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DUAL MODE GAMBIT SIMULATION—SCALE STUDY

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1. INTRODUCTION

The scale study work was prompted by the potential use of the Gambit system in a dual mode, both in its present configuration as a surveillance system and to extend its capabilities to a search system. The dual mode requirement was for the imagery to achieve a NIIRS 4 rating at an altitude of 350 miles. The influence on performance of film type, illumination conditions, scale, and system dynamics were factors that had to be considered.

The initial approach was to solve the problem analytically. That study indicated the search mode would achieve the required performance level. To confirm the analytical results, the scale study was designed to estimate performance based on assessment of simulation imagery by the actual users—photointerpreters.

Two films were chosen for this study, SO-209 and SO-112. Requirements were for resolution limits considerably greater than SO-208 and appropriate GRD at 350 miles to get a NIIRS 4 rating. SO-209 is the slower of the films and its anticipated application would be during the summer. The greater energy level during that part of the year would minimize exposure times and consequently reduce the amount of image motion. SO-112 was intended for wintertime use, since it is a faster film than SO-209, although its resolution is less.

A major consideration of the simulation work was the selection of scales to give a reasonable incrementation both in scale and rating. The boundaries were essentially determined by the two modes of operation, surveillance and search. As a linear relationship exists between rating and log GRD, the spacing of the scale intervals was determined in a log scale domain to give uniform incrementation. The rating information generated can be applied to find an expected rating at a specific scale or used in the future with a statistical distribution of scale during a mission to predict an average rating level.

The scope of this project (for each film) was to determine if that film could perform the mission. This judgment would be based on achievement of a NIIRS 4 rating for the search mode. Accordingly, PI rating experiments were designed to assess the impact of scale on quality. However, under similar acquisition parameters, absolute ratings of simulation and operational imagery can vary, but within an experiment, differences in rating between images are accurate. Therefore, a third film, SO-208, was included in the experimental design to serve as a reference point for SO-209 and SO-112. Operational quality levels are known for SO-208 and in the experimental context, the SO-208 ratings can serve as a baseline comparison for the other films.

The scale study analyzed the suitability of SO-209 and SO-112 for their respective winter and summer acquisitions applications. The question of whether these films could perform the mission was to be answered on the basis of the NIIRS rating level achieved. It should be emphasized that the study was not intended to select films. Imagery exists for such a task, but the scope of the scale study was to determine the performance levels of SO-112 and SO-209 films.

2. TASK SUMMARY

The basic objective of the scale study analysis was to investigate the rate of change of quality with scale. Within this framework, the specific effects of solar altitude, aerial contrast, and image motion were examined to provide exposure recommendations and performance predictions of several films. The following tasks are performed to:

1. Determine the rate of change of quality with scale through contrast for SO-209 film at a 34-degree solar altitude for three aerial contrasts, zero motion, and best exposure.
2. Determine the rate of change of quality with scale through contrast for SO-112 film at a 19-degree solar altitude for three aerial contrasts, zero motion, and best exposure.
3. Determine the rate of change of quality with scale through contrast for SO-208 film at a 34-degree solar altitude for three aerial contrasts, zero motion, and best exposure to provide a quality baseline for comparison with SO-209 and SO-112 films.
4. Determine the effect of motion and exposure on image quality and provide exposure recommendations for SO-209 and SO-112 films for 0.7 atmospheric transmission at 34- and 19-degree solar altitudes, respectively.

To accomplish these tasks, the scale study comprised two programs. The initial phase was to design and produce an image data base with the appropriate acquisition parameters. Then, utilizing this photography, a series of image quality experiments were performed to analyze the effect of scale on quality and to provide recommendations for operational exposures.

3. IMAGE DATA BASE

The scale study imagery was produced at the Image Simulation Facility in conjunction with the Five Film Study photography. The total set comprises more than 24,000 images taken under a wide variety of conditions. Film type, illumination, image motion, exposure, and photographic scale were all varied during the photography. Selection of the imaging parameters was based on the systems being simulated and the tasks to be performed. Descriptions of the simulation parameters and a matrix of the acquisition parameters follow.

3.1 SIMULATION GEOMETRY

The acquisition geometry requirements were basically those for the previous Three Film Study. Camera orientation simulated a platform moving north to south operating in the aft mode with 10-degree pitch and 15-degree roll requirements, resulting in a net camera look angle of 18 degrees. The latitude specifications were 55 and 70 degrees north, and based upon the Three Film Study analysis, correspond to sun angles of 34 and 19 degrees and sun azimuths of 162 and 164 degrees, respectively. A third sun position was established at a 45-degree solar altitude and 159-degree azimuth from true north and provides another typical acquisition condition for both systems. The net image motion direction was set to have an in-track to cross-track ratio of 5:7. The test pattern array was rotated so that the four principal resolution targets had their elements aligned along in-track and cross-track directions, and the OB targets were rotated so that the motion direction would be approximately 45 degrees to their long axes.

3.2 TARGET ARRAY

The target array used in the scale study consisted of selected air and ground order-of-battle objects surrounded by several test patterns. Four scale models of the MiG-25 Foxbat were used; the 1:87, 1:100, and 1:150 scales being purchased in kit form while a 1:48 scale model was constructed using the 1:87 scale aircraft as a pattern. These planes were painted to achieve a nominal 36 percent reflectance and were positioned on background of 25 percent reflectance. In addition, realistic insignia were added to the AOB. Models of the SU-85 tank destroyer (at 1:50 and 1:87 scale) were also included in the scene, being 14 percent reflectance on an 8 percent background.

Two lenses were used in the data base production, a 13- and 5.5- millimeter Switar. The reduction ratio at which a lens is operated and the model scale of a target combine to produce a net simulated scale. For example, a 1:150 model scale denotes the ratio of model size to real object size. At the Simulation Facility, the 13-mm lens was used at a 1:769 reduction, image size to model size. When the 1:150 target was photographed with the 13-mm Switar, the simulated scale is 1:115,000, image size to real object size. Table 3-1 lists the models in the target array and the resultant simulated scales.

Test patterns included in the target array were:

1. Six 1951 USAF resolution targets
2. Log periodic target
3. Two VEM edge targets
4. Double annulus ring target
5. Sieman's star target.

A ground truth photograph of the target array is contained in Appendix B.

Table 3-1—Simulated Scales

AOB	Model Scale	Simulated Scale, ×1,000, 13 mm (769 × reduction)	Simulated Scale, ×1,000, 5.5 mm (1746 × reduction)
A	1:48	37	84
B	1:72	55	126
C	1:100	77	175
D	1:150	115	262
GOB			
A	1:87	67	152
B	1:150	115	262

3.3 ILLUMINATION CONDITIONS

Aerial contrast and the sun-to-sky ratio for typical acquisition conditions were provided by another contractor. The initial phase of data base production involved the set-up and calibration of these illumination conditions. The procedure involves determination of the effect of each of the illumination parameters, sun, sky, and haze, utilizing photometric measurements. From this, a set of aim voltage settings for the lighting are derived for each aerial contrast/sun-sky ratio condition. Subsequently, the film is used as a radiance sensor by photographing uniform reflectance patches through an exposure range and measuring the transmission densities of the processed imagery. The resultant aerial contrast and sun-sky ratio are calculated through sensitometric comparisons, and voltage corrections can be made if required.

This method was proven effective as measurements of the aerial contrast and sun-sky ratio in the final imagery were on the average within 5 percent of the aim specifications.

3.4 IMAGE MOTION

Image motion is simulated by introducing motion at the target plane during exposure. Both the type and magnitude of motion can be varied to simulate actual acquisition conditions. Linear, sinusoidal, and rapid deceleration motion at levels from 0 to 16 micrometers in the image plane are available.

In the scale study, linear motion levels of 0, 2, 4, 8, and 16 micrometers were used during the photography. It was necessary to modify the motion apparatus to simulate equal magnitudes of motion with the two lenses used in the scale photography. Because the motion is introduced in the object plane, the shorter focal length lens required a greater relative movement to produce the same amount of image plane motion as the longer lens. An additional lever arm was positioned in the rod connecting the motion drive to the model.

3.5 CAMERA

The Mark III camera was designed and fabricated for the simulation facility, and allows for precise replication of photographic parameters.

A wide variety of 70-millimeter-width materials are accepted by this camera. During exposure, a vacuum platen holds the film flat against three reference pins that define a repeatable focal plane. The lens is moved relative to the film plane by a differential micrometer to provide small focus changes. The lens mount has three-point suspension to allow alignment of the optical axis to the film plane. An electronic shutter and filter holder are positioned in front of the lens.

A laser technique is used to align the film plane, optical axis, and the object/model plane center. The alignment is verified by test photography of a resolution target array.

To provide the range of scale required for this study, 13- and 5.5-millimeter Switar lenses were used. MTF and resolution measurements indicated the quality of the two lenses to be nominally equivalent.

3.6 FILM

The imagery was processed and duped according to operational specifications. A wide range of printing levels was used to ensure the optimum dupe exposure was available for each level of original negative exposure. Table 3-2 lists the processing/duplication specifications for the scale study films.

Table 3-2 — Processing/Duplication Specifications

Film	Developer	Process	Duplication Film
SO-209	41 DN-V	Yardleigh	SO-332
SO-112	40 DN-V	Yardleigh	SO-332
SO-208	19 DN-V	Yardleigh	SO-192

3.7 FINAL PHOTOGRAPHY

Table 3-3 presents a matrix summary of the conditions under which the target array was photographed. Three duplicate exposures were made at each exposure level. Also included in the data base are the images of large (4 × 4 feet) paint patches of known reflectances. These patches were photographed at each illumination condition and provide references for aerial contrast and sun-sky ratio calculations and for tonal transfer analysis.

Table 3-3 — Condition Matrix

Solar altitude	34 Degrees			45 Degrees			19 Degrees		
Illumination conditions [Aerial contrast (A/C) and sun/sky (S/S) ratios] for each film	A/C	S/S	Film	A/C	S/S	Film	A/C	S/S	Film
	2.27	6.06	209			209	1.92	2.55	209
	1.92	3.39	112	2.38	8.37	112	1.63	1.21	112
	1.63	1.86	315			315	1.41	0.44	315
Linear smear	0, 2, 4, 8, 16 micrometers			0, 2, 4, 8 16 micrometers			0, 2, 4, 8, 16 micrometers		
Exposure range (stops)	+2, +1, +1/2, 0, −1/2, −1, −2			+2, +1, +1/2, 0, −1/2, −1, −2			+2, +1, +1/2, 0, −1/2, −1, −2		

Scales (×1,000) AOB: 37, 55, 77, 84, 115, 126, 175, 262
GOB: 67, 115, 152, 262

4. IMAGE QUALITY EXPERIMENTS

There were two types of questions addressed by the scale study. One dealt with the determination of the rate of change of quality with scale and the other with the recommendation of an optimum exposure in the presence of system motion. These correspond to, in an experimental context, a scale change experiment and an exposure motion tradeoff experiment (EMTO).

Three films, SO-208, SO-112, and SO-209 were involved in the scale change experiments. For each film, preliminary experiments were performed to select the best duplicate printing level per ON exposure and then the best ON exposure per atmosphere. When completed, the effect of scale on quality was tested through scale at three aerial contrasts.

Two EMTO experiments were conducted, one each for SO-112 and SO-209 films. For these, only the best duplication printing level per original negative (ON) exposure needed to be selected prior to the EMTO experiment. The tradeoff analysis was performed at one scale and one aerial contrast for seven ON exposures and four motion magnitudes.

Fig. 4-1 outlines the basic experimental flow chart. Optimum duplication determination serves a dual purpose as it is the first quality experiment for both the scale change and EMTO analyses. The latter analysis follows immediately; but in the scale change work, the optimum ON exposure must be determined first.

Several measurement programs were also carried out on the imagery. Quantification of aerial contrast and sun/sky ratio values required densitometry. Both macro and micro readings were necessary to confirm equivalence of the illumination parameters for the 13- and 5.5-millimeter lenses. In addition, the density measurements are essential to relate simulation to operational exposures. Resolution readings of the targets surrounding the model array were made to assess the performance of each lens in the final photography sets. These measurements verified that both lenses were operating at comparable levels.

The processed original negatives were each printed through a wide range of duplication policies to ensure that the optimum printing level was obtained for each of the ON exposures. For each film, the initial step involved phototechnologist-screening of the available duplicates. Rank-order method was used to select the best four or five policies per ON exposure out of a dozen or more candidates. The chosen policies are then incorporated into experiments for photointerpreter evaluation.

The complete set of scale study image experiments are shown in Fig. 4-2. Essentially, they are the flow plan of Fig. 4-1 replicated for the three films. Alterations to the basic plan are that no EMTO was necessary for SO-208 and the additional EMTO shown for SO-112 (experiment 632-12) was performed for the Five Film Study. In addition, a quality comparison among the three films was performed (experiment 632-14). A summary of the experiments, categorized by films, follows.

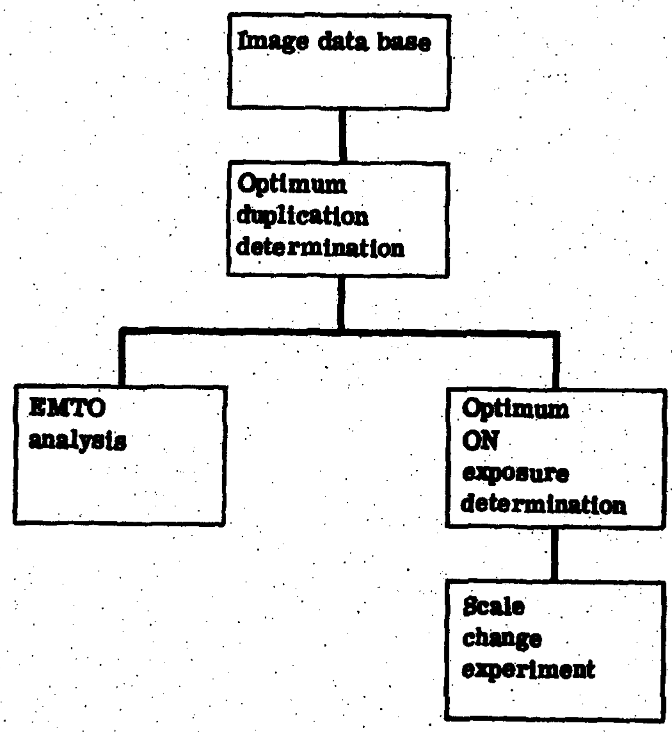

Fig. 4-1 — Basic experimental flow chart

PI EXPERIMENTATION

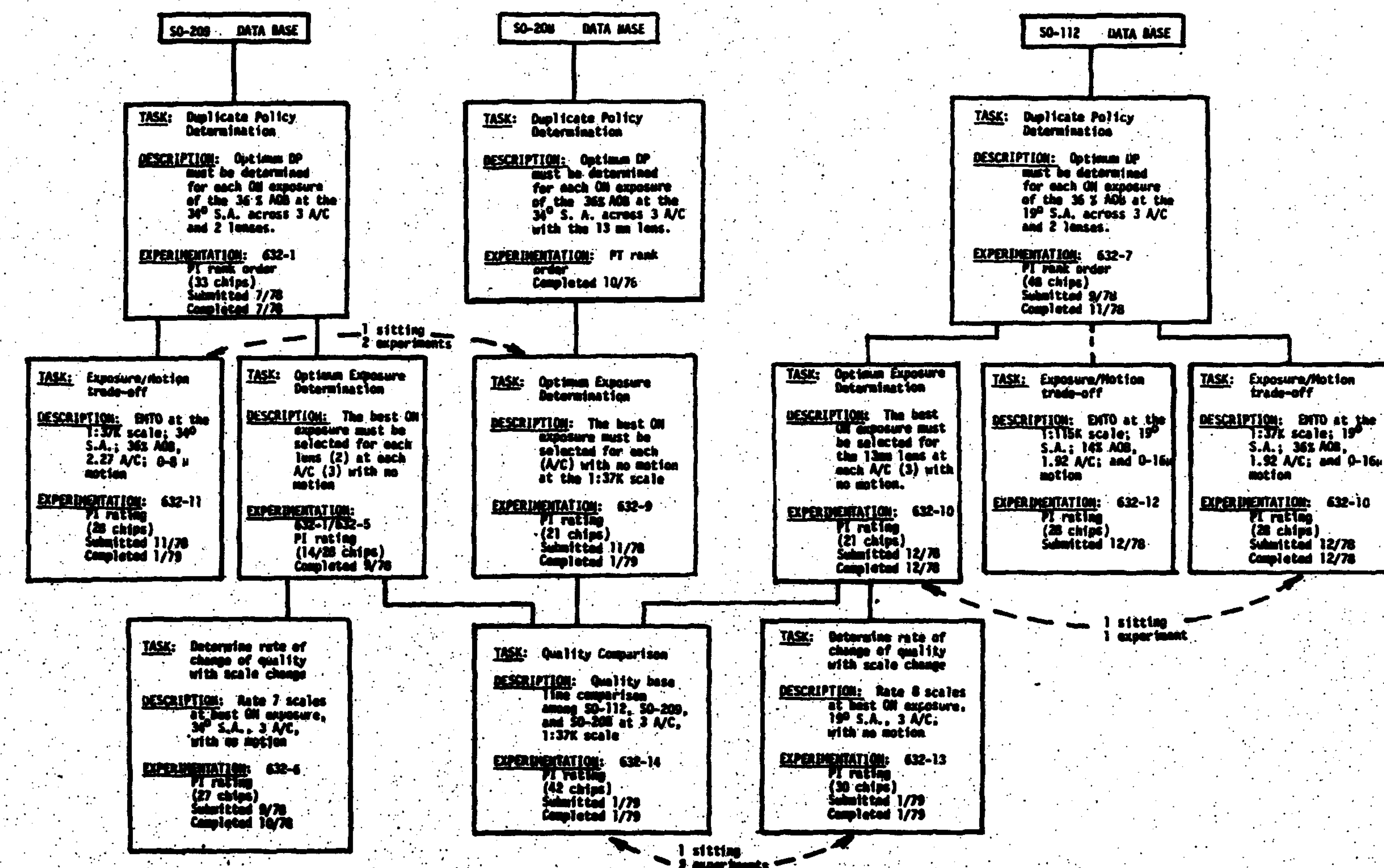

Fig. 4-2 — Complete set of image experiments flow chart

4.1 FILM SO-209

Experiment 632-1

The initial scale study experiment contained imagery from both lenses, the 115,000- and 126,000-scale AOB's from the 13- and 5.5- millimeter lenses, respectively. The reader is reminded that these scale values refer to the net simulated scale; image size to real object size. These are obtained by photographing a model (whose scale is given by model size to real object size) at a given reduction (image size to model size). The 115,000 scale resulted from the smallest model (1:150 scale) on the target array being photographed with the 13-mm lens at a 769x reduction. The 126,000 scale was realized by photographing the second largest target model (1:72 scale) at a 1,746x reduction with the 5.5-mm Switar. The imaging conditions were identical for both lenses: 34 degrees solar altitude, 0.6 atmospheric transmittance, and zero motion.

Photointerpreters were presented with a range (4-6) of duplicate printing levels for each of the seven ON exposures. For each group of DP's, the PI's rank ordered the images in quality and gave a NIIRS rating to the best DP. The rank order data was analyzed to determine the optimum duplication policies for each SO-209 exposure. Mean ratings were plotted as a function of exposure and a smoothed curve was drawn through the points. The peak of that curve indicates the optimum ON exposure and the quality levels for each scale. Nearly a full rating unit difference was shown between the two scales. The proximity of the scales, but the significant disparity in rating of the 13- and 5.5-mm images, suggested a possible difference in the quality of the two lenses. However, it was considered that the observers might be making a categorical distinction between the two images. Although the simulated scales are close, the larger size of the total 13-mm lens image may have contributed to an impression of better quality. This issue was considered in the following experiment.

Experiment 632-4

Seven scales, 55,000 to 262,000, at 34-degree solar altitude, 0.6 atmosphere, and with zero-motion, were PI-rated in this experiment. To offset the possible categorical distinction, 13-millimeter lens images with 8-micrometer motion were inserted within the context of zero-motion chips from both lenses. By doing this, observers were presented with several consecutive cases where the larger 13-millimeter lens image was of lower quality than the 5.5-millimeter lens. The intended effect was to counterbalance a rating bias due to overall image size. The result was a linear relationship between rating and log scale. A difference still existed between the 115,000 and 126,000 scale although the magnitude was half that found in experiment 632-1. In the other 13-/5.5-millimeter overlap, 84,000/77,000 respectively, there was not an abnormal discrepancy in rating. Later experiments continued to bear out these relationships, which may imply the issue is associated with the models.

Experiment 632-5

Experiment 632-1 found optimum DP and optimum ON exposure at the 0.6 atmosphere. With reference to the PI DP preferences, optimum policies were chosen for the 0.7 and 0.5 atmospheres by PT rank-order experiments. Experiment 632-5 was a PI rating of the 0.7 and 0.5 atmospheres for the 13- and 5.5-millimeter lenses at the 84,000 and 77,000 scales, respectively. Densitometric and resolution measurements had previously indicated the exposures through both lenses to be virtually identical, and the results of this experiment confirmed the optimum exposures to be the same.

Experiment 632-6

Seven scales were rated in this experiment at optimum ON exposure for three aerial contrasts to determine the rate of change of quality with scale. Again, 13-mm chips with motion were inserted to offset a rating bias. Plotting mean rating as a function of scale showed a linear relationship with apparently no significant difference in slope for each contrast. Such a model was adopted and a linear regression technique using indicator variables was used for analysis of the data. The indicator variable method allows all the data to be used in defining the slope of the rating/log scale line with the effect of aerial contrast manifested by different intercepts. Three lines result from this method, the differential effects of contrast illustrated by vertical shifts of the rating/log scale functions (see Section 6, page 6-43).

Experiment 632-11

This experiment generated the data required for the SO-209 exposure motion tradeoff. PI data was obtained at four motion magnitudes (0, 2, 4, and 8 micrometers) across seven exposures (simulation 0 ± 2 stops) at the 34-degree solar altitude and 0.7 atmosphere. On the basis of the motion/exposure rating values and a statistical model of the system dynamics, an operational exposure recommendation was made that compensates for the effect of system motion.

Optimum ON exposure is found from the peak of the zero-motion curve. However, the rating data was based on a target of 36 percent reflectance on a 25 percent background, but the average operational target reflectance is 12 percent. The peak exposure determined from the experimental data must therefore be adjusted to account for the target reflectance difference. By characterizing the 36/25 percent R AOB by 30 percent average reflectance, the reflectance difference was defined by the exposure difference, Δ log E, presented to the film by a 12 and 30 percent reflectance target. Accounting for this shift, the optimum zero-motion exposure was specified on terms of an aim-developed density of 12 percent reflectance at that exposure, termed D_0. Another contractor supplied a recommended D_0 and the operational exposure times through solar altitude. Based on the difference in log exposure space of the two D_0's, a set of recommended operational exposure times was calculated. These represent the optimum exposure of a 12 percent target through solar altitude for the zero-motion case (see Section 6, page 6-105).

Information was furnished that characterized the statistical distribution of system motion. As there is a rating that corresponds to every motion/exposure combination, the statistical nature of motion dictates that the rating also be statistical. A computer algorithm was developed to incorporate rating values with the distribution of system motion. Operational exposure data, as a function of solar altitude, was supplied to which simulation exposures were correlated by sensitometric considerations. Inputting an absolute exposure into the computer technique resulted in the expected mean values of rating with motion in terms of simulation exposure. The difference in exposure between this curve's peak and the zero-motion rating curve is the amount of exposure compensation required to optimize rating at that exposure/solar altitude. Repeating this procedure for other exposures characterizes the amount of exposure compensation necessary as a function of solar altitude. With this information, the recommended zero-motion exposure times were adjusted for motion, and are summarized in a plot of recommended exposure time versus solar altitude for the zero-motion and motion correction cases (see Section 6, page 6-111).

4.2 FILM SO-208

Experiment 632-9

The SO-208 film imagery was produced with only the 13-millimeter lens. As experimental work had been done in the past with this film, optimum duplication was selected on the basis of PT judgments.

Selection of optimum exposure at three aerial contrasts was the task of experiment 632-9. Only the 13-millimeter lens was involved, and the 1:37,000 scale AOB was PI rated at seven simulation exposures, a range of four photographic stops, across three aerial contrasts. Data reduction was straightforward, the mean ratings were plotted as a function of exposure for each aerial contrast. Smoothed curves were drawn through the points and optimum exposure defined as the peaks of the curves. These results would be applied in experiment 632-14, quality comparison among films.

4.3 FILM SO-112

Experiment 632-7

The task of the initial SO-112 film experiment was selection of optimum duplicate policies. Prior PT screening experiments reduced the PI load by narrowing the range of DP choices. Ten PI's rank-ordered the duplicates and their total set of observations reduced by summing the ranks at each ON exposure. To further lessen the PI burden, the experiment was designed to rank all exposures at the median of the three aerial contrasts, the 0.6 atmosphere, but only one exposure, SIM 0, at the 0.7 and 0.5 atmospheres. The same DP was chosen for all three contrasts at SIM 0, and with supporting evidence from PT ranking, the PI selections were extrapolated for all exposures at the 0.7 and 0.5 atmospheres.

Experiment 632-10

This experiment was originally conceived to be an optimum ON exposure selection across aerial contrasts for both lenses. However, as in the case of the SO-209 film, densitometric considerations and resolution measurements implied that the exposure was equivalent through each lens. As experiment 632-5 verified that for the SO-209 film the optimum exposure for the 13-millimeter lens was identical to that of the 5.5-millimeter lens, it was decided to test for only the best exposure on SO-112 film for the 13-millimeter lens and to utilize that selection as the 5.5-millimeter lens optimum exposure as well. This approach allowed the EMTO for the SO-112 film to be incorporated into the same experiment, substantially decreasing PI labor and turnaround time, as well as data reduction time and expenses. In total, the experiment consisted of 42 chips, with subsets of 21 and 28 chips constituting the exposure determination and EMTO, respectively. All observations were at the 1:37,000 scale and 19-degree solar altitude with the exposure determination performed at all three aerial contrasts and the EMTO at only the 0.7 atmosphere with 0, 4, 8, and 16-micrometer image motion.

