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FINAL TECHNICAL REPORT

on

AUTOMATIC STEREO PERCEPTION OF AERIAL PHOTOGRAPHY BY MEANS OF OPTICAL CORRELATION

by

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R. Vesper

GPL DIVISION
GENERAL PRECISION, INC.
63 Bedford Road
Pleasantville, New York

Contract No. DA-44-009-Eng-4966
Project No. Task ST35-12-001-02A

Prepared for

U. S. ARMY ENGINEER

GEODESY, INTELLIGENCE AND MAPPING
RESEARCH AND DEVELOPMENT AGENCY

Fort Belvoir, Virginia

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Further information concerning this project may be obtained from Mr. Randall D. Esten, Chief, Photogrammetry Division, U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency, Fort Belvoir, Virginia, telephone EDgewater 9-5500, Ext. 62140.

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[redacted]

FOREWORD

This report was prepared by GPL Division - General Precision, Inc., Pleasantville, New York, on Contract No. DA-44-OOR-Eng-4966 with the U. S. Army Engineer, Geodesy, Intelligence and Mapping Research and Development Agency, Fort Belvoir, Virginia. The work was administered under the direction of Mr. J. Wiley Halbrook of GIMRADA.

The work reported herein covers the entire contract period from March 8, 1962 through November 30, 1962, and was performed under the direction of Mr. L. Goldfischer, Manager of the Advanced Techniques Section of the Research and Advanced Development Division of GPL. The principal contributors were Mr. R. Vesper, experimental work, and Mr. S. Belchis, analysis and instrumentation studies.

ABSTRACT

This is the final technical report on a study of Automatic Stereo Perception of Aerial Photography by Optical Correlation. It includes a discussion of the principles of optical correlation and the application to stereo measurements; a description of some potential stereo correlator instrumentations; a study of the behavior of the autocorrelation function as the sample size is reduced; a comparison of stereo measurements under three different conditions, and an investigation of improved configurations.

The principal result is that optical correlation is suitable for stereo measurements. It is felt that optical stereo correlators will ultimately prove superior to electronic versions because the bulk of the computation is performed in the compact optical front end.

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1. INTRODUCTION

This is the final technical report on a study of Automatic Stereo Perception by means of Optical Correlation under Contract DA-44-009-ENG-4966. Work on this contract began on March 8, 1962; the technical effort was terminated on November 30, 1962. The entire contract interval is covered in this report.

The primary goal of this program was the determination of the accuracy and resolution attainable in measuring parallactic displacement (between identical features on a stereo pair of photographs) by optical correlation techniques. The program consisted principally of experimental studies, supported by analysis where required, aimed at achieving the stated goal.

The techniques of optical area correlation have been the subject of a continuing study at GPL, in part under company sponsorship and in part under contract with the Air Froce. A brief discussion of these techniques and how they are used to measure stereo displacements is given under succeeding subheadings to this section. Concluding Section 1 is a description of three possible stereo correlator instrumentations.

The experimental program started with autocorrelation measurements as a function of the size of the limiting system aperture. The results of these measurements are presented in Section 2 along with a description of the experimental correlator assembly. Certain analytical results pertaining to autocorrelation function measurements made over a finite domain (as when one transparency is restricted in extent by a limiting aperture) are also given in Section 2.

In the stereo correlation studies, it was originally intended to work with stereo pairs made over real terrain, involving irregular profiles and contours. However, at the suggestion of Mr. J. W. Halbrook, technical supervisor for GIMRADA, a modification was made in the program plan to simplify the evaluation of the correlation technique when used in stereo measurements. The modification consisted of setting up two simple relief models, a cone and a pair of planes tilted relative to each other. These models were overlaid with photographic prints to provide detail and then stereo pairs of photographs were made of the assemblies. It was felt that the separation of the major sources of error would be more easily accomplished when working with a simulated terrain whose altitude varies as a simple function of position.

The results of the stereo displacement measurements for the two model terrains are presented in Section 3. The first efforts consisted of profile measurements on the cone. Difficulties with this model near its apex led to the construction of the tilted plane model. Both profiles and contours were measured on the latter. The contour measurements were repeated, for comparison, with a Fairchild Stereometer borrowed from GIMRADA, and this data showed less dispersion by about a factor of two. Subsequently, the experimental correlator assembly was modified by the insertion of a cylindrical lens to compensate for the astigmatic quality of the match between the two members of a stereo pair. Remeasurement of the contours with the modified correlator yielded data with less dispersion than that of the Stereometer by another factor of two. The improvement gained with the cylindrical lens was, thus, quite marked.

All of the correlation measurements described in Sections 2 and 3 were made by scanning for the peak of the correlation function with a point detector. Previous work at GPL [Ref. 1] indicated ways of enhancing the contrast of the correlation peak by means of periodic defocussing and synchronous detection. The addition of an area detector to this scheme has been shown to eliminate the need for scanning, the position of the correlation peak being identified by a null in the detector output. Certain modifications of these techniques were proposed and studied as applied to stereo correlation. One scheme, using a rotating diffraction grating and an area detector was tried experimentally, but the first results were not useable and time did not permit further exploration of the subject. This topic is reported in Section 4.

An overall view of the program is attempted in Section 5. It is concluded that optical area correlation does appear to be suitable for stereo measurements and it is conjectured that it could result in a smaller and less complex equipment than electronic stereo correlators since the bulk of the computation is performed in the optical analogue front end. However, much work remains to be done before an optical stereo correlator is realized.

1.1 Principles of Optical Area Correlation

The optical area correlation technique is addressed to the problem of matching or bringing into registration two areas containing essentially the same pictorial content. The simplest example of this type occurs when one is required to rotate and translate one of a pair of identical transparencies (showing a particular scene) until it is in perfect registration with the other member of the pair. Placing such a pair of transparencies in contact, holding them up to the light and shifting one with respect to the other, the viewer will observe maximum light transmitted through the pair when best registration is achieved. Strictly speaking, what will be observed is that when the two transparencies are misaligned from best registration by a small amount, whether by displacement or rotation or both, the amount of light transmitted through the pair is reduced. It is this effect which is at the heart of the optical area correlation technique.

The experiment just described can be made to yield quantitative results when performed in a slightly modified form. In place of the eye, a converging lens and photodetector are used. The entrance pupil of the lens defines the effective area of the transparency pair that is seen by the detector. It is assumed that the two transparencies are substantially larger than the area defined by the lens aperture and that the illumination is uniform. The experimental arrangement is illustrated in Figure 1.

The transmissivity at any point on either transparency is a function of the position of the point in question. Assume that coordinate axes are drawn in an identical manner on each member of the pair. The transmissivity function may then be written as $T(x, y)$ where $0 \leq T \leq 1$. If the two transparencies are initially aligned to best registration and then one is displaced without rotation by an amount u and v, where u and v are referred to the x and y axes respectively, the light falling on the detector and the detector output will be proportional to

$$I = \frac{1}{A}\iint_A T(x, y)\ T(x - u, y - v)\ dx\ dy \qquad (1)$$

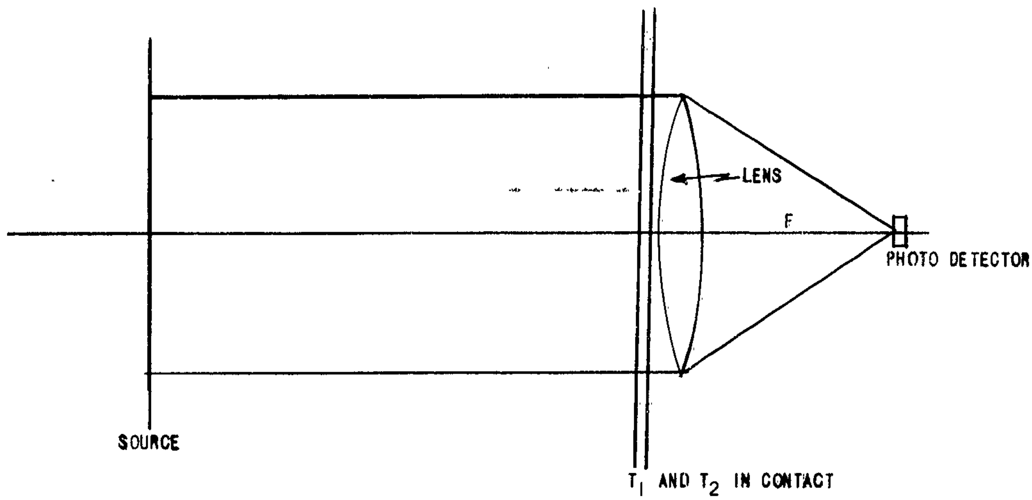


FIGURE 1

CORRELATOR CONFIGURATION: TRANSPARENCIES IN CONTACT

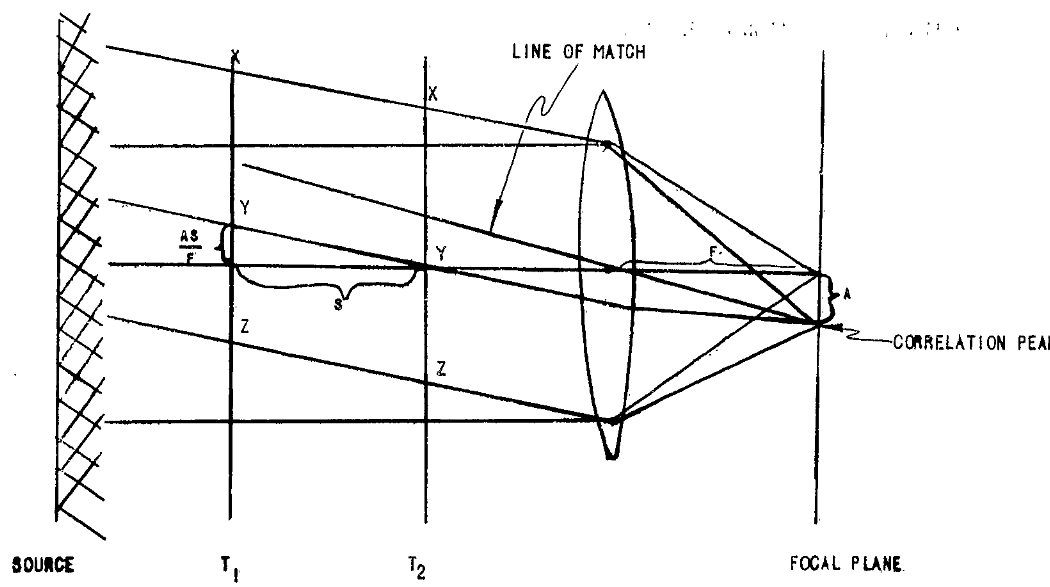


FIGURE 2

CORRELATOR CONFIGURATION: SEPARATED TRANSPARENCIES where A is the effective area of the transparency pair as limited by the lens aperture. Equation (1) is arrived at by noting that the intensity at the detector is the sum of the contributions of a parallel bundle of rays, each of which is attenuated by the product of the transmissivities at the two transparency points intersected in travelling from source to lens. If the coordinates of one of the points are (x, y), the coordinates of the point in contact with it are $(x - u, y - v)$ because of the displacement. Hence the product of transmissivities is $T(x, y)\ T(x - u, y - v)$ as shown in (1).

The form of equation (1) is identical to that of a two-dimensional correlation function with the exception that the area of integration is finite. When the area of integration is sufficiently large, (1) approaches the true autocorrelation function of $T(x, y)$ defined (and statistically homogeneous) over the infinite domain. The virtues of the true autocorrelation function are that it is a maximum for zero displacement, is symmetrical about the peak and is independent of the choice of origin of coordinates. These are all very convenient properties relative to the matching problem.

A useful modification to the scheme of keeping the transparencies in contact occurs when the two transparencies are separated by a significant distance as depicted in Figure 2. This arrangement has the advantage that the intensity pattern in the focal plane of the lens is an analogue of the correlation function defined in (1) for this case. To demonstrate the truth of the last statement, it is sufficient to observe that the intensity at any point in the lens focal plane is the sum of the contributions of a parallel bundle of rays each of which intersects the two transparencies in a pair of points (one on each transparency) whose displacement from each other is constant over the bundle. For example, suppose that the two transparencies are lined up along the optic axis of the lens. Let the origin of coordinates in each transparency plane and in the focal plane be the point where the optic axis of the lens intersects that plane. The intensity at point (a, b) in the focal plane of the lens is then proportional to

$$I(a, b) = \frac{1}{A} \iint_A T(x, y)\ T(x - \frac{as}{f}, y - \frac{bs}{f})\ dx\ dy \qquad (2)$$

where f is the focal length of the lens, s is the separation between the two transparencies, and A is the effective area of integration as defined by the limiting system aperture. The forms of equations (1) and (2) are seen to be identical.

The configuration shown in Figure 2 is the form used in applying optical area correlation to the measurement of stereo displacements. With this arrangement, the peak of the correlation function occurs on the line of match, i.e., the line along which one of the two transparencies must be translated to be brought into match with the other.

1.1.1 Need for Diffusionless Transparencies

The development leading to equation (2) above and the result that the intensity pattern in the lens focal plane is an analogue of the correlation function implies and depends upon diffusionless transmission through the transparency closest to the lens. If the transmission through this last transparency is diffuse, a smearing of the sharp features of the correlation function takes place resulting in loss of contrast of the correlation peak. Severe enough smearing may cause the peak effectively to disappear.

Diffuse transmission is characterized by the fact that radiation entering the diffusing medium as a narrow beam, such as could be described by a single ray, leaves the medium as a broad beam. The emergent beam can only be described as a collection of rays diverging from the point of exit. Thus, each parallel bundle of rays converging to a point in the focal plane in the absence of diffusion becomes a divergent collection of parallel bundles converging to a blob in the focal plane when diffusion does occur. The imperfect convergence which accompanies diffusive transmission is the cause of the smearing of the correlation pattern which occurs under these conditions.

In previous correlator work at GPL, the critical transparencies used were of a high contrast variety, i.e., the information content was represented by collections of clear and opaque regions. These transparencies were made on Kodalith Ortho Type III film, on which the clear areas are non-diffusing. Hence, the problems associated with diffusion in the critical transparency were first appreciated in the early experimental work on this program when using continuous tone transparencies. To resolve these difficulties a study was made to determine methods of making high-resolution, non-diffusing transparencies.

Four different types of transparencies yielding acceptably low diffusion were uncovered in the course of the investigation. These are: a) dye transfer transparency, b) Kodak Aerographic glass plate, c) Kodalith film and d) Kodak Fine Grain Positive film. The dye transfer transparency is the least diffusive but also requires the most processing. The glass plate is clumsy to handle and subject to breakage. Although Kodalith film has a higher resolution capability than Fine Grain Positive film, the resolution capability of the latter (90 lines/mm) is adequate and requires the least processing. Hence, Fine Grain Positive film was used whenever new transparencies were required. A detailed description of the investigation leading to these conclusions may be found in Reference 2.

1.2 Application to Stereo Measurements

Stereo measurements are based upon the fact that the positional relationship between equal altitude terrain contours (and the features contained on each) is different in the two members of a stereo pair of photographs. This is a manifestation of the perspective effect and arises when a scene containing relief is looked at from different angles. Assume that the stereo pair is made sequentially with a horizontally stabilized aerial camera mounted in an aircraft flying straight and level. Examination of the photographs would reveal that the size and shape of equal altitude contours was the same in the two members but that the displacement between pairs of contours at different altitudes changes from one member of the stereo pair to the other. The change in contour separation is always in the direction of the line of flight and is a function of the altitude difference between the two contours. If the two members of the stereo pair were placed in contact (and aligned in rotation) only the contours for a single altitude level could be made to match at one time; by displacing one member relative to the other along the line of flight, contours at any other single altitude level could be made to match.

In the separated transparency correlator configuration of Figure 2, the system aperture is chosen small enough so that the match region lies at essentially a single altitude. Over such small single altitude regions, the two members of a stereo pair are nearly identical and the position of the peak of the correlation function occurs on the line of match in the focal plane of the lens as in the autocorrelation case. The position of the correlation peak may be determined by scanning the lens focal plane with a point detector or by other more sophisticated means. If the lens and system aperture are held fixed and the two stereo transparencies moved as a pair (each in its own plane) so that different regions are examined, it would be found that the position of the correlation peak would remain unchanged for all regions at the same altitude. On the other hand, because of stereo displacement, the line of match is different for two regions at different altitudes and, therefore, the correlation peak positions will be different for two such regions. The displacement of the correlation peak for the fixed geometry of Figure 2 is, in the absence of noise, a function only of the altitude difference between the two regions in question. It is this displacement which was measured in the experimental stereo correlation work described in Section 3.

1.3 Some Stereo Correlator Instrumentations

The simplest photogrammetric instrument making use of correlation between small areas on a rectified stereo pair would be a profile plotter. This type of instrument would use the separated transparency configuration of Figure 2 with either the stereo pair or the aperture, lens, and detector frame assembly being moved in a linear raster scan pattern. The two transparencies would initially be aligned so that the correlation peak is at a reference position in the detector plane (lens focal plane) when the system aperture is centered about a control point of known elevation. The magnitude and direction of the displacement of the correlation peak from its reference position, as the aperture is centered around each point in the scene during the raster scan, is indicative of the amount of elevation or depression of the profile at that point relative to the altitude of the control point.

To achieve contour plotting capability with the configuration of Figure 2, it would be necessary to use two adjacent aperture-lens-detector assemblies. One of these assemblies would be used to sense any departure from the contour being mapped and the other would be used to determine the terrain slope at each point, thereby permitting the generation of the correct error sense. Operation of the contour sensing aperture and detector would be similar to the operation of the profile plotter. When a departure from the contour is indicated, the difference in the displacements of the two correlation peaks from their reference positions would indicate the terrain slope in the vicinity of the contour and hence the direction of motion required to return to the contour.

