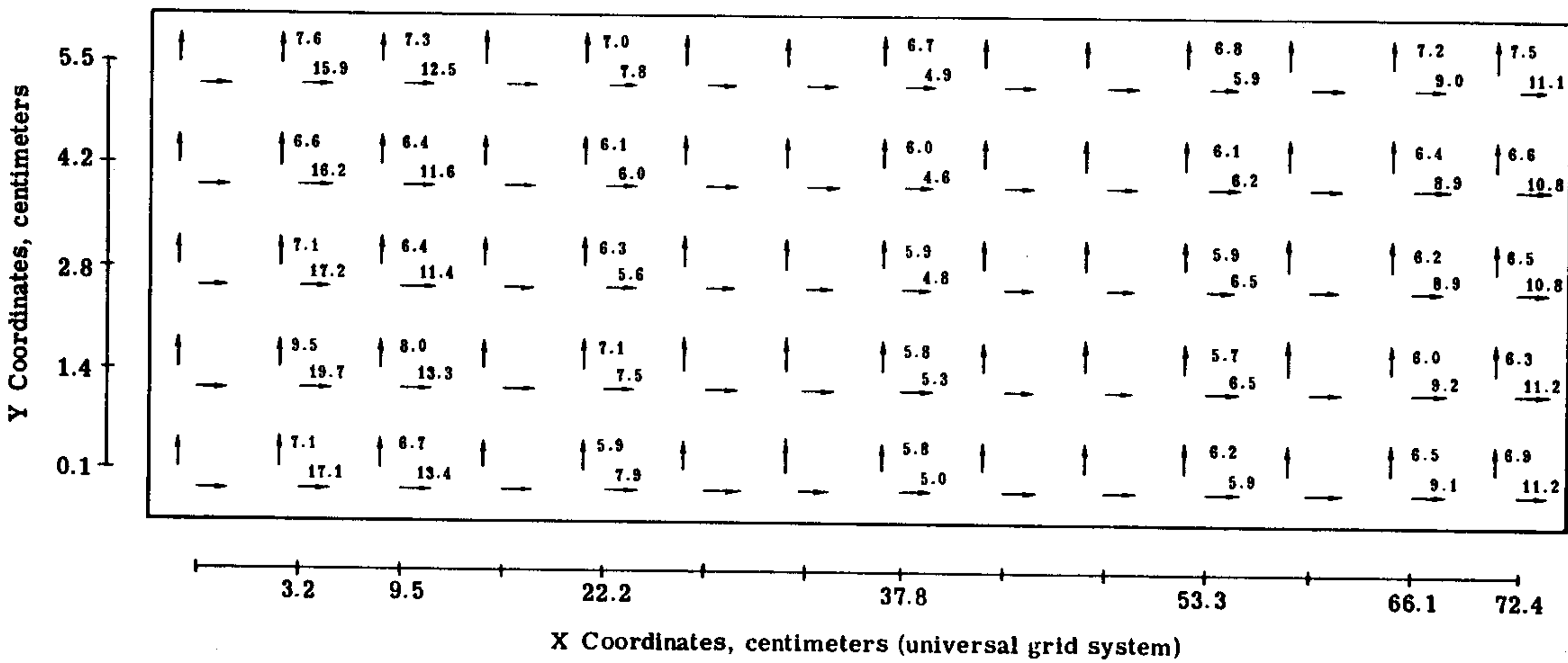

Fig. 2-1 — GRD distribution for mission 1105, FWD; GRD values in feet; low contrast (2:1) (film flatness from HIVOS AGT tests, frame no. 10; average of nine operations)

NOTE: Ephemeris data: average for first priority targets

| Along track
→ Cross track

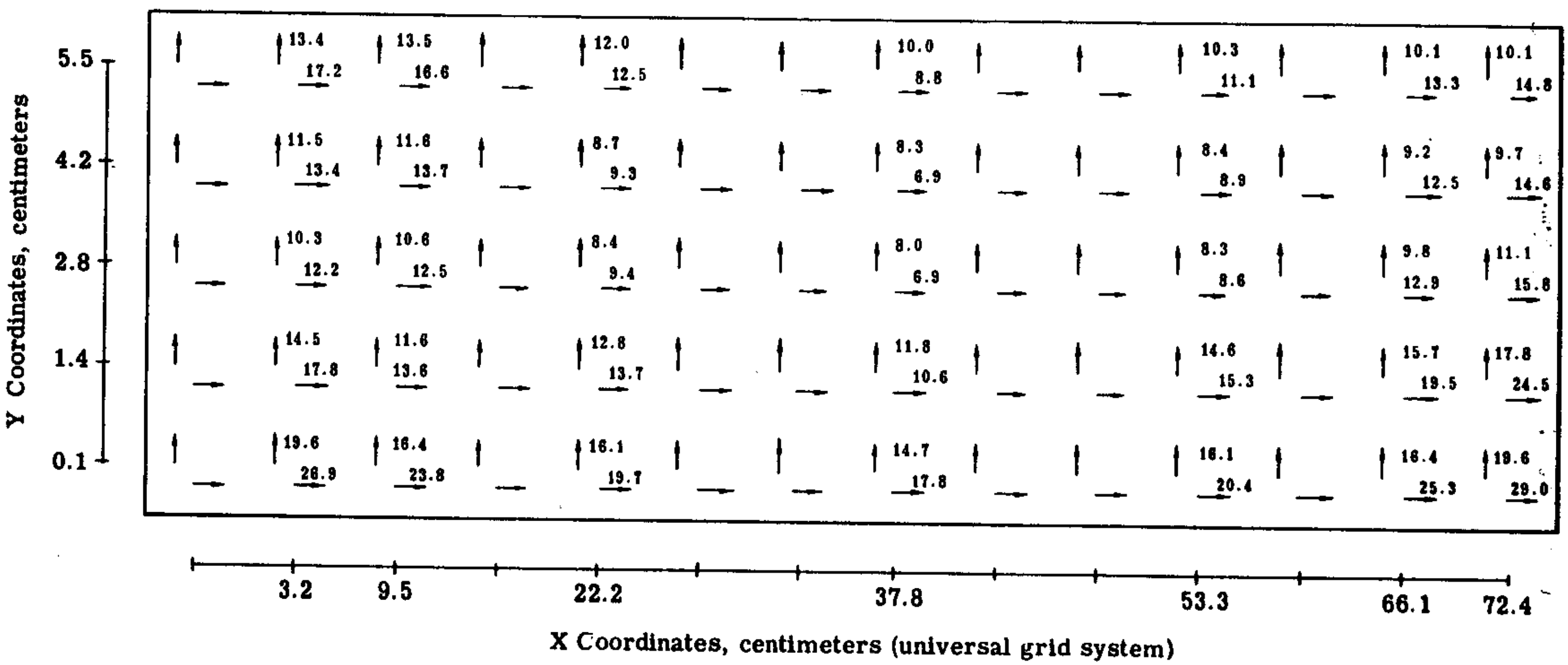

Fig. 2-2 — GRD distribution for mission 1105, AFT; GRD values in feet; low contrast (2:1) (film flatness from HIVOS AGT tests, frame no. 10; average of two operations)