Reduction of optimum exposure data was straightforward. The mean ratings were plotted as a function of simulation exposure for each aerial contrast and the peaks of the smoothed curves indicated best exposure. The EMTO analysis was essentially identical to that of the SO-209 film in experiment 632-11. As the rating data was obtained using a 36 percent reflectance AOB on a 25 percent R background, an exposure shift was calculated for the average acquisition reflectance of 12 percent. Then, the zero-motion aim exposure was characterized by an ON density to which a 12 percent reflectance should be taken, based on the optimum simulation exposure shown by the PI data and the Δ log E shift for the 36/25 percent R to 12 percent R compensation. This recommended exposure was converted to an absolute exposure time by comparison with the operational exposure time/aim density data from another contractor. For the zero-motion case, the recommended exposure times as a function of solar altitude was generated. PI ratings were incorporated with the system motion statistics to find expected mean values of rating with motion. By generating a set of rating/exposure curves at different solar altitudes, the amount of required exposure compensation as a function of solar altitude was determined. This amount of exposure correction necessary for motion compensation was used to modify the zero-motion exposures, which resulted in a plot showing the recommended exposure time versus solar altitude for the zero-motion case and the motion correction case (see Section 6, page 6-109).

Experiment 623-13

The rate of change of quality of SO-112 film with scale was determined in this experiment utilizing PI ratings of eight scales, 1:37,000 through 1:262,000, at three aerial contrasts. Optimum exposures were used in each case. To offset a rating bias due to overall image size, 13-millimeter chips with 8-micrometer motion were inserted into the experiment. The analysis of rating and log scale was performed as in the SO-209 experiment (632-6). The regression of rating and log scale was linear and the differential effects of contrast represented by vertical shifts of the rating/log scale functions. (See Section 6, page 6-51).

Experiment 632-14

The final experiment of the scale study undertook a quality comparison among the films. SO-112, SO-209, SO-208, and SO-315 films were PI rated at three aerial contrasts for the 1:37,000, 1:55,000, and 1:115,000 scales. Optimum exposures as determined by the preceding experimentation were used in all cases. The individual scale experiments for SO-209 and SO-112 films (experiments 632-6 and 632-13, respectively) determined the rate of change of quality with scale, but comparisons between those films could not be made as the rating values should not be taken out of the context of the particular experiment. Relative differences were examined in experiment 632-14, and the third film, SO-208, was included as operational quality levels are known and therefore provided a quality baseline for comparisons. The SO-315 data was not analyzed as part of this program, but was included in the PI evaluation to acquire rating information for a Five-Film study experiment.

Data from the individual experiments was combined with that of the multifilm experiment. Ratings were averaged over atmosphere for each scale value. The results of experiments 632-6 and 632-13 were assimulated into those of experiment 632-14, thereby describing the quality change with scale of SO-209 and SO-112 films over the 1:37,000 to 1:262,000 range and the SO-208 film for the 1:37,000 to 1:115,000 range (see Section 6, page 6-61).

The composite of all data (see Section 6, page 6-63) shows a higher level of performance for the SO-209 film relative to the SO-112, and for the SO-112 film with respect to the SO-208. It should be noted however, that the SO-112 film was simulated for a 19-degree solar altitude at which the aerial contrasts are lower than for the 34-degree solar altitude of the SO-209 film. The lower solar altitude also causes longer shadows on target, which may affect the perceived quality. It is recommended that SO-112 film be analyzed under identical illumination conditions.

The reader is referred to Appendix A for an illustrated summary of the effect of scale on quality. Photomicrographs of the SO-209 and SO-112 imagery are positioned on the rating versus log scale lines resulting from experiment 632-14.

Appendix C examines the rating/log scale results in the domain of a rating versus log GRD plot and compares this present work with an existing calibration line.

4.4 SMEAR MODEL ANALYSIS

An additional set of data analysis was performed to supply a contractor with smear-exposure bias functions for SO-209 and SO-112 films. The EMTO experiments, 632-10 and 632-11, provided rating curves through simulation exposure at constant magnitudes of motion. From these motion/exposure curves, a series of smear rate curves was generated. Along a smear rate curve the amount of image motion is a function of the exposure time. For example, if there is 16 micrometers of motion at a SIM 0 + 2 stops exposure, there would be 8, 4, 2 micrometers at SIM 0 + 1, SIM 0, and SIM 0 − 1, respectively.

Two measures were derived from each of these curves. The exposure compensation to achieve maximum rating with smear relative to the zero-motion curve was computed as was the magnitude of the smear at the optimum zero-motion exposure, D_0. From these figures, the amount of log exposure bias for optimum image quality was portrayed as a function of smear at D_0 (see Section 6, pages 6-115 and 6-117). The resultant smear-exposure bias functions are then utilized in this contractor's smear-exposure tradeoff study.

4.5 EXTENDED ALTITUDE AND FORMAT ANALYSIS

The exposure/motion tradeoff gives an expected loss in quality due to motion at the scale of the imagery (1:37,000). The quality loss is considered only at the center of the format, which is appropriate for a pointing task. However, as the height is increased, the motion changes; and the task changes. Though the motion magnitude is reduced at higher altitudes, the task has become a search task and we are concerned with the entire format.

To determine the loss in expected quality at other scales than 1:37,000, one needs rating as a function of motion and exposure at each scale. One then takes the motion statistic appropriate for that altitude and format position and calculates the expected rating.

If the rating/GRD relationship was a linear relationship, we could take the rating/motion/exposure data at the 1:37,000 scale and shift it downward the required amount. However, the relationship is not linear and interactions between motion/contrast and exposure exist. To do the experiment properly, one needs new rating data at the desired scales. However, if we wish to obtain an estimate of the size of the effect, we can ignore the interaction effects and just treat the exposure/motion data as if it was obtained at another scale, except for the overall rating level.

A nominal set of conditions were chosen to represent the higher altitude ($h = 350, 470$; $\Omega = 25$), and the smear rates were calculated across the format. At $h = 350$, the motion smear rates are reduced by a factor of 6 from $h = 70$, while they are reduced by a factor of 8 at $h = 470$.

To calculate the effects of these smear magnitudes on the rating, exposure/motion tradeoffs were done for SO-209 and SO-112 films at $h = 350$, $\Omega = 25$, SA = 34 degrees, on-axis and at the 50 and 75 percent format positions. The expected loss in quality due only to the motion is shown in Table 4-1.

Table 4-1 — Rating Loss

	SO-209	SO-112
50 percent format	−0.06	−0.05
75 percent format	−0.11	−0.08

5. RECOMMENDATIONS

Accomplishments of the scale study were: the analysis of the effect of scale on quality, and operational exposure recommendations for two films. This work suggests several analyses that should be conducted to explore Gambit system acquisition utilizing the existing image data. Descriptions of these recommendations are presented in the following paragraphs.

5.1 SOLAR ALTITUDE VERSUS QUALITY FOR SO-112 FILM

In the scale study, SO-112 and SO-209 films were limited to one solar altitude each, 19 degrees for SO-112 and 34 degrees for SO-209. Aerial contrast decreases with sun angle, therefore SO-112 was disadvantaged as its aerial contrasts were lower than those of the SO-209. The results show SO-209 to be the more effective film, but this may be due to its higher contrast. It is proposed to make a direct comparison of the films' performances by including SO-112 at the same aerial contrast/sun angle combinations as the SO-209. This analysis would use scale study imagery presently available, and would be accomplished through subjective rating experiments.

5.2 RECONCILIATION OF D_0 DIFFERENCE

During both the SO-209 and SO-112 films exposure motion tradeoff studies, the difference in recommended exposure (Aim D_0) suggested by the rating analysis and presented by a co-contractor became apparent. Although the difference is not large, there will be an effect on quality as a function of D_0 since it affects both the motion tradeoff and density level. It is proposed to investigate the conflict between the two studies by working interactively between groups to scrutinize each other's quality and density measuring procedures to substantiate any difference and to recommend any action that should be taken.

5.3 INTERACTION OF SCALE AND MOTION

As a continuation of the Scale Study, a small analytical study was performed to estimate the effect of motion at the intended acquisition scales. The shortcoming of this study was the extrapolation of quality versus motion data obtained at only one scale. The assumption had to be made that this data would apply to other scales as well. This implies that there is no interaction between motion and scale, which may not be true. It is suggested that quality ratings be obtained through motion and scale to quantify any interaction, and to apply this data to define the effect of motion through the appropriate scales. If there is an interaction, we will also investigate the possible effect on the recommended exposure/motion tradeoff point.

5.4 INVESTIGATION OF OPERATIONAL PERFORMANCE

Recent performance history on SO-209 and SO-112 films indicated SO-112 to be the preferred material. The scale study indicated the reverse to be true, SO-209 being better. It is proposed to investigate the difference by examining the acquired data to determine why the apparent discrepancy.

5.5 CONTRAST VERSUS QUALITY

The scale study did not specifically investigate the effect of contrast on resultant quality. Because of the high signal-to-noise ratio (SNR) of these materials, it may be that a quality gain could be achieved at low contrasts. This could be estimated if the data bases were further exploited to include the 0.6 and 0.5 atmospheres to complement the 0.7 atmosphere quality data. The rate of change of quality as a function of contrast could then be applied to expected acquisition circumstances to estimate performance and/or to extend the possible useful range of low contrast acquisitions.

5.6 INTERACTION OF SCALE AND OBLIQUITY

The scale study data base included only one look angle. Although look angle affects scale, the ability to study only the effect of scale change on quality was considered in this experiment so the data would not be confounded with obliquity effects. It is recommended to study several scales at different look angles to establish the impact of obliquity on quality. Experiments should be designed to assess the expected performance levels as a function of look angle and to define the obliquity term. This information, coupled with the expected acquisition scenarios, could be used to estimate system utility.

6. ANNOTATED BRIEFING

This Section contains the Scale Study Briefing with annotation for each viewgraph.

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1/22/79

"SCALE STUDY"

22 JANUARY 1979

19 MARCH 1979

9632.LDJ

OBJECTIVES

The Scale Study program began in early 1978 and was completed in early 1979. The initial phase was conducted at the Image Simulation Facility and produced an image data base on three films, SO-208, SO-112, and SO-209. These films were processed and duplicated operationally and then utilizing this photography, a series of image quality experiments was performed to analyze the effect of scale on quality and to provide recommendations for operational exposures.

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OBJECTIVES

- PRODUCE AN IMAGE DATA BASE ON SO-208, SO-315, SO-112, AND SO-209
- DETERMINE THE RATE OF CHANGE OF QUALITY WITH SCALE
- EXPOSURE RECOMMENDATION FOR SO-112 AND SO-209

IMAGE DATA BASE PRODUCTION

The Scale Study image data base was produced in conjunction with the Five Film Study. Imaging parameters were varied to simulate acquisition conditions of the Gambit system and to provide a sufficient range of these variables to support image quality experiments.

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IMAGE DATA BASE PRODUCTION

- SUBSET OF IMAGES PRODUCED FOR "FIVE FILM STUDY"
- VARIABLES
  - 5 FILMS
  - 8 SCALES
  - EXPOSURE
  - MOTION
  - SOLAR ALTITUDE
  - CONTRAST

FILM TYPES

Simultaneous production of both Scale and Five Film Study data bases was conducted during the first half of 1978. Three films, SO-208, SO-112, and SO-209, were used for the scale work; and in addition to those, SO-464 and SO-315 comprised the Five Film Study imagery.

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FILM TYPES

SO-208	- SCALE STUDY AND 5 FILM STUDY
SO-464	- 5 FILM STUDY
SO-315	- 5 FILM STUDY
SO-112	- SCALE STUDY AND 5 FILM STUDY
SO-209	- SCALE STUDY

PHOTOGRAPHIC PARAMETERS

The photographic parameters were designed to simulate Gambit system acquisition. The camera/orientation/look angle requirements resulted in a net compound angle of 18 degrees. Image smear of five magnitudes was simulated by introducing linear motion at the target plane during exposure. The films were exposed through a range of four photographic stops, with the mean level, SIM 0, adjusted to provide the expected optimum exposure.

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PHOTOGRAPHIC PARAMETERS

CAMERA/LOOK ANGLE	- AFT CAMERA WITH 10^{o} PITCH AND 15^{o} ROLL (18^{o} COMPOUND ANGLE)
LINEAR MOTION	- 5 LEVELS 0, 2, 4, 8 AND 16 MICRONS (USING 5/7 IN-TRACK TO CROSS-TRACK RATIO)
EXPOSURE RANGE	- 7 LEVELS +2, +1, +½, 0, -½, -1, -2 PHOTOGRAPHIC STOPS

ILLUMINATION

The aim illumination conditions were supplied by another contractor based on their SCAT II program. Those requirements translated into determining the proper voltage settings of the sun, sky, and haze lights to provide the correct illumination. Three quartz-iodine reflector floodlights were positioned to simulate three solar altitudes. Sky illumination was provided by banks of floodlights surrounding the target area. The effect of haze on aerial contrast was controlled by adding uniform radiance across the format by locating a beam splitter close to the lens and introducing the haze energy from a nearby diffuse source.

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ILLUMINATION

SOLAR ALTITUDE

19^{o}

34^{o}

45^{o}

AERIAL CONTRAST

THREE ATMOSPHERIC TRANSMISSIONS

0.5

0.6

0.7

ILLUMINATION CONDITIONS

The radiant energy produced by the sun, sky, and haze sources was calibrated as a function of voltage using both a telephotometer and the film as sensors. These relationships were utilized to predict aim voltage settings for given sun/sky ratios and aerial contrasts. Then a set of photography was shot and processed at the simulation facility to check these aim settings and to aid in making voltage corrections. Through iteration of this procedure, the best voltage settings were established for each illumination condition. This page summarizes the aim and measured aerial contrasts and sun/sky ratios of the scale study data base.

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ILLUMINATION CONDITIONS

FILM	SOLAR ALTITUDE	ATMOSPHERIC TRANSMITTANCE	AERIAL CONTRAST (7:33) AIM	AERIAL CONTRAST (7:33) (MEASURED)	SUN/SKY RATIO AIM	SUN/SKY RATIO (MEASURED)
SO-209	34^{o}	.7	2.27	2.19	6.06	5.72
		.6	1.92	1.91	3.39	3.47
		.5	1.63	1.62	1.86	1.91
SO-112	19^{o}	.7	1.92	1.91	2.55	2.63
		.6	1.63	1.66	1.21	1.10
		.5	1.41	1.41	.44	.46
SO-315	34^{o}	.7	2.27	2.19	6.06	6.19
		.6	1.92	1.91	3.39	3.47
		.5	1.63	1.62	1.86	1.71
SO-208	34^{o}	.7	2.42	2.29	6.89	5.30
		.6	2.04	1.91	3.77	4.34
		.5	1.70	1.62	2.04	1.71

TARGET ARRAY

Four MiG-25 Foxbats were used in the scale study target array. These AOB were painted to achieve a 36 percent reflectance and were located on a 25 percent reflectance background, simulating realistic aircraft and concrete runway reflectances. Eight simulated scales were attained using 13 and 5.5-millimeter Switar lenses. The image scales listed are × 1,000.

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TARGET ARRAY

- TEST PATTERNS
- 4 AOB - 36% AOB ON 25% R BACKGROUND
- AOB

AOB	MODEL SCALE	SIMULATED SCALE 13mm	SIMULATED SCALE 5.5mm
A	1:48	37	84
B	1:72	55	126
C	1:100	77	175
D	1:150	115	262

APPROXIMATE RELATIONSHIP BETWEEN SIMULATION AND ACTUAL

All the simulation imagery was produced at a 20-degree look angle. The points along the vertical dotted line show the scales (in thousands) obtained by photographing the target array with the two lenses. The curves show, for a given altitude (in miles), the equivalent scales simulated at other look angles. For example, 1:55,000 scale at 20-degree look angle simulates the same scale at a 40-degree look angle at 100 miles.

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APPROXIMATE RELATIONSHIP

BETWEEN SIMULATION AND ACTUAL

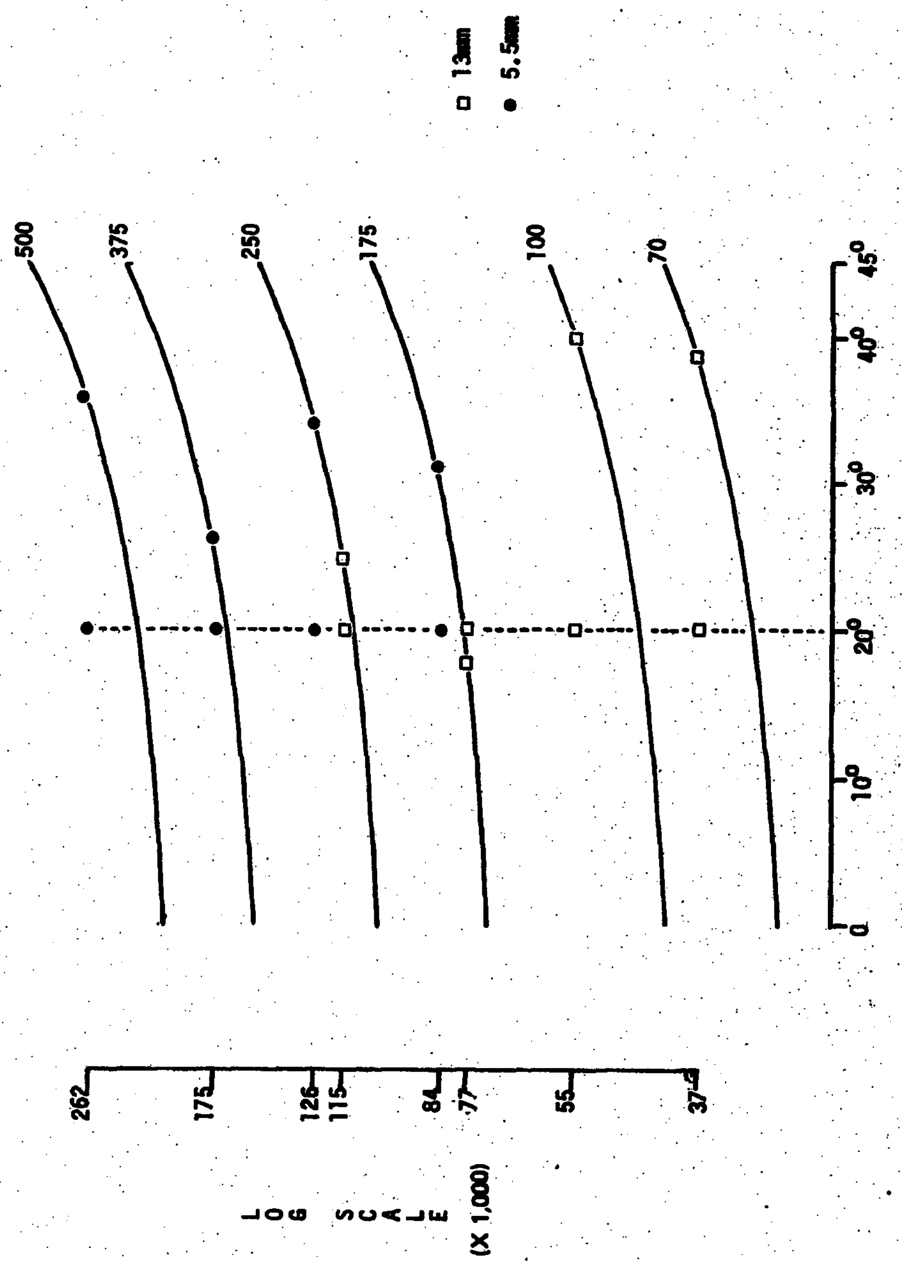

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IMAGE QUALITY EXPERIMENTS

- DETERMINE THE RATE OF CHANGE OF QUALITY WITH SCALE CHANGE
- EXPOSURE MOTION TRADE OFF ANALYSIS

IMAGE QUALITY EXPERIMENTS

The image quality experiments in the Scale Study were designed to answer two types of questions. One was to determine the rate of change of quality with scale change; and the other, to provide an exposure recommendation by analyzing the tradeoff between exposure and motion.

EXPERIMENTAL DESIGN

The effect of scale on quality was investigated for three films, SO-208, SO-112, and SO-209. To accomplish this, preliminary experiments were performed to select the best duplication printing level per ON exposure and then the best ON exposure for each atmosphere. Following that work, the effect of scale was tested through a range of scales at three aerial contrasts.

Two EMTO experiments were conducted, one each for SO-112 and SO-209 films. In this case, the preparatory experiments involved only optimum duplication selection. Both tradeoff analyses were performed at one aerial contrast for seven ON exposures and four motion magnitudes.

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EXPERIMENTAL DESIGN

EFFECT OF SCALE ON QUALITY

- SO-208, SO-112, SO-209
- BEST DUPLICATE EXPOSURE PER ON EXPOSURE
- BEST ON EXPOSURE
- THROUGH SCALE
- 3 AERIAL CONTRASTS (.5, .6, .7 ATMOSPHERIC TRANSMISSION)

EXPOSURE MOTION TRADE OFF (EMTO)

- SO-112, SO-209
- BEST DUPLICATE EXPOSURE PER ON EXPOSURE
- 7 ON EXPOSURES
- 1:37K SCALE
- 1 AERIAL CONTRAST (.7 ATMOSPHERIC TRANSMISSION)

EXPERIMENT PLAN

The order of execution is outlined in the experiment plan. Optimum duplication determination serves a dual purpose as it is the first quality experiment for both the scale changes and EMTO analyses. The latter analysis follows immediately, but in the scale change work, the optimum ON exposure must first be determined.

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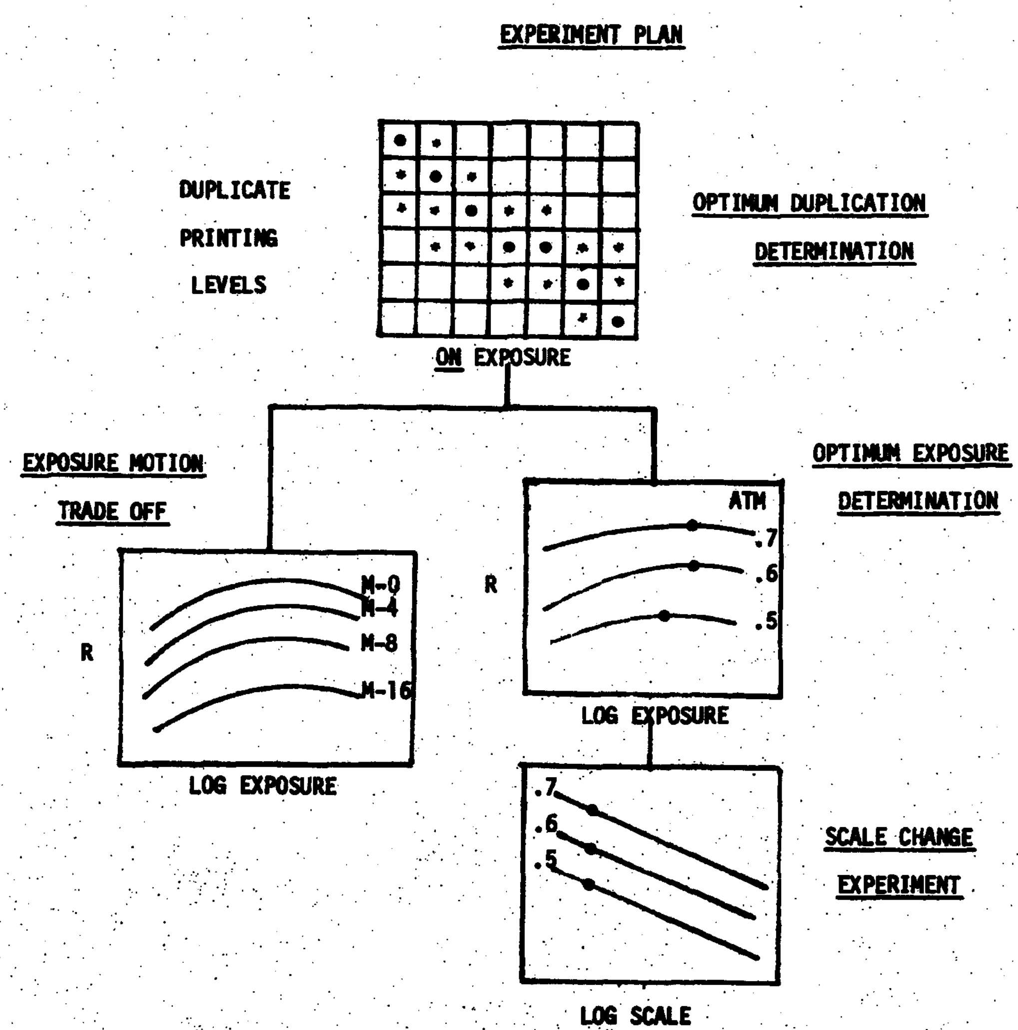

PI EXPERIMENTATION

The complete set of scale study image experiments are shown. It is essentially being the flow plan of the previous page replicated for the three films. Alterations to the basic plan are that no EMTO was necessary for SO-208 and the additional EMTO shown for SO-112 (Exp. 632-12) was performed for the five Film Study. In addition, a quality comparison among the three films was performed (632-14). Where possible, experiments were combined, either by blending together or by executing in succession, to expedite PI turnaround time.