2. AUTOCORRELATION STUDIES

It was previously noted that the two members of a stereo pair can be brought into registration only over small regions which are essentially at one altitude. Ideally, for the purpose of measuring stereo displacement, it would be desirable to make the match between common features at a point, thereby uniquely determining the altitude at each point. Practically, it is possible to make a correlation match only over an area containing some amount of detail. Hence, it is necessary to examine the consequences of enlarging or diminishing the match region.

The larger the area used for stereo correlation purposes, the more likely is the elevation ascribed to the point at the center of the match area to be contaminated by altitude variations over the rest of the region. The average slope of the terrain over the match area can be compensated by the addition of a cylindrical lens to the correlator as described later in Section 3.2.3.3. However, variations around the average slope are weighted randomly and do not cancel out completely. As the match area is reduced, variations in altitude with respect to the average slope tend to diminish and errors resulting from such variations also tend to be reduced.

On the other hand, the correlation function, whose peak position is used as a measure of stereo displacement, is an average statistic whose quality improves with the quantity of independent data available for its computation. As the match area is decreased, the position of the correlation peak becomes a less accurate indicator of the line of match and is less easily distinguished from a noise-like background.

Thus, two opposing tendencies are present; increasing the match area improves the quality of the correlation function but lessens the uniqueness of the stereo displacement measurement whereas reducing the match area enhances the uniqueness of the measurement but reduces the quality of the match. It appears reasonable to expect that an optimum sized match area exists for each stereo pair, yielding the minimum total error caused by the two effects just discussed.

The effect of reducing the system aperture, and thereby the match area, on the quality of the autocorrelation function was examined experimentally and then analytically. The results of these studies are presented in Sections 2.2 and

2.3. Section 2.1 below describes the physical arrangement used in making the experimental study.

2.1 Basic Experimental Correlator Assembly

The basic experimental correlator assembly is shown in Figure 3. The main function of this assembly was the measurement of the position of the correlation peak generated by a small area on a stereo pair of transparencies. The critical dimensions of the assembly are given in Figure 4. The relative position of the detector, lens, iris and transparency mounts on the optical bench, as given in Figure 4, remained constant throughout the measurements.

The light box was a diffuse incandescent source of light, uniform to better than 1 db (10%) over the useable area (10" x 10"). The two transparencies were held in individual mounts which could be displaced in the horizontal direction, perpendicular to the ways of the optical bench. The total travel available in each mount was 2 inches. Changes in transparency positions were measured to an accuracy of 0.001 inches by means of the dial indicator attached to each mount (next to lower right hand corner of reference transparency in Figure 3). The limiting aperture of the system was an iris positioned close behind the reference transparency. The lens was mounted behind the iris, with its optic axis passing through the iris center and parallel to optical bench axis. One focal length behind the lens was a photomultiplier limited by a small aperture to act as a point detector. The position of the detector could be adjusted within a one inch diameter circle in the focal plane. Changes in the position of the point detector were read directly with an accuracy of 0.0001 inches from the micrometers used to make the adjustment. The detector output was directly proportional to the total light intensity incident on the small detector aperture.

The output of the detector was amplified and a DC background level was removed (when so desired). The amplified detector output was used to drive either an ammeter or a pen recorder. Observed variations in the amplified detector output current were directly proportional to the variations in light intensity on the detector.

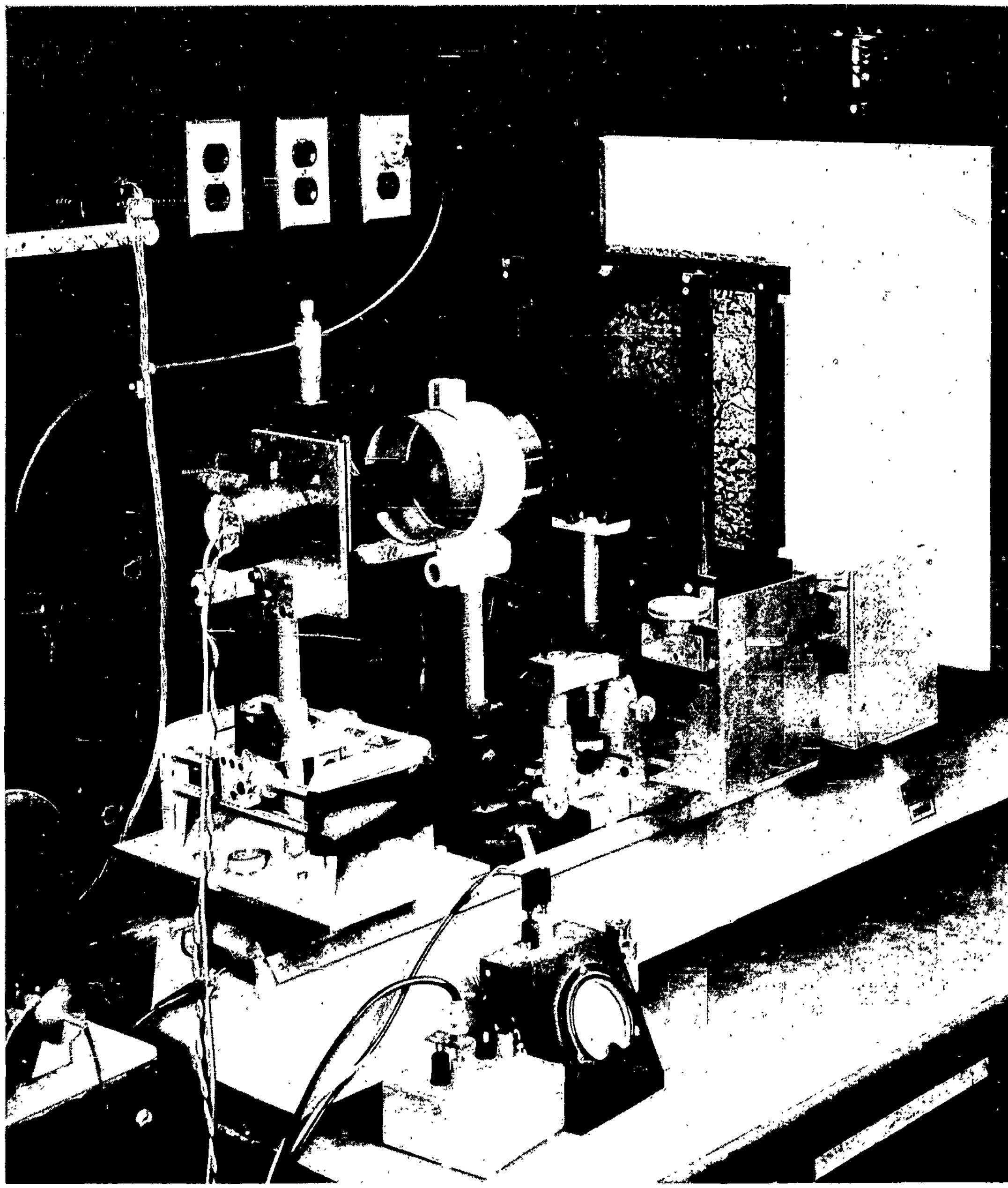


FIGURE 3

Photo of Experimental Optical Correlator

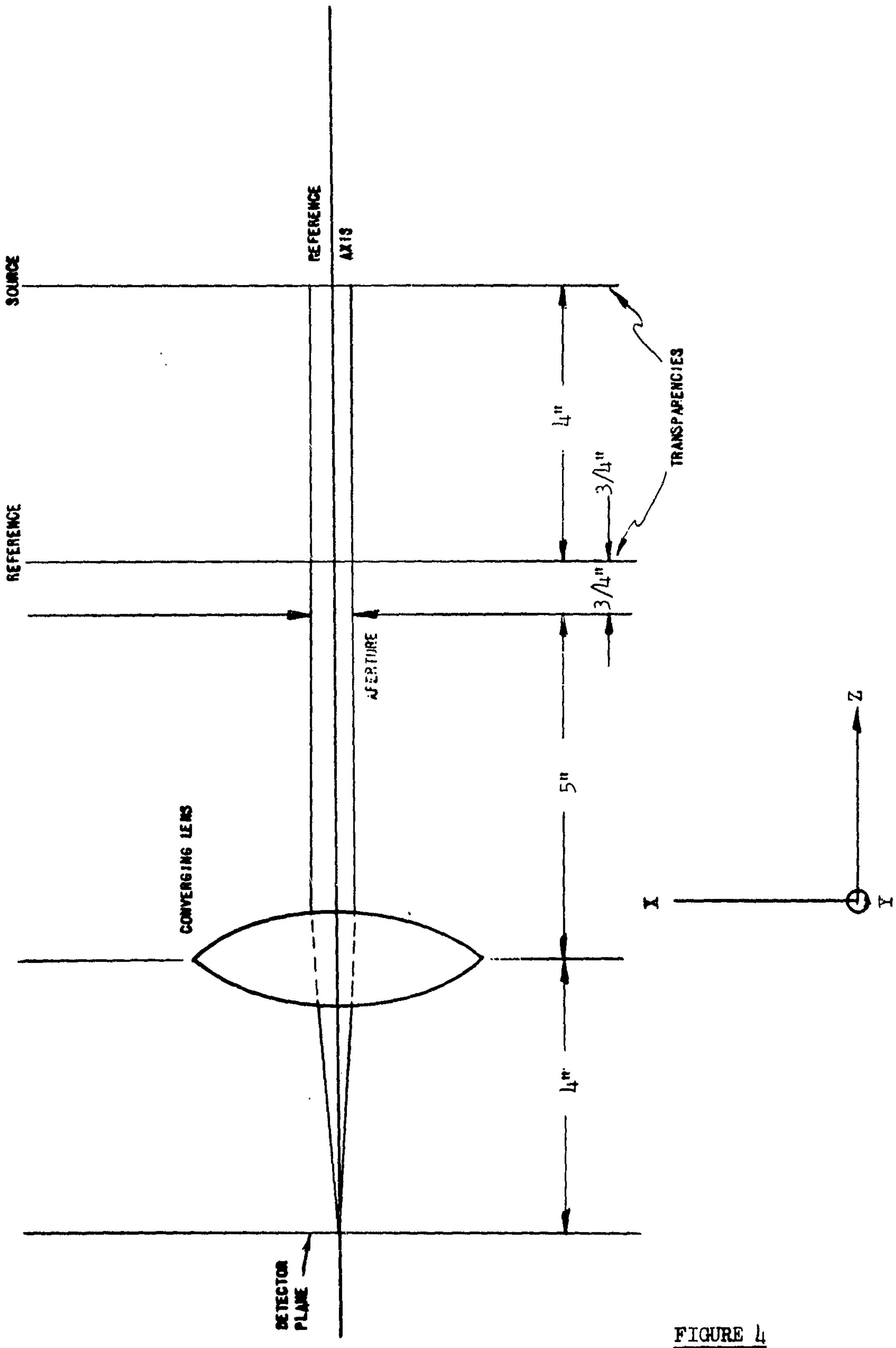


FIGURE 4

EXPERIMENTAL CORRELATOR

2.2 Experimental Aperture Reduction Study

All of the measurements reported in this section were made with the dodged aerial photograph shown in Figure 5. (This was #175-228 on a roll of aerial film borrowed from GIMRADA.) Since these were autocorrelation measurements, both transparencies in the experimental correlator were identical copies of the scene in Figure 5. The detector aperture for these tests was 0.020 inches in diameter. Scans of the correlation function were made by driving the cross motion carriage of the reference transparency (the one closer to the lens) from the chart motor of the pen recorder displaying the amplified detector output. Three different aperture sizes were used: 1/2" D, 3/8" D, and 1/4" D. Reproductions of the recordings obtained during these scans appear in Figures 6, 7, and 8. A point by point scan of the correlation function using a 3/4 inch aperture, made by moving the reference transparency through equal increments and reading the amplified detector output on an ammeter, appears in Figure 9. The true alignment position is indicated on each of the four scans.

The significant feature observed in this series of correlation function scans is the increase in the background fluctuation as the size of the aperture is decreased. However, it also appears from these scans that once the correlation peak has been located with a large aperture, it can be "tracked" with a smaller aperture. Detailed measurements were made of the horizontal position of the peak as the aperture was decreased. These measurements were made by noting the location of the peak on the dial indicator as the reference transparency was shifted in a horizontal direction. A peak shift of less than 0.002 inches was indicated for various aperture sizes down to 3/8 inch. The width of the autocorrelation function at the half amplitude points (or the correlation distance) was 0.075 inches, using the best estimate available, i.e., the measurements made with the 3/4 inch aperture (Figure 9). Thus, the worst peak shift was less than 3% of the correlation distance for an aperture diameter equal to five correlation distances. Although these measurements were not too extensive, they strongly confirm the expectation that the accuracy of the correlation match deteriorates as the aperture diameter approaches the correlation distance.

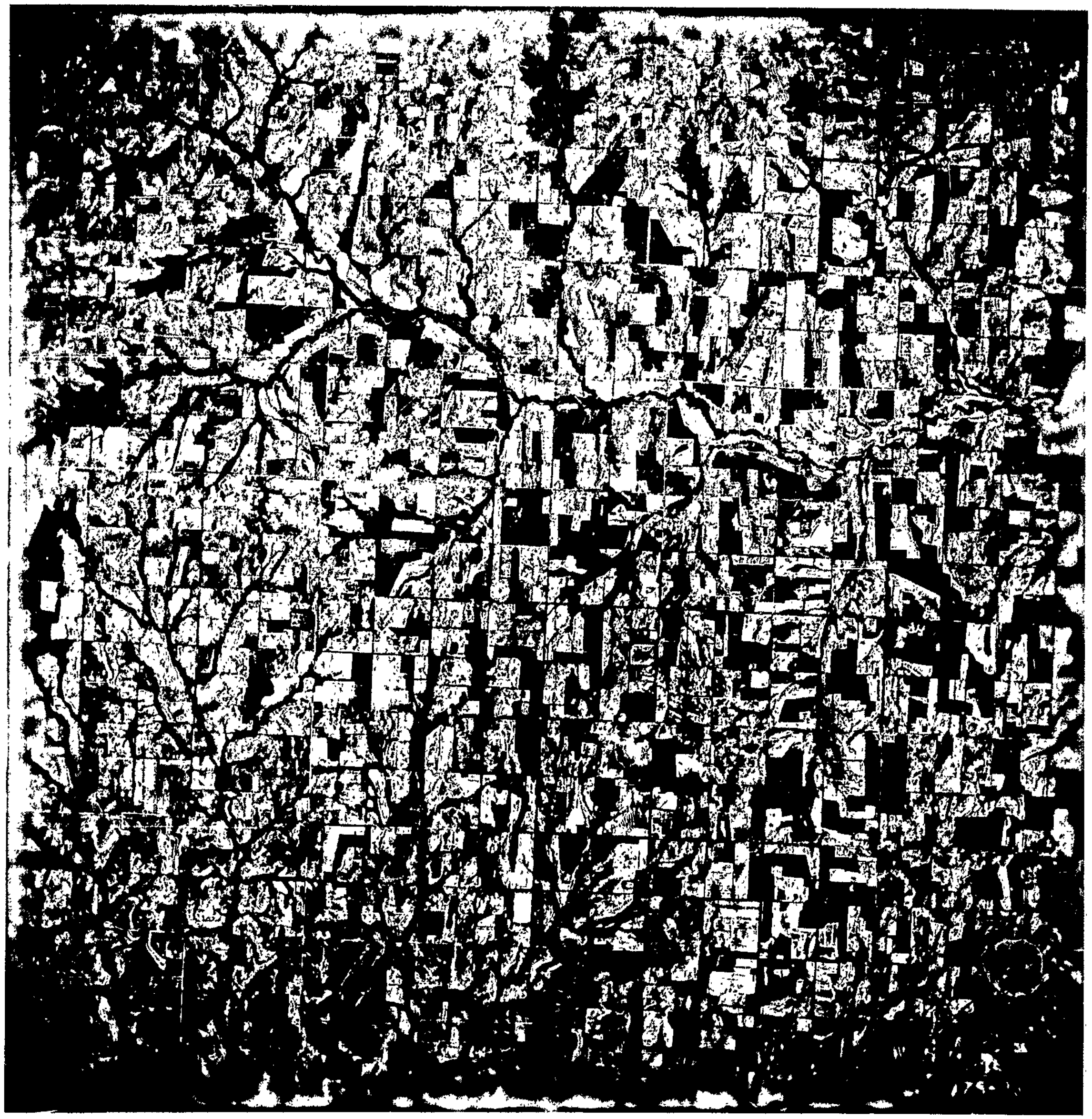
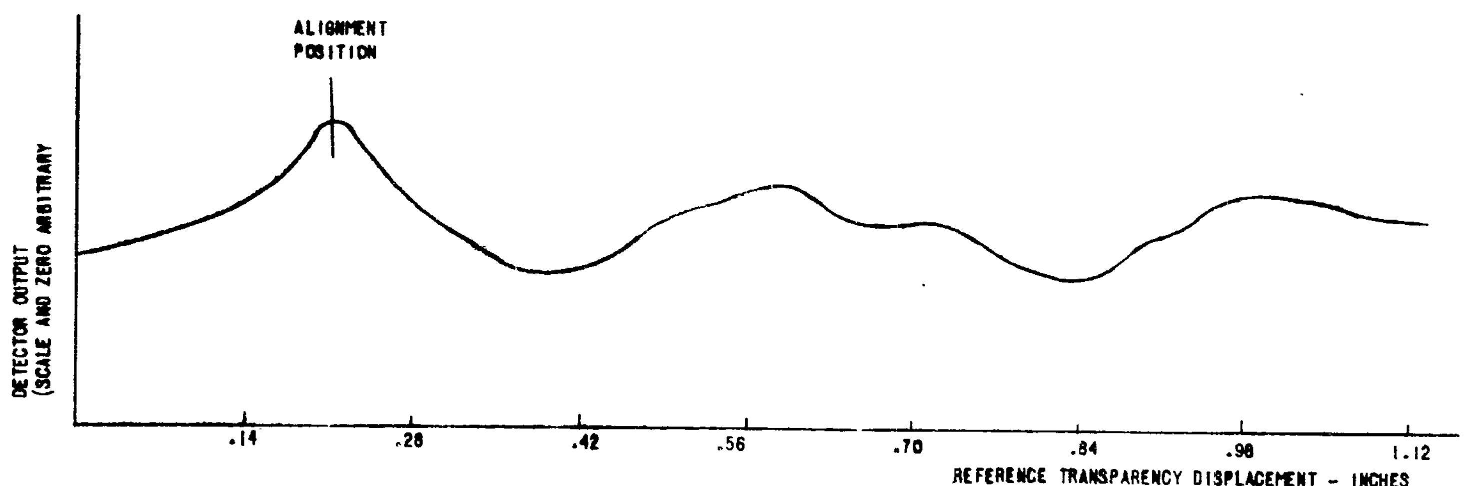