NOTE: Ephemeris data: average for first priority targets

| Along track
— Cross track

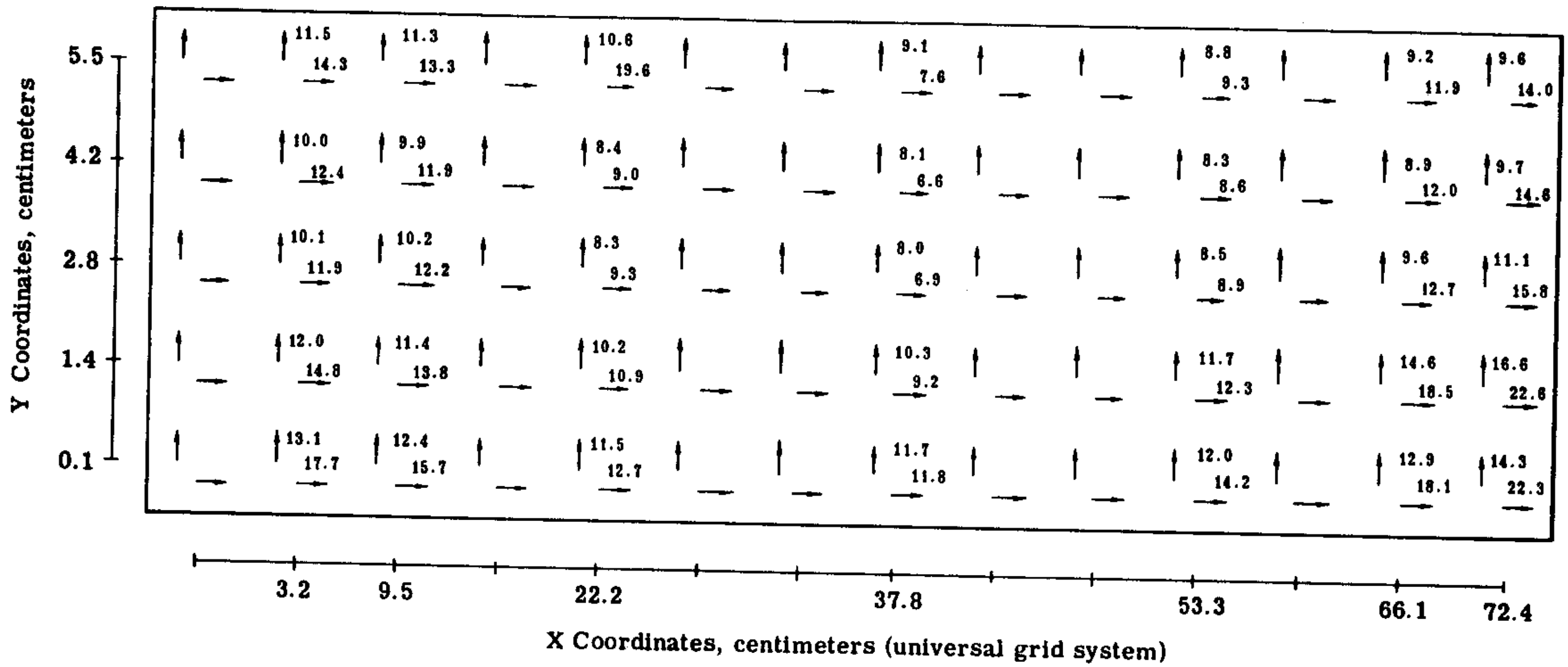

Fig. 2-3 — GRD distribution for mission 1105, AFT; GRD values in feet; low contrast (2:1) (film flatness from HIVOS AGT tests, frame no. 6; average of six operations)