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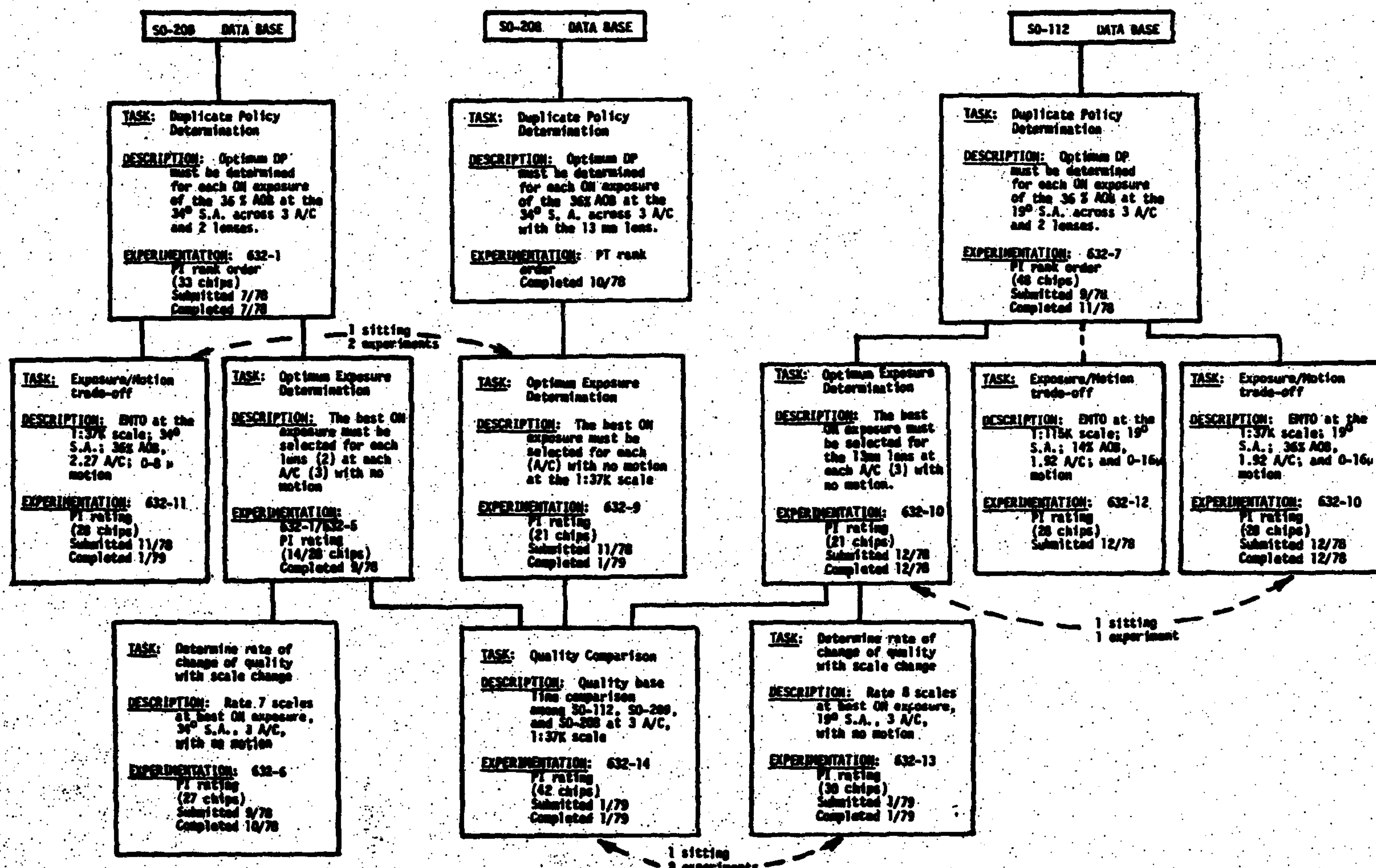
PI EXPERIMENTATION



THROUGH SCALE PER FILM

The components of the SO-209 and SO-112 films scale change experiments are shown schematically on the opposite page. Seven scales were rated across three aerial contrasts with the SO-209. The largest scale available, 1:37,000 was omitted in this experiment, as it was felt the apparent high quality of SO-209 images might cause a truncation at the maximum available rating. This did not turn out to be so, and that maximum scale was included in a later experiment. The SO-112 experiment was conducted with all eight scales and three contrasts.

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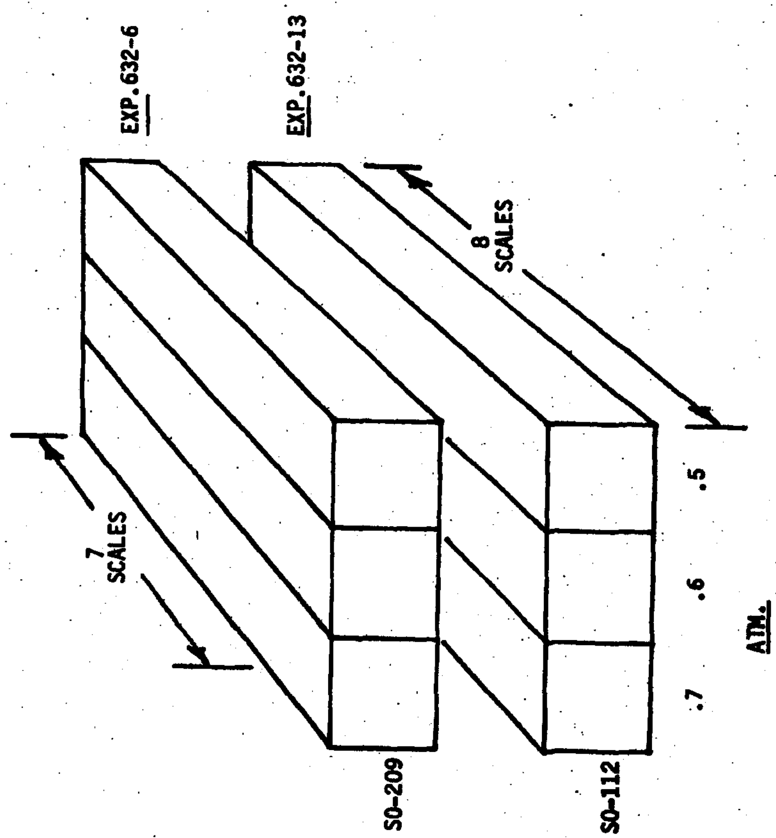
THROUGH SCALE PER FILM



ANALYSIS MODEL

The analysis model anticipated a linear relationship between rating and log scale, based on experience with rating and log GRD. If the atmosphere (aerial contrast) affected rating independently of scale, its effect would be realized as a vertical displacement of the rating/log scale function resulting in a set of parallel lines. Similarly, film type could also influence the functions by vertical shifts.

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ANALYSIS MODEL

RATING = K_1 LOG SCALE + K_2 ATMOSPHERE + K_3 FILM TYPE

K_1 = CALIBRATION

K_2 = ADDITIONAL SHIFT BETWEEN ATMOSPHERES

K_3 = ADDITIONAL SHIFT FROM FILM DIFFERENCE

FULL EQUATION

The analysis model on the previous page made the assumptions of no interactions between the factors; the full equation considers two of the possible interactions, that of film and atmosphere and atmosphere and scale. The first would manifest itself if the vertical shifts of the rating/log scale lines, due to atmosphere, varied in magnitude for different films. If the second interaction were present, the atmosphere differentially affecting low and high scales, the slope of the rating/log scale lines would vary with aerial contrast.

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FULL EQUATION

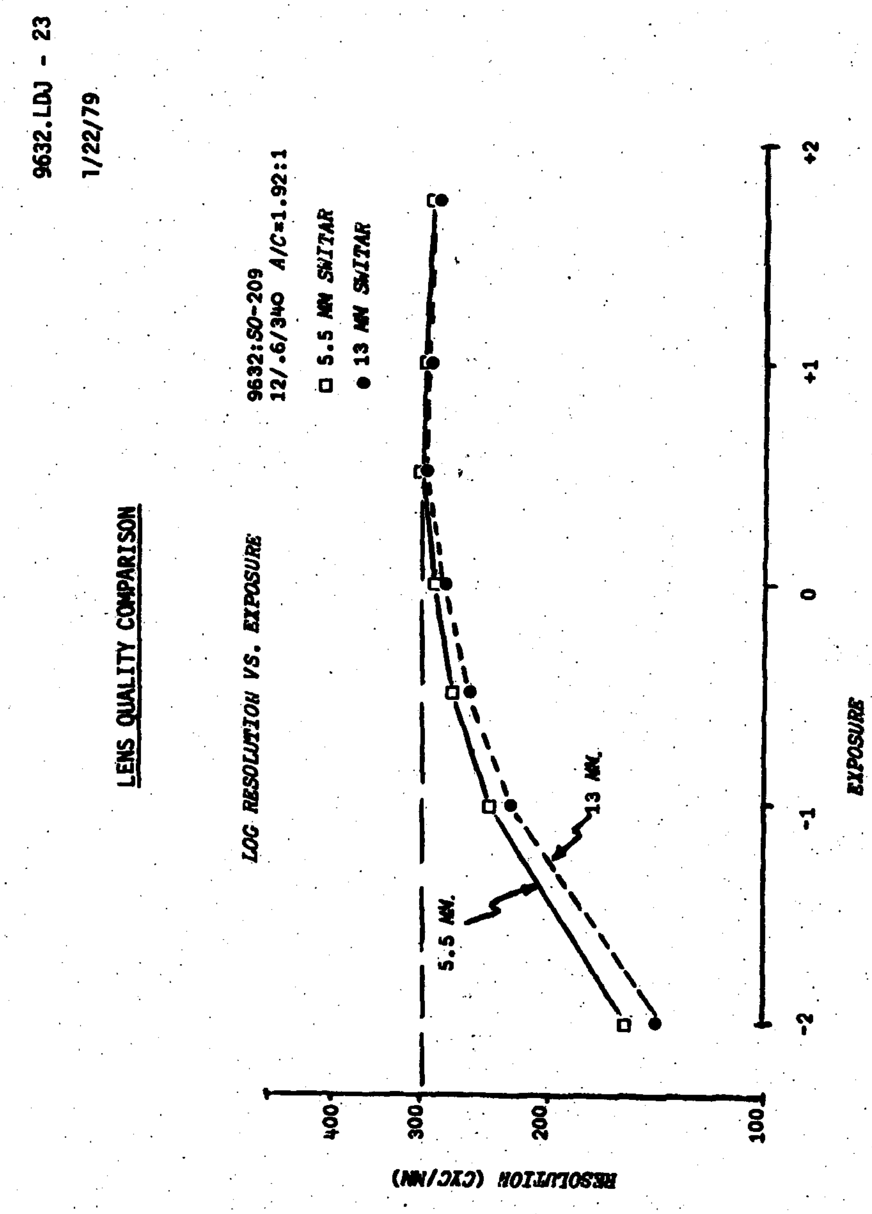
$$R = K_1 \text{ LOG SCALE} + K_2 \text{ ATMOSPHERE} + K_3 \text{ FILM TYPE} + K_4^* \text{ (FILM X ATM)} + K_5^* \text{ (ATM X SCALE)}$$

K_4^* = 1 FILM IS MORE AFFECTED BY ATMOSPHERE THAN OTHER FILM

K_5^* - THE ATMOSPHERE EFFECT MAY BE DIFFERENT FOR LOW SCALES AND HIGH SCALES

LENS QUALITY COMPARISON

Two lenses were used to produce eight simulated scales using four AOB targets. Preliminary comparisons had shown the lenses to be nominally equivalent. Resolution readings of the final photography sets were made for each of the films and indicated that the lenses were operating equivalently.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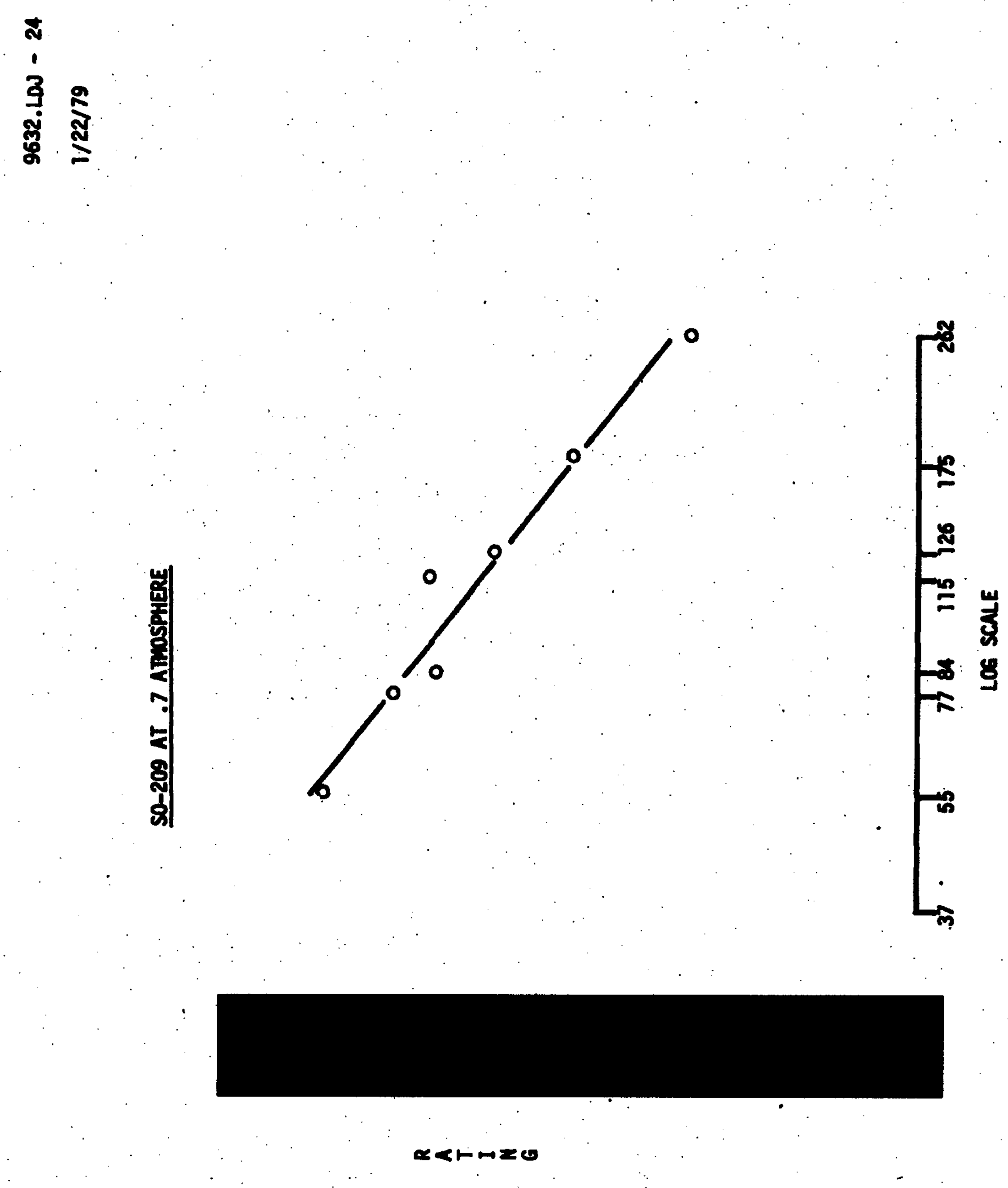
LENS QUALITY COMPARISON
LOG RESOLUTION VS. EXPOSURE
9632:SO-209
12/.6/340 A/C=1.92:1
5.5 MM SWITAR
13 MM SWITAR
5.5 MM.
13 MM.
RESOLUTION (CYC/MM)
400
300
200
100
-2
-1
0
+1
+2
EXPOSURE

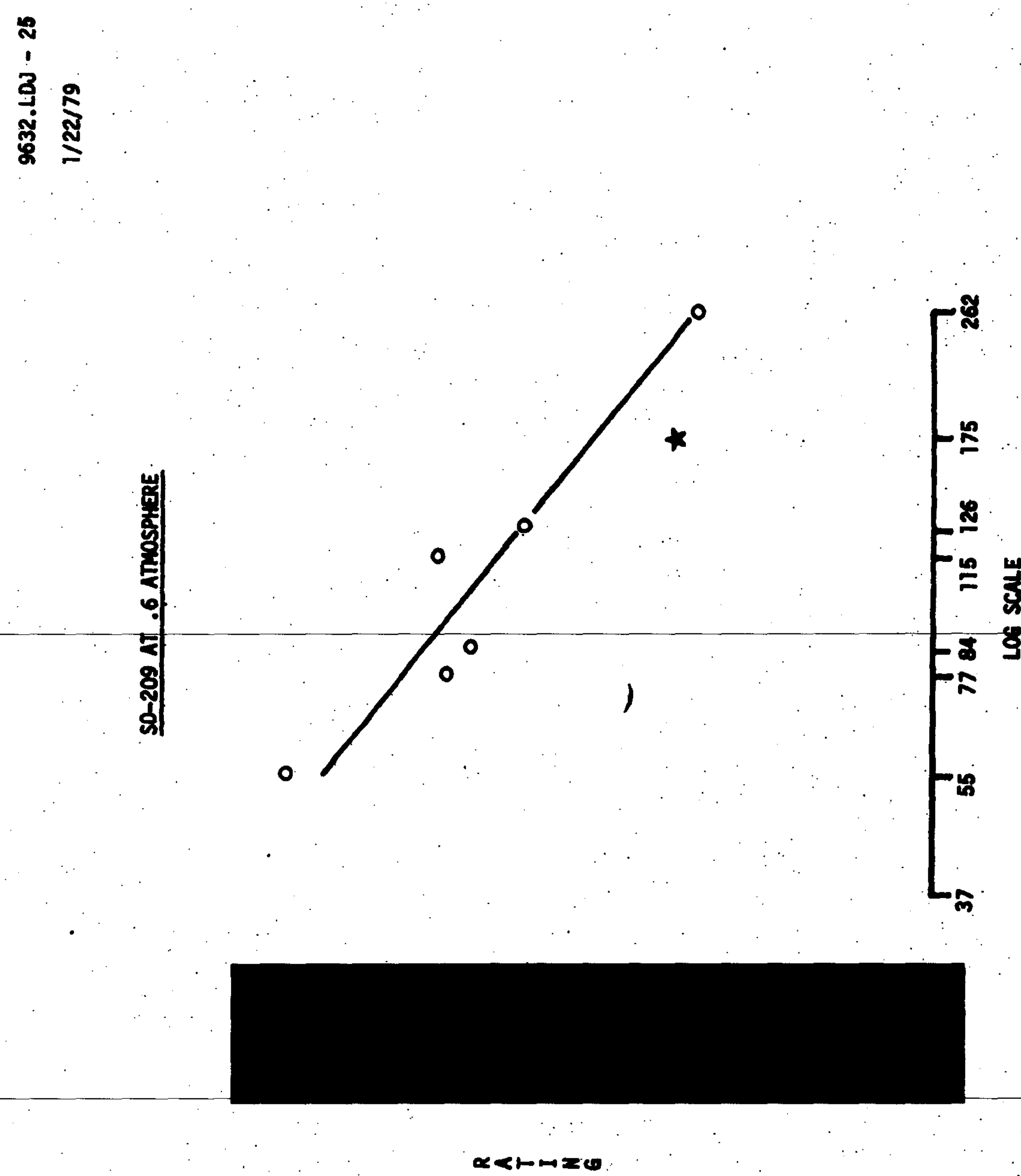
SO-209 AT 0.7 ATMOSPHERE

Linear regression fit to rating/log scale for SO-209 at the 0.7 atmosphere. The circles represent the actual data points.


9632.LDJ - 24
1/22/79
SO-209 AT .7 ATMOSPHERE
[redacted]
RATING
37
55
77
84
115
126
175
282
LOG SCALE

SO-209 AT 0.6 ATMOSPHERE

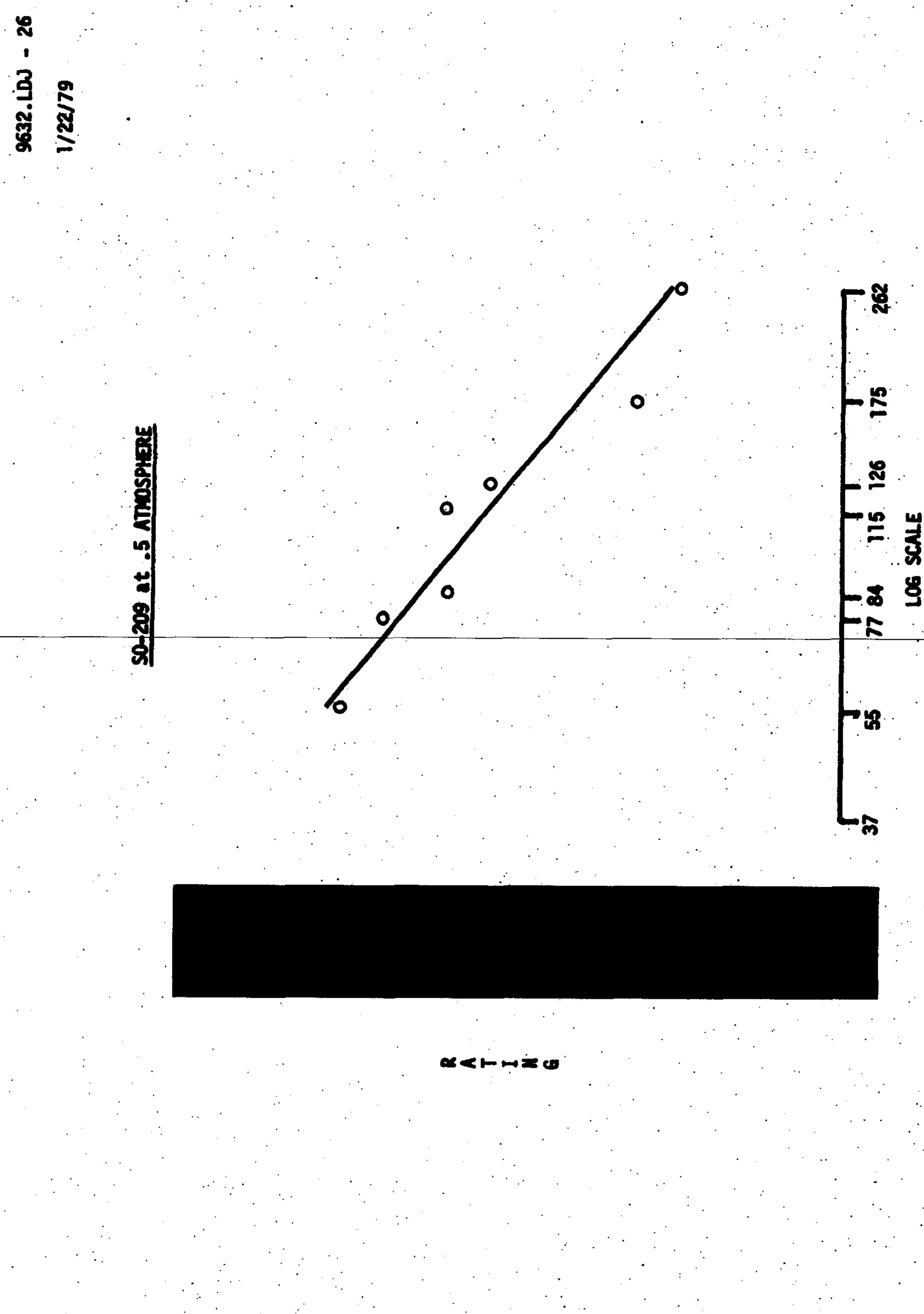
Linear regression fit to rating/log scale for SO-209 film at the 0.6 atmosphere, with data points shown as circles. The starred point at log scale equals 175 was not used in the regression as that image was partially obscured due to dirt being on the beam splitter during that set's photography.


9632.LDJ - 25
1/22/79
SO-209 AT .6 ATMOSPHERE
37
55
77
84
115
126
175
262
LOG SCALE
RATING

[redacted]

SO-209 AT 0.5 ATMOSPHERE

Linear regression fit to rating/log scale for SO-209 film at the 0.5 atmosphere. The circles represent the actual data points.

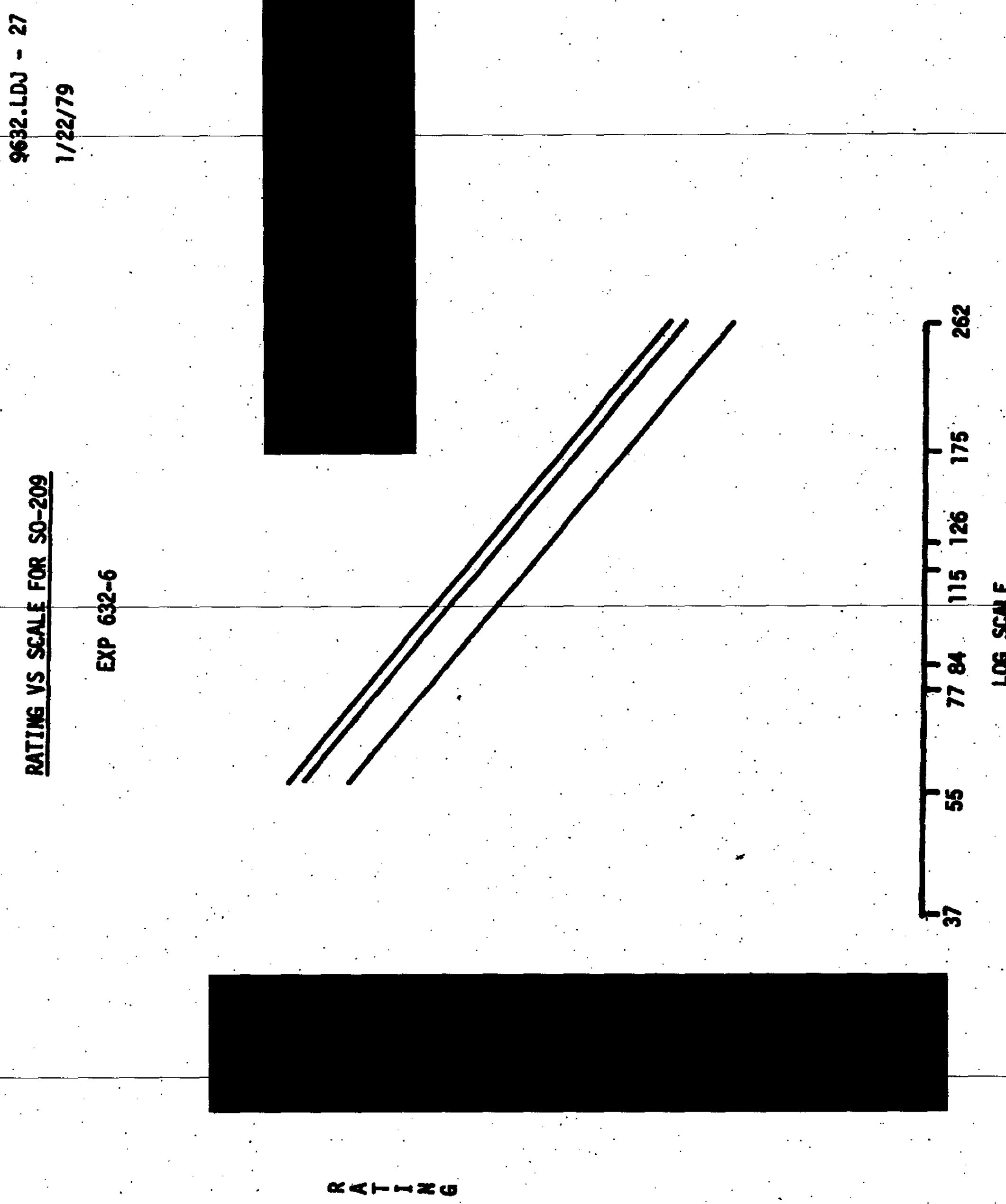

9632.LDJ - 26
1/22/79
SO-209 at .5 ATMOSPHERE
262
175
126
115
84
77
55
37
LOG SCALE
RATING

[redacted]

RATING VERSUS SCALE FOR SO-209

Summary of experiment 632-6 results, showing rating as a function of log scale for three aerial contrasts.