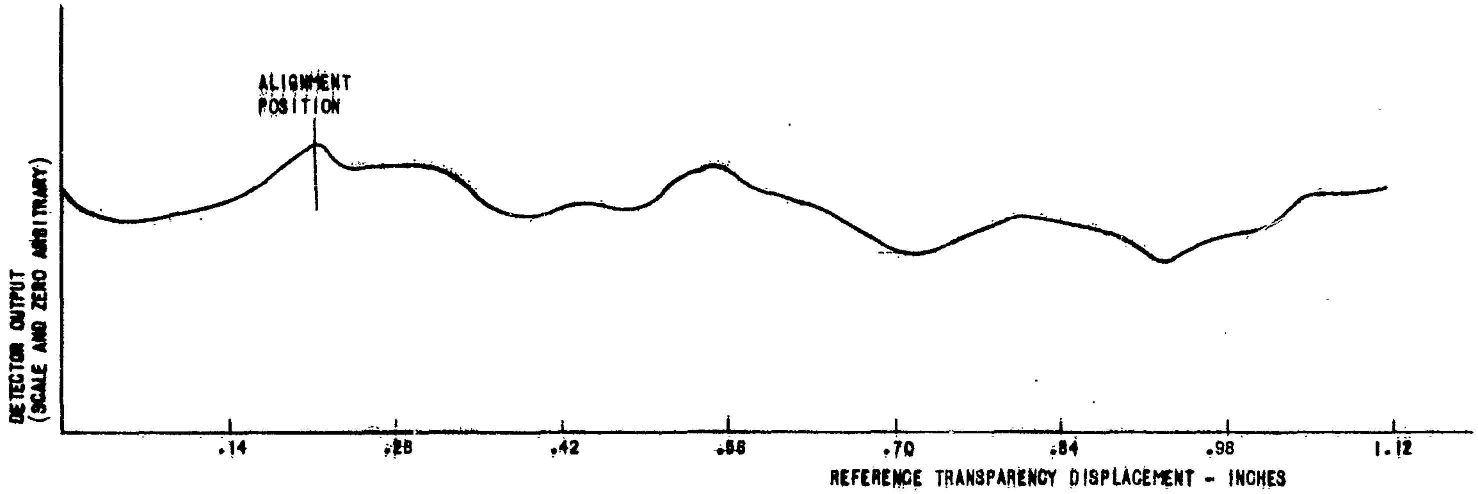
FIGURE 5

DODGED AERIAL PHOTOGRAPH USED IN TESTS



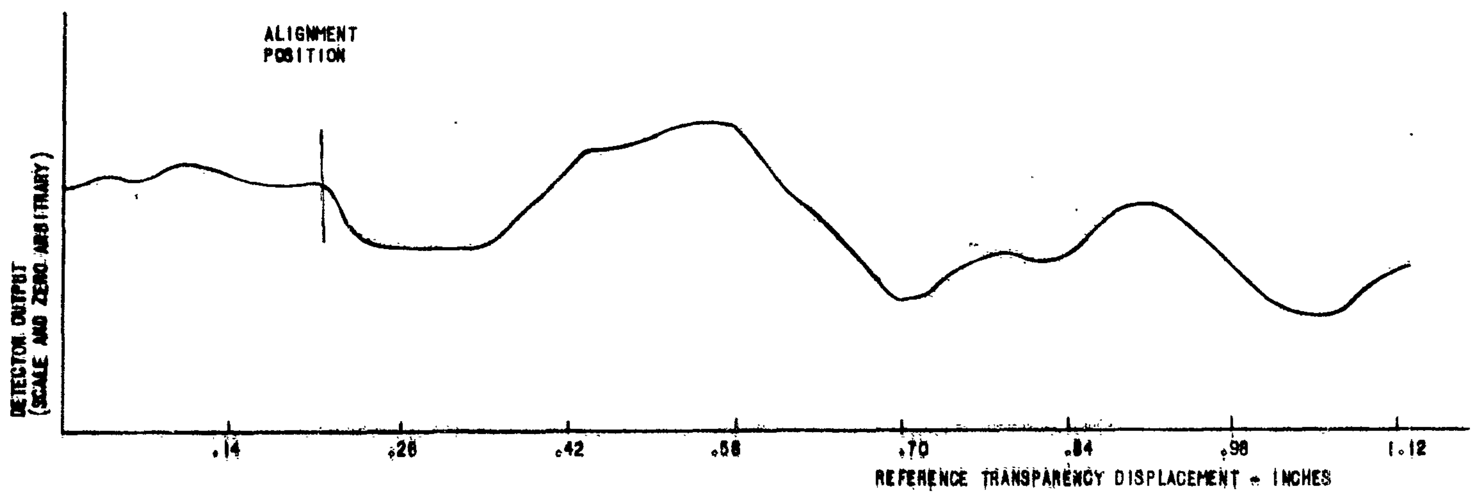
HORIZONTAL SCAN THROUGH CORRELATION PEAK - 1/2 INCH APERTURE

FIGURE 6



HORIZONTAL SCAN THROUGH CORRELATION PEAK - 3/8 INCH APERTURE

FIGURE 7

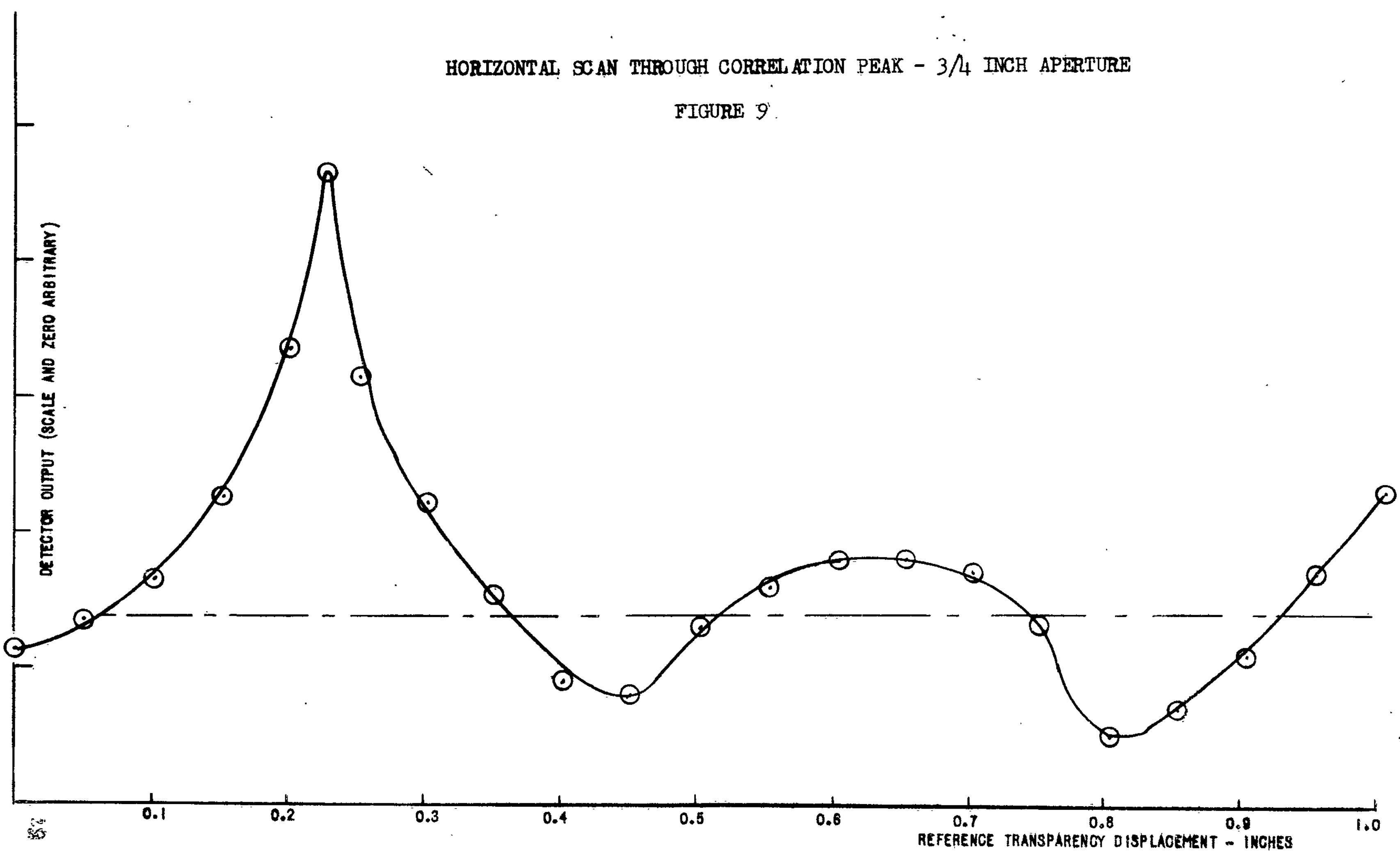


HORIZONTAL SCAN THROUGH CORRELATION PEAK - 1/4 INCH APERTURE

FIGURE 8

HORIZONTAL SCAN THROUGH CORRELATION PEAK - 3/4 INCH APERTURE

FIGURE 9



2.3 Analytical Studies

The analytical studies were made to find a means of characterizing the accuracy of sample correlation measurements. In the case of autocorrelation (two identical transparencies correlated over an "infinite" area), the correlation function is a perfect indicator of the best match position. Since the stereo correlator uses a small sample area on the two transparencies, it is not always a perfect indicator of match.

Consider a case of one-dimensional correlation. Let $R_T(\xi)$ be the autocorrelation function (for infinite sample length) and $R_T(\xi, S)$ be the sample autocorrelation function for a sample of length S. The variance of $R_T(\xi, S)$ about $R_T(\xi)$ is an indication of the usefulness of the sample autocorrelation function for match purposes. The variance is derived in Reference 2 as

$$\sigma_R^{\,2}(\xi, S) = \frac{2}{S^2} \int_0^S (S - t)\left[R_T^{\,2}(t) + R_T(t-\xi)R_T(t+\xi) - 2m^4\right] dt \tag{3}$$

where m is the average transmittance.

This equation is based on the assumption that the transmittance function of each transparency is normally distributed about the average transmittance value. The validity of this assumption has been strengthened by the conclusions presented in Reference 3.

It is informative to substitute a specific autocorrelation function for $R_T(\xi)$. A reasonable approximation to the correlation function observed in actual measurement is:

$$R_T(\xi) = \exp\left(-\frac{\xi^2}{\xi_o^{\,2}}\right) \tag{4}$$

Since $R_T(0.832\ \xi_o) = 0.5$, the correlation distance for this function is $1.664\ \xi_o$. Substituting equation (4) into (3) and integrating yields

$$\sigma_R^{\,2}(\xi, S) = \frac{2}{S^2/\xi_o^{\,2}}\left[1 + \exp\left(-2\frac{\xi^2}{\xi_o^{\,2}}\right)\right]\left\{\frac{S}{\xi_o}\sqrt{\frac{\pi}{2}}\;\varphi\left(\frac{2S}{\xi_o}\right) - \frac{1}{4}\left[1-\exp\left(-2\frac{S^2}{\xi_o^{\,2}}\right)\right]\right\} \quad (5)$$

where

$$\varphi(2\frac{S}{\xi_o}) = \int_0^{2\frac{S}{\xi_o}} \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{\xi^2}{2}\right)d\xi \quad (6)$$

Substituting $\xi = 0$, the position of true best match, into equation (5) yields

$$\sigma_R^{\,2}(0, S) = \frac{4}{S^2/\xi_o^{\,2}}\left\{\frac{S}{\xi_o}\sqrt{\frac{\pi}{2}}\;\varphi\left(\frac{2S}{\xi_o}\right) - \frac{1}{4}\left[1 - \exp\left(-2\frac{S^2}{\xi_o^{\,2}}\right)\right]\right\} \quad (7)$$

Equation (7) shows that the variance of the correlation function always decreases when S/ξ_o is increased and as S/ξ_o is made large, the variance becomes inversely proportional to S/ξ_o. Thus, an important parameter with respect to the accuracy of correlation measurements is seen to be the ratio of sample size to correlation distance.

The correlation function can be separated into two components, the component in the immediate vicinity of the peak and the background function. The noise fluctuations in the background function disappear when the sample length is infinite. As the sample aperture (S) is decreased, the background fluctuations increase. The variance of the background is given by equation (5) for values of $\xi > 2\xi_o$. When S/ξ_o is small, and $\xi > 2\xi_o$, $\sigma_R^{\,2} \to 2$ and ground variations submerge the peak in noise thereby increasing the difficulty of acquisition.

In any actual match application, the two transparencies are not identical. The expected transparency differences include coordinate shifts, and rotations, dimension scale factor, transmittance scale factor, and additive and multiplicative noise. Coordinate shifts, rotations, and uniform scale change, can, in theory, be sensed and should result in no system error. Non-uniform scale variations and noise will, however, result in match errors. Thus, the three basic sources of match error are:

a) the limited size of the transparency sample being correlated;

b) scale variations for which adjustments cannot be made;

c) differences in pictorial content, i.e., noise.

3. STEREO CORRELATION STUDIES

3.1 Model Terrains

The purpose of the stereo correlation studies was to determine the accuracy of an optical correlator when used to measure altitude profiles and contours from stereo pairs of transparencies. This determination was to be made through a comparison of measured and known sets of parallactic displacements. The comparisons would have been quite involved if the altitude profiles were not relatively simple functions. The accuracy of these comparisons depended primarily on how well the altitude profiles were known. In order to achieve maximum accuracy and avoid unnecessary complications, model terrains of simple geometric shape were built to serve as subject matter for stereo photographs. The shapes were formed from alimunum and were overlaid with pictorial information. Preliminary measurements were made on the model overlaid with a dot pattern. This pattern gave a known correlation function which was used to check the system for proper operation. The pictorial information used in the main body of measurements was taken from the dodged aerial photograph shown in Figure 5. This photograph was taken at an altitude of approximately thirty thousand feet with a six inch focal length aerial camera. There is a flat section on each model terrain for which the stereo pairs used in the tests have the same scale factor as the original 9" x 9" print. The stereo pairs were made by photographing the models from two points in a plane parallel to this flat section.

3.1.1 Cone Shaped Model

The first model shape tested was a "mountain" consisting of a cone with its base on a flat plate. The cone dimensions and the two camera positions, P_1 and P_2, are shown in Figure 10. Two stereo pairs from the cone are shown in Figure 11. One pair shows the dot pattern on the cone, the other shows the cone covered with information from the aerial photograph.

3.1.2 Tilted Plane Model

The second model tested had the shape of a partially tilted plane. The dimensions of the tilted plane and the two camera positions are shown in Figure 12. The stereo pair for the tilted plane model is shown in Figure 13.