NOTE: Ephemeris data: average for first priority targets

| Along track
— Cross track

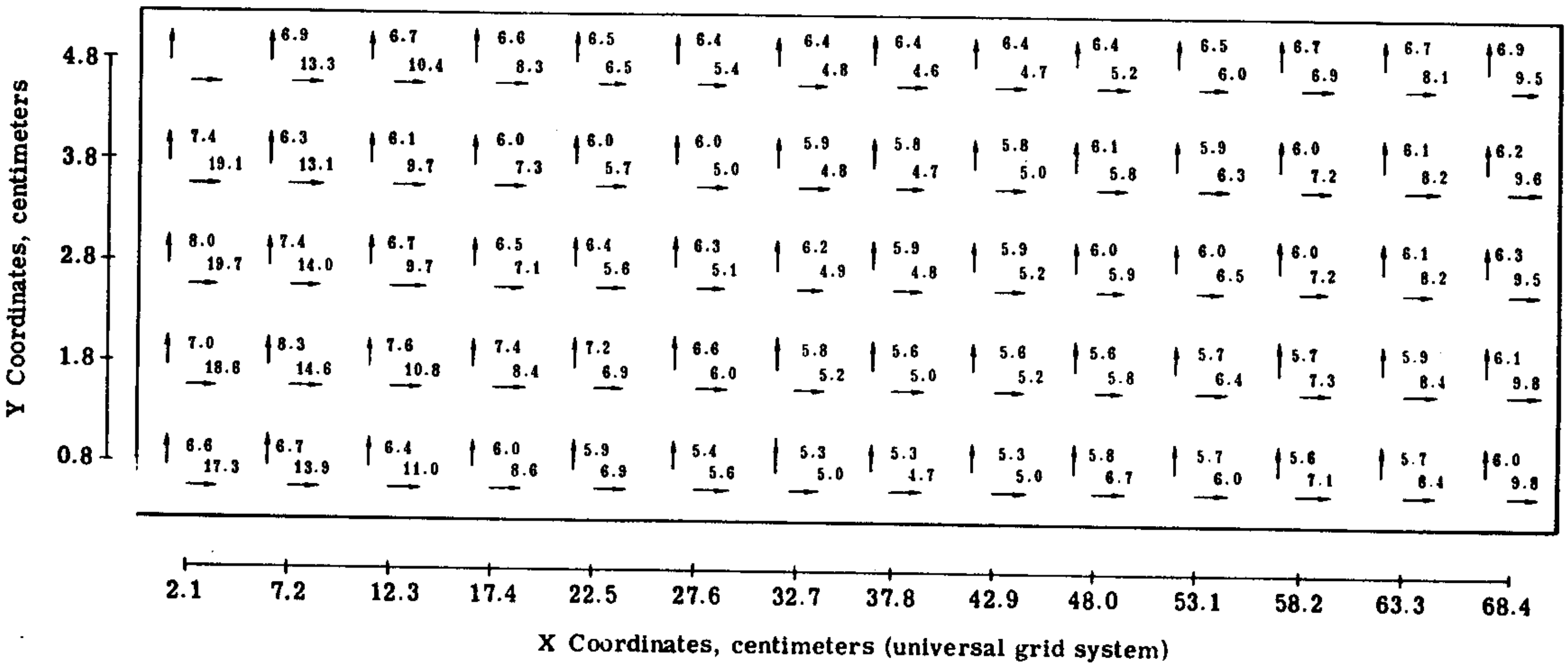

Fig. 2-4 — GRD distribution for mission 1105, FWD; GRD values in feet; low contrast (2:1) (film flatness from HIVOS AGT tests, frame no. 10; operation no. 6)

NOTE: Ephemeris data: average for first priority targets

| Along track
— Cross track

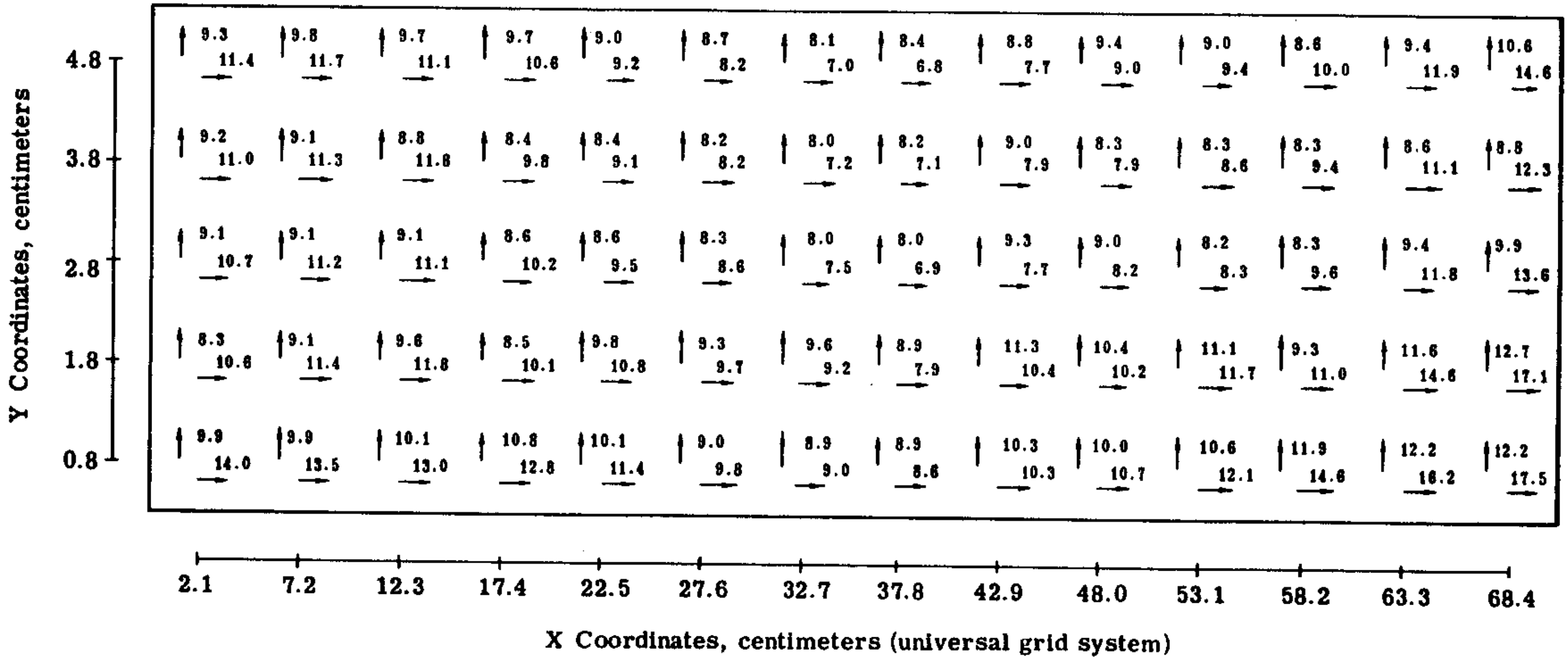

Fig. 2-5 — GRD distribution for mission 1105, AFT; GRD values in feet; low contrast (2:1) (film flatness from HIVOS AGT tests, frame no. 10; operation no. 6)