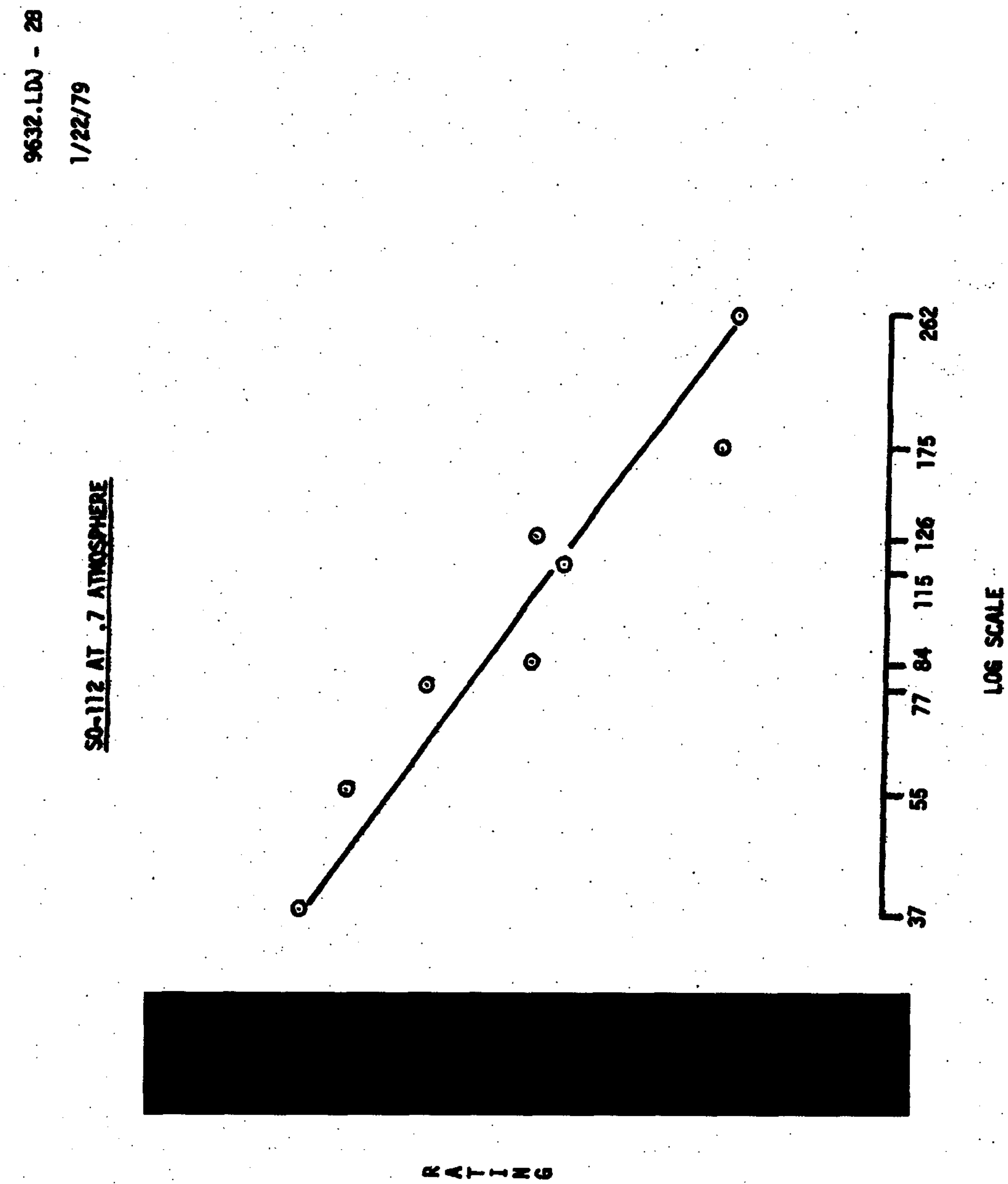
[redacted]



[redacted]

SO-112 AT 0.7 ATMOSPHERE

Linear regression fit to rating/log scale for SO-112 at the 0.7 atmosphere. The circles indicate the actual data points.


9632.LDJ - 28
1/22/79
SO-112 AT .7 ATMOSPHERE
37
55
77
84
115
126
175
262
LOG SCALE
RATING

[redacted]

SO-112 AT 0.6 ATMOSPHERE

Linear regression fit to rating/log scale for SO-112 at the 0.6 atmosphere. The circles indicate the actual data points.

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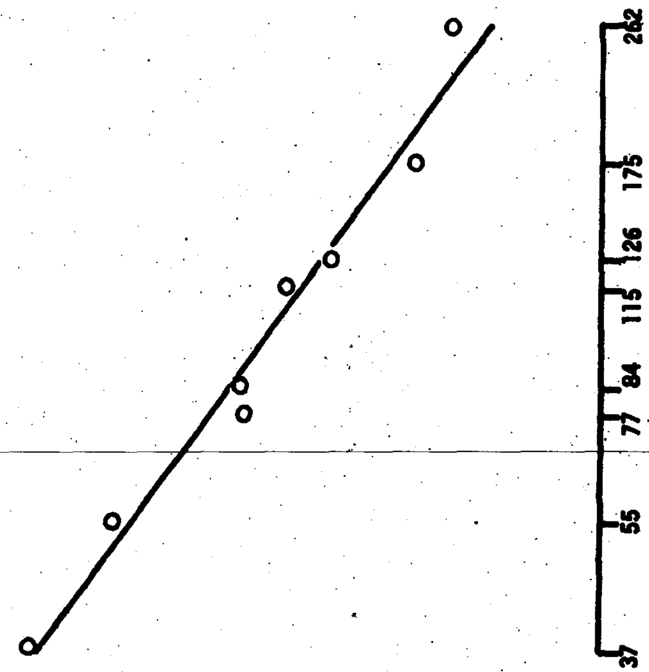
SO-112 AT .6 ATMOSPHERE



[redacted]

RATING

SO-112 AT 0.5 ATMOSPHERE

Linear regression fit to rating/log scale for SO-112 at the 0.5 atmosphere. The circles indicate the actual data points.

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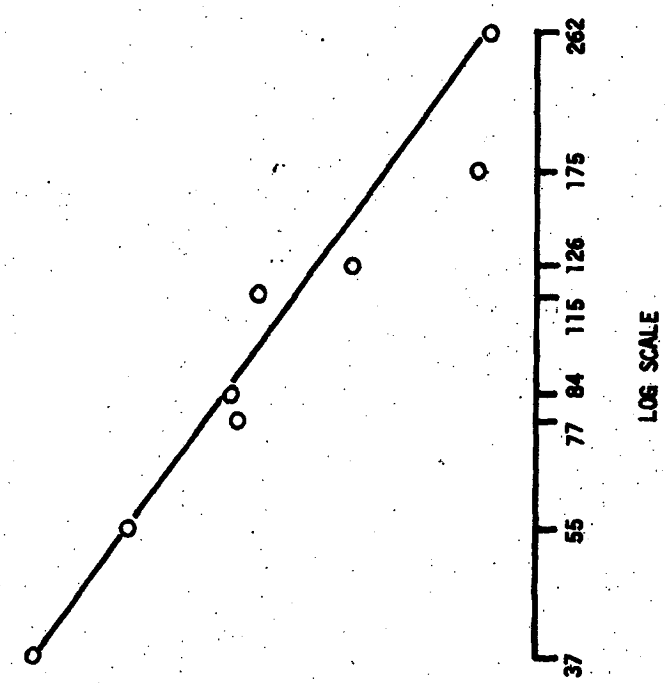
SO-112 AT .5 ATMOSPHERE



[redacted]

RATINGS

RATING VERSUS SCALE FOR SO-112

Summary of experiment 632-11 results, showing rating as a function of log scale for three aerial contrasts.

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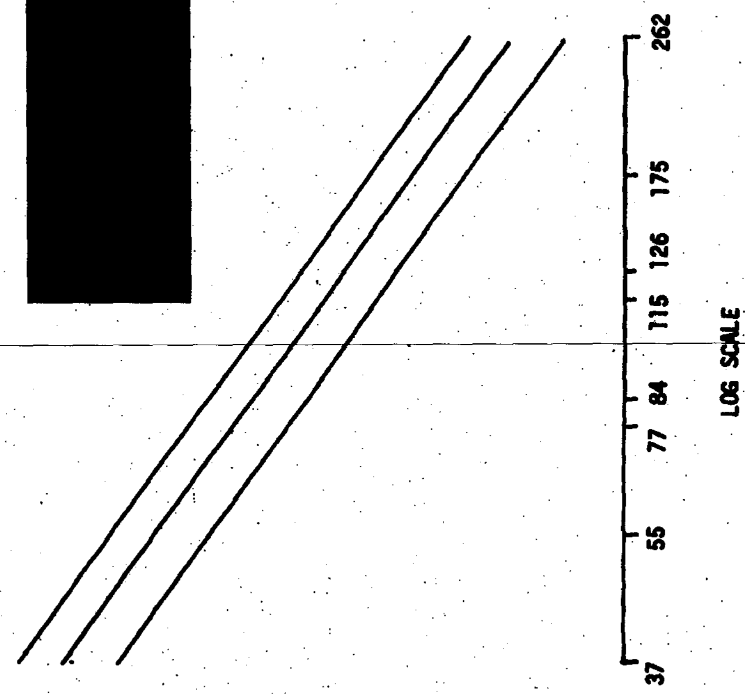
RATING VS SCALE FOR SO-112

EXP 632-13

[redacted]



[redacted]

RELATIVE COMPARISON AMONG FILMS

The results of the SO-112 and SO-209 scale change experiments cannot simply be combined to compare the films' performances. Variations in the absolute rating levels could exist between experiments. Experiment 632-14 provided the framework within which relative comparisons among the films could be made. Four films were rated at three scales and three atmospheres within the context of this one experiment. With that information, the prior scale experiment data could then be assimilated into the results of experiment 632-14.

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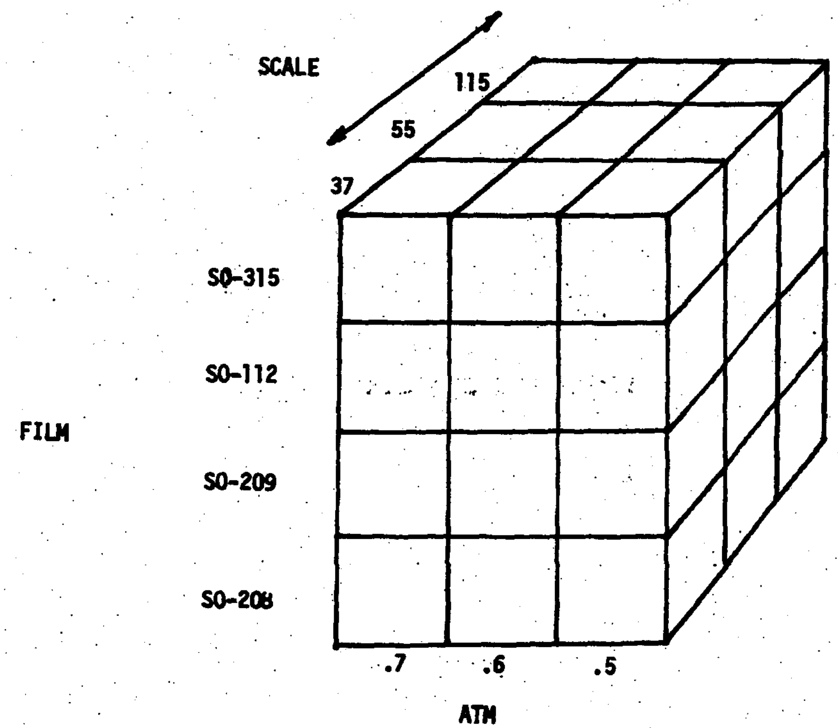
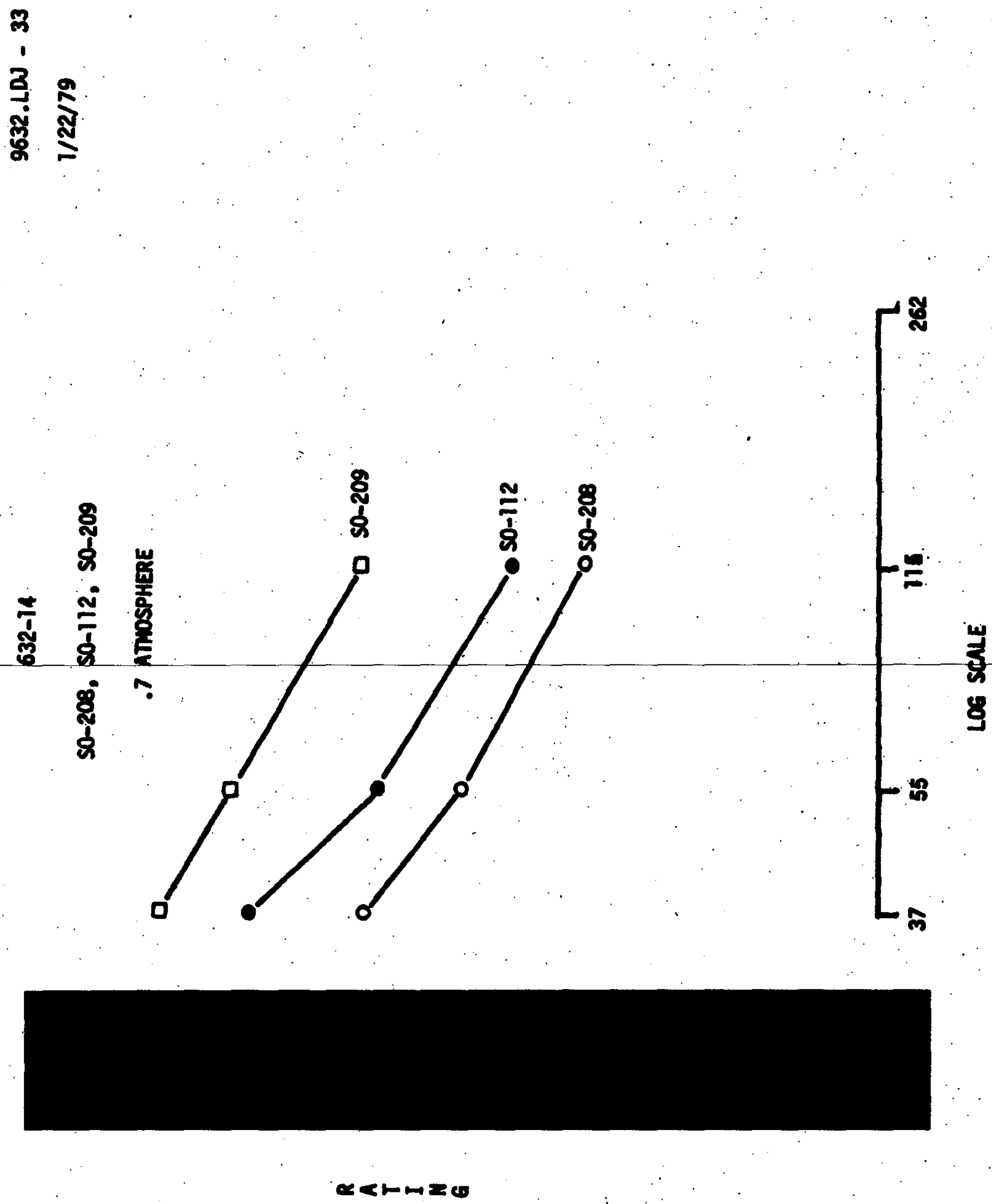
RELATIVE COMPARISON AMONG FILMS



EXPERIMENT 632-14

EXPERIMENT 632-14

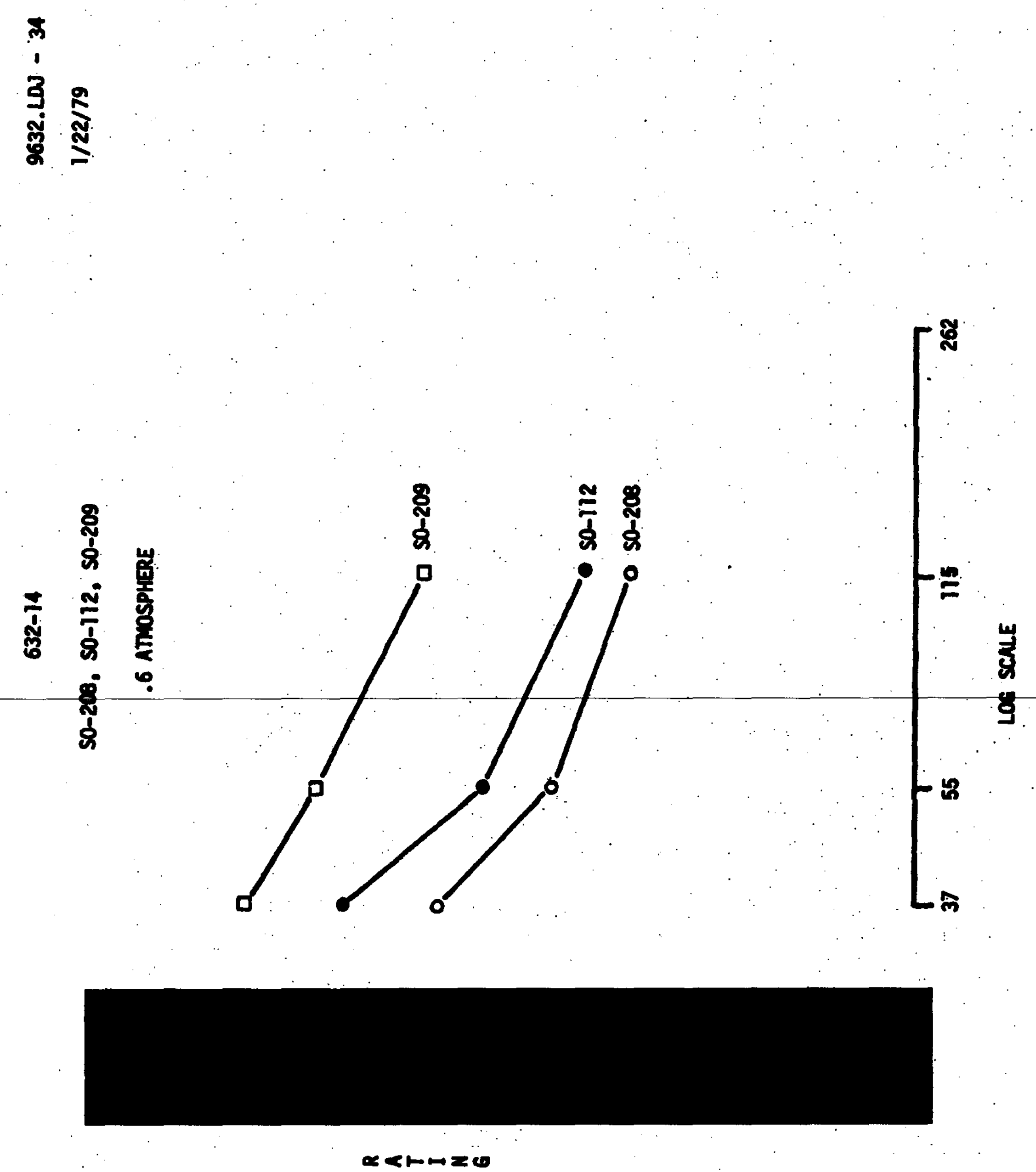
Results of experiment 632-14 for SO-208, SO-112, and SO-209 at the 0.7 atmosphere.


9632.LDJ - 33
1/22/79
632-14
SO-208, SO-112, SO-209
.7 ATMOSPHERE
SO-209
SO-112
SO-208
262
115
55
37
LOG SCALE
RATING

[redacted]

EXPERIMENT 632-14

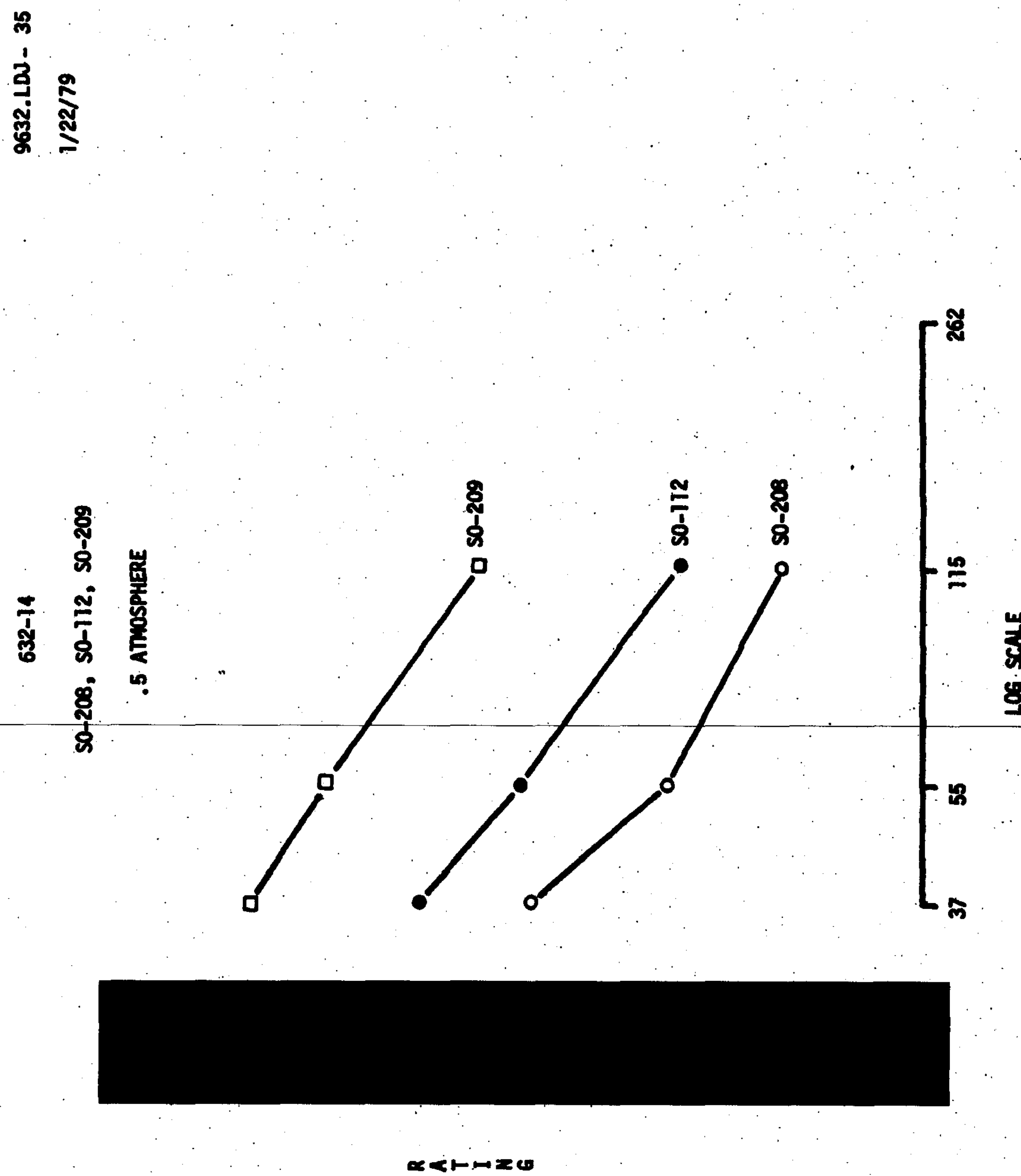
Results of experiment 632-14 for SO-208, SO-112, and SO-209 at the 0.6 atmosphere.


9632.LDJ - 34
1/22/79
632-14
SO-208, SO-112, SO-209
.6 ATMOSPHERE
SO-209
SO-112
SO-208
37
55
115
262
LOG SCALE
RATING

[redacted]

EXPERIMENT 632-14

Results of experiment 632-14 for SO-208, SO-112, and SO-209 at the 0.5 atmosphere.


9632.LDJ - 35
1/22/79
632-14
SO-208, SO-112, SO-209
.5 ATMOSPHERE
SO-209
SO-112
SO-208
37
55
115
262
LOG SCALE
[redacted]
RATING

COMBINATION OF INDIVIDUAL AND MULTI-FILM EXPERIMENT DATA

The results of each scale experiment, 632-6, 632-14, and 632-14, were summarized by averaging across atmosphere. Thus each film's rating/log scale relationship was represented by a single line for an "average" atmosphere condition. The earlier SO-209 and SO-112 lines were put into the context of the experiment 632-14 results by shifting them to coincide in the region overlapped by 632-14.