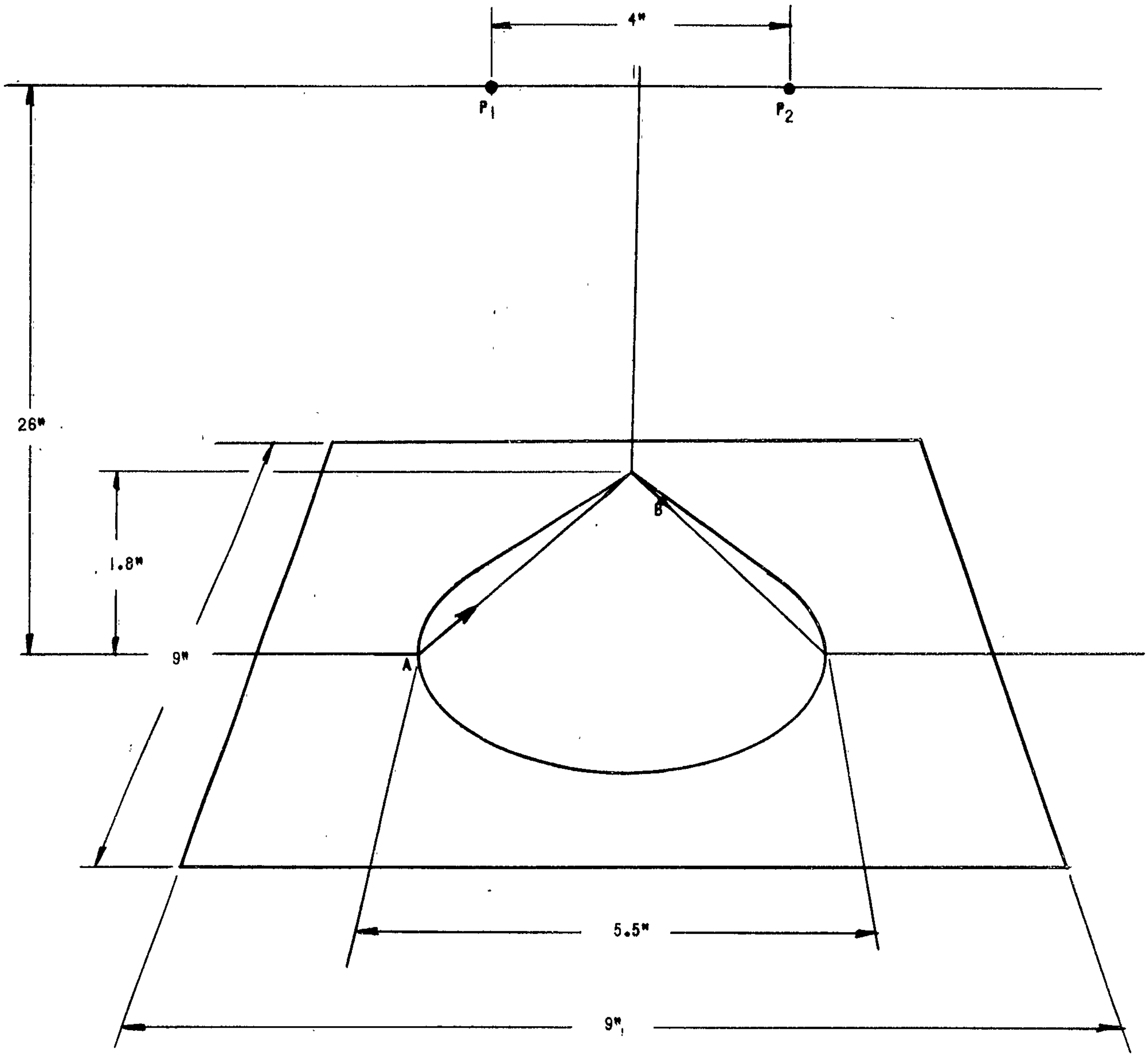


FIGURE 10

CONE MODEL

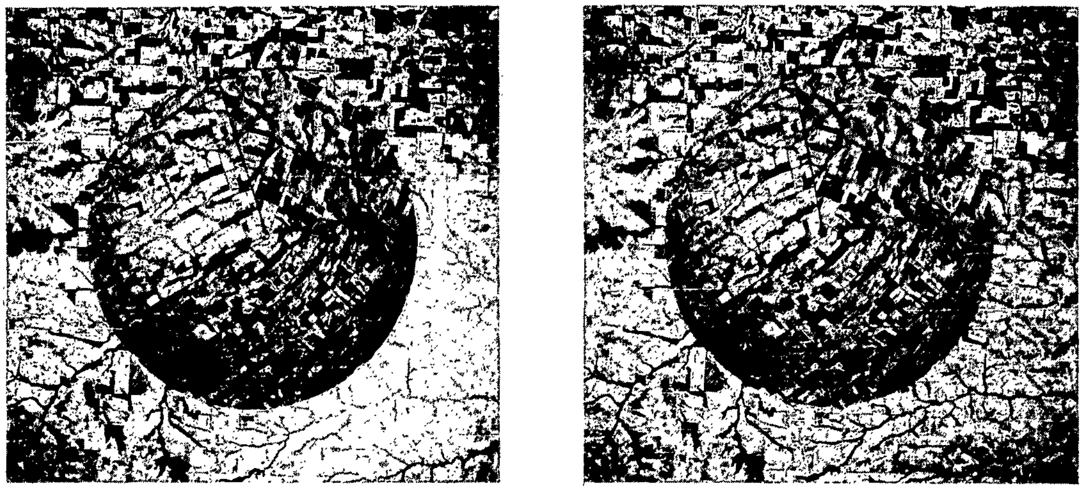


Figure 11A
Stereo Pair of Cone Overlaid With Aerial Photograph

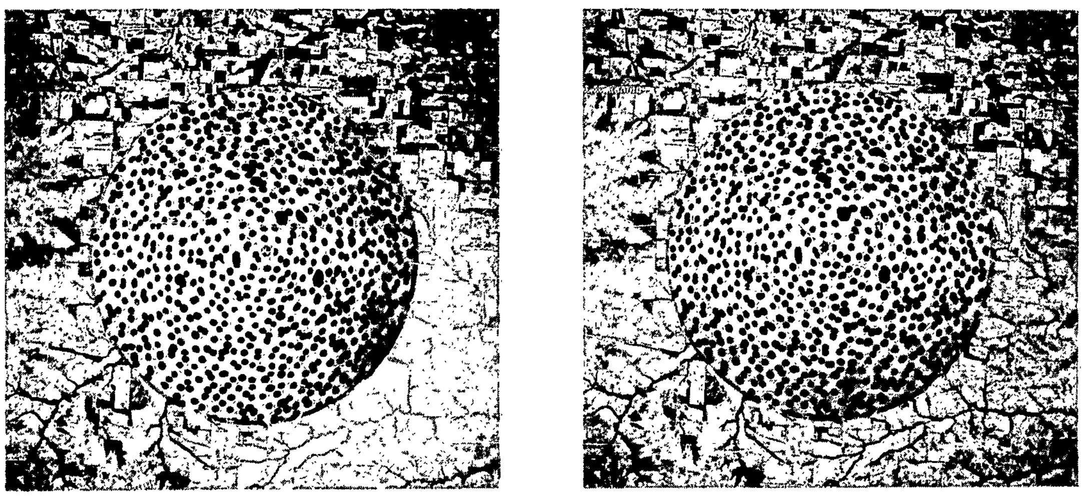


Figure 11B
Stereo Pair of Cone Overlaid With Dot Pattern

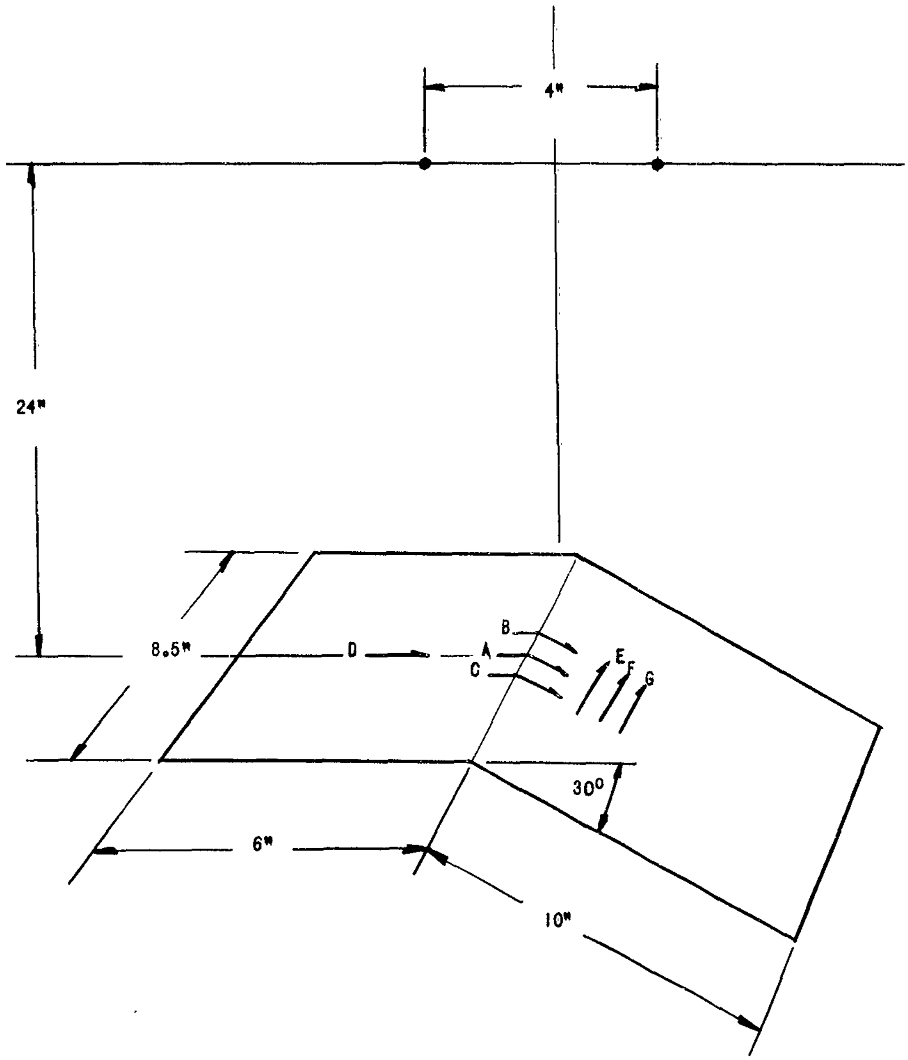


FIGURE 12

TILTED PLANE MODEL

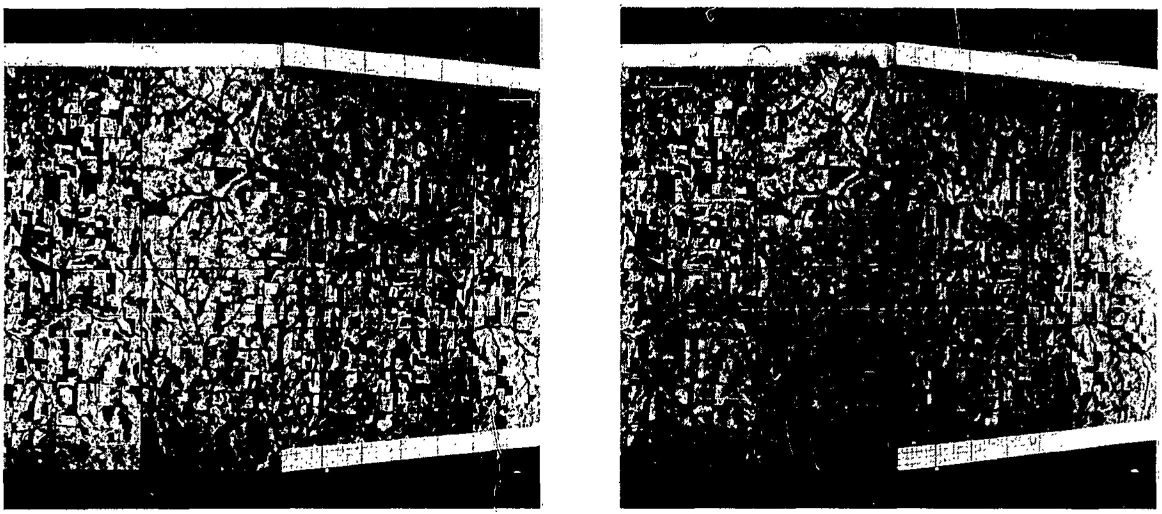


Figure 13
Tilted Plane Overlaid With Aerial Photograph

3.2 Measurements

The basic experimental correlator assembly was used in all of the correlation measurements on the terrain models. The measurements consisted of scans along straight lines of the transparencies. All of the scanned lines are shown in the model drawings of Figures 10 and 12. Measurements of parallactic displacement were made at equally separated points along the lines of scan. The expected parallactic displacement for each datum point in the set was determined by calculations based on the geometry used in generating the stereo pairs and the known shape of the model. The correlator error was the difference between the expected and the measured parallactic displacements.

All of the scans were made by moving the two transparencies transverse to the ways of the optical bench by means of cross motion carriages. Both transparencies were first displaced by equal amounts and then the parallactic displacement was measured by either of two methods. The first method, used in the measurements of Sections 3.2.1 and 3.2.3, entailed keeping the detector on the optic axis of the lens in the detector plane during the scan. The parallactic displacement was measured by adjusting the source transparency until the correlation peak was on the detector. The difference between the reference and source transparency positions necessary to make the peak fall on the detector was the measured parallactic displacement for that point. The second measuring method, used in Sections 3.2.3.1 and 3.2.3.3, was to determine the parallactic displacement by noting the shift (away from the lens optic axis) required to cause the peak of the correlation function to fall on the point detector. The separation between the transparencies along the direction of the optical bench was equal to the focal length of the lens (see Figure 4). With this type of geometry, a displacement of the peak in the detector plane by an amount (x_o, y_o) was always equivalent to an effective shift of the source transparency relative to the reference transparency by $(-x_o, -y_o)$. Since the transparency mounts could only be adjusted with precision in the scan direction, the second method had to be used in those cases where displacements were measured in a direction orthogonal to the scan line.

3.2.1 Cone Profiles

The first scan line on the cone model, made with the dot pattern stereo pair, is shown as line A in Figure 10. A plot of the measured stereo displacement for scan line A as a function of the reference transparency position is given in Figure 14. The slope of the expected stereo displacement as a function of reference transparency position is shown by a solid line in Figure 14. Most of the data fitted the known slope quite well. The gradual increase in the slope of the data points was due to the weighting of the correlation peak position (discussed in Section 3.2.1.4 of Reference 1). In brief, the correlation peak was biased away from the position of parallactic displacement for the feature in the center of the iris. This bias was due to the presence of a significantly strong amount of correlating information from an altitude other than that of the central feature. For example, when the center of the iris was on the flat base plate, but near the cone base, the ideal parallactic displacement was zero. However, since half of the correlating information was from the side of the cone, the correlation peak resulting from all the information in the iris was at a position corresponding to an altitude slightly above the base plate.

The dot pattern was used to check for basic system problems. The data in Figure 14 indicated that the system was working satisfactorily. The dot pattern stereo pair was replaced by the stereo pair in which the cone was covered with the aerial photograph. A second scan, made through the apex of the cone, is shown as line B in Figure 10. The data points and the expected profile for this scan are plotted in Figure 15. The scattering of the data points near the cone apex indicated either that there was a large system error or that the weighting near the apex was quite complex. The latter explanation proved to be necessary. The calculation of the weighting function for cone measurements near the apex was complicated and lengthy. Since continuing along this line would have retarded the stereo correlator measurements, the cone model was abandoned in favor of the tilted plane terrain model.