NOTE: Ephemeris data: average for first priority targets

↑ Along track
→ Cross track

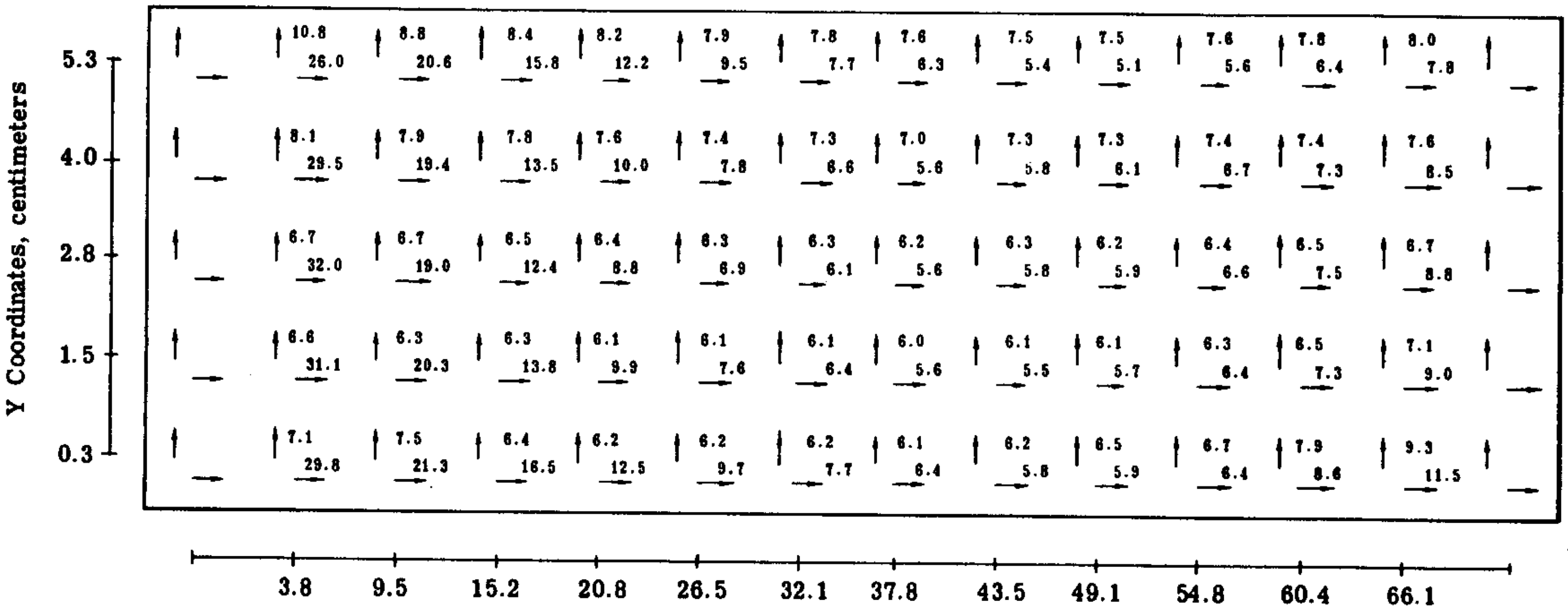

Fig. 2-6 — GRD distribution for mission 1104, FWD; GRD values in feet; low contrast (2:1) (film flatness from vacuum AGT test)

NOTE: Ephemeris data: average for first priority targets

| Along track
— Cross track

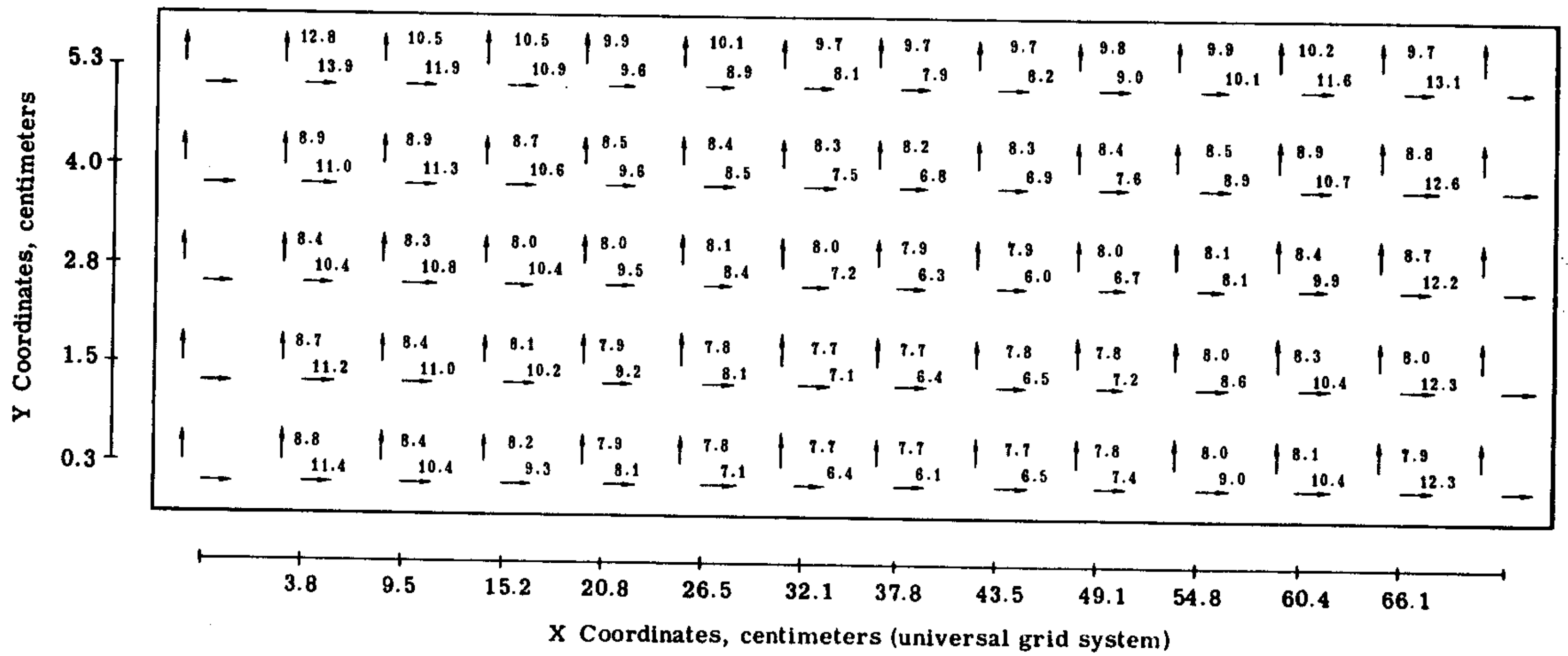

Fig. 2-7 — GRD distribution for mission 1104, AFT; GRD values in feet; low contrast (2:1) (film flatness from vacuum AGT test)

NOTE: Ephemeris data: average for first priority targets

↑ Along track
→ Cross track

Table 2-1 — CORN Target Resolution Readings and Predictions,* feet, Mission 1105 for FWD-Looking Camera

Pass	Frame	Along Track		Cross Track	
		Average Reading	Predicted GRD	Average Reading	Predicted GRD
16	13	12-16	5.7	>16	6.7
16	7	8	4.9	8	6.3
16	7	9	5.1	9.2	6.4
32	3	>16	6.2	6.5	5.8
32	13	8-12	5.6	8	5.3
32	5	7.2	5.6	7.7	6.2
64	4	11.3	6.6	12	9.4
145	6	8-12	5.8	7.5	6.1
161	12	14	6.1	14	5.9
177	21	8-12	6.9	8-12	7.7

*Predictions applicable to targets of 2:1 contrast.

Table 2-2 — CORN Target Resolution Readings and Predictions,* feet, Mission 1105 for AFT-Looking Camera

Pass	Frame	Along Track		Cross Track	
		Average Reading	Predicted GRD	Average Reading	Predicted GRD
16	19	12	7.5	12	9.3
16	13	9.5	8.1	9	9.9
16	13	8	7.7	8	9.6
32	9	8.2	8.6	7.8	10.0
32	19	7.2	9.0	8	8.5
32	11	7.4	7.8	7.4	8.0
64	10	9	7.6	8.4	9.7
145	12	10	9.5	7	12.9
161	18	10	6.9	10	7.0
177	27	8-12	7.0	8-12	8.9

*Predictions applicable to targets of 2:1 contrast.