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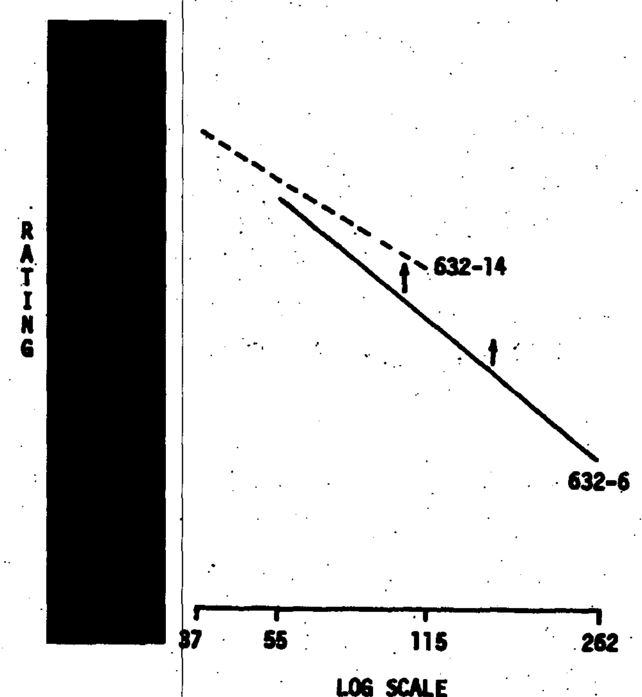
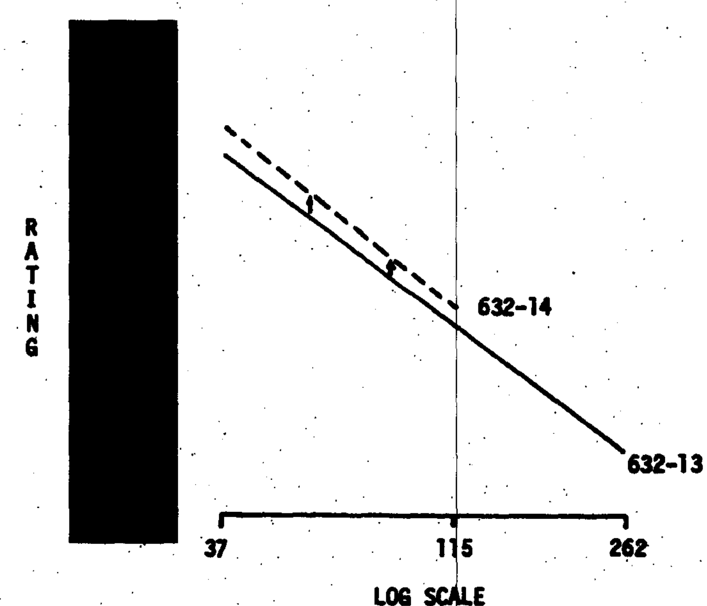
COMBINATION OF INDIVIDUAL & MULTI-FILM EXPERIMENT DATA

SO-209



SO-112



SO-209 AND SO-112 AVERAGE ATMOSPHERE RELATIVE TO SO-208

The final assembly of curves from the scale experiments shows the rate of change of quality with scale for SO-209, SO-112, and SO-208. The SO-208 provides a quality baseline for comparison as operational quality levels are known for that film. It should be noted that the SO-112 was simulated at a 19-degree solar altitude at which the aerial contrasts are lower than for the 34-degree solar altitude of the SO-209.

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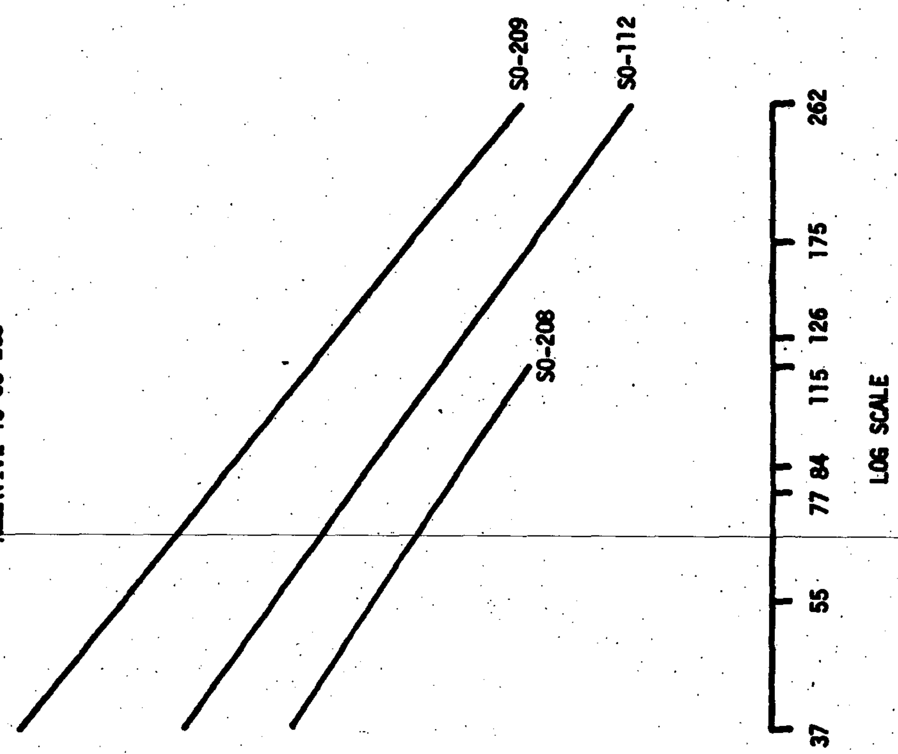
SO-209 & SO-112
AVERAGE ATMOSPHERE
RELATIVE TO SO-208



[redacted]

RATING

FILM/ATMOSPHERE INTERACTION

The interaction of film and atmosphere was studied to a limited extent using data from experiment 632-14. Ratings were averaged over the three scales of that experiment for each film and plotted as functions of atmosphere. The difference in the curve shapes suggest that the interaction does exist; aerial contrast affecting rating more with SO-208 and SO-112 than with SO-209.

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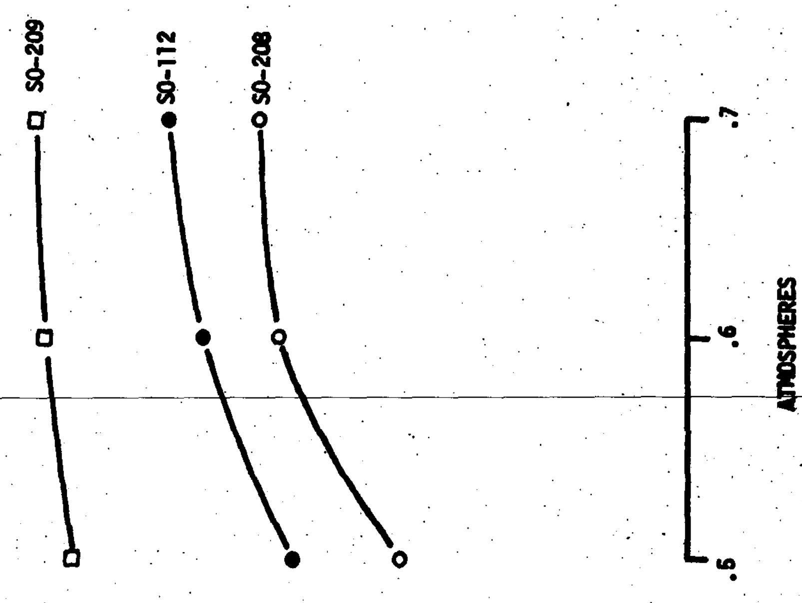
FILM/ATMOSPHERE INTERACTION

AVERAGE RATING OVER THREE SCALES

EXP 632-14



[redacted]

EMTO ANALYSIS

Exposure/motion tradeoff analyses were performed for SO-112 and SO-209. PI rating experiments were conducted to generate rating data as functions of exposure level and motion magnitude. Then, based on a statistical model of the system motion, exposure recommendations were calculated which compensated for the system motion and yielded the maximum quality rating.

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EMTO ANALYSIS

SO-112 & SO-209

- PI RATING
- EXPOSURE ANALYSIS
- MOTION ANALYSIS
- TRADE OFF

~~SECRET~~/G/H/HANDLE VIA BYEMAN CONTROL SYSTEM

PI EXPERIMENTS

The EMTO experiments were each conducted for one scale and one atmosphere. The images were rated through seven exposures and four magnitudes of motion.

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PI EXPERIMENTS

- SO-112 & SO-209
- 1 SCALE (1:37)
- 1 AERIAL CONTRAST
- 7 EXPOSURE LEVELS (+2 to -2 STOPS LOG E)
- MOTION
  - SO-112 (0, 4, 8, 16 μm)
  - SO-209 (0, 2, 4, 8 μm)

EXPOSURE MOTION

An exposure/motion tradeoff analysis determines the effect of system motion on mean rating. To accomplish this, the results of the simulation imagery must be placed in the context of operational parameters. Simulation exposures are correlated with system exposure times by comparison of aim density, D_0, with developed densities on the simulation imagery. The system motion statistic describes the distribution of image motion at a given amount of exposure. The PI rating data is then used to transform the distribution of image motion into a distribution of ratings, from which an expected mean rating is found for that exposure.

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EXPOSURE/MOTION

- DETERMINE EFFECT OF SYSTEM MOTION ON MEAN RATING
  - AIM D_o
  - EXPOSURE FOR AIM D_o
  - SYSTEM MOTION STATISTIC
  - RATING AS A FUNCTION OF MOTION/EXPOSURE

SO-112 PI RATING—THROUGH MOTION AND EXPOSURE

The required rating data was generated for SO-112 in experiment 632-10. Illumination conditions simulated a 19-degree solar altitude and a 0.7 atmospheric transmittance, which yields a 1.91 aerial contrast. The 1 : 37,000 scale AOB target with 0, 4, 8, and 16 micrometers of image motion was rated by 10 PI's. The solid curves are the resultant smoothed rating curves for each motion magnitude.

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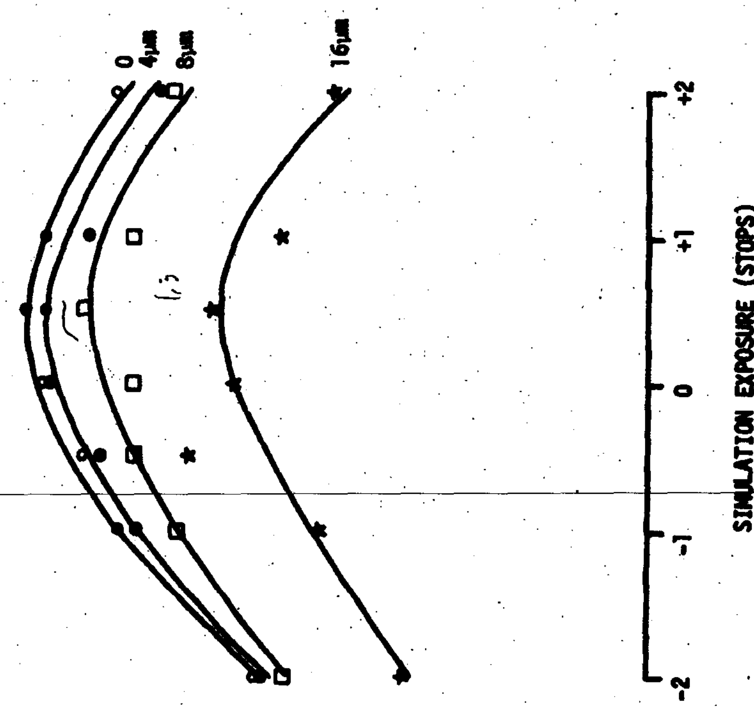
SO-112

PI RATING

THRU MOTION AND EXPOSURE



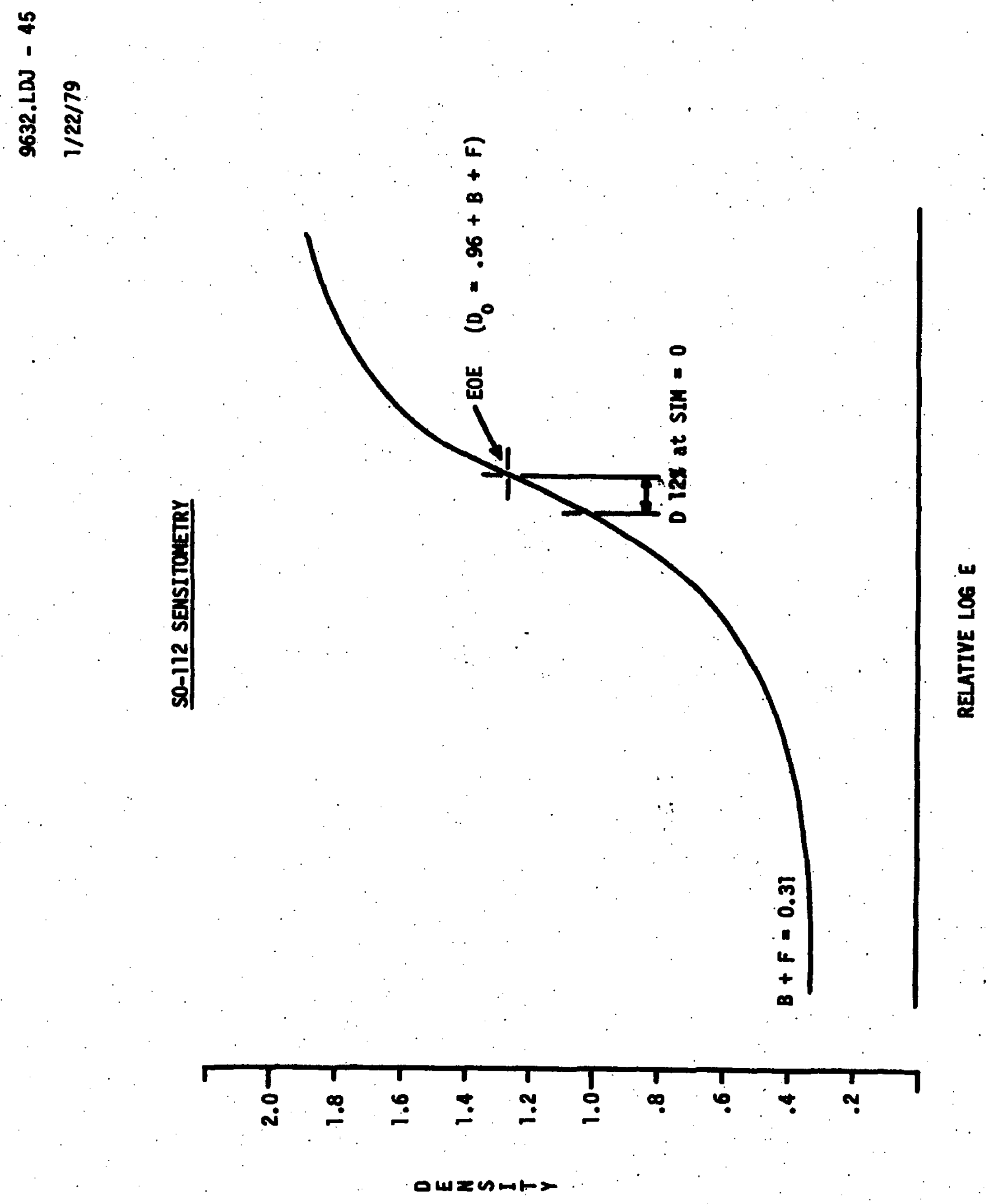
[redacted]

RATING

SO-112 SENSITOMETRY

Simulation exposures are described by the number of stops above or below a "simulation zero" exposure level. This SIM 0 exposure was chosen to approximate the aim exposure for that film, which is described by the developed density of a 12 percent reflectance object. The prediction of that exposure is based on comparison between the characteristic curve from operational processing and the densities developed by processing at the simulation facility.

The operational exposures are specified by the developed density of a 12 percent reflectance and by the exposure time (as a function of solar altitude) necessary to achieve the aim density, D_0. The equivalent operational exposure, EOE, can be located on the simulation axis by finding the difference in log exposure for the aim D_0 and the density of a 12 percent reflectance at SIM 0. Knowing this and the exposure time at EOE, each of the simulation exposures can be defined by their equivalent operational exposure times.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1/22/79
SO-112 SENSITOMETRY
EOE (D_o = .96 + B + F)
D 12% at SIM = 0
B + F = 0.31
RELATIVE LOG E
DENSITY
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2

EFFECT OF MOTION ON QUALITY

The expected mean rating is calculated separately for each exposure. For example, at SIM + 2, rating is known at 0, 4, 8, and 16-micrometer motion. The equivalent operational exposure time can be determined, and the system motion statistics describe the distribution of motion. Combining this information yields a distribution of ratings, from which the mean rating is calculated for SIM + 2. This procedure is repeated at half-stop increments through exposure.

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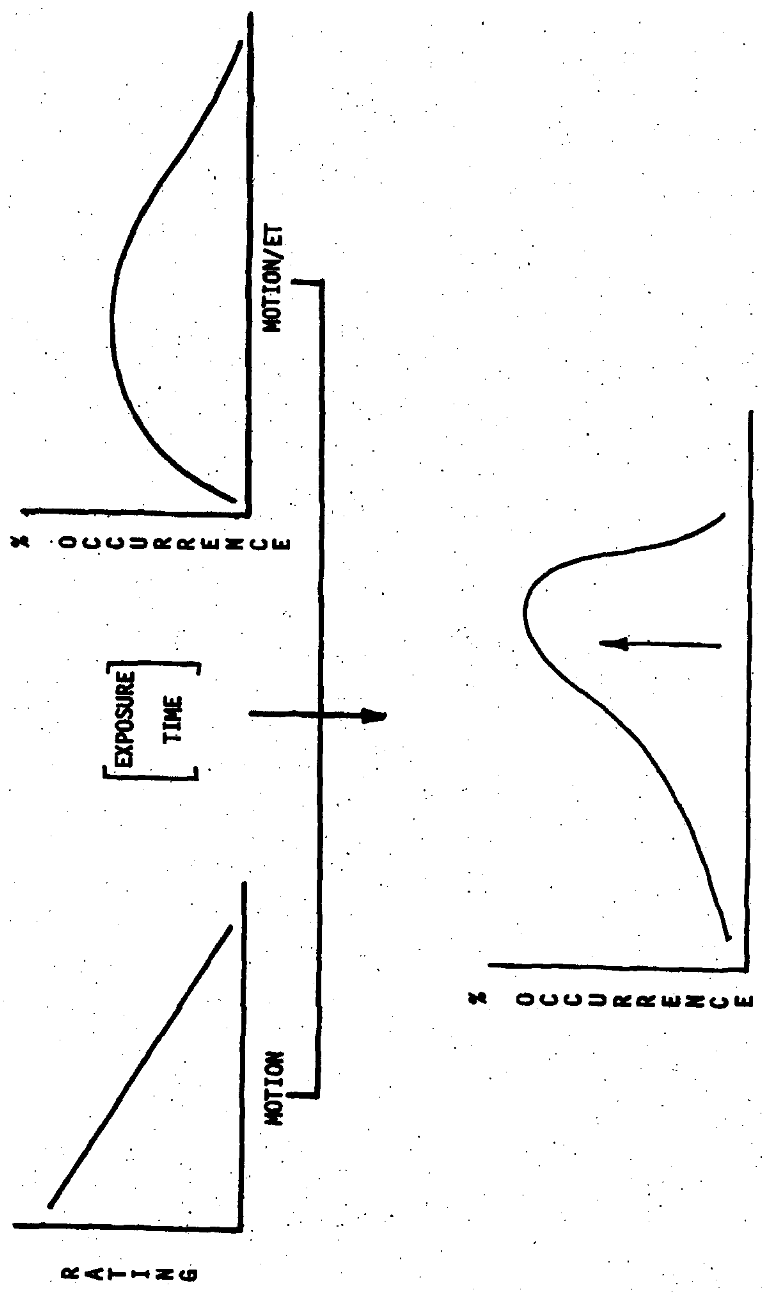
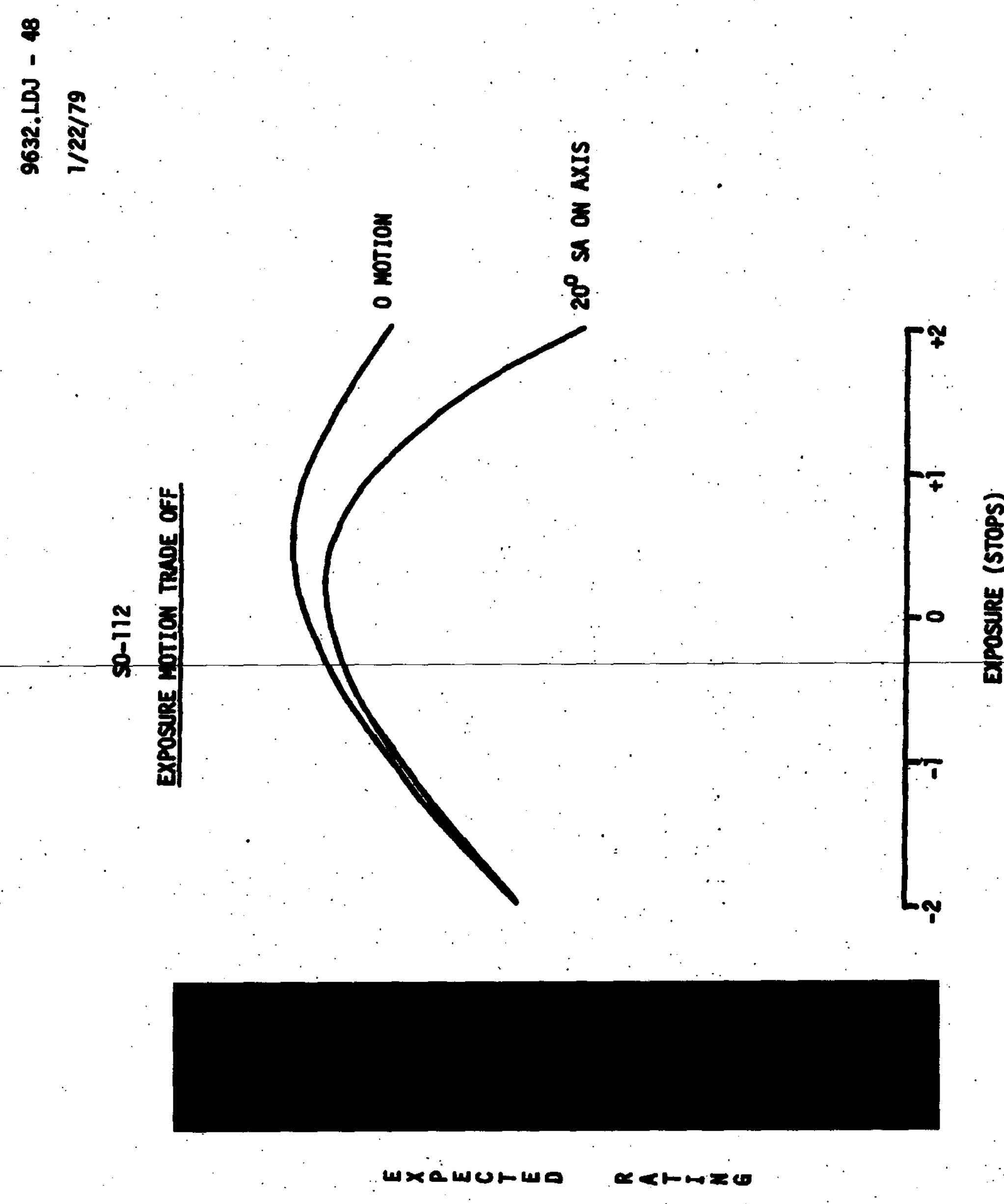
EFFECT OF MOTION ON QUALITY



SO-112 EXPOSURE MOTION TRADEOFF

The results of the SO-112 EMTO are shown on the opposite page. The zero-motion curve is the ratings obtained through exposure if there was no image motion. The lower curve represents the expected ratings at a 20-degree solar altitude accounting for the on axis image motion. The peaks of the curves are not at the same exposure, less exposure being required to optimize rating with motion. Had the zero-motion exposure been used for the motion case, less than the maximum possible rating would have been achieved. That optimum rating can be attained by less exposure, and consequently less motion, and is the optimum tradeoff point of exposure and motion.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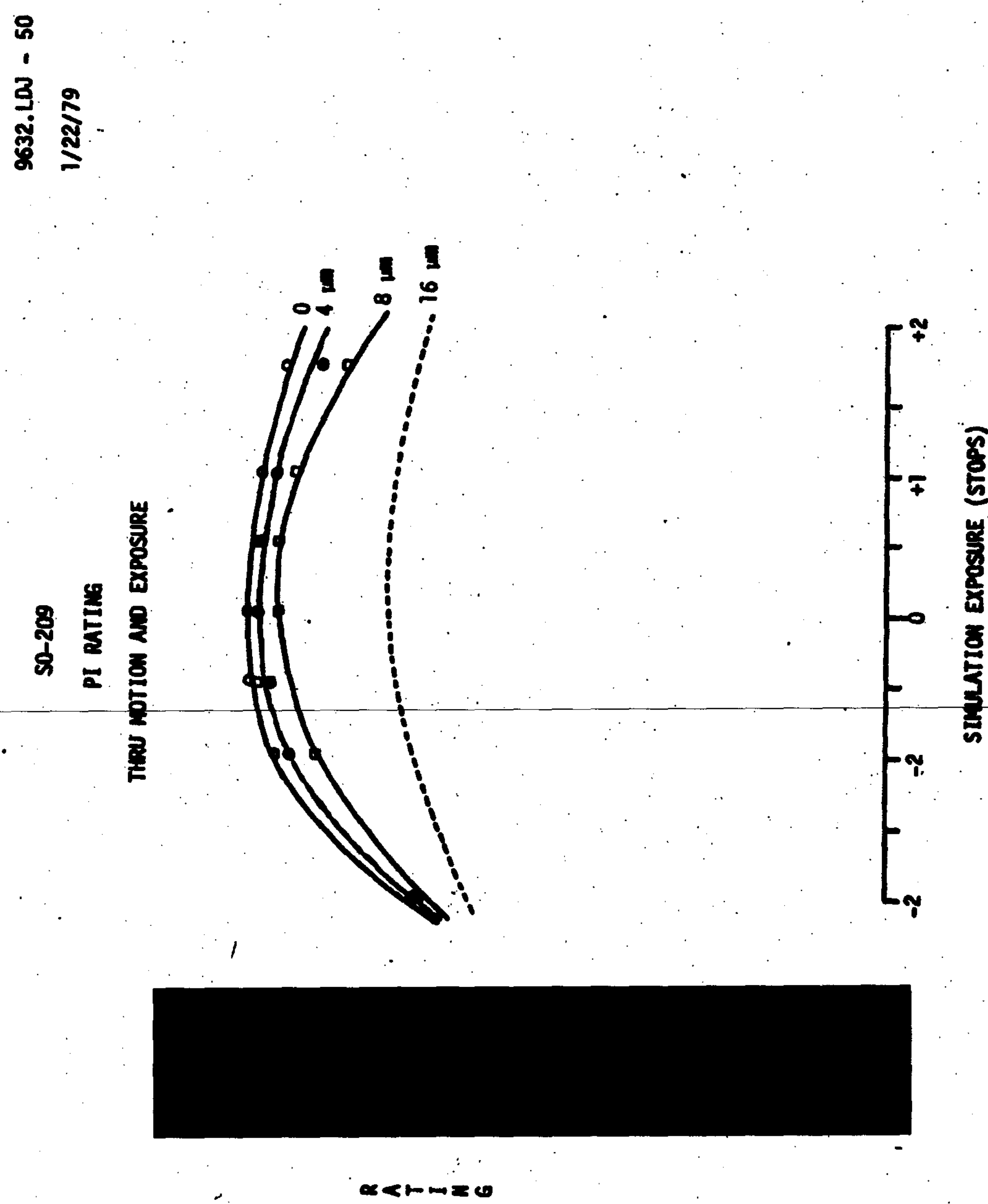
1/22/79
SO-112
EXPOSURE MOTION TRADE OFF
0 MOTION
20° SA ON AXIS
[redacted]
EXPECTED RATING
-2
-1
0
+1
+2
EXPOSURE (STOPS)