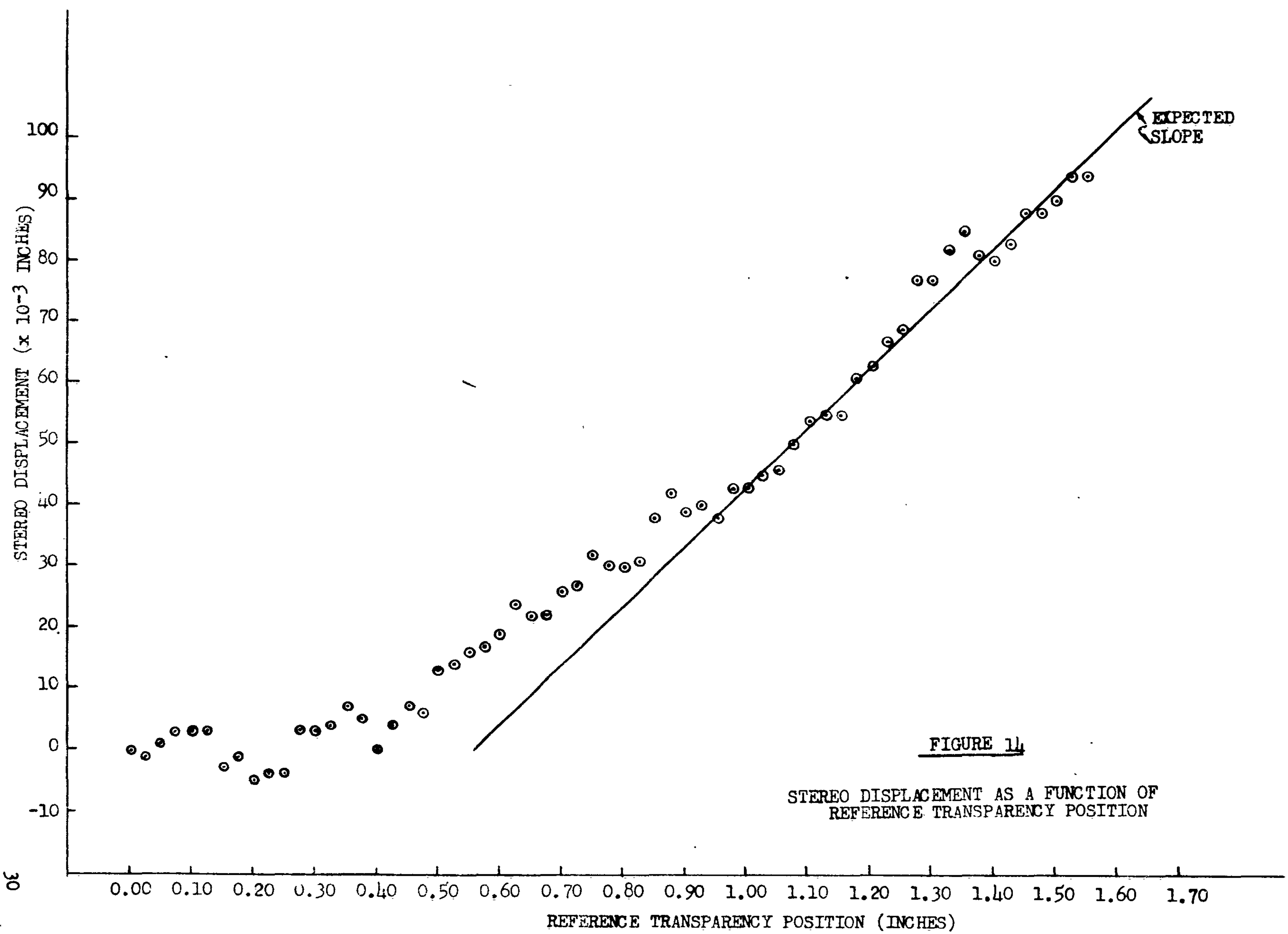


FIGURE 14

STEREO DISPLACEMENT AS A FUNCTION OF REFERENCE TRANSPARENCY POSITION

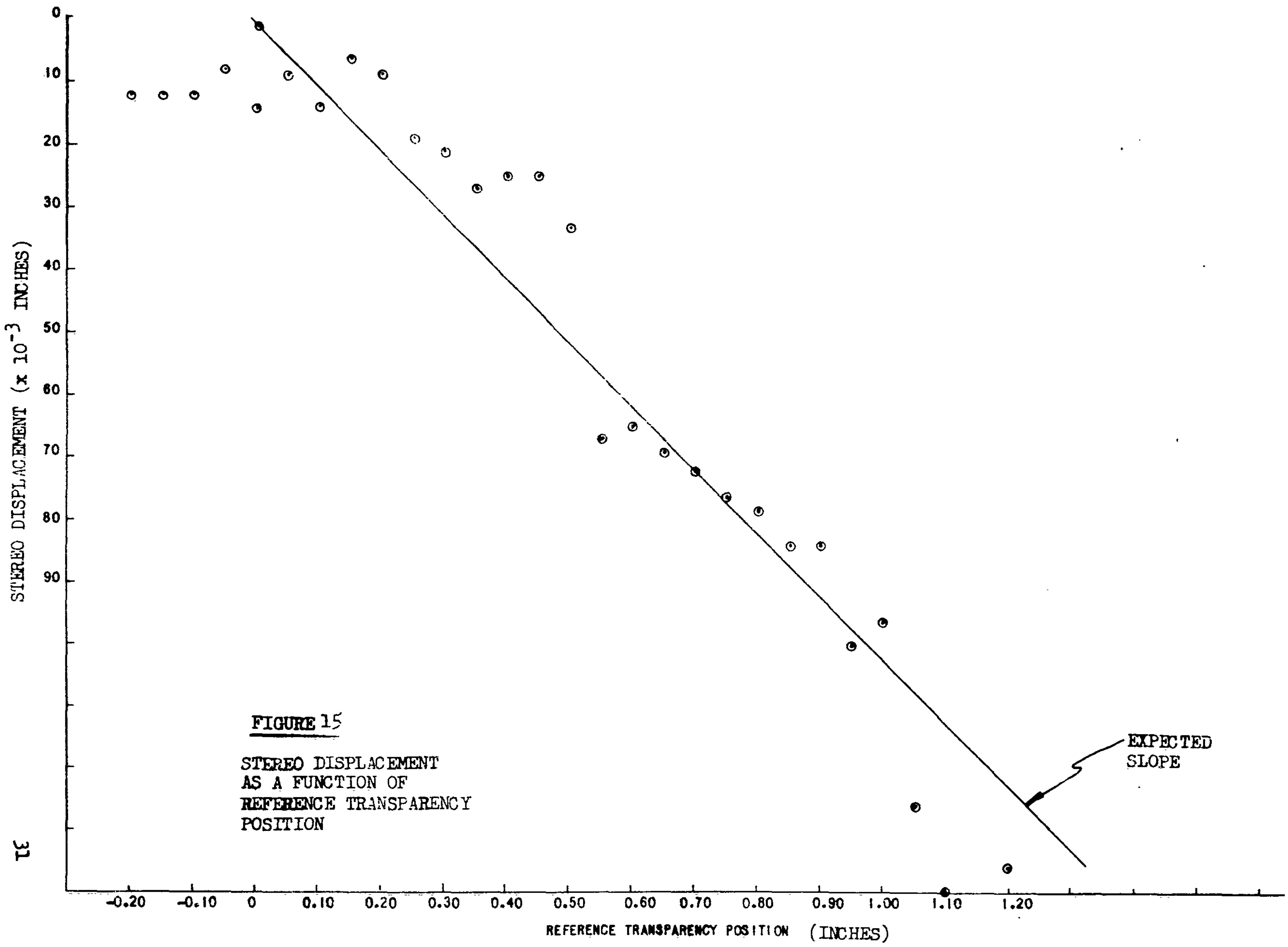


FIGURE 15

STEREO DISPLACEMENT
AS A FUNCTION OF
REFERENCE TRANSPARENCY
POSITION

3.2.2 Tilted Plane Profiles

This series of measurements was used to find the main sources of error in the stereo correlator. The error was shown to be caused by the one-dimensional smearing of the correlation function due to the scale factor difference, in the flight path direction, in a stereo pair of transparencies. The smearing broadened and reduced the correlation function, making the peak harder to locate. When this condition existed, a shift in the peak position could result from the uneven distribution of the correlation information over the range of altitudes within the sample aperture. Both the error in measurement of the peak position and the shift in the actual location of the peak position are due to smearing and its associated effects.

The stereo pair for the tilted plane was mounted and aligned in the experimental optical correlator assembly. Three parallel scans, shown in Figure 12 as lines A, B, and C, were made through the bend in the tilted plane. The data points and the expected profiles, calculated with the weighting function included, are plotted in Figures 16, 17, and 18. The data points did not track as well as expected. A series of scans were made to determine the sources of error. The first scan, labelled D in Figure 12, was made on the flat, untilted portion of the model. The expected stereo displacement for this line was known to be a constant (zero). Figure 19 is a plot of the data points and the expected line. The error was significantly smaller than that for the tilted section. This indicated that the errors in Figures 16, 17 and 18 were not due to the information content, but had something to do with the stereo effect. The next measurement was a scan along a contour, scan E in Figure 12, with the peak position measured in the contour direction, not in the direction of stereo displacement. The data for scan E is plotted in Figure 20. The error was still significantly smaller than that for scans A, B, and C. Large errors were present only when the peak position was measured in the direction of stereo displacement on the tilted portion of the plane. The basic difference in the correlation functions in these cases is the presence of smearing and the associated effects of uneven distribution of correlating information for those scans made on the slope.