3. FILM EFFECTS ON SYSTEM PERFORMANCE

3.1 MOISTURE CONTENT DURING MISSION

The moisture content of the film during the mission is very important because it affects, directly, its physical properties. In Section 1, it was mentioned that nonuniform moisture content along the width of the film results in film buckling or curling. This effect is also discussed in Section 3.2.

From data supplied by the film manufacturer, the moisture content of 3404 film is about 1.6 percent of its dry weight for ambient conditions (atmospheric pressure, 70°F temperature, and 50 percent relative humidity). The base itself contains moisture in the amount of about 0.25 percent of its dry weight. Therefore, most of the moisture at ambient conditions is contained within the gelatin layers.

Table 3-1 shows the amount of water contained in a full supply of film for a KH-4B mission. The water shown in Table 3-1 evaporates when the film is subjected to the vacuum of the mission environment. The rate of evaporation is affected primarily by the temperature and pressure inside the supply cassette. However, since the film is wrapped into a spool, the ends of the spool tend to dry faster than the center, resulting in nonuniform moisture content along the width of the film.

Table 3-1 — Water Content of Film at 50 Percent Relative Humidity

	3404 Film Two Full Supply Spools, Each Containing 16,000 Feet of Film		SO-380 Film Two Full Supply Spools, Each Containing 24,000 Feet of Film	
	Weight, pounds		Weight, pounds	
Dry base		132.2		121.2
Dry gelatin		26.8		40.2
Water in base	0.3		0.3	
Water in gelatin	2.3		3.5	
Total amount of water	2.6	2.6	3.8	3.8
Total weight		161.6		165.2

Data provided by the film manufacturer shows that if the 3404 film is wound into a 50-foot spool under a tension of 40 ounces and subjected to a vacuum (10^{-3} mm Hg), it looses 90 percent of its moisture content within 24 hours. It is certain that this evaporation rate is not typical of a KH-4B mission, because the film is wound into two large spools, each spool containing 16,000 feet of 3404 film or 24,000 feet of SO-380 film. Both spools are contained in an enclosed supply cassette. The quantities of water which evaporate after a very long period of time are shown in Table 3-1 (2.6 pounds for 3404 and 3.8 pounds for SO-380). It is, therefore, conceivable that inside the supply cassette the pressure is higher than 10^{-3} mm Hg for a number of days. In addition, the spools are wound under a tension of 7.5 pounds. The evaporation rate is reduced whenever the winding tension and/or the vapor pressure are increased. In any case, from the data available it is estimated that most of the moisture (90 percent or more) has evaporated within 4 days from the beginning of a mission. Therefore, one would expect that any tendency of the film to curl during the B part of a mission cannot be attributed to nonuniform moisture content in the film. The rate at which the moisture content evaporates during the mission is very important and a laboratory test should be conducted to determine this rate. A full supply cassette should be introduced into a vacuum chamber and the change of its weight with time in the chamber should be recorded. The reduction in weight should be equal to the amount of water that has evaporated.

3.2 NONUNIFORM MOISTURE CONTENT VERSUS FILM FLATNESS

In order to point out the significance of a uniform moisture content along the width of the film, the following example has been worked out:

1. Start with film at 50 percent relative humidity wrapped into a spool.

2. The spool is introduced into a vacuum and loses 90 percent of its moisture content; the remaining moisture represents an average of 5 percent relative humidity.

3. The edges of the film are completely dry while the center contains the maximum residual moisture. The distribution of moisture across the width of the film is approximately half a sine wave or parabolic. The edges of the film have zero relative humidity and the center has 7.85 percent relative humidity, so the average relative humidity is 5 percent.

4. The difference in relative humidity between the center and the edges results in a differential coefficient of shrinkage between the center and the edges of 0.135 percent* (about 0.07 percent for 3404 film).

5. Assume that the film is introduced into a panoramic camera without any further changes to its humidity content.

6. While a frame is being exposed, the film is being lifted and supported by the focal plane rollers which are located about 0.9 inch apart.

7. Due to the differential shrinkage between the edges and the center of the film, the length of the film at the center will be 0.0012 inch longer for a corresponding length along the edge of the film of 0.9 inch. This extra length can be accommodated by the film buckling or arching at the center of format as shown in Fig. 3-1. The displacement Δ shown in Fig. 3-1 is 0.020 inch.

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*Film manufacturer's data.

For a real system, this example tends to be an oversimplification of the film dynamics. Tension applied by the camera reduces considerably the displacement Δ. However, the residual displacement is a flatness error.

This example points out the significance of maintaining uniform moisture content in the film.

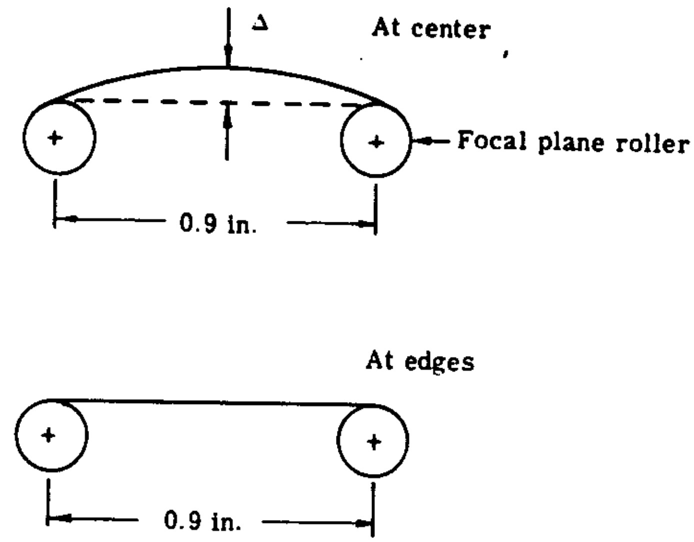

Fig. 3-1 — Film buckling

3.3 OTHER PHYSICAL PROPERTIES

The physical properties of the film are a compromise for a relative humidity of 50 percent. In vacuum, it should be expected that the physical behavior of the film would be much poorer, whether there is any moisture left in it or not. It is possible that the film may tend to curl when in equilibrium with a very dry environment (all moisture removed from film) and that the curling tendency may be strongly influenced by the manufacturing process through variations in the thickness and modulus of elasticity of its base.