SO-209 — PI RATING THROUGH MOTION AND EXPOSURE

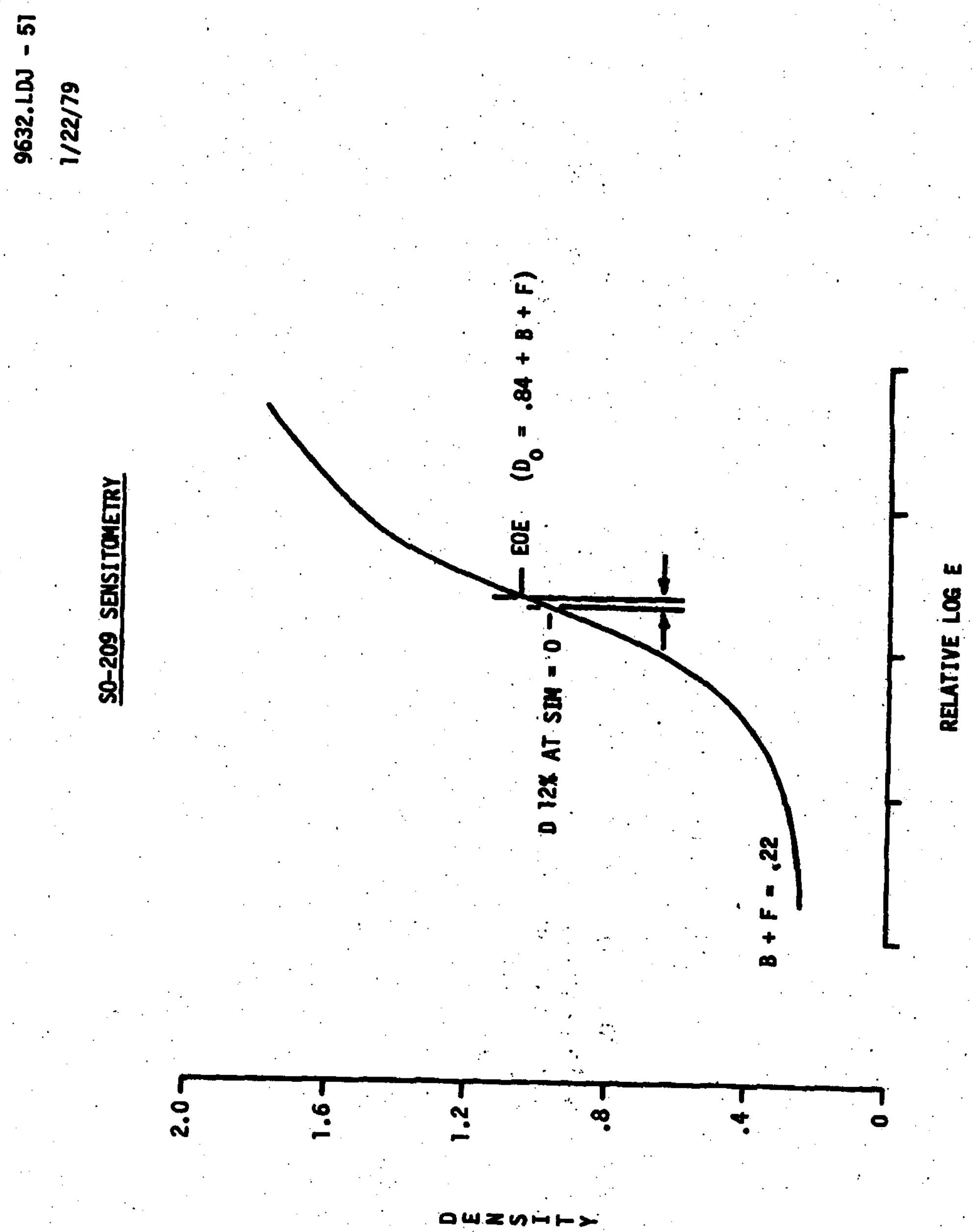
In experiment 632-11, the 1:37,000 scale AOB on SO-209 was rated by 10 PI's. The illumination conditions simulated a 34-degree solar altitude and a 0.7 atmospheric transmittance (2.19 aerial contrast). Prior indications were that little system motion existed, therefore the rating experiment was conducted with motion magnitudes of 0, 2, 4, and 8 micrometers. However, analysis of the motion statistics demonstrated that motion had to be considered beyond 8 micrometers. It was necessary to extrapolate the existing data to the 16-micrometer case, and is shown by the dotted line.


9632.LDJ - 50
1/22/79
SO-209
PI RATING
THRU MOTION AND EXPOSURE
0
4 µm
8 µm
16 µm
+2
+1
0
SIMULATION EXPOSURE (STOPS)
RATING

[redacted]

SO-209 SENSITOMETRY

The characteristic curve of the SO-209 film was utilized to calculate the difference in exposure between SIM 0 and the equivalent operational exposure. This enables the relative simulation exposures to be defined by equivalent operational times.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SO-209 SENSITOMETRY
(D$_o$ = .84 + B + F)
EOE
D 12% AT SIM = 0
B + F = .22
RELATIVE LOG E
DENSITY
2.0
1.6
1.2
.8
.4
0

SO-209 EXPOSURE MOTION TRADEOFF

The results of the SO-209 EMTO are shown on the opposite page. The zero-motion curve is the ratings obtained through exposure if there was no image motion. The lower curve represents the expected ratings at a 35-degree solar altitude in the presence of on axis image motion. The shift in the peaks signifies the exposure compensation required to account for system motion and optimize performance.

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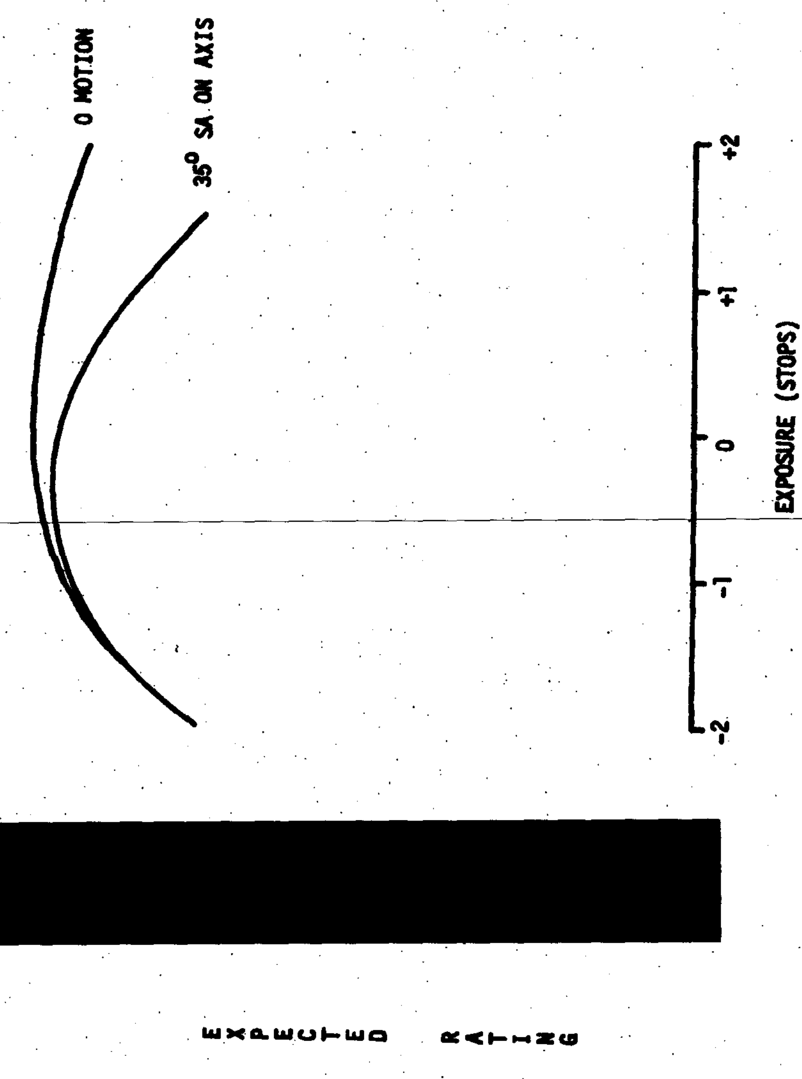
SO-209

EXPOSURE MOTION TRADE OFF



[redacted]

EXPECTED RATING WITH EMTO AT 20-DEGREE SOLAR ALTITUDE

The SO-209 exposure motion tradeoff was performed for the case of a 20-degree solar altitude. The rating data and motion model were the same, but the distribution of motion changed due to the change in energy and therefore, exposure at that solar altitude. The loss in rating at the 1:37,000 scale is shown by the squares. The SO-209 is a slower film and requires more exposure, thus its distribution of motion extends to greater magnitudes than does the SO-112 distribution. Consequently, the SO-209 experiences a greater loss in rating. As scale increases, the magnitude of image motion decreases, and the expected loss in rating would also decrease. The dotted lines illustrate the approximate trends of expected ratings for these films, but are not representative of actual data.

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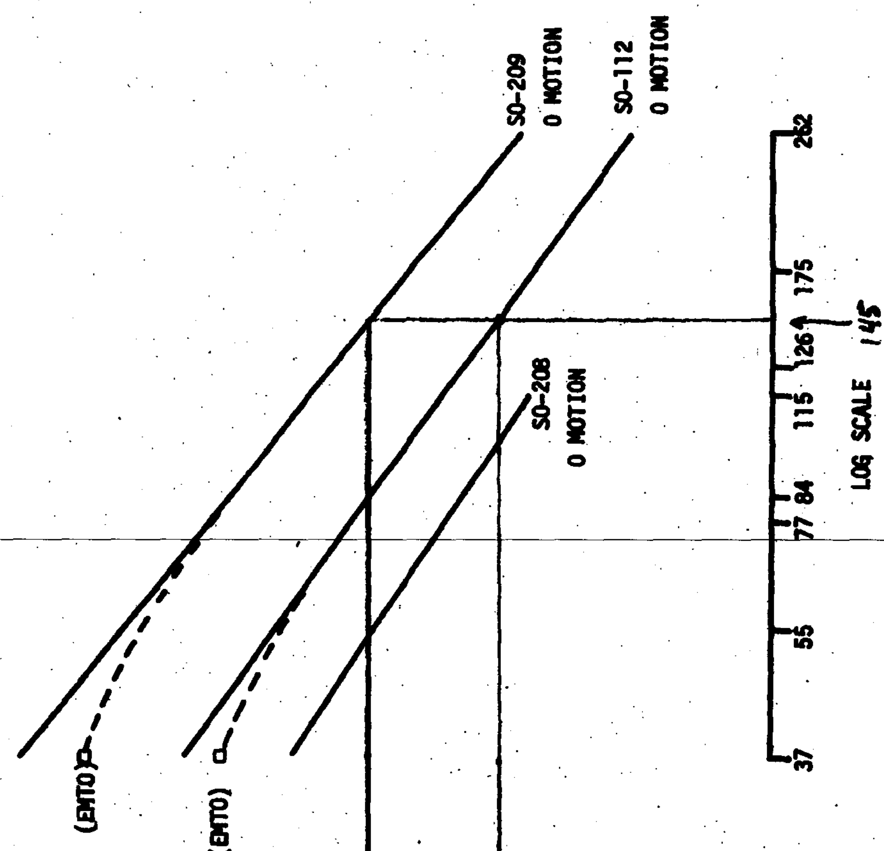
EXPECTED RATING WITH EMTO AT 20° SA



[redacted]

RATING

OPERATIONAL EXPOSURE RECOMMENDATION

Recommendations for operational exposure times were made for SO-209 and SO-112 films. To do this, the differences between simulation and operational parameters had to be specified and the required adjustments made. This entailed relating simulation target reflectances to the average acquisition reflectance and converting simulation exposures into operational context.

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OPERATIONAL EXPOSURE RECOMMENDATION

- SIMULATED TARGET REFLECTANCES MUST BE RELATED TO AVERAGE ACQUISITION REFLECTANCE
- DEFINE OPTIMUM EXPOSURE WITH REFLECTANCE ADJUSTMENT
- CONVERT OPTIMUM SIMULATION EXPOSURE TO ABSOLUTE OPERATIONAL EXPOSURE

TARGET REFLECTANCE ADJUSTMENT

The average acquisition reflectance equals 12 percent. The scale study target, upon which the PI ratings were made, was a 36 percent reflectance AOB situated on a 25 percent reflectance background. The peak of the rating versus exposure curve indicates the optimum exposure for the 36/25 R target. Obviously, a darker target, 12 percent reflectance, would require more exposure. To calculate the necessary increase in exposure, the 36/25 R target was characterized by 30 percent average reflectance and then, the difference in exposure presented to the film by 12 percent and 30 percent reflectance targets was calculated.

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TARGET REFLECTANCE ADJUSTMENT

- PI RATING DATA BASED ON 36% AOB ON 25% BACKGROUND
  CHARACTERIZE TARGET BY 30% AVERAGE REFLECTANCE
- AVERAGE ACQUISITION REFLECTANCE = 12%
- DEFINE EFFECT OF REFLECTANCE DIFFERENCE BY THE EXPOSURE DIFFERENCE ($\Delta \log E$) PRESENTED TO THE FILM BY A 12% AND 30% REFLECTANCE TARGET

EXPOSURE SHIFT CALCULATION

The first method of calculating the exposure shift used simultaneous equations. The illumination received by the film is the sum of the sun and sky energy reflected by the target plus a constant haze component. The aerial contrast is known and is defined by the ratio of the energy from a 33 percent and 7 percent reflectance. The absolute exposure values of a 30 percent R and 12 percent R target need not be found, but rather just their difference in exposure, $\Delta \log E$. Therefore, the 12 percent exposure was set to equal 1, yielding two equations, (1) and (2), and two unknown, S and H. The unknowns were solved for, a 30 percent exposure (30 percent Exp = .30 (S) + H) calculated, and the difference in exposure found.

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EXPOSURE SHIFT CALCULATION

- METHOD OF SIMULTANEOUS EQUATIONS

  (1) 12% EXP. = .12 (S) + H

  (2) AERIAL CONTRAST = $\frac{.33\ (S) + H}{.07\ (S) + H}$

  WHERE S = SUN + SKY

  H = HAZE

- LET 12% EXP. = 1
- AERIAL CONTRAST KNOWN
- THEREFORE, 2 EQUATIONS, 2 UNKNOWNS
- SOLVE FOR 30% EXPOSURE
- CALCULATE Δ log E = (log $E_{30\%}$) - (log $E_{12\%}$)

EXPOSURE SHIFT CALCULATION

A second method to calculate the exposure shift was based on film sensitometry. The developed densities were plotted against the log of their respective reflectances. The difference in exposure of 12 percent R and 30 percent R was found by transferring their densities through the characteristic curve into the exposure domain.

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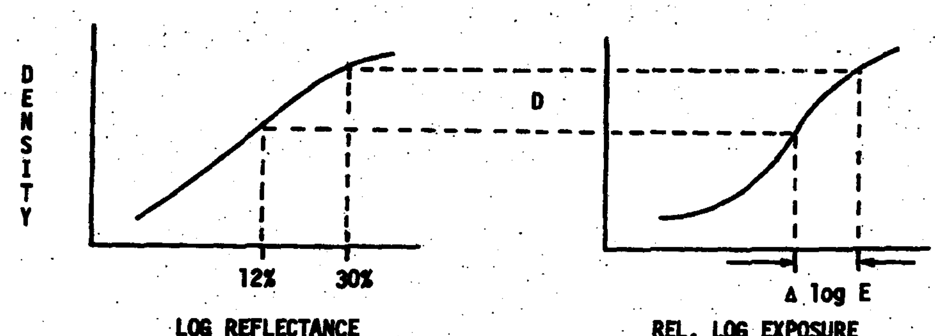
EXPOSURE SHIFT CALCULATION

- SENSITOMETRIC METHOD
  - CONSTRUCT COMPOSITE CHARACTERISTIC CURVE
  - PLOT DENSITY AS A FUNCTION OF LOG REFLECTANCE AT EXP = SIM 0
  - SOLVE FOR Δ log E GRAPHICALLY



REFLECTANCE ADJUSTMENT SUMMARY

The results of the two methods are summarized on the opposite page. It can be seen that the procedures are in excellent agreement, within 0.01 log exposure units for both films.

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REFLECTANCE ADJUSTMENT SUMMARY

	SO-112	SO-209
AERIAL CONTRAST	1.91	2.19
Δ log E SIMUL. EQ.	.186	.223
Δ log E SENSITOMETRY	.18	.23
$\overline{\Delta \log E}$	.18	.23

OPTIMUM SIMULATION EXPOSURE AND D_0 RECOMMENDATION

The previous pages' calculations are now used to correct optimum exposure. The peak of the rating vs. exposure curve indicated the best exposure for a target of 30 percent average reflectance. For the average acquisition reflectance of 12 percent, the optimum exposures are increased to account for the reflectance difference and are defined by the additional log exposure relative to the SIM 0 exposure. This recommendation is placed in absolute terms by defining the developed density, D_0, a 12 percent reflectance would have at this exposure.

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OPTIMUM SIMULATION EXPOSURE & D_o RECOMMENDATION

OPT. EXPOSURE	SO-112	SO-209
36/25% AOB	SIM 0+.14 logE	SIM 0+.05 logE
12% R	SIM 0+.32 logE	SIM 0+.28 logE

D_o	SO-112	SO-209
12% DENSITY	1.64	1.58
B + F	.31	.22
12% D ABOVE B+F	1.33	1.36

12 PERCENT REFLECTANCE AIM DENSITIES—ZERO-MOTION CASE

The SO-112 D_0 recommendation of the rating analysis was compared to that given by R.S., and the difference quantified by the Δ log exposure between the two. For the zero motion case, the rating analysis indicates an exposure that is 0.24 log E units greater.

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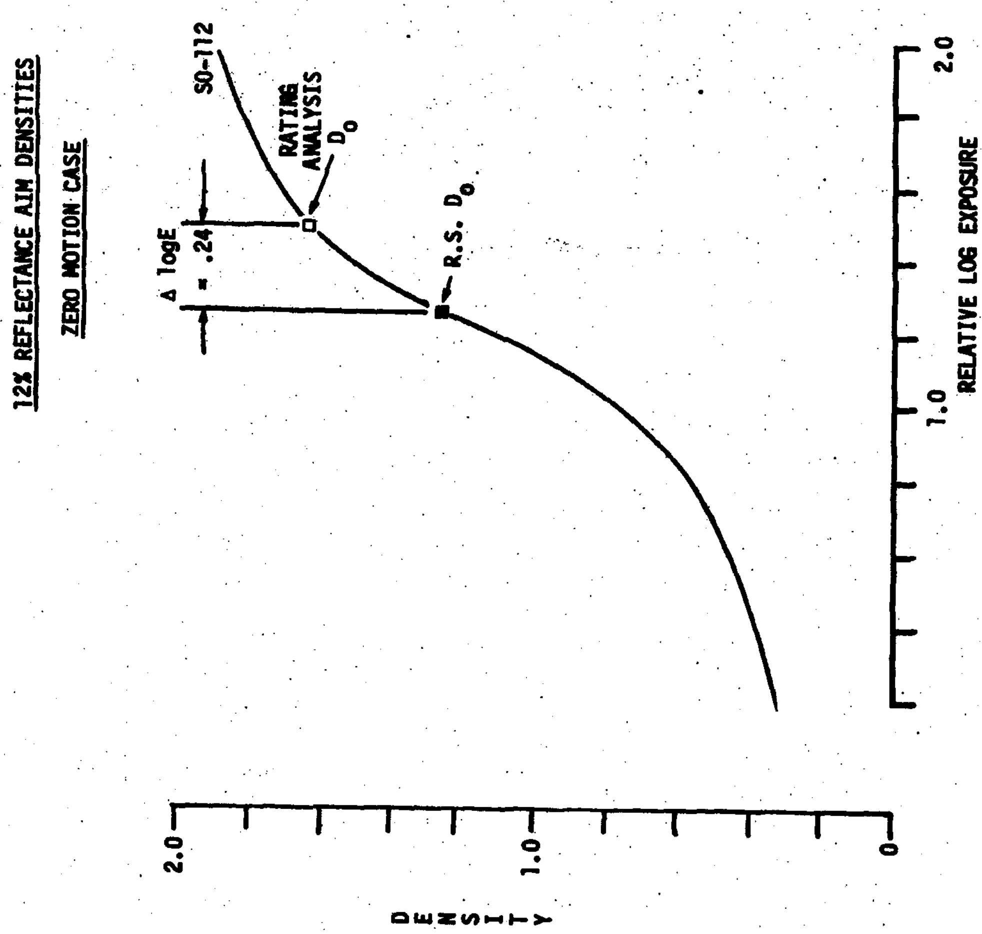

12 PERCENT REFLECTANCE AIM DENSITIES—ZERO-MOTION CASE

The SO-209 D_e recommendations were compared and the difference calculated in the exposure domain. For the zero-motion case, the rating analysis recommends a higher density and therefore an exposure that is 0.27 log E units greater.

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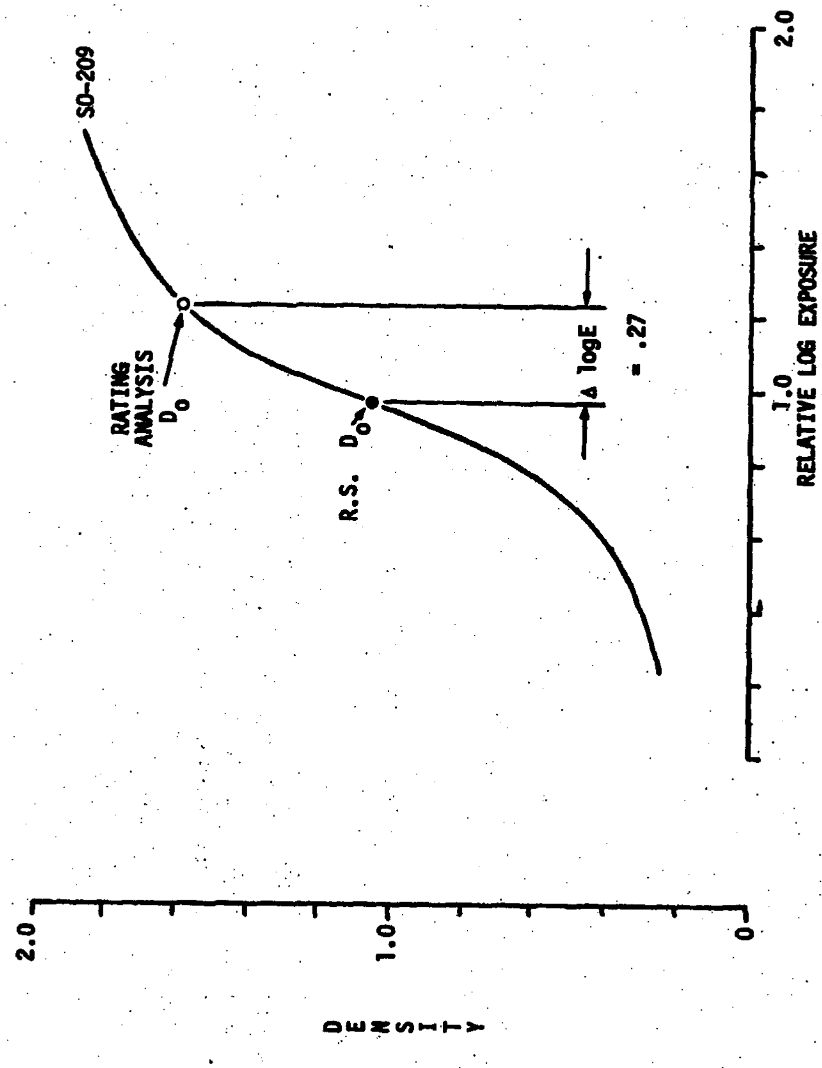
12% REFLECTANCE AIM DENSITIES

ZERO MOTION CASE



RECOMMENDED EXPOSURE TIME—ZERO-MOTION CASE

Along with their D_0 recommendation, R.S. supplied the system exposure time through solar altitude. As shown on the previous two pages, the rating analysis has suggested a greater optimum exposure for both films. This exposure increase modifies each R.S. exposure time by a factor of the D_0 log E difference raised to a power of ten.