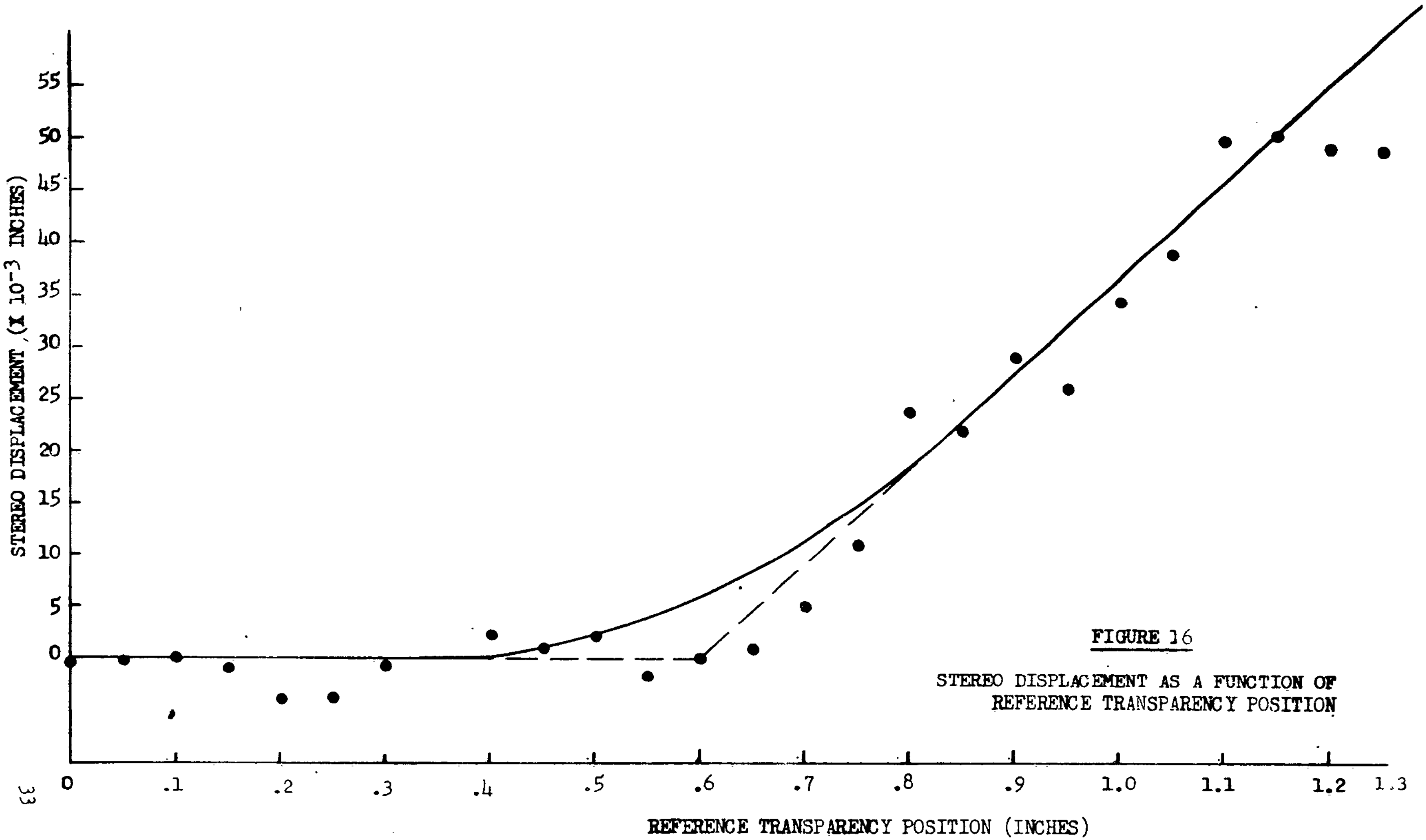


FIGURE 16

STEREO DISPLACEMENT AS A FUNCTION OF REFERENCE TRANSPARENCY POSITION

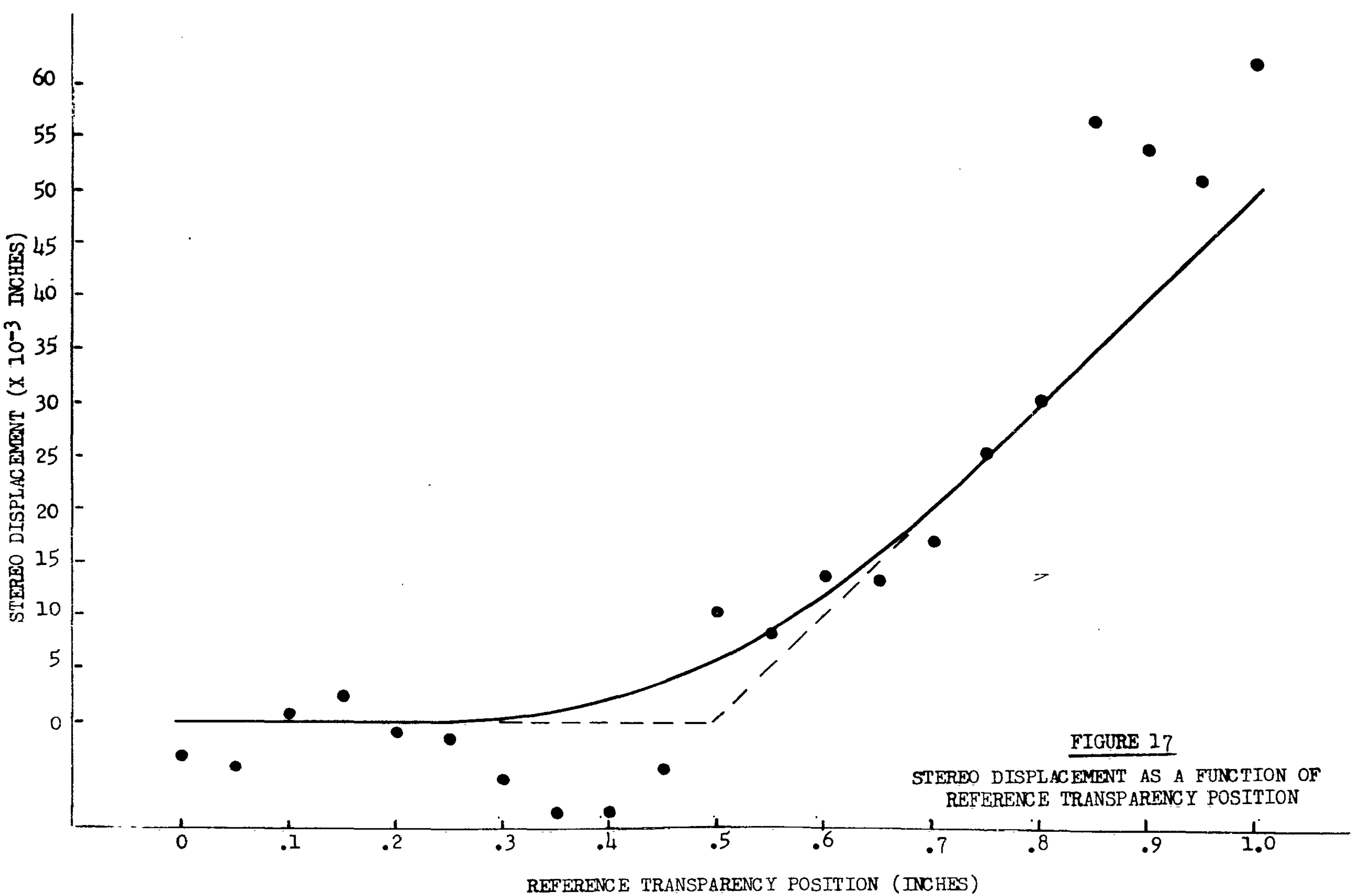


FIGURE 17

STEREO DISPLACEMENT AS A FUNCTION OF REFERENCE TRANSPARENCY POSITION

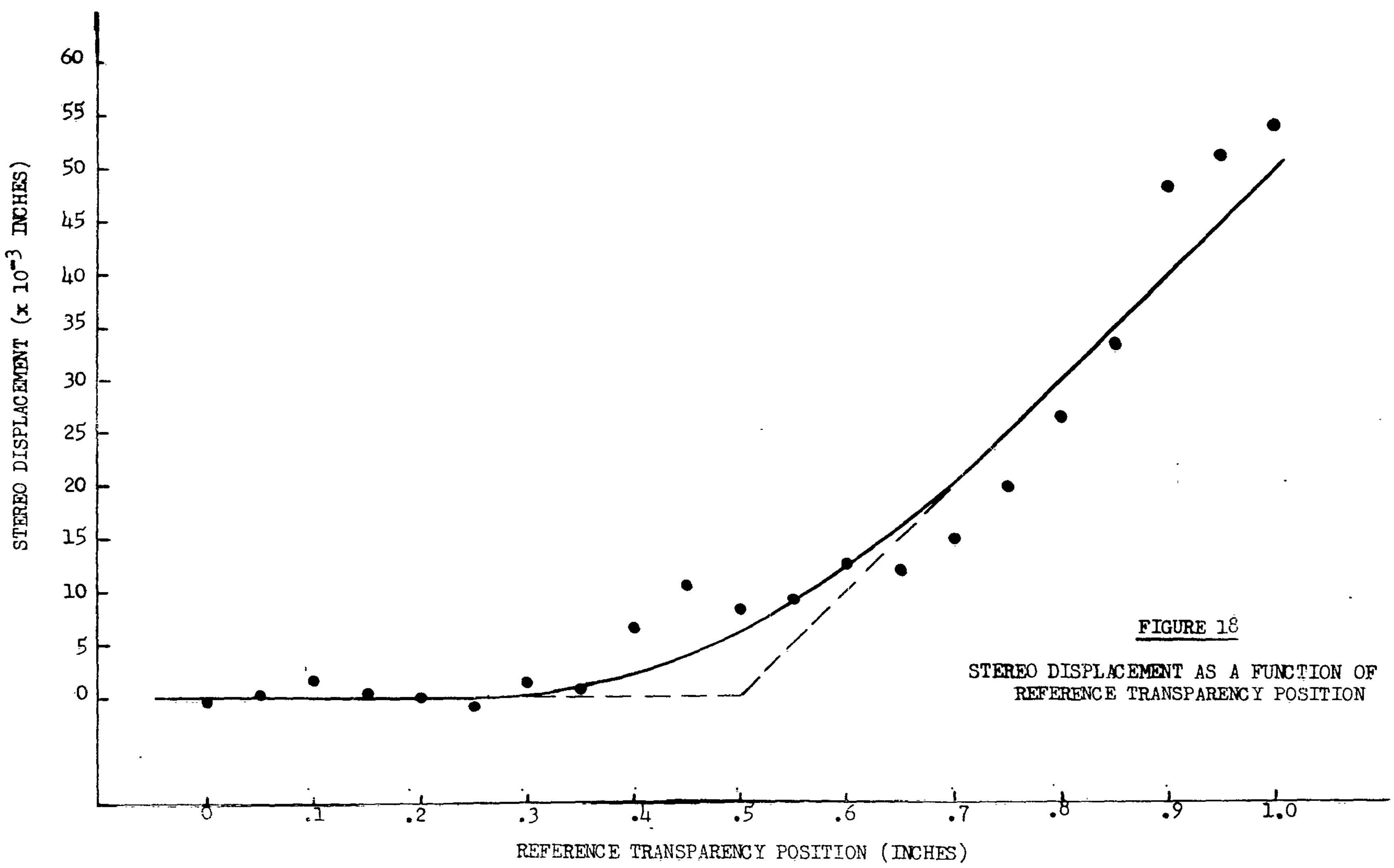


FIGURE 18

STEREO DISPLACEMENT AS A FUNCTION OF REFERENCE TRANSPARENCY POSITION

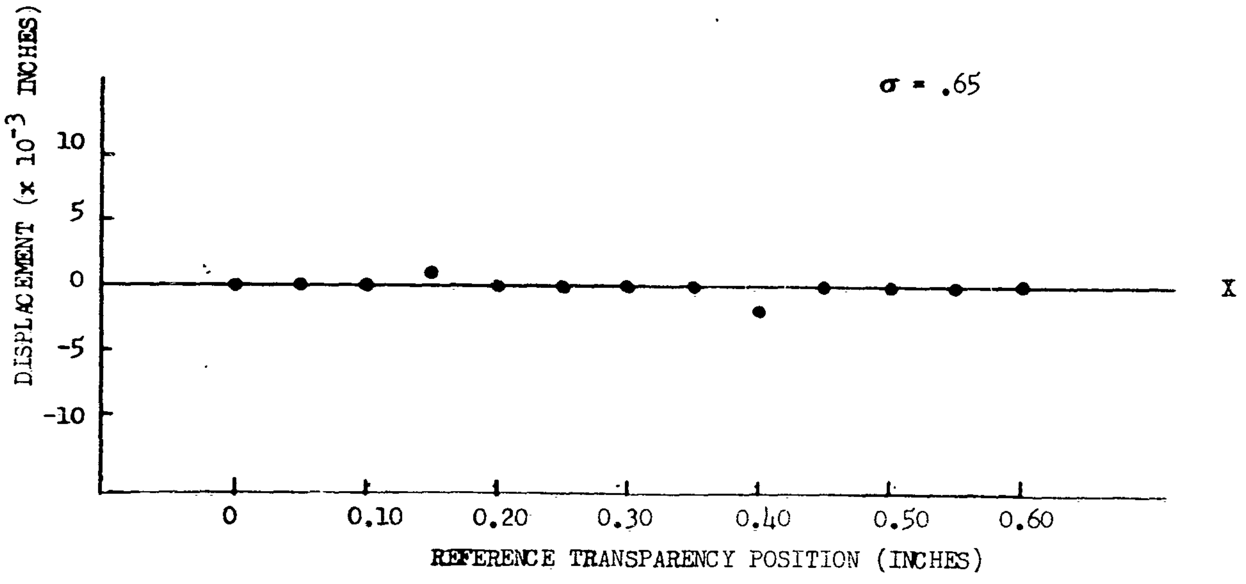


FIGURE 19

PEAK DISPLACEMENT AS A FUNCTION OF
REFERENCE TRANSPARENCY POSITION

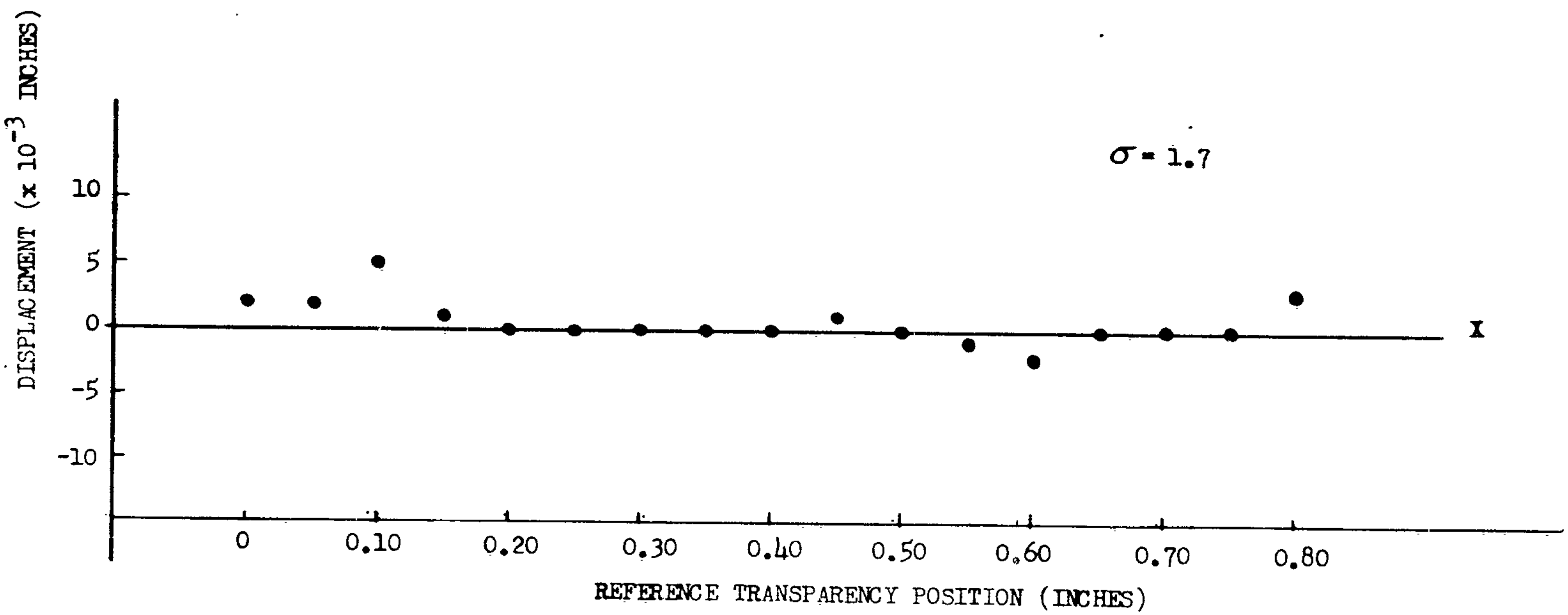


FIGURE 20

PEAK DISPLACEMENT AS A FUNCTION OF
REFERENCE TRANSPARENCY POSITION

3.2.3 Tilted Plane Contours

Tilted plane contour measurements were made along the three contours shown in Figure 12 as lines E, F, and G. Three separate sets of measurements were made on each of the three contours; one set was made with the basic correlator; a second set was made with a stereometer and a third set was made with the correlator modified by a cylindrical lens. In each set, the stereo displacement was measured at right angles to the contour lines. A best fit straight line was calculated as a measure of the error. The correlation coefficient (R) was also calculated for each scan to find how well the data points conformed to a straight line. When the value of the correlation coefficient is very close to one, the best fit straight line is a good approximation to the best fit curve of the data. The non-zero slope of the best fit straight line is due to alignment inaccuracies and is not a system error.

3.2.3.1 Basic Correlator Measurements

The three scans were first made with the basic correlator assembly used to make the measurements in Section 3.2.2. The data points are plotted in Figure 21 with the best fit straight lines. The errors due to smearing were present in this measurement since the correlation function was measured in the direction of stereo displacement.

3.2.3.2 Stereometer Measurements

The three scans were next made, for comparison purposes, with a stereometer supplied by GIMRADA (a Fairchild Stereocomparagraph). The data for each scan is plotted with the best fit straight line in Figure 22. The stereometer data had approximately half the standard deviation of the stereo correlator data in Figure 21. One advantage of the stereometer is that the measurement of the altitude at a point involves using only the information in a relatively small area around that point. Hence, weighting or smearing is not significantly present. However, the measurement must be made by a trained person possessing good visual stereo perception.

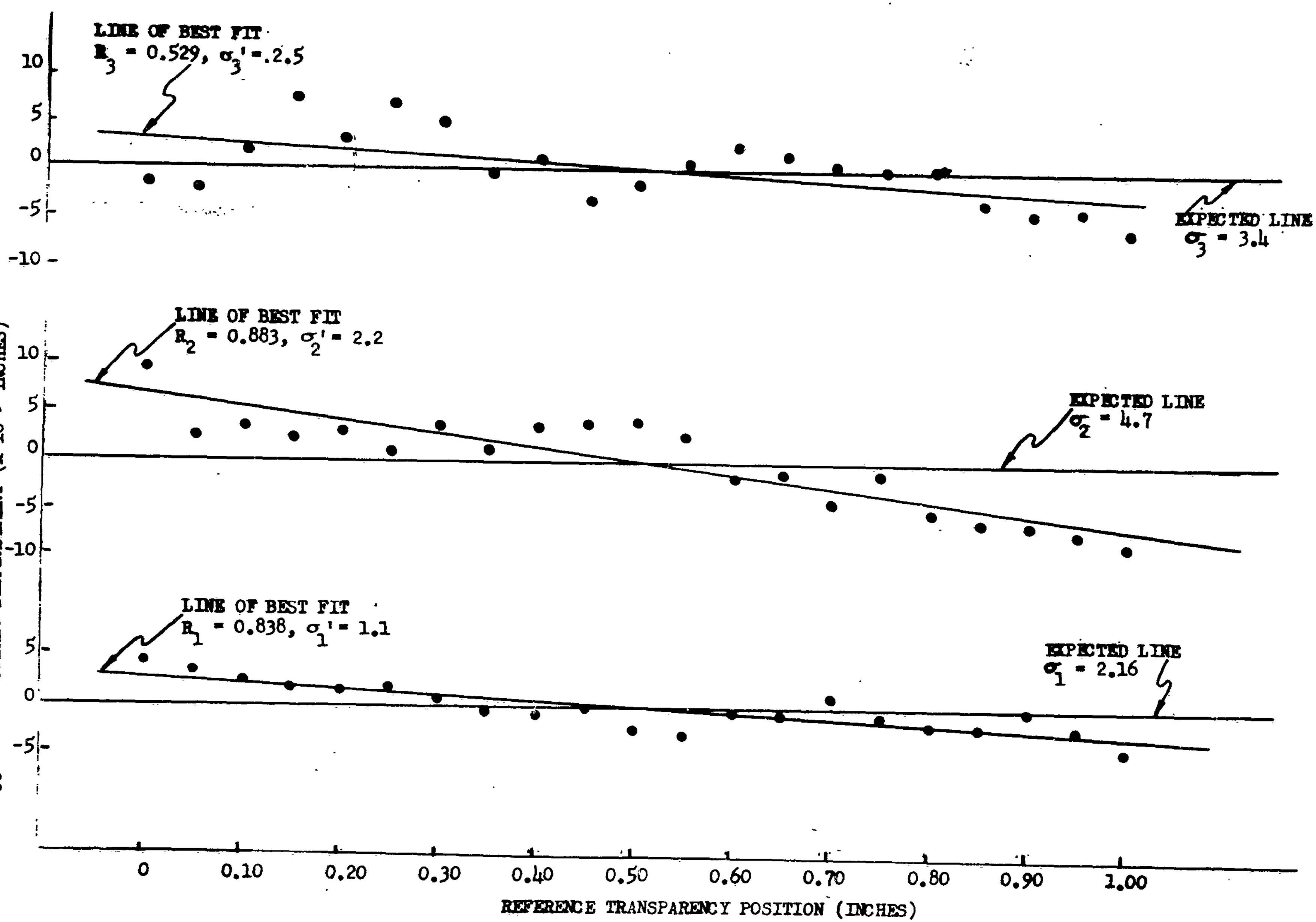


FIGURE 21 STEREO DISPLACEMENT AS A FUNCTION OF REFERENCE TRANSPARENCY POSITION

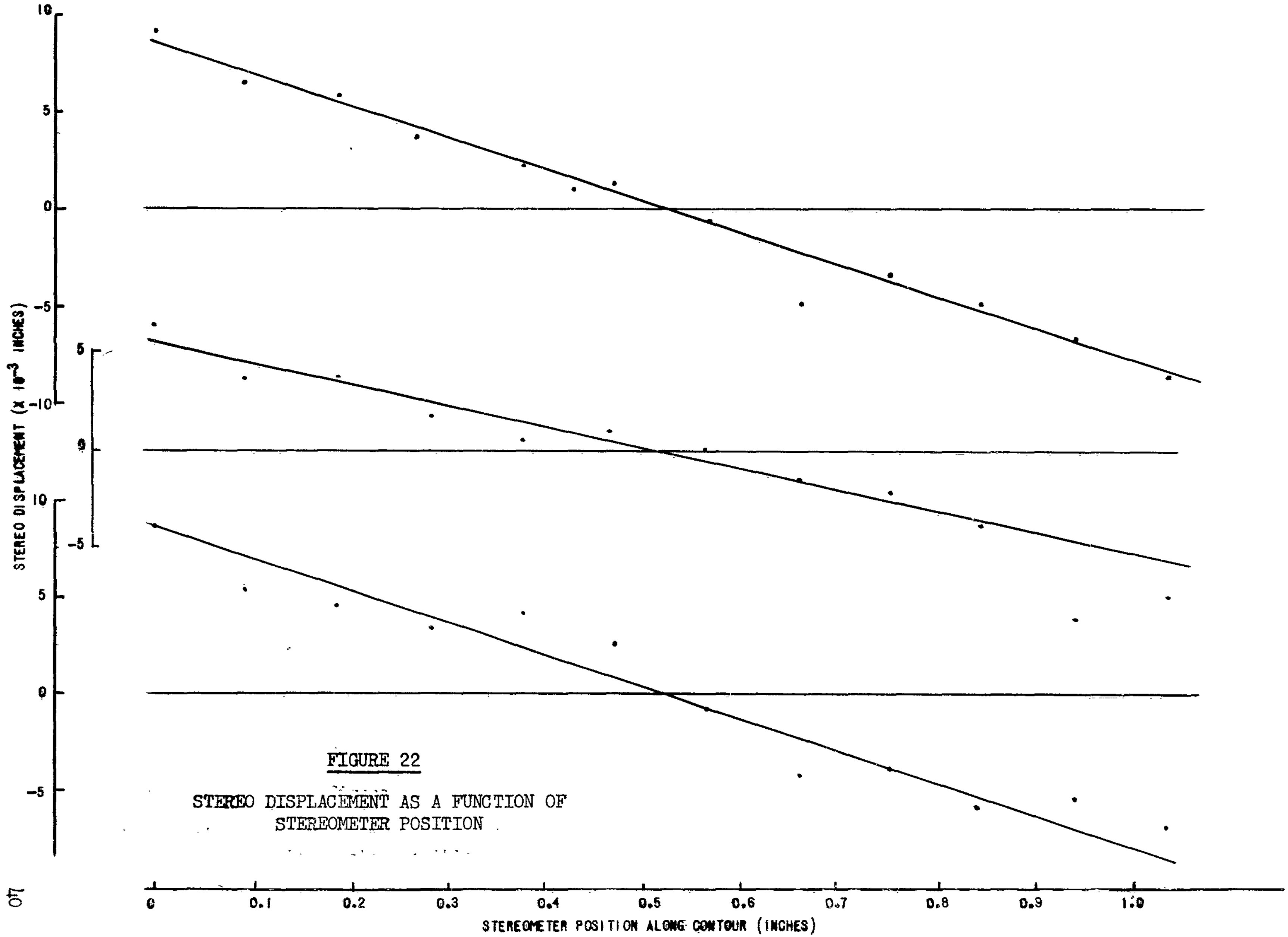


FIGURE 22

STEREO DISPLACEMENT AS A FUNCTION OF STEREOMETER POSITION

3.2.3.3 Cylindrical Lens Modified Correlator Measurements

In Section 3.2.2, the main source of error was stated to be the smearing of the correlation function. The amount of smearing can be significantly reduced by the addition of a correcting cylindrical lens to the basic correlator assembly. Consider the manner in which the smearing is generated.

When the two transparencies in the correlator are identical, the rays which contribute to the correlation peak converge in the focal plane of the spherical lens (lens 1) and smearing does not occur. Consider four parallel rays each passing through a pair of identical features in the two transparencies. Figure 23a is a sketch of the correlator assembly with two transparencies, T_1 and T_2, showing the four rays converging to a point (the peak of the correlation function) in the focal plane of lens 1. The two transparencies in a stereo pair are identical only when the terrain is perfectly flat and horizontal. If the original terrain had a linear slope in the y direction, the rays intersecting identical pairs of features in the stereo pair would not converge to one point as in Figure 23a, but to two points as in Figure 23b. The slope has separated what were previously four parallel rays into two sets of two parallel rays each. Had rays from all the features been drawn in Figure 23b they would converge to a straight line parallel to the direction of stereo displacement in the focal plane of lens 1. This line is representative of the smearing of the correlation function. If a cylindrical lens is added to the system, the direction of the rays can be altered in one dimension without affecting them in an orthogonal dimension. Figure 23c shows a cylindrical lens, lens 2, behind the original lens. The two transparencies are the same as those in Figure 23b. The cylindrical lens is used to converge the rays in the y direction to a single point while not disturbing the already sharp convergence in x. The point image in Figure 23c is just as sharp as that in Figure 23a.