The contractor's experience with the UTB film shows that extreme variations in the film flatness tests can be observed by simply changing spools of film. This behavior suggests that there are differences in the physical properties of the various spools of film. It has not as yet been possible to control physical properties of the film to the extent one would desire. The manufacturing tolerances on the thickness and the modulus of elasticity of the base are important because they affect the curling and buckling properties of the film under the forces developed by the gelatin layers.

4. TAKEUP TENSION TESTS

During February and March of 1969, a series of evaluation tests were conducted on several takeup units including takeup units from the CR-5 system. The tests included evaluation of low temperature and vacuum environments, supply voltage sensitivity, and warmup time. The objective of the tests was to determine their effects on dynamic operation of film tension at the takeup (output) side of the camera.

4.1 LOW TEMPERATURE EFFECT

The A takeup from the CR-5 (T307) system was reassembled after recovery and was operated over a full range of wrap radius at 75 and 45 °F. The dynamic tension at 45 °F was 2 ounces lower for an empty spool and 1 ounce lower near a full spool (Fig. 4-1). The most important results of these tests are shown in Fig. 4-2. The two upper curves show how the static (takeup spool not rotating) tension varies with spool diameter. The takeup tension is adjusted statically with an empty spool (spool diameter = 3.9 inches). The top curve would correspond to system CR-4 (static tension = 46 ounces with an empty spool). The second curve corresponds to system CR-5 (static tension = 35 ounces with an empty spool). The third curve is the dynamic tension of the spool versus spool diameter, corresponding to the second static tension curve. Comparing the curves of Fig. 4-2, one reaches the conclusion that the average dynamic tension for system CR-5 was probably about 17 ounces, while for system CR-4 the dynamic tension was about 24 ounces. Therefore, it appears that the dynamic tension for system CR-5 was about 29 percent lower than the dynamic tension for system CR-4. It should be emphasized though that the actual dynamic tension of the panoramic cameras during mission 1105 is not known. Furthermore, it is questionable as to whether or not the dynamic tension shown in Fig. 4-2 is a close approximation to the actual dynamic tension for mission 1105 for the following reasons:

1. Takeup unit T307 was disassembled after recovery in order to remove the film for processing.
2. The unit was improperly assembled (excessive preload on bearings) after removal of its film load.
3. The bearings failed during the tests conducted at the contractor's facility, and the failure was attributed to the excessive preload.
4. The unit was disassembled for the second time, the bearings were replaced, and the unit was reassembled again. Then the tests shown in Fig. 4-2 were run.

Nevertheless, the test results shown in Fig. 4-2 are the best information available on the dynamic tension of system CR-5, and one is forced to assume that the most probable dynamic tension was 17 ounces.

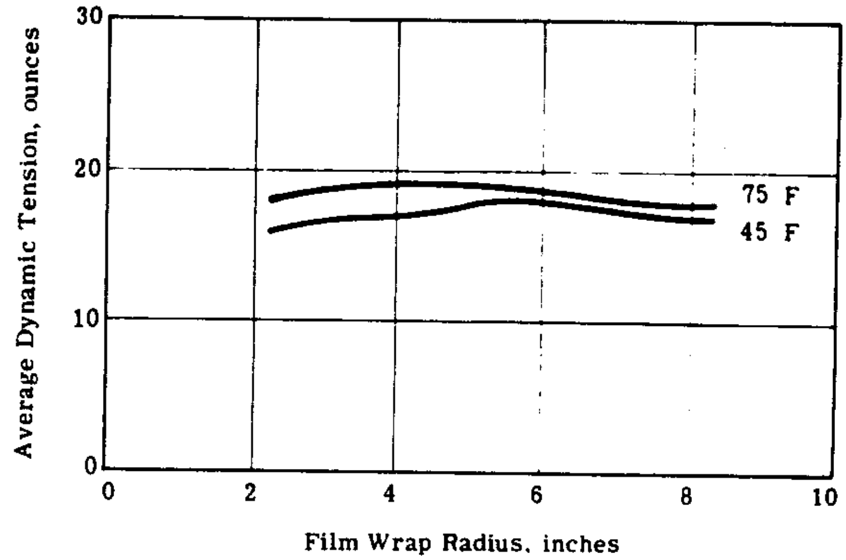

Fig. 4-1 — Dynamic takeup tension versus film wrap radius

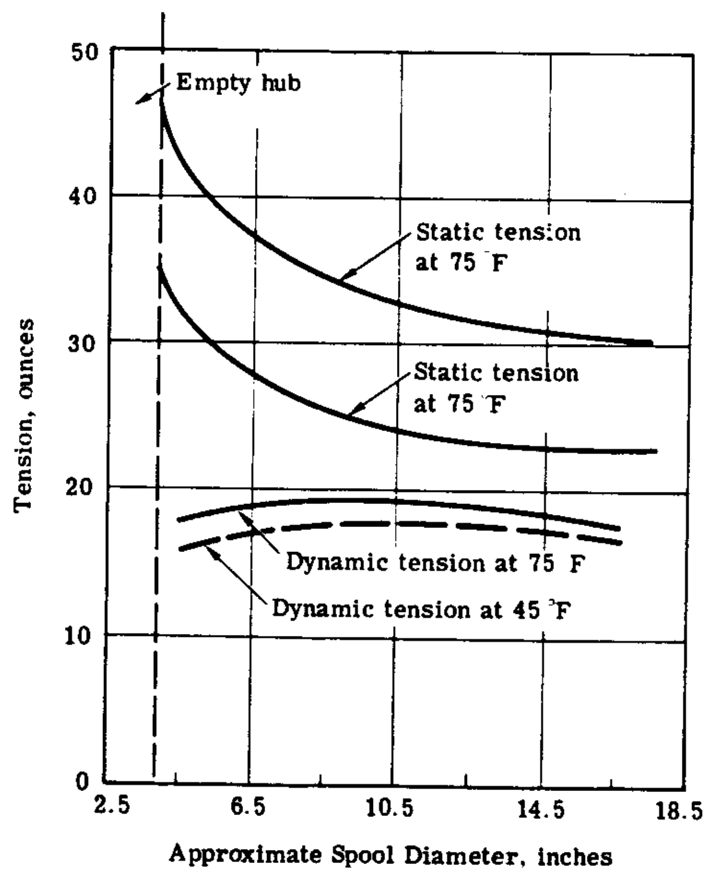

Fig. 4-2 — Dynamic takeup tension versus spool diameter (takeup unit no. T307)

4.2 VACUUM EFFECTS

During the SO-380 vacuum evaluation tests in March 1969, camera number 331 of system CR-15 was instrumented with supply and takeup film tension monitors, and film flatness and smear tests were conducted in vacuum. Takeup A (unit number T333) was shown to successfully operate in vacuum with dynamic tension variations of 1 to 2 ounces (Fig. 4-3). It is believed that a substantial portion of this decrease was due to the drain on the batteries caused by the tension instrumentation.