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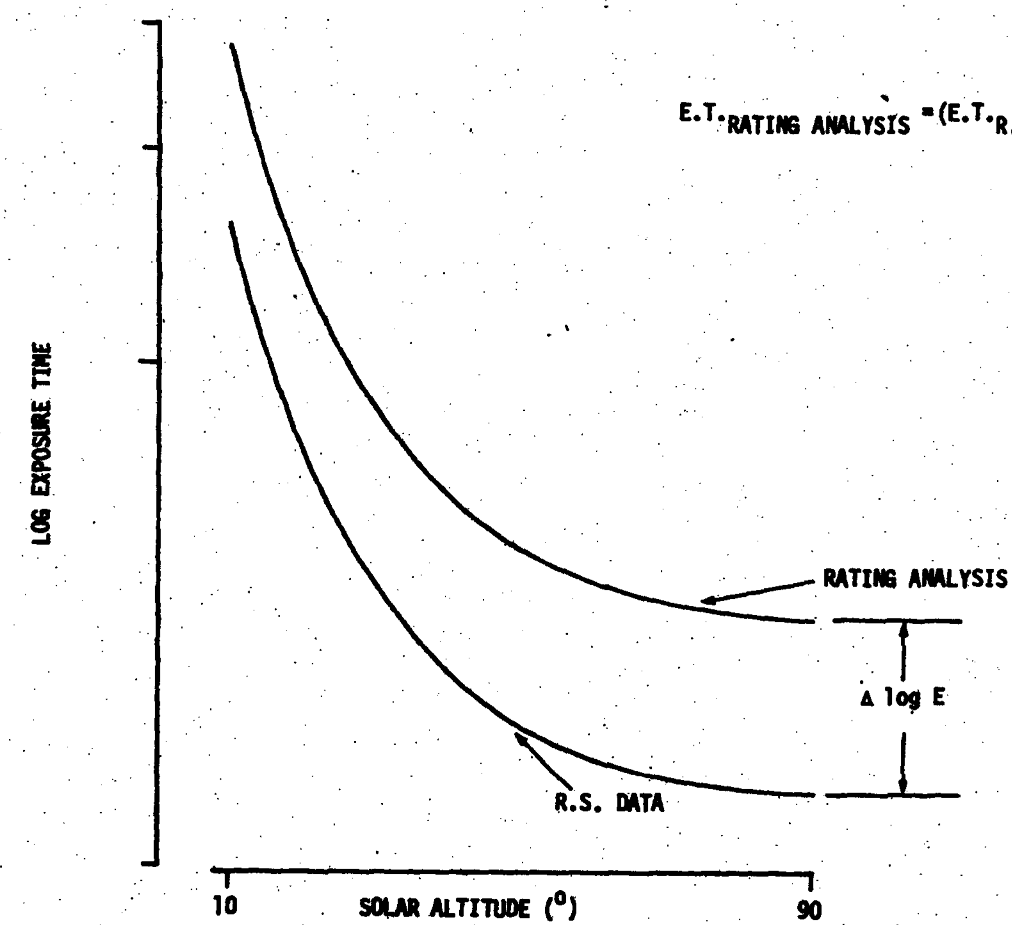
RECOMMENDED EXPOSURE TIME

ZERO MOTION CASE

$$E.T._{RATING\ ANALYSIS} = (E.T._{R.S.\ DATA}) \times (10^{\Delta \log E})$$



EMTO CORRECTION

The exposure motion tradeoffs had been performed for only 20 and 34-degree solar altitudes. Their impact was to specify the optimum decrease in exposure from the zero-motion case which would maximize rating in the presence of motion. The analysis was extended to the other solar altitudes and the exposure corrections, $\Delta \log E$, were calculated for the other sun angles. These corrections modify the zero-motion exposure time by a factor of the log exposure raised to a power of 10.

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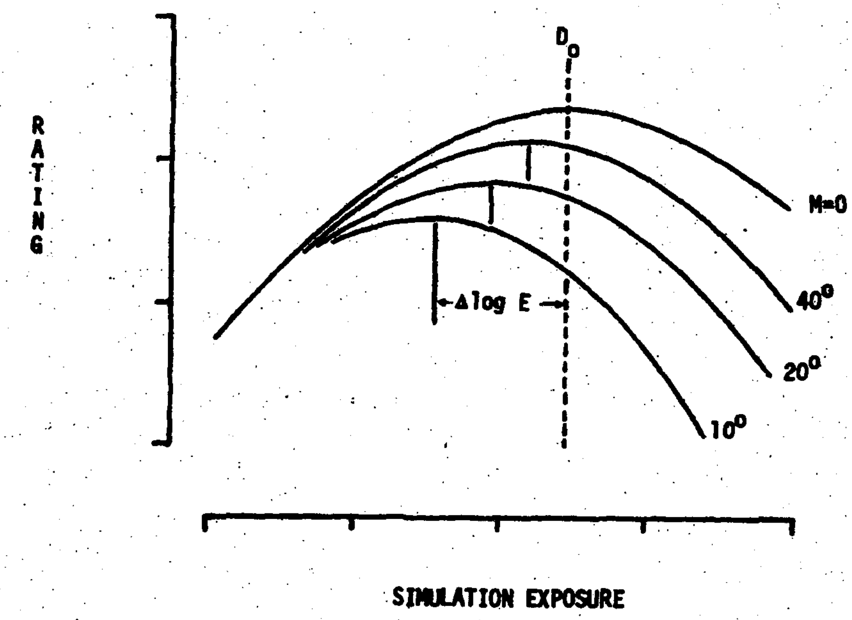
EMTO CORRECTION



- ADJUST RECOMMENDED ZERO MOTION EXPOSURE
- $ET_{MOTION} = ET_{ZERO} \times 10^{\Delta \log E}$

RECOMMENDED EXPOSURE TIME VERSUS SOLAR ALTITUDE—SO-112

The summation of the exposure recommendations for SO-112 are shown opposite. The R.S. data was modified for the optimum zero motion exposure as indicated by PI ratings, and this curve was then corrected for system motion.

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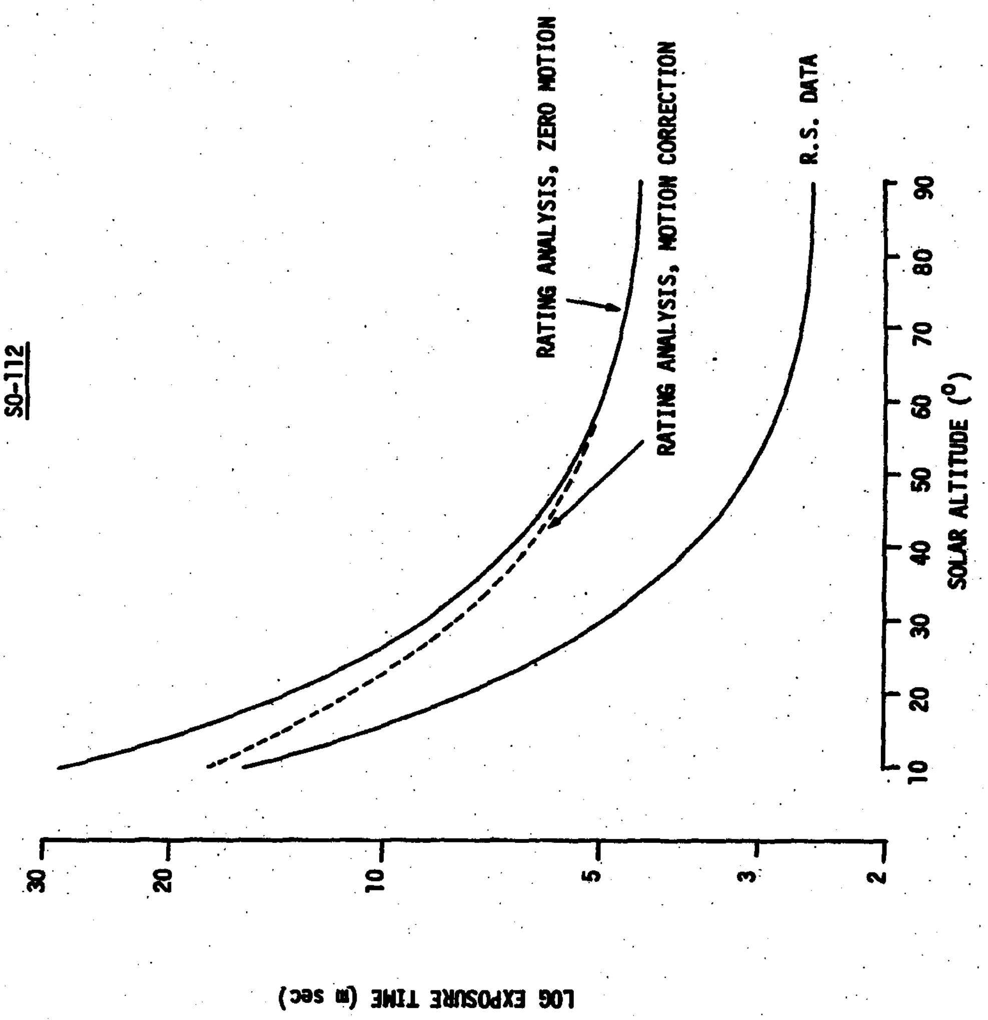
RECOMMENDED EXPOSURE TIME VS SOLAR ALTITUDE

SO-112



RECOMMENDED EXPOSURE TIME VERSUS SOLAR ALTITUDE—SO-209

The summation of the exposure recommendations for SO-209 are shown opposite. The R.S. data was modified for the optimum zero-motion exposure as indicated by PI ratings, and this curve was then corrected for system motion.

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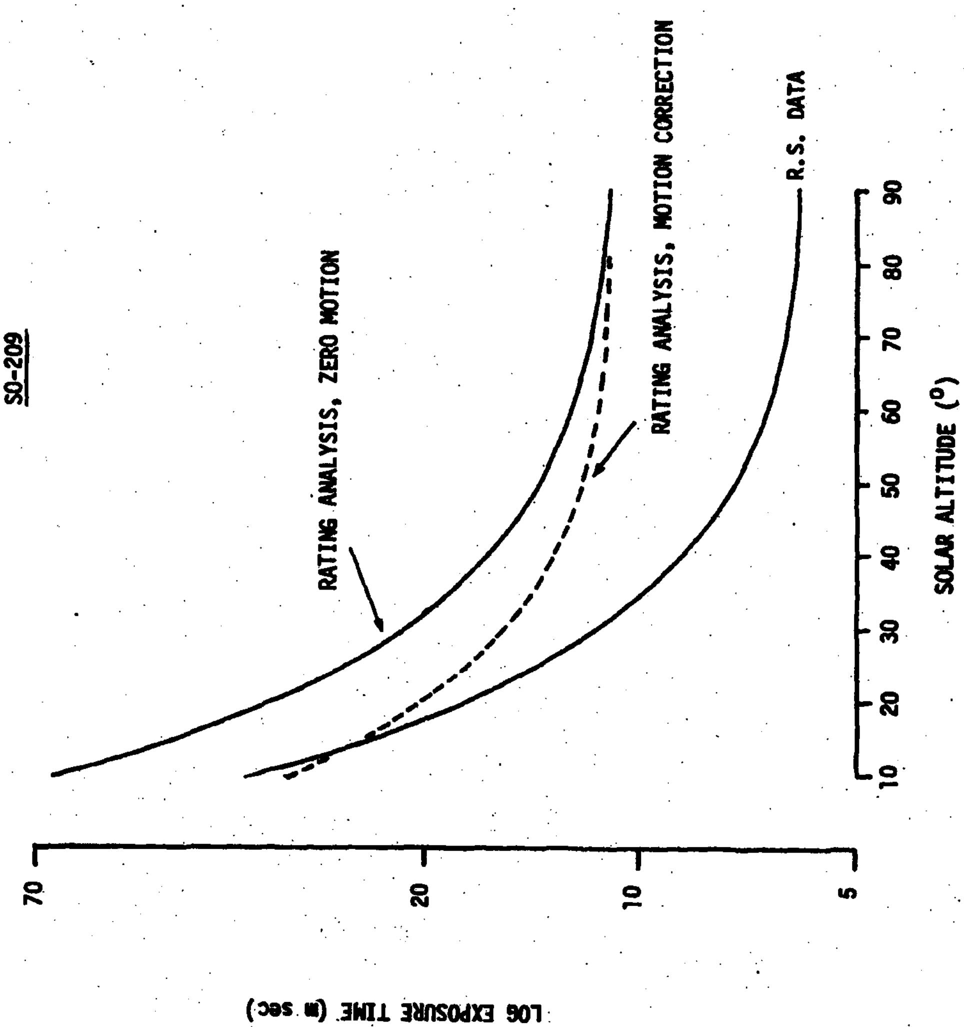
RECOMMENDED EXPOSURE TIME VS SOLAR ALTITUDE

SO-209



SMEAR MODEL ANALYSIS

An additional set of data analysis was performed to supply a co-contractor with smear-exposure bias functions for SO-209 and SO-112 films. The EMTO data provided rating curves through simulation exposure at constant magnitudes of motion. From these curves, smear rates were generated. Along a smear rate curve, the amount of image motion is a function of the exposure time. As in the illustration, starting with 16 micrometers at SIM 0 + 2 stops, there would be 8, 4, and 2 micrometers at SIM 0 +1, SIM 0, and SIM 0 -1, respectively. Two measures were derived from each smear curve. The exposure compensation to achieve maximum rating with smear relative to the peak of the zero-motion curve was computed as was the magnitude of smear at the optimum zero-motion exposure, D_0.

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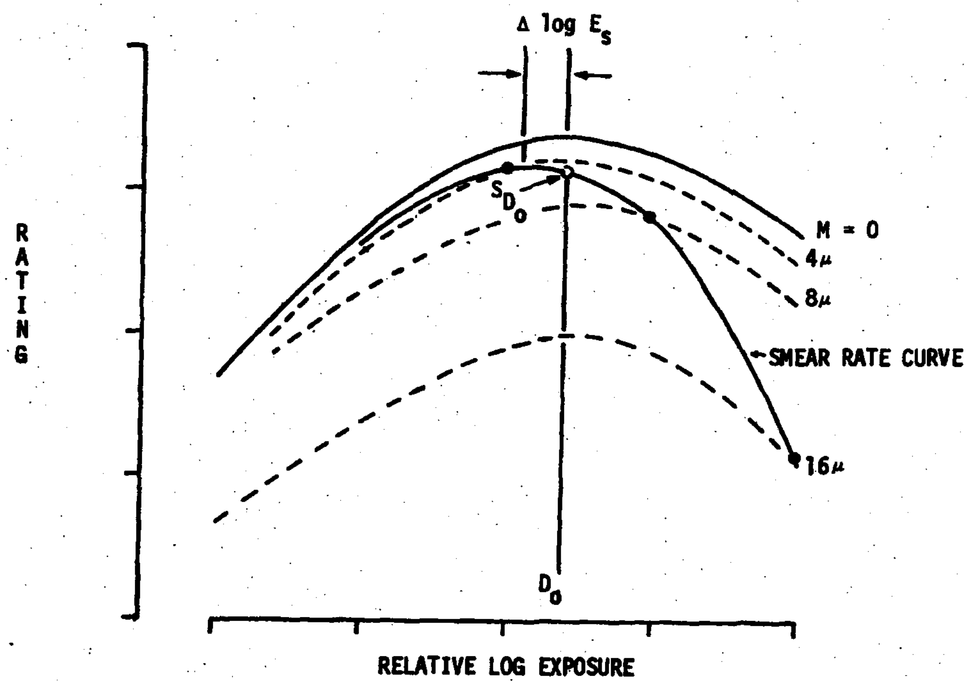
SMEAR MODEL ANALYSIS

- GENERATE SMEAR RATE CURVES FROM MOTION/EXPOSURE CURVES



- CALCULATIONS: (1) log E BIAS FROM D_o = Δ log E_s
  (2) MOTION AT D_o = S_{D_o}

SMEAR-EXPOSURE BIAS FUNCTION—SO-112

The results of the smear rate analysis are shown here for SO-112 film. The amount of log exposure bias for optimum image quality is plotted as a function of smear at D_0. The chart values of Δ log E and smear are the actual points, not the smoothed curve.

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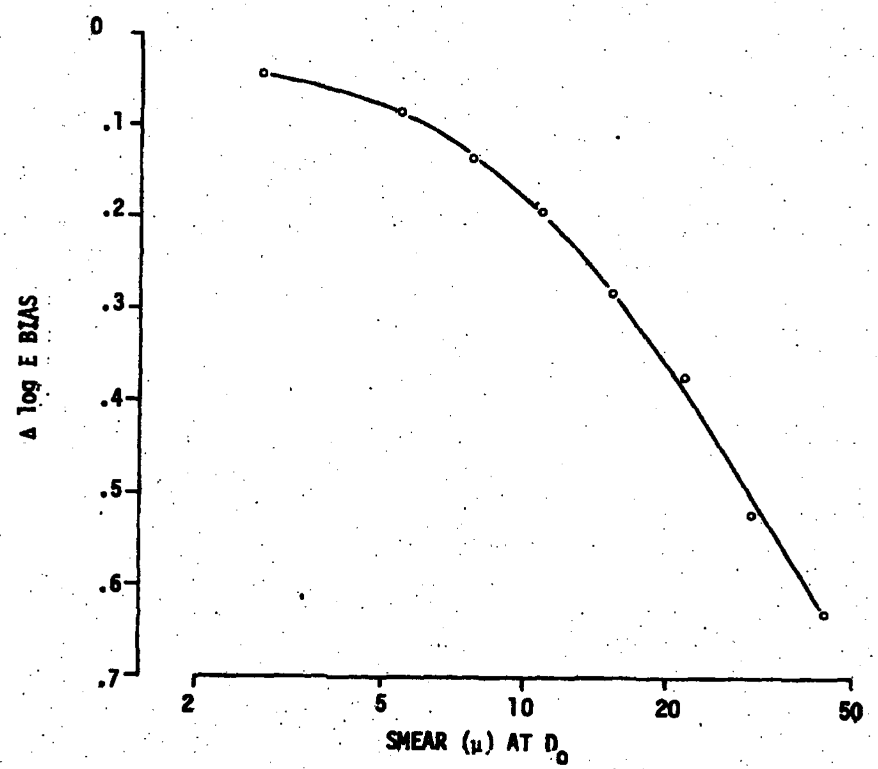
SMEAR-EXPOSURE BIAS FUNCTION

SO-112



Δ log E	SMEAR (μ)
.045	2.1
.084	5.5
.135	7.8
.195	10.9
.285	15.5
.375	21.8
.525	30.8
.630	43.6

SMEAR-EXPOSURE BIAS FUNCTION—SO-209

The results of the smear rate analysis are shown here for SO-209 film. The amount of log exposure bias for optimum image quality is plotted as a function of smear at D_0. The chart values of Δ log E and smear are the actual points, not the smoothed curve.

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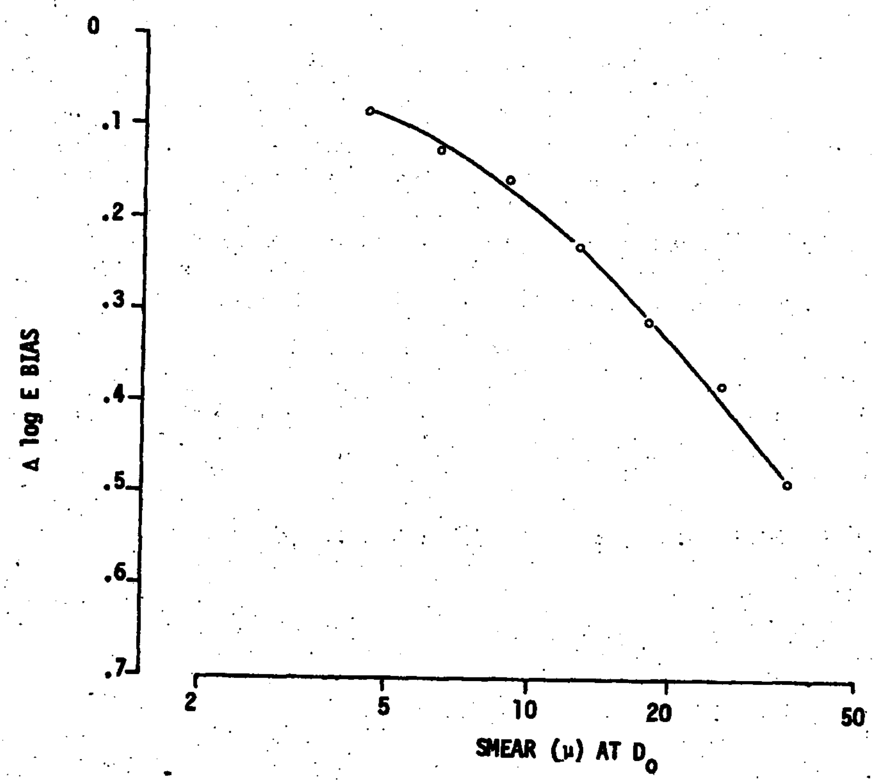
SMEAR-EXPOSURE BIAS FUNCTION

SO-209



Δ log E	SMEAR (μ)
.086	4.5
.125	6.4
.155	9.0
.230	12.7
.311	18.0
.380	25.4
.485	35.8

EFFECT OF MOTION FOR DIFFERENT HEIGHT AND FORMAT

The exposure/motion tradeoffs performed in the scale study considered only the motion at the center of the format, which was appropriate for a pointing task. However, as the height is increased, the motion magnitude is decreased, but the task becomes a search task and the entire format should be considered.

To properly analyze the effect of motion at other altitudes, new rating data should be generated at the appropriate scales. Interactions exist between motion/contrast and exposure, and the existing rating data cannot simply be scaled downward for other altitudes. However, to estimate the effect of format and height, the interaction was ignored in this present work, and the exposure/motion data treated as if it were obtained at another scale. A nominal set of conditions was chosen to represent the higher altitude and the smear rates were calculated across the format.

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EFFECT OF MOTION FOR DIFFERENT H. AND FORMAT

- USE OF SYSTEM PARAMETERS TO DEFINE MOTION STATISTIC
- CALCULATE SMEAR AT EACH FORMAT POSITION TO BOUND EFFECT
- CHOOSE A NOMINAL SET OF CONDITIONS

$h = 350, 470$

$\Omega = 25$

EXAMPLES

An example calculation is shown on the opposite page, for H = 250 and a 25-degree obliquity. For each scan orientation, the on axis and field contributions are added to find the total contribution. The total intrack and crosstrack calculations are then vector summed to specify the total smear.

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EXAMPLES

	h	Ω degrees	PERCENTILE	AXIS CONTRIB. h = 70 r/s	$(Vcn/h)_n$	AXIS CONTRIB. @h r/s	FIELD POINT	FIELD CONTRIB. r/s	TOTAL CONTRIB. r/s	TOTAL	SMEAR
It	350	25^0	50%	94	.19	17.9	50	59	76.9		
										83.25	0.37µ/ms
Xt	350	25^0	50%	80	.19	15.2	50	16.7	31.9		

RATE OF MOTION FOR 50 and 90 PERCENT FOR THREE DIFFERENT HEIGHTS

The rate of motions are shown for three altitudes at a 25-degree obliquity as functions of format position. At each altitude, the rates were calculated for the 50 and 95 percentiles of the smear distribution. These percentiles mean that 50 and 95 percent of the smear is less than that rate.

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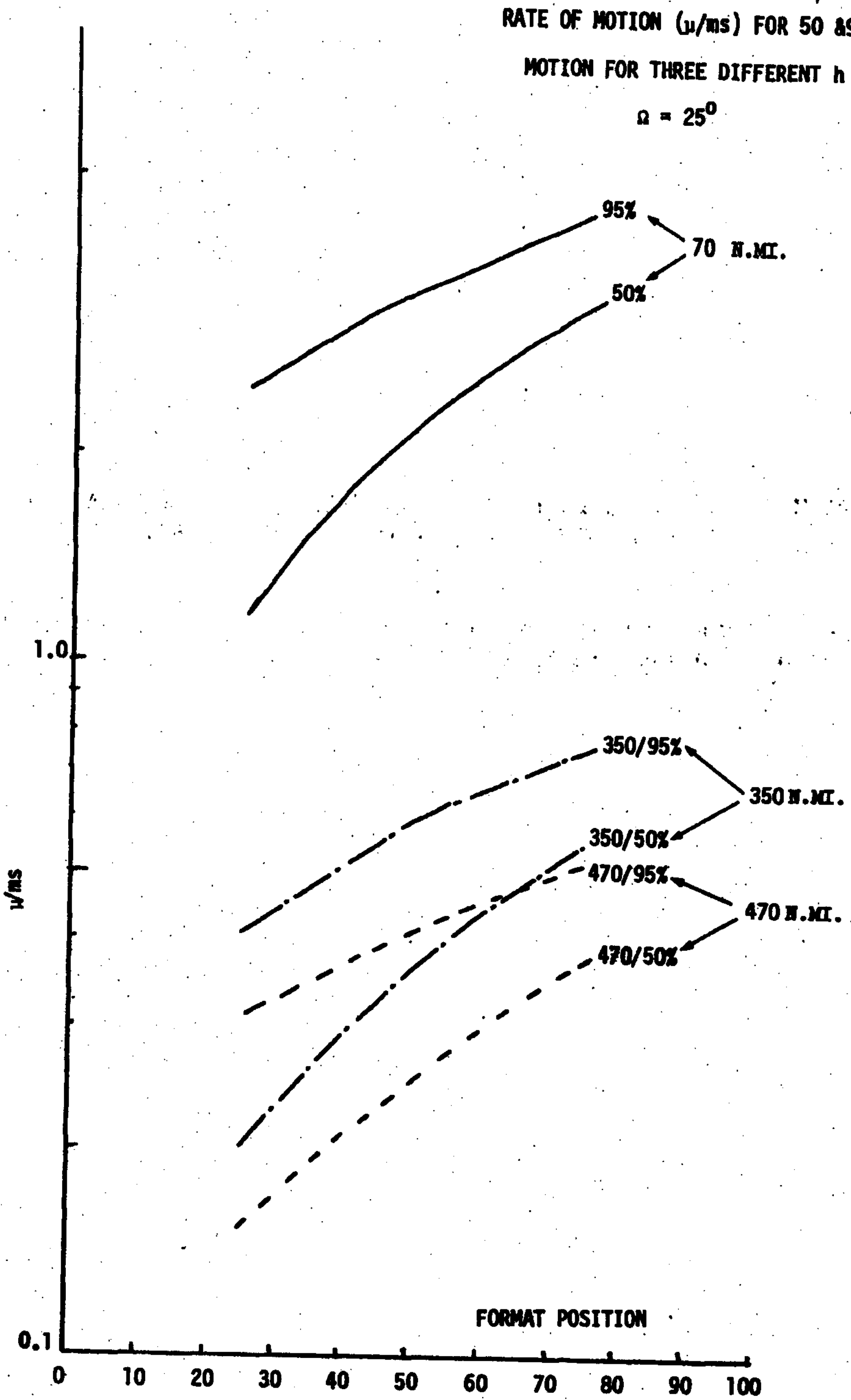

95 PERCENT MOTION MAGNITUDE ACROSS FORMAT BY MATERIAL AND SOLAR ALTITUDE FOR TWO DIFFERENT HEIGHTS

The amounts of motion across format are shown for SO-209 and SO-112 films at altitudes of 70 and 350 nautical miles for various solar altitudes.