A cylindrical lens was added to the basic correlator assembly and measurements were made of the errors with the smearing reduced. This lens was placed between the detector and lens of the basic correlator

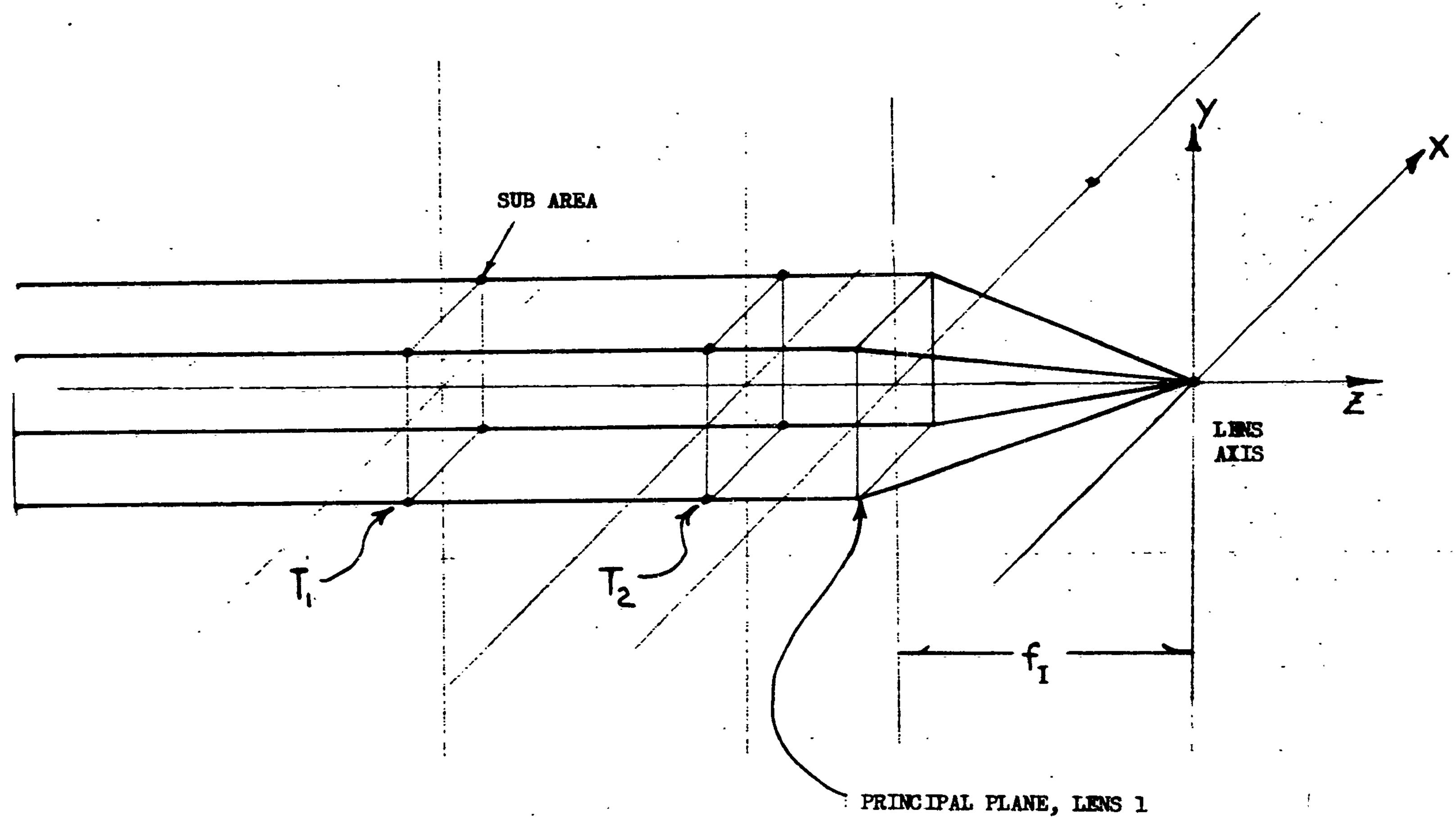


FIGURE 23a

CORRELATION WITHOUT STEREO DISPLACEMENT

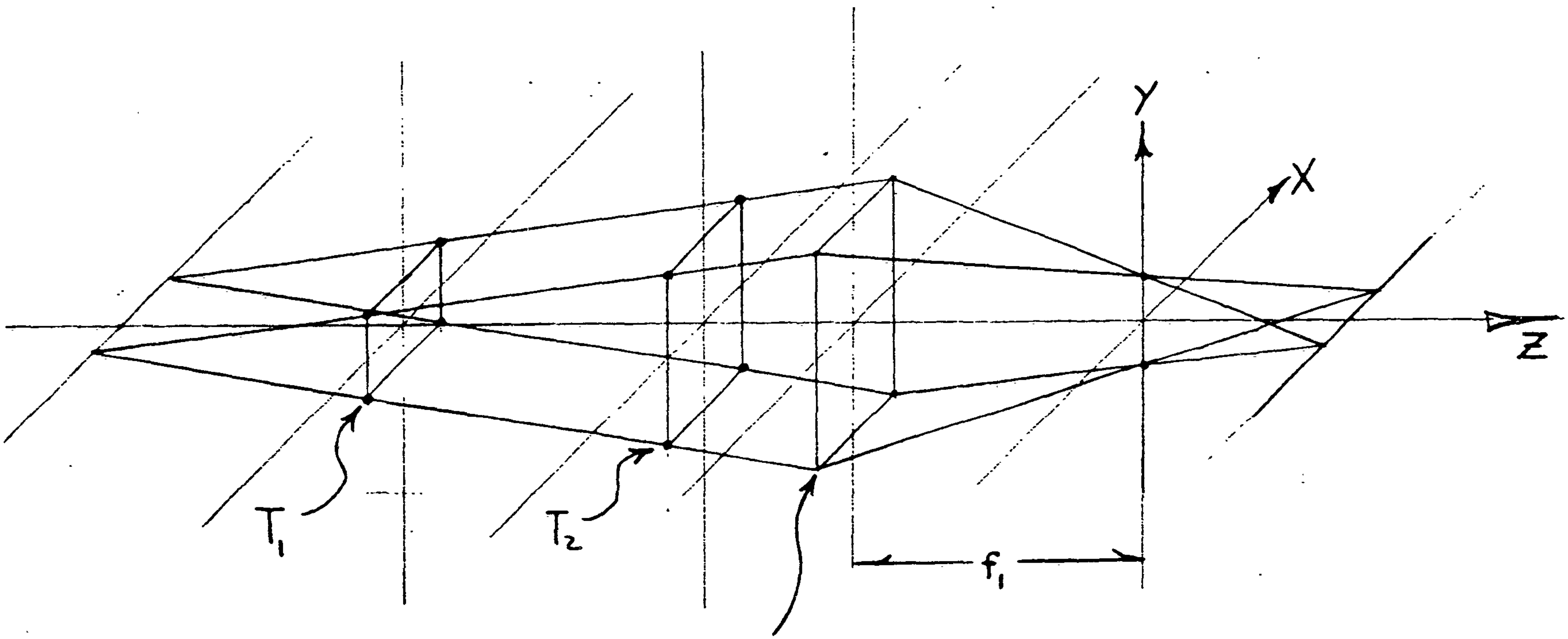


FIGURE 23b

CORRELATION WITH STEREO DISPLACEMENT

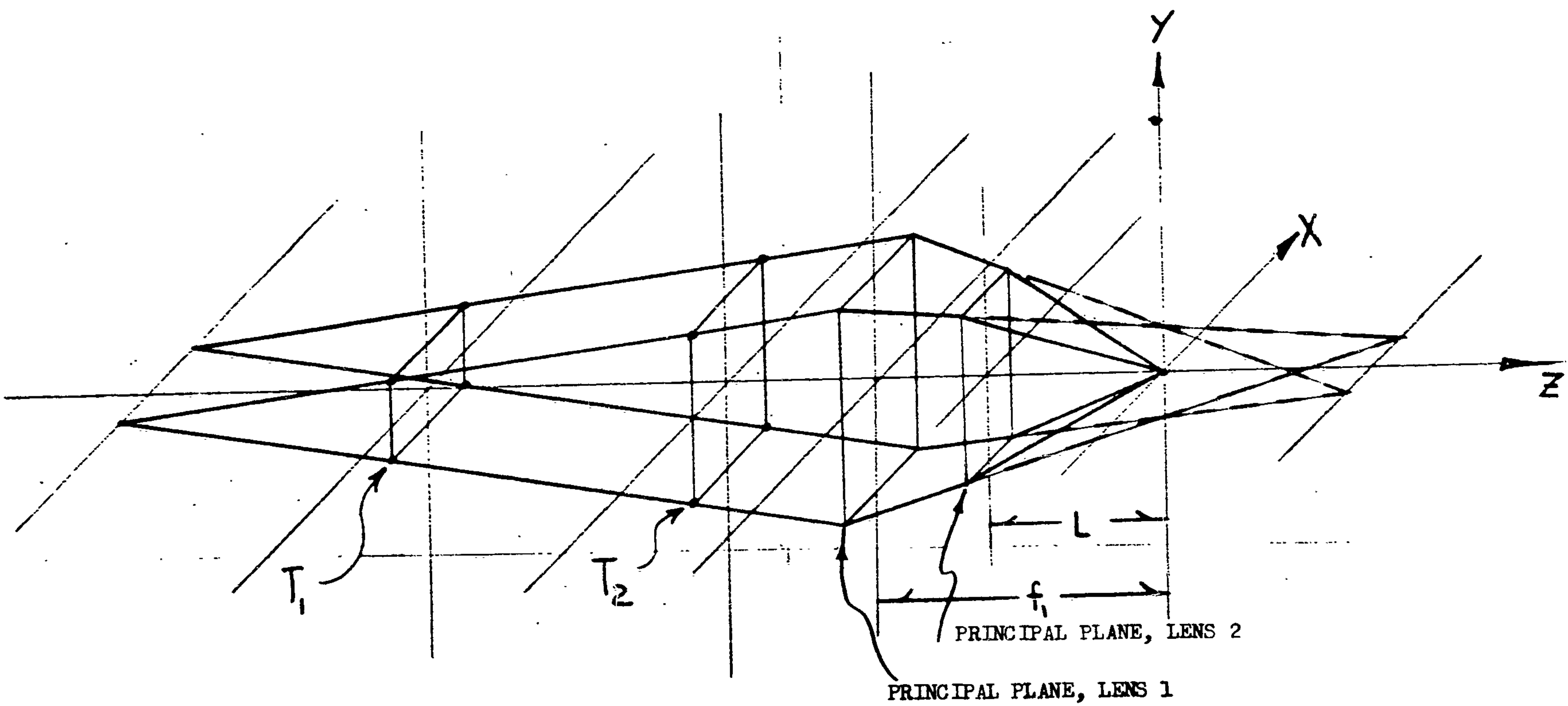


FIGURE 23c

CORRELATION WITH CORRECTED STEREO DISPLACEMENT

E

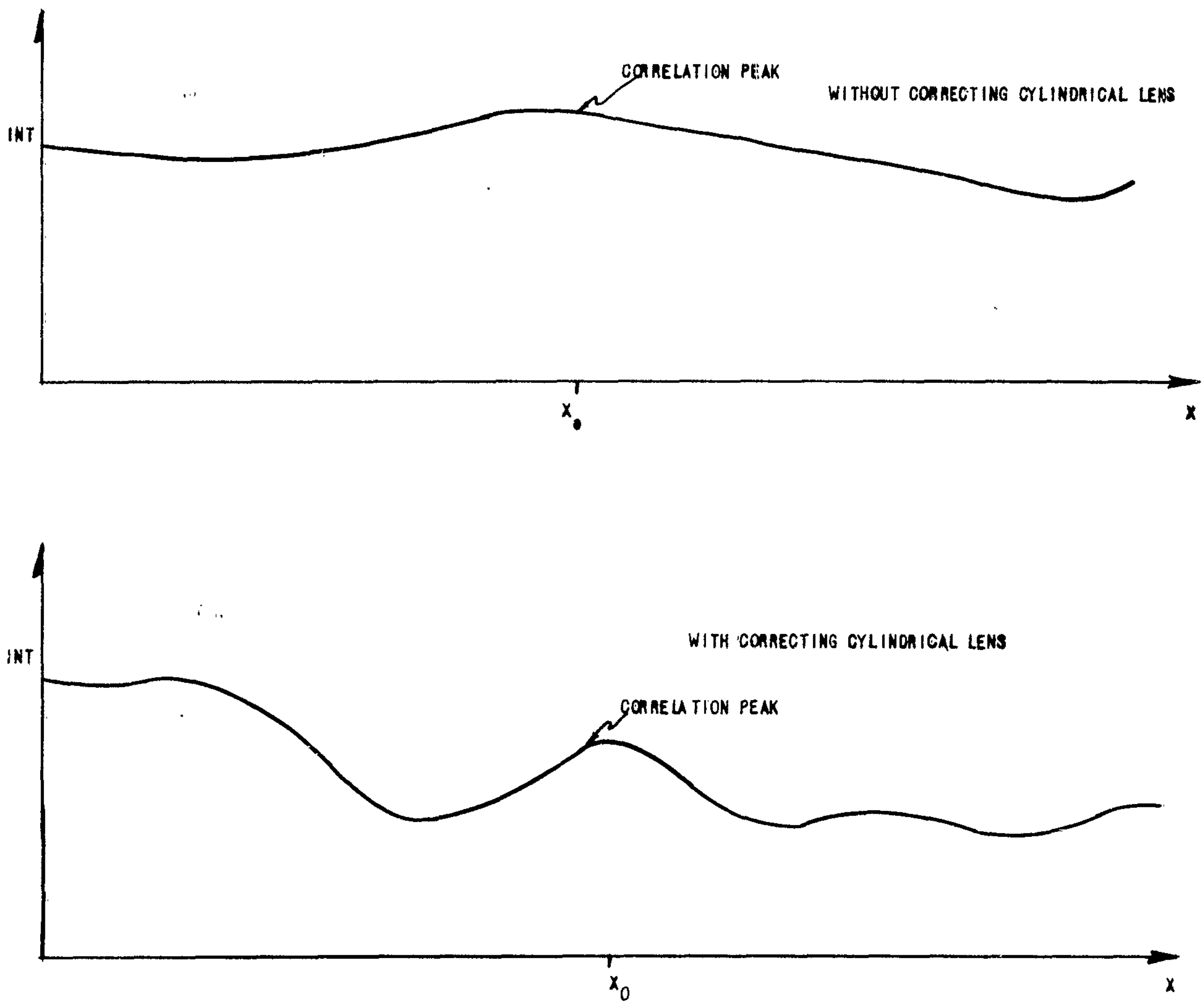
assembly as in Figure 23c. Care had to be taken in locating the lens so as to avoid overcompensating, which could reintroduce the unwanted smearing. Scans of the intensity distribution in the detector plane were made before and after the addition of the cylindrical lens (Figure 24). The cylindrical lens significantly sharpened and strengthened the correlation function in the immediate vicinity of the peak.

Three contour scans were then made with the cylindrical lens in the system. Figure 25 is a plot of the data for the three scans with the standard deviation given for each contour scan. The improvement, in terms of greatly reduced dispersion of the data around the line of best fit, when compared to both the stereometer and best correlator scans, is readily apparent.

3.2.3.4 Comparison of Contour Data

The addition of the cylindrical lens reduced the errors of the experimental correlator assembly by a factor of more than three. The errors of the modified correlator were also lower than those of the stereometer. The cylindrical lens measurements were made at the end of the term of the contract. It is believed that even more accuracy could have been achieved had more time been available.

The smaller errors associated with the cylindrical lens were measured on the stereo pair of the tilted plane. In a more practical situation, the terrain will not be flat and the position of the cylindrical lens will have to be adjusted for the average slope around each point being measured. The cylindrical lens can not eliminate all of the smearing, but would remove the smearing arising from the average slope in the sample. Since this smearing is a principal source of error, the cylindrical lens would always be of significant value.

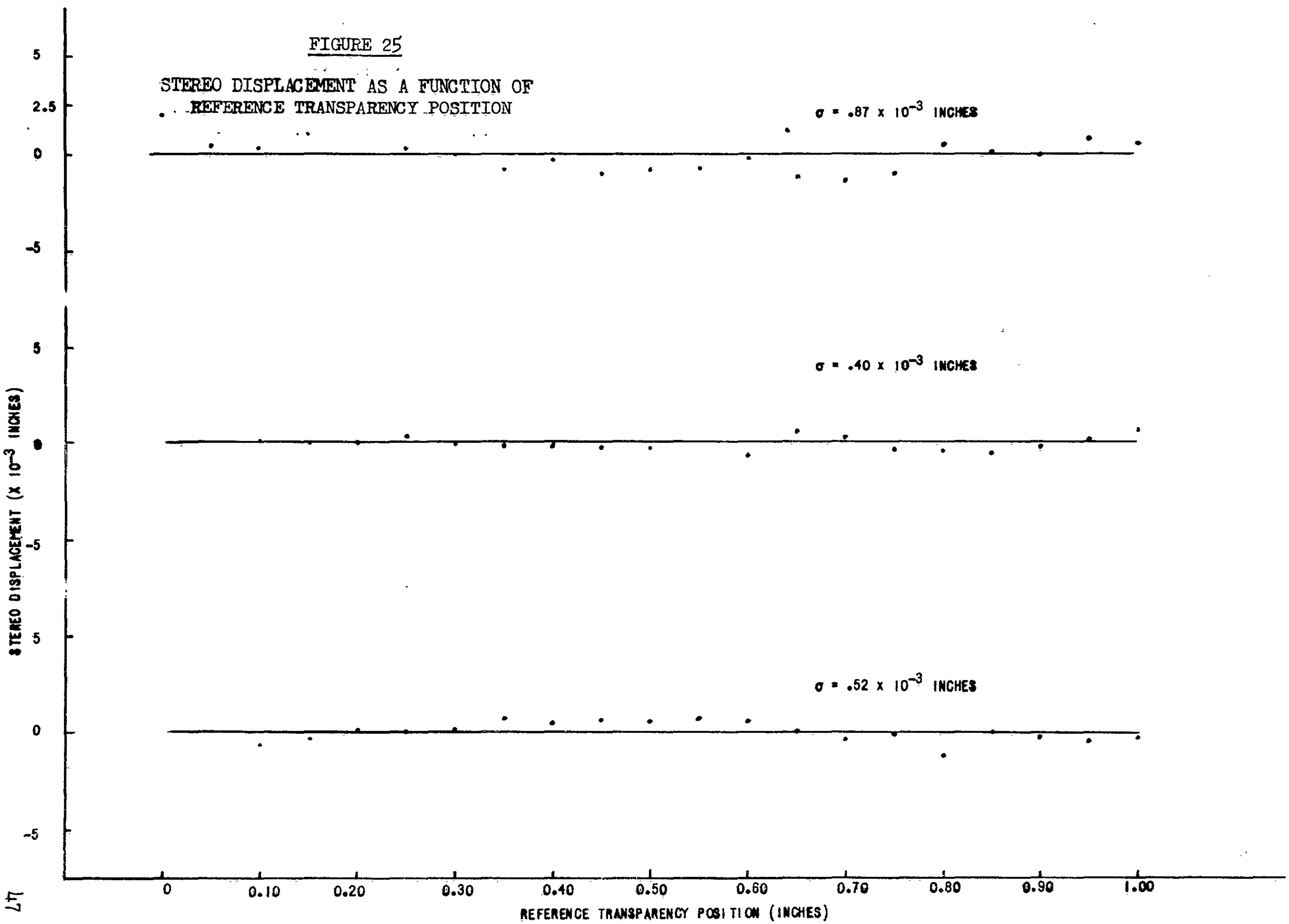


<u>FIGURE 24</u>

POINT DETECTOR SCANS

FIGURE 25

STEREO DISPLACEMENT AS A FUNCTION OF REFERENCE TRANSPARENCY POSITION



4. INSTRUMENTATION IMPROVEMENT STUDIES

The correlation measurements described in previous sections of this report were all made with a point detector. The position of the correlation peak was determined by scanning for maximum intensity in the detector plane. The results described in Section 2.2, in particular, revealed that the correlation peak is imbedded in a non-uniform background and has relatively low contrast relative to this background. This leads to difficulties in acquiring and accurately locating the peak position. It was shown, in addition, that this situation gets worse as the limiting system aperture is decreased. The purpose of the studies described in this section was to devise techniques for enhancing the contrast of the correlation peak with respect to the background and to develop a null method for indicating the peak position so as to eliminate the necessity for scanning. Some of the concepts employed in the problem of improving the contrast of the correlation peak were first conceived under Air Force sponsorship and are described more fully in Reference 1.