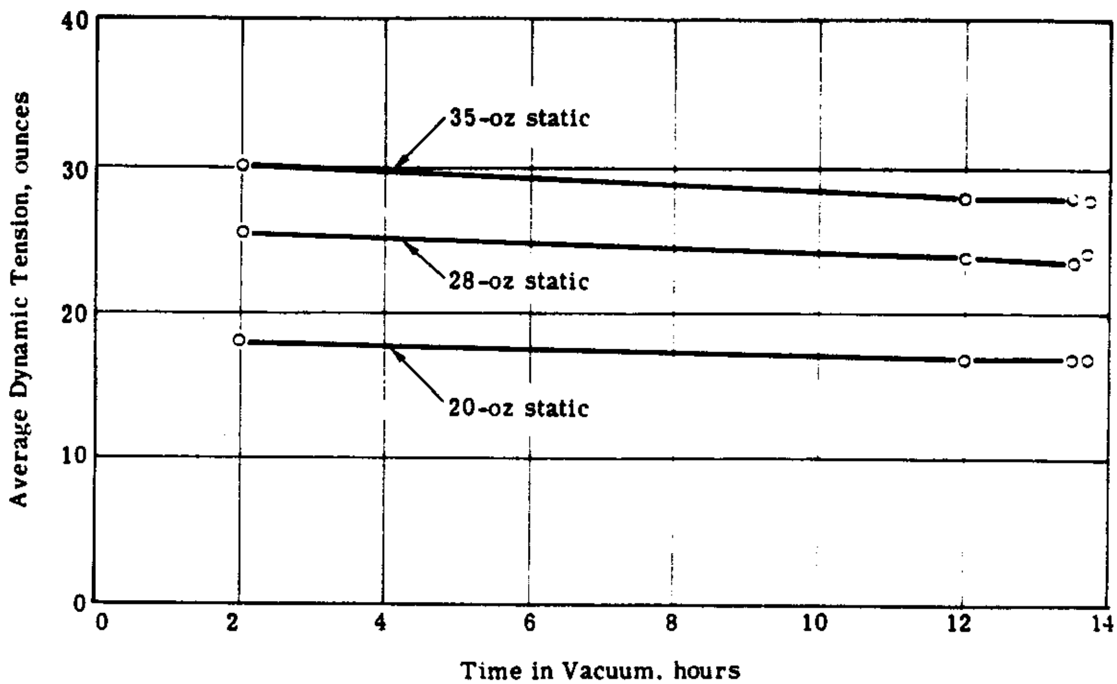

Fig. 4-3 — Dynamic takeup tension versus time in vacuum (MI331/T333, side 2) (film wrap radius of 6.5 inches)

4.3 WARMUP TIME

Upon application of power to the takeup, there is a period of motor current drift which is believed to be the thermal stabilization time of the tension control circuit. The increase in motor current during a 15-minute stall test is 13 percent (Fig. 4-4), and an equivalent change in dynamic tension can be assumed.

4.4 VOLTAGE SENSITIVITY

The variation of dynamic tension with the unregulated battery supply voltage is shown in Fig. 4-5. The gradient is seen to be about 0.4 ounce per volt. The battery voltages varied between 24.30 and 25.60 vdc on mission 1104, which is equivalent to a 0.53-ounce variation in tension. The voltage variation for mission 1105 was 24.30 to 24.56 volts, or a difference of 0.26 volt, corresponding to a change in tension of 0.1 ounce.

4.5 CONCLUSIONS

Systems CR-1, CR-2, CR-3, and CR-4 had static (empty spool) takeup tension settings of 46 ounces, while for system CR-5, the static tension was set at 35 ounces due to strain marking of the SO-380 film. It appears that the 35-ounce setting may have resulted in a reduction of dynamic tension of about 29 percent. There is no doubt that the lower dynamic tension had an adverse affect on film flatness. However, the apparent poor film flatness conditions for mission 1105 cannot be attributed entirely to the lower dynamic takeup tension.