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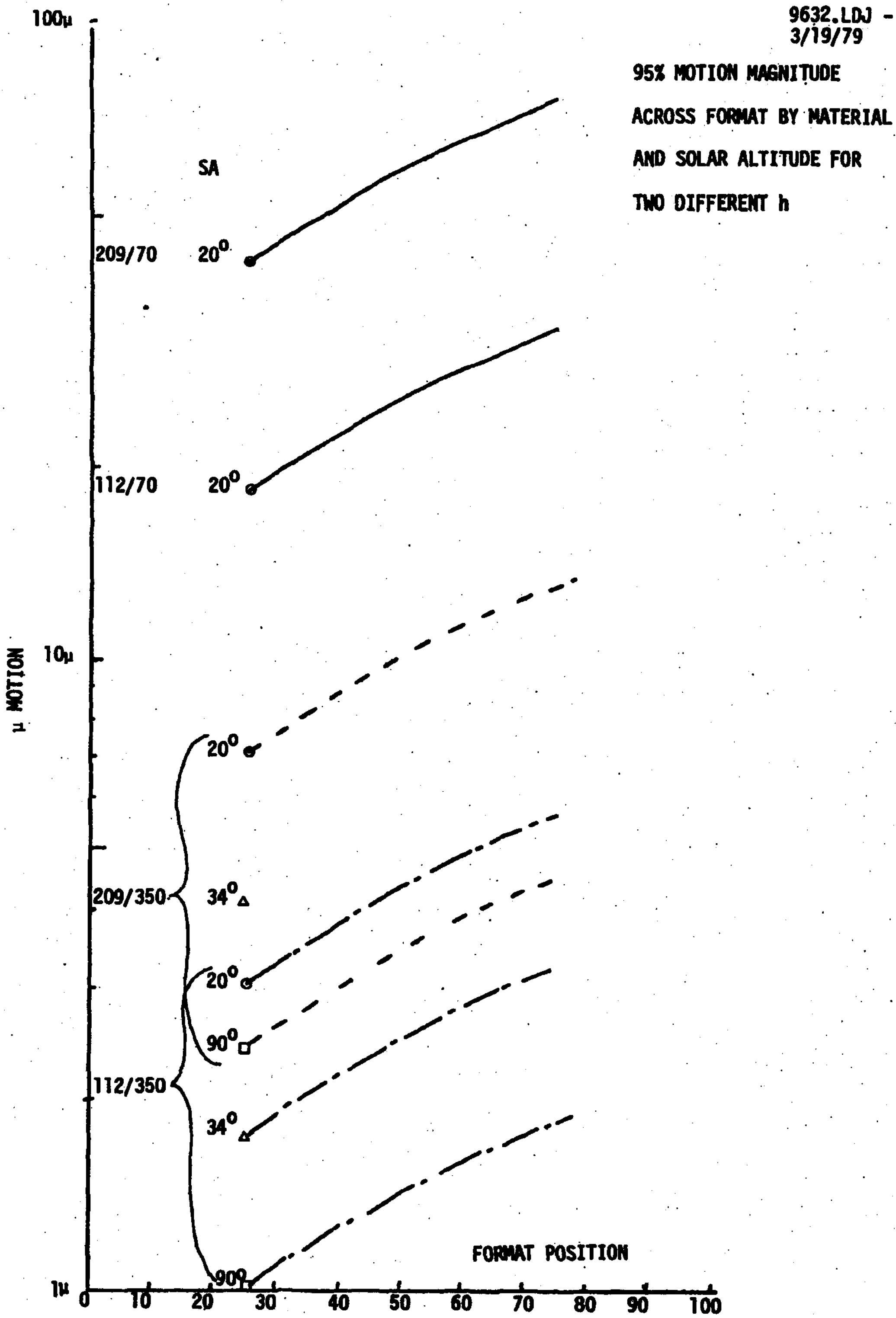

MOTION AT HEIGHT OVER FORMAT

With reference to the previous page, it is shown that the motion magnitudes are large for both films at 70 miles and are reduced by a factor of approximately 6 at 350 miles. SO-209 has more motion than SO-112 due to longer exposure times, and at 350 miles the worst condition for SO-209 is at the 75 percent format with 95 percent of the motion less than 12 micrometers. Looking at a 34-degree solar altitude and at 50 percent of the format, 95 percent of the motion is less than 6 micrometers for SO-209 and 2.5 micrometers for SO-112.

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MOTION AT HEIGHT OVER FORMAT

- THE MAGNITUDES ARE LARGE AT h = 70
- AT h = 350 THE MAGNITUDES ARE DOWN APPROXIMATELY 5 TIMES
- THE WORST CONDITION FOR 209: 20° SA, at 75% FORMAT 95% OF THE MOTION IS LESS THAN 12μ
- AT 34° SA, AND AT 50% IN FORMAT, 95% OF THE MOTION IS LESS THAN 6μ FOR 209 and 2.5μ FOR 112

EMTO

To gauge the effect on rating of the off-axis motion rates, EMTO's were performed at an altitude of 350 miles, 34-degree solar altitude, and 25-degree obliquity. As stated previously, the existing exposure/motion data was treated as it was obtained at this scale. To properly estimate the expected rating, new PI rating data should be generated for the appropriate scale.

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EMTO

- EXPOSURE/MOTION TRADE-OFFS WERE DONE AT ONE h, AT THREE DIFFERENT FORMAT POSITION FOR EACH MATERIAL

- THE CHOSEN CONDITIONS WERE:

  $h = 350$

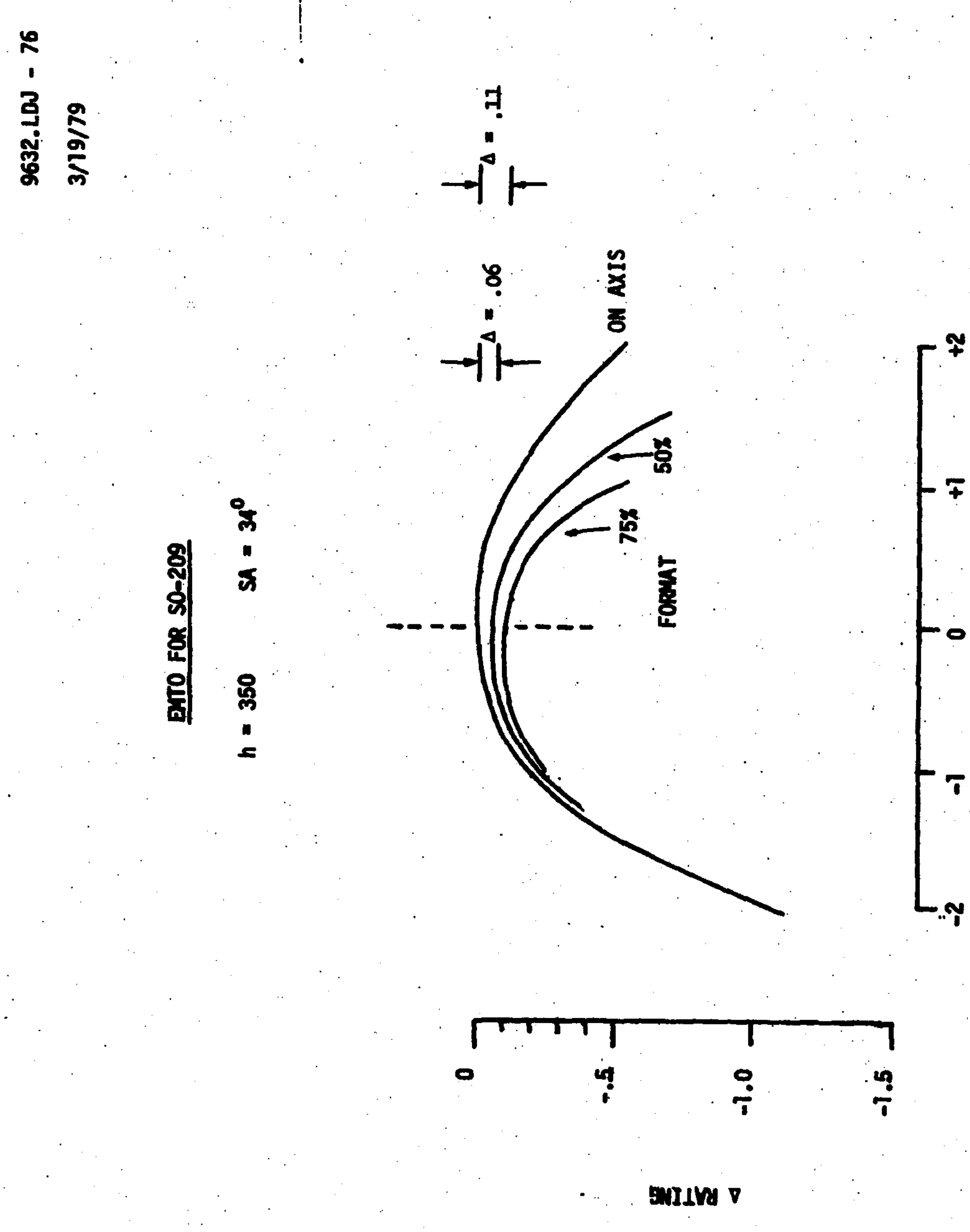
  $\Omega = 25^{0}$

  $SA = 34^{0}$

  WORST CASE OFF AXIS RATES

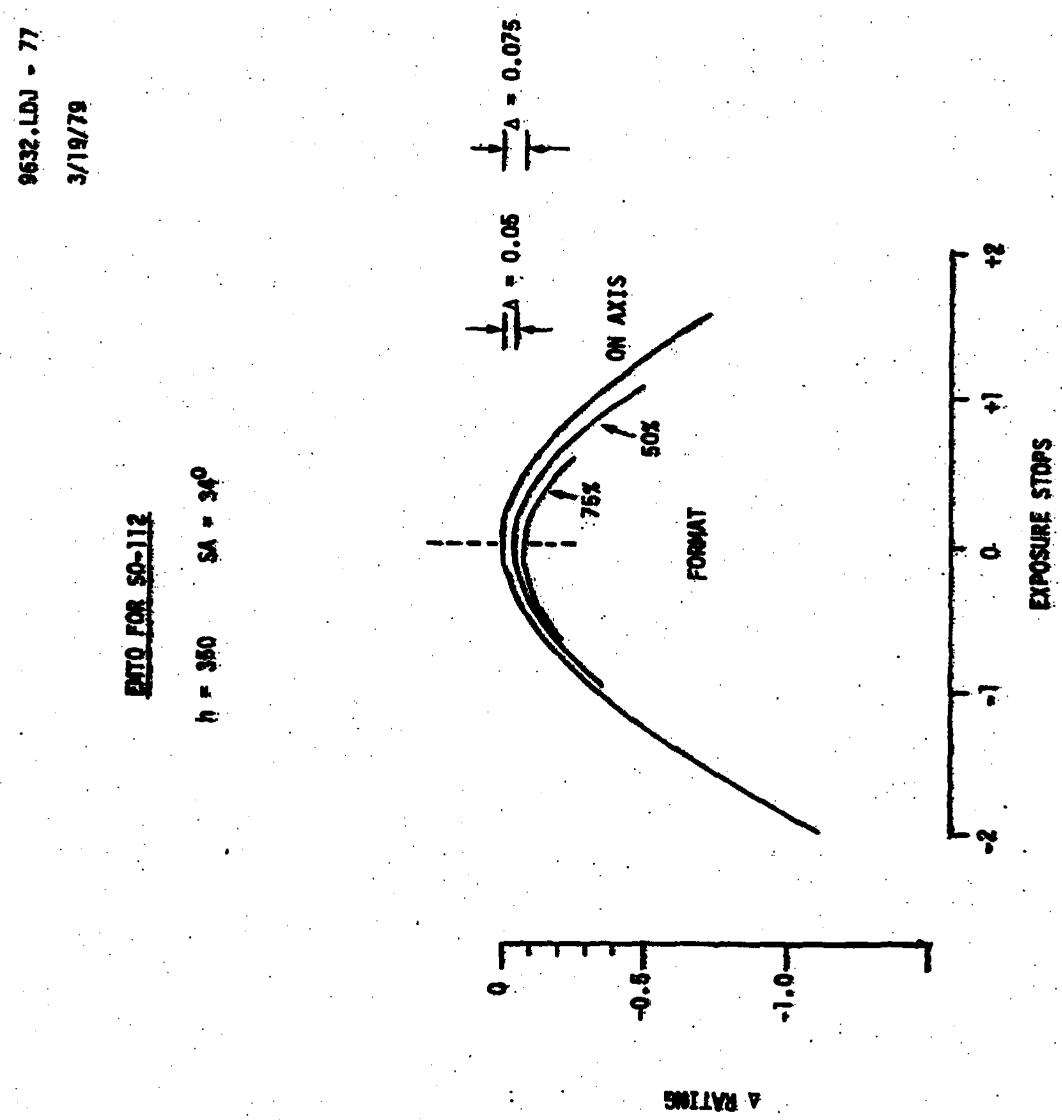
EMTO FOR SO-209

The expected ratings are shown for SO-209 on-axis and at 50 and 75 percent of the format. The rating axis is a relative scale and is intended to show the rating loss that could be expected for the off-axis cases. At 75 percent of the format, a loss of 0.11 rating would be incurred.


9632.LDJ - 76
3/19/79
EMTO FOR SO-209
h = 350 SA = 34°
Δ = .06
Δ = .11
ON AXIS
50%
75%
FORMAT
0
-.5
-1.0
-1.5
Δ RATING
-2
-1
0
+1
+2
EXPOSURE (STOPS)

EMTO FOR SO-112

The expected ratings are shown for SO-112 on-axis and at 50 and 75 percent of the format. The rating axis is a relative scale and is intended to show the loss in rating that could be expected for the off-axis cases. The drop in rating is slightly less for the SO-112 than for SO-209, and is approximately 0.08 rating units at 75 percent of the format.


9632.LDJ - 77
3/19/79
EMTO FOR SO-112
h = 350 SA = 34°
Δ = 0.05
Δ = 0.075
ON AXIS
50%
75%
FORMAT
EXPOSURE STOPS
-2
-1
0
+1
+2
Δ RATING
0
-0.5
-1.0

EMTO RESULTS

The expected rating losses are summarized for SO-112 and SO-209 at the 50 and 75 percent format positions. There is no appreciable shift in the peak exposure for these two format positions, therefore the optimum exposure remains at the on-axis exposure point.

9632.LDJ - 78

3/19/79

EMTO RESULTS

- CALCULATION OF LOSS IN RATING DUE ONLY TO MOTION
- EXPOSE FOR OPTIMUM ON AXIS QUALITY

RATING LOSS

	SO-209	SO-112
50% FORMAT	-0.06	-0.05
75% FORMAT	-0.11	-0.08

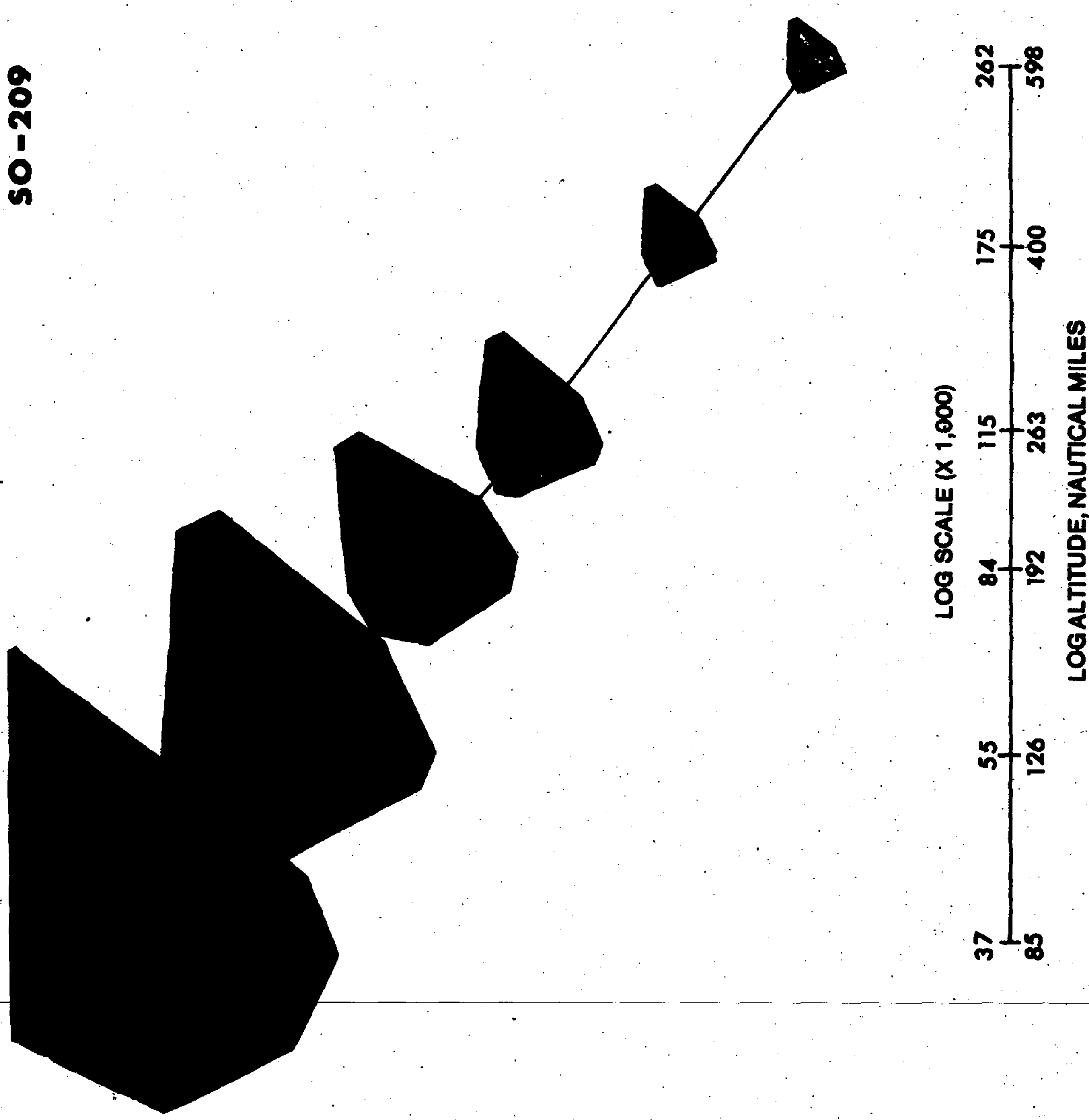
APPENDIX A

SCALE STUDY IMAGERY

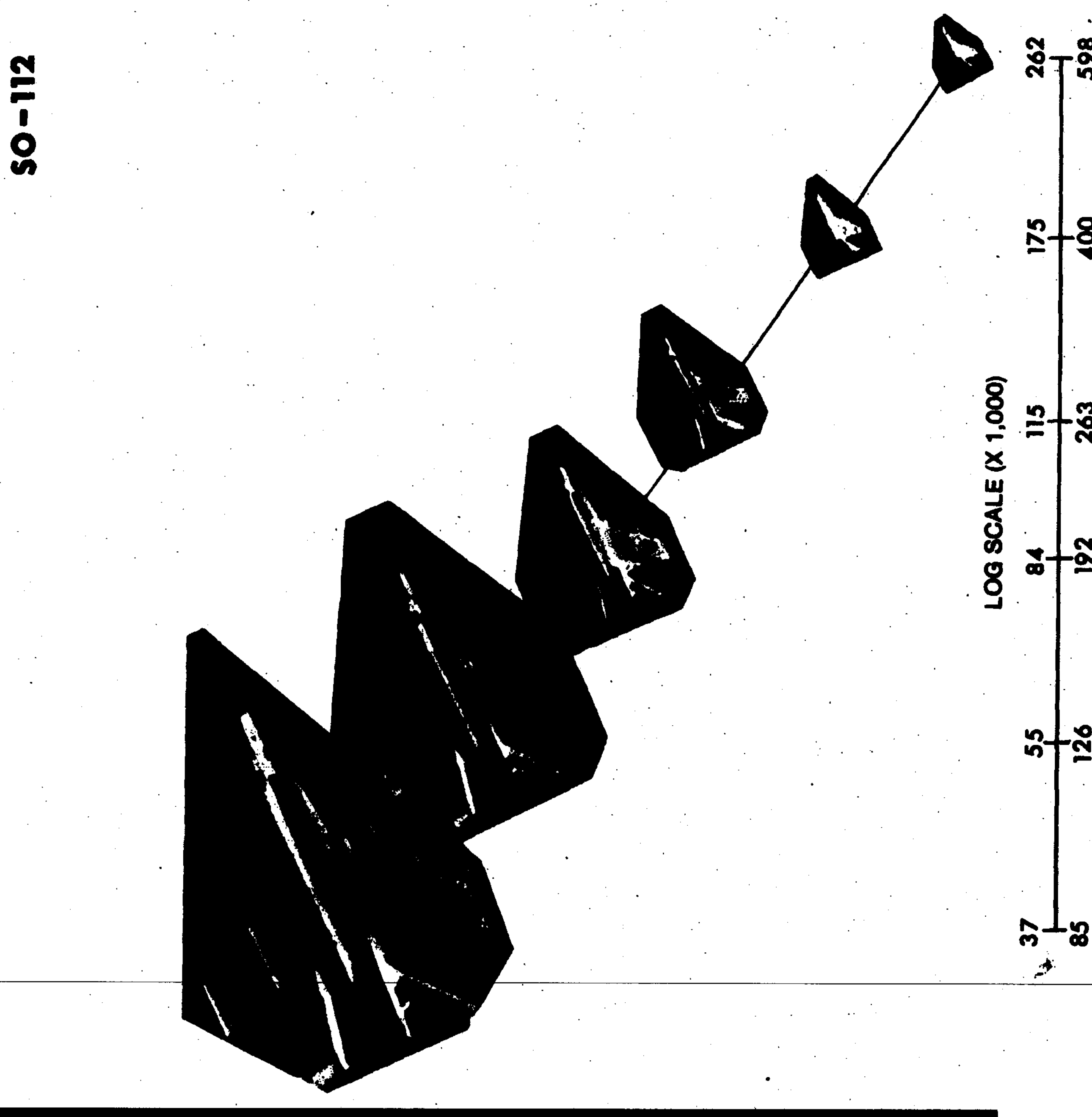
The following pages illustrate the results of the SO-112 and SO-209 scale study work. Photomicrographs of the simulation imagery are positioned along the line showing the change in rating with scale. The magnification from the duplicate positives to the prints is approximately 128x. Photographic scale and the approximate corresponding altitude for a 20-degree look angle are shown along the horizontal axis.

For these illustrations, the relationship of rating and scale is described by the average rating per scale from three atmospheric transmittances, 0.7, 0.6, and 0.5. Averaging all three conditions was chosen to summarize the results of the scale work as all the PI data is utilized to represent the effect of scale on quality. The photomicrographs are copies of the imagery produced at the 0.7 atmosphere, which is considered to be the average atmospheric condition. It should be noted that the simulation of these films was for different acquisition periods, and that although atmospheric transmittance was equivalent, aerial contrast was greater for the SO-209 imagery.

SO-209



[redacted]


SO-112
LOG SCALE (X 1,000)
37
55
84
115
175
262
85
126
192
263
400
598

[redacted]

Appendix B

SCALE STUDY TARGET ARRAY

Appendix C

RATING/LOG GRD

The scale study results were summarized by illustrating the NIIRS ratings of SO-209 and SO-112 relative to SO-208 as functions of log scale (Section 6, page 6-63). The object rated was an AOB model of 36 percent reflectance on a 25 percent reflectance background. The ratings were an average for the three illumination conditions (0.7, 0.6, and 0.5 atmospheric transmittances) and were acquired for the case of zero motion and optimum ON exposure.

In this section, the same results are described by a rating versus log GRD plot. GRD was calculated at an aerial contrast of 1.91:1 for all three films. Six tri-bar resolution targets surrounding the target array were read by three readers at three replicate exposures. Peak resolution was converted into GRD for given scales, and with the corresponding ratings at the 1.91:1 AC, rating/log GRD lines constructed for each film. There is a slight convergence in the lines, but at a GRD in the [redacted] range, SO-209 would give approximately a half a rating unit increase in quality over SO-208. For SO-112, the increase would be about 2/10 of a unit greater than SO-208. The dotted line is an existing system calibration line. The experimental results have nearly the same slope as this line and are within a quarter rating unit of the calibration line at a given GRD.

[redacted]

Fig. C-1 — Rating versus log GRD, 1.9:1 contrast