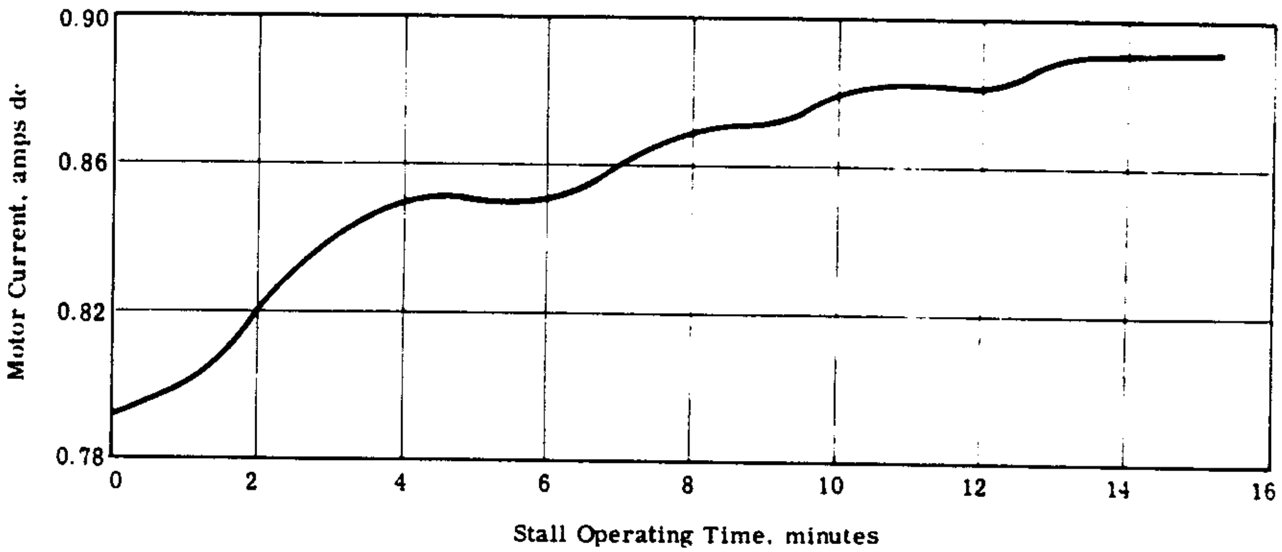

Fig. 4-4 — Takeup motor current versus stall operating time

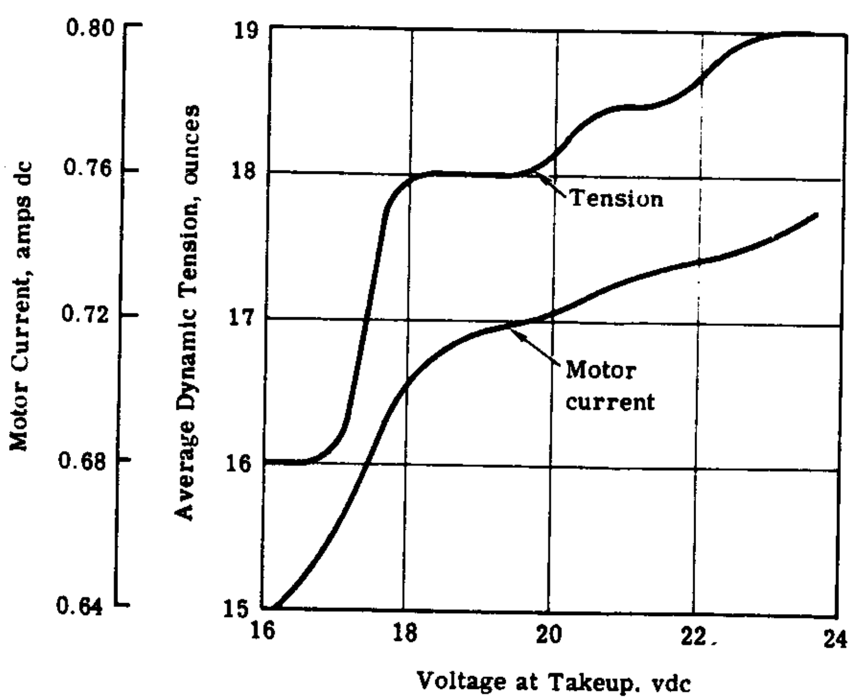

Fig. 4-5 — Dynamic takeup tension and current versus supply voltage

5. GENERAL CONCLUSIONS AND RECOMMENDATIONS

The results of the contractor's GRD prediction computer program for systems CR-4 and CR-5 shows that if system CR-5 had performed as anticipated from the better HIVOS flatness tests, the performance of its FWD camera should have been superior to the performance of the FWD camera of system CR-4.

On the basis of the best information available*, it appears that the dynamic takeup tension for takeup unit A (T307) of system CR-5 was probably about 17 ounces, about 7 ounces lower than the dynamic tension of system CR-4.

From Section 4 it is apparent that adjustments of the static tension provide poor control on the actual dynamic tension.

In terms of physical properties, the UTB film is poorer than 3404. Since the base of a film provides strength to the film and stability to its physical properties, reducing the thickness of the base without increasing its stiffness will result in a film whose physical properties are more variable and susceptible to manufacturing tolerances and the mission environment. The UTB film should be weaker than the 3404 film by:

1. 1.7× for shrinkage forces
2. 4.6× for bending moments.

Due to the weakness of the base in UTB film, it will be necessary to take the following steps in order to achieve acceptable and consistent film flatness levels in the KH-4B panoramic cameras:

1. The dynamic film tension within the panoramic cameras should be increased as far as possible.

2. The moisture content of the film should be controlled throughout the mission. This may be accomplished by predrying the film in a chamber, rewinding it into the supply cassette, and pressurizing either the cassette or the vehicle with dry nitrogen. During the ascent mode, the nitrogen may be released at a controlled rate so that a certain positive pressure difference exists between the interior of the cassette and the exterior of the vehicle.

3. The manufacturing process of the UTB film should be re-examined and it may be necessary to tighten the tolerances on thickness and modulus of elasticity of the material.

It seems that the system performance in the B part of mission 1105 was not affected by the film moisture content, because, according to the information presently available†, the film should have completely dried out within the A part of the mission. Hence, the system performance in the B

*See Section 4.1.
†Eastman Kodak.

part was most likely adversely influenced by the lower system tension [not necessarily 17 ounces which is the most probable dynamic tension for takeup unit A (T307)] and unknown variations in the physical properties of the film due to tolerances in the manufacturing process. It is very important, though, to determine the moisture evaporation rates during the mission for the UTB and 3404 films.

The fact that very good film flatness results have been achieved with UTB film many times in a vacuum chamber suggests that a panoramic camera could maintain the required film flatness tolerances consistently once the flatness disturbing properties of the UTB film have been identified and properly controlled.

It is the contractor's position that, on the average, the performance of a panoramic camera with UTB film is expected to be different than its performance with 3404 film. However, the difference in performance between the two films may not be significant in future missions and, in any case, must be carefully weighted against the known advantage of the UTB film (50 percent more coverage).

Increasing the dynamic tension within the limits imposed by film tracking considerations is expected on the average to improve the performance of a camera with UTB film. Furthermore, if the moisture content of the film were to be controlled during the mission, the performance is expected to improve further. However, there is no guarantee that the increased dynamic tension and the control of the moisture of the film will result in consistently good image quality. Therefore, it is necessary to determine the average loss in performance that would be acceptable with UTB film conditioned by the increased coverage. It is the contractor's opinion that the use of the UTB film should provide an advantage over 3404 film, if the performance of a panoramic system was equal to or better than the performance of the CR-5 system during the B part of the mission.

Finally, the contractor offers the following recommendations for the KH-4B systems to be loaded with UTB film:

1. The tension of each panoramic camera should be adjusted dynamically between 35 and 25 ounces, provided that no film tracking problems develop. The dynamic tension should be adjusted to be about 5 ounces lower than the minimum dynamic tension at which tracking difficulties become evident.

2. Final acceptance flatness tests should be conducted in vacuum, using film of the same emulsion number as the film utilized in the corresponding mission.

3. The rate of moisture evaporation should be determined by measuring, in vacuum, the change in weight with time of a KH-4B supply cassette loaded with UTB film.

4. The UTB film utilized for laboratory tests conducted in a vacuum chamber or the film supply of a mission should be completely dried out.

5. Methods for stiffening the film base should be investigated. It might be possible to reinforce the film base with glass fibers.

6. The physical properties of the UTB film in vacuum and its manufacturing process should be re-examined. It might be possible to suppress any curling tendencies of the film in vacuum by altering the manufacturing process or the tolerances.