4.1 Diffusion Chopping

The intensity pattern which appears in the detector plane may be thought of as consisting of two components. One of these is associated with the average transmission of the reference transparency (see Figure 4) over the limiting aperture and the other is associated with the variation of transmission around the average, i.e., the information content within the aperture. The first of these components is in fact a defocussed image of the source transparency, containing primarily the lower spatial frequencies of the source information; this is the component giving rise to the non-uniform, noise-like background previously mentioned. The second component is the useful portion of the correlation function, containing the distinctive peak along the line of match. Since the variation of transmission of the reference around its average constitutes, in effect, a limited band high pass filter, the second component (containing the correlation peak) may be thought of as a high pass version of the source. Thus, the two components -- background and correlation peak -- are seen to reside in different portions of the space frequency spectrum, and, therefore, to be separable by space filtering techniques under suitable conditions.

The general method studied for enhancing the contrast of the correlation peak by space filtering involved the application of a controlled, periodic diffusion. As previously discussed in Section 1.1.1, the occurrence of diffuse transmission in the critical reference transparency causes smearing of the correlation function in the detector plane. In the context of the previous paragraph, this amounts to processing the intensity pattern in the detector plane with a low pass filter, thereby affecting the correlation peak more strongly than the background. To the extent that the correlation peak and the background do not overlap in the space frequency domain, it should be possible by means of diffusion to strongly attenuate the correlation peak without substantially affecting the background. On the other hand, if diffusion can be caused to occur periodically and only the periodically varying part of the pattern in the lens focal plane is sensed by the application of synchronous detection, the background should be effectively suppressed and the contrast of the correlation peak significantly improved.

The first scheme advanced to make use of periodic diffusion involved rotating a half diffusing, half non-diffusing disk of uniform average transmission between the reference and lens as indicated in Figure 26. Because of its function, the rotation disk was labelled as a diffusion chopper. For the diffusing medium, it was proposed to use a uniform halftone film and for the non-diffusing medium, a uniform grey Fine Grain Positive film of the same average transmission. The smearing effect of a regular rectangular halftone screen is illustrated by the photograph in Figure 27, which shows the diffraction smeared image of a dot of light. Without the halftone in the optical system, the image consisted of the central dot alone. By analogy, when the diffusion chopper is rotating continuously in the configuration of Figure 26, the image of the correlation function in the detector plane will appear alternately smeared and unaffected.

Point detector scans of a correlation function before and after insertion of a half tone diffuser into the system appear in Figure 28; smearing of the peak is quite evident here. Hypothetical scans of a correlation function with and without diffusion and the resultant synchronous demodulator output appear in Figure 29. The output of the synchronous demodulator is the lowest

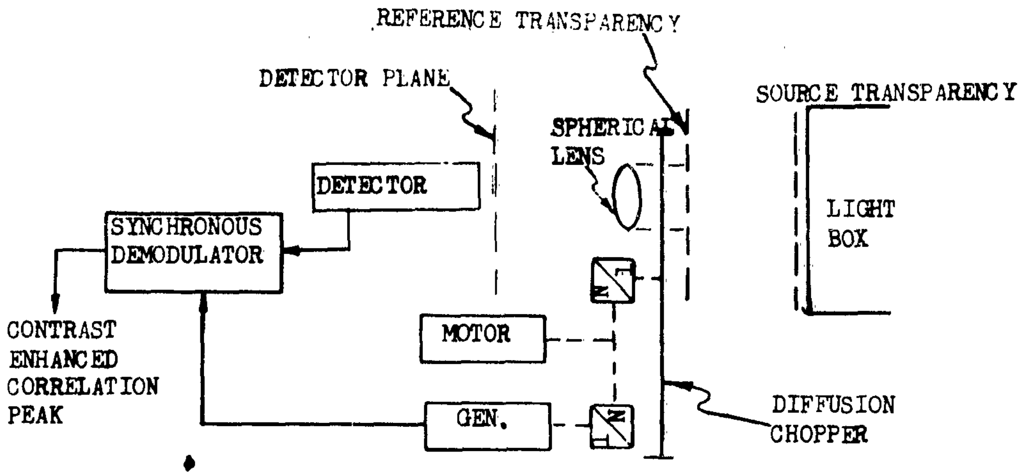


FIGURE 26a

DIFFUSION CHOPPER CORRELATOR

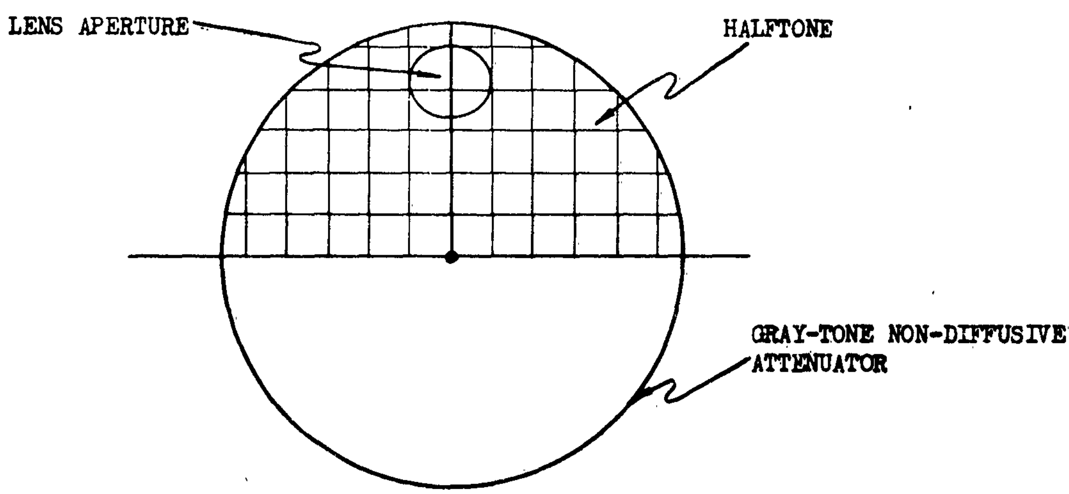


FIGURE 26b

DIFFUSION CHOPPER GEOMETRY

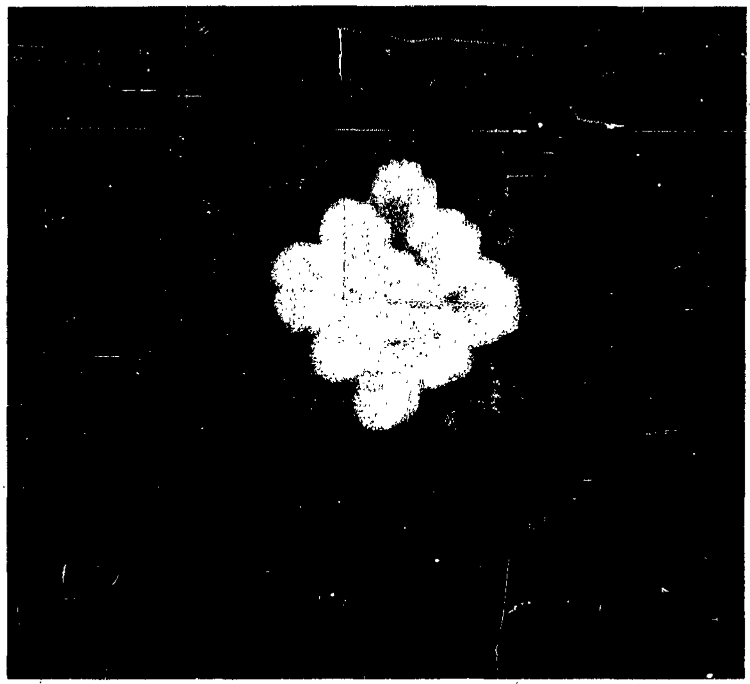


FIGURE 27

DIFFRACTION PATTERN PRODUCED BY A REGULAR RECTANGULAR SCREEN AND (LARGE) POINT SOURCE

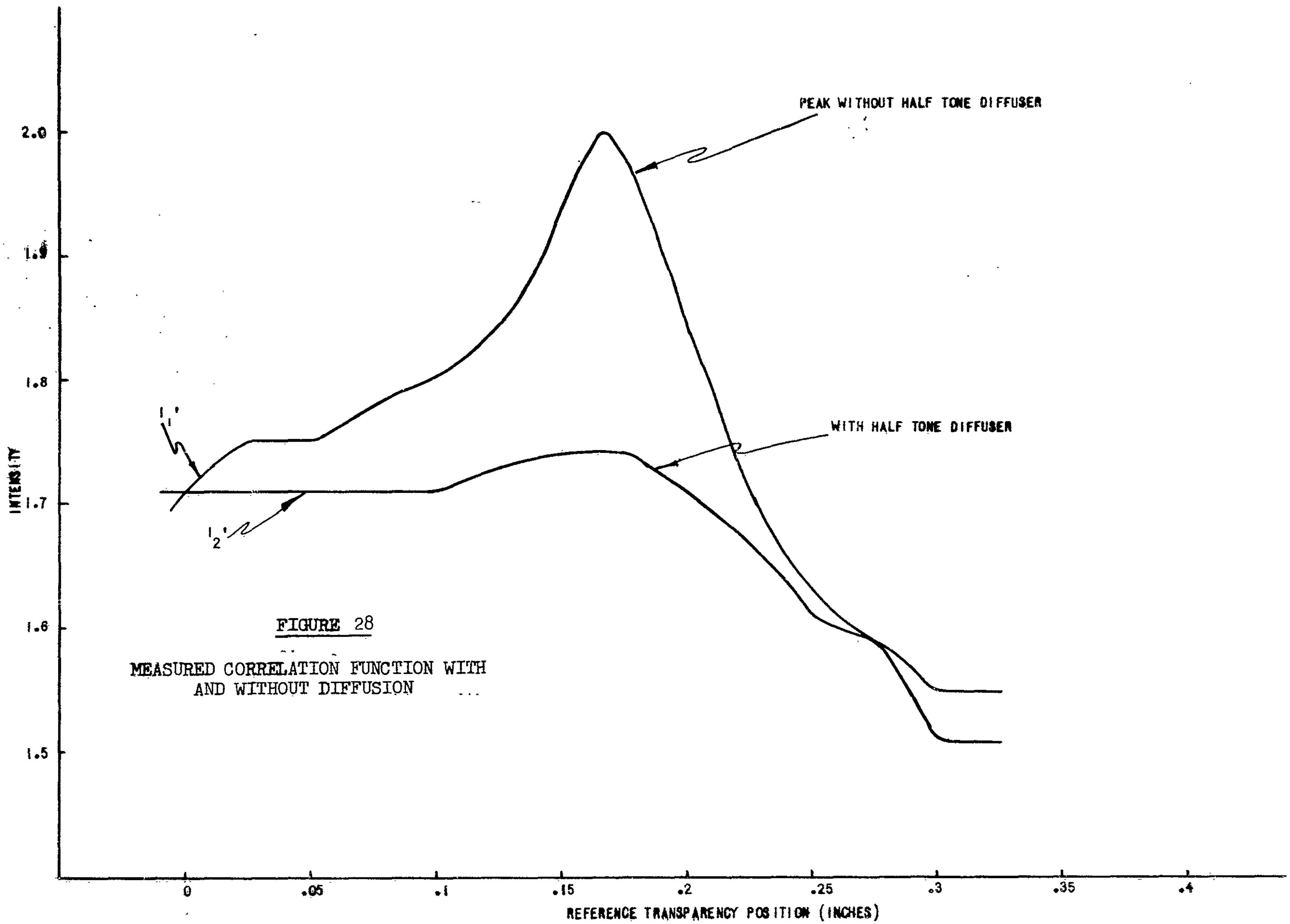


FIGURE 28

MEASURED CORRELATION FUNCTION WITH
AND WITHOUT DIFFUSION

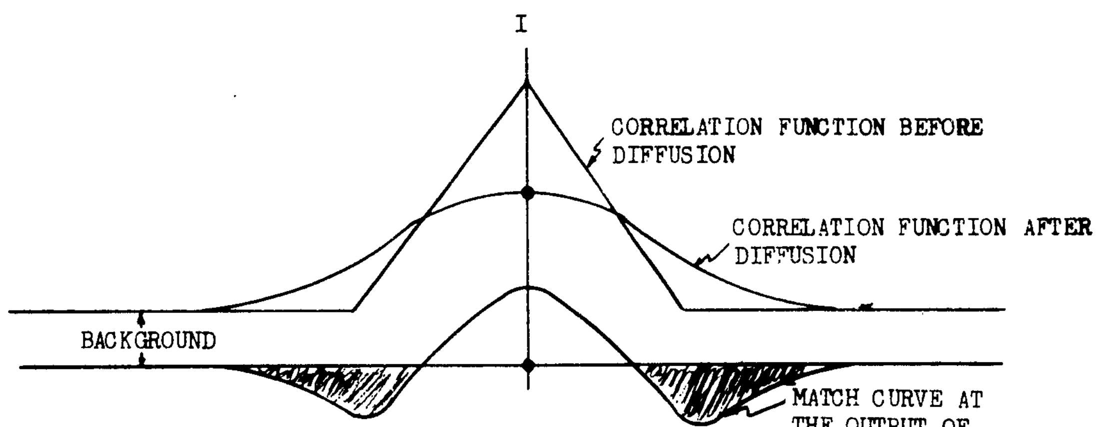


FIGURE 29

HYPOTHETICAL POINT DETECTOR SCANS SHOWING THE EFFECTS OF DIFFUSION AND DIFFUSION CHOPPING curve in the figure and represents essentially the difference between the intensities before and after diffusion. Hence, at the output of the synchronous demodulator, the background will have been eliminated; the match curve will have negative lobes on the skirts because the intensity at these points is increased by diffusion. It should be noted, however, that even though the background may be suppressed by diffusion chopping, the use of a point detector necessitates a scanning operation to locate the peak of the match curve.

An area detector, such as the RTT (Radiation Tracking Transducer) manufactured by Micro Systems, Inc., of San Gabriel, California, may be used to eliminate the scanning operation. The RTT, shown schematically in Figure 30 is a photovoltaic detector whose outputs indicate the position of the center of power of the incident light with respect to coordinate axes which intersect at the center of the cell. The outputs appear as voltages across two pairs of terminals, each of which indicates one component of the displacement vector. When the center of power is at the center of the cell, both outputs are nulled. This detector is described at length in Reference 1.

When using the RTT in conjunction with the diffusion chopper, it would be necessary to demodulate the outputs of the two terminal pairs in synchronism with the rotation of the diffusion chopper. It is also necessary that the degree of smearing be sufficient to move some of the power in the correlation peak off the face of the detector, causing the apparent center of power in the correlation peak to migrate periodically toward the center of the cell. Since the background intensity is largely unaffected by the diffusion chopping, the output of the synchronous demodulators reflect primarily the apparent periodic excursion of the correlation peak toward the center of the RTT. Thus, when the correlation peak is located at the center of the RTT (in the absence of diffusion chopping), the outputs of the synchronous demodulators (which process the terminal voltages of the cell) will be nulled and the position of the peak may be established without scanning.

One potential source of difficulty with the diffusion chopper is the need to match the average transmission through the diffusing and non-diffusion sectors. To the extent that this cannot be accomplished with precision, spurious signals will be generated caused by chopping of the background intensity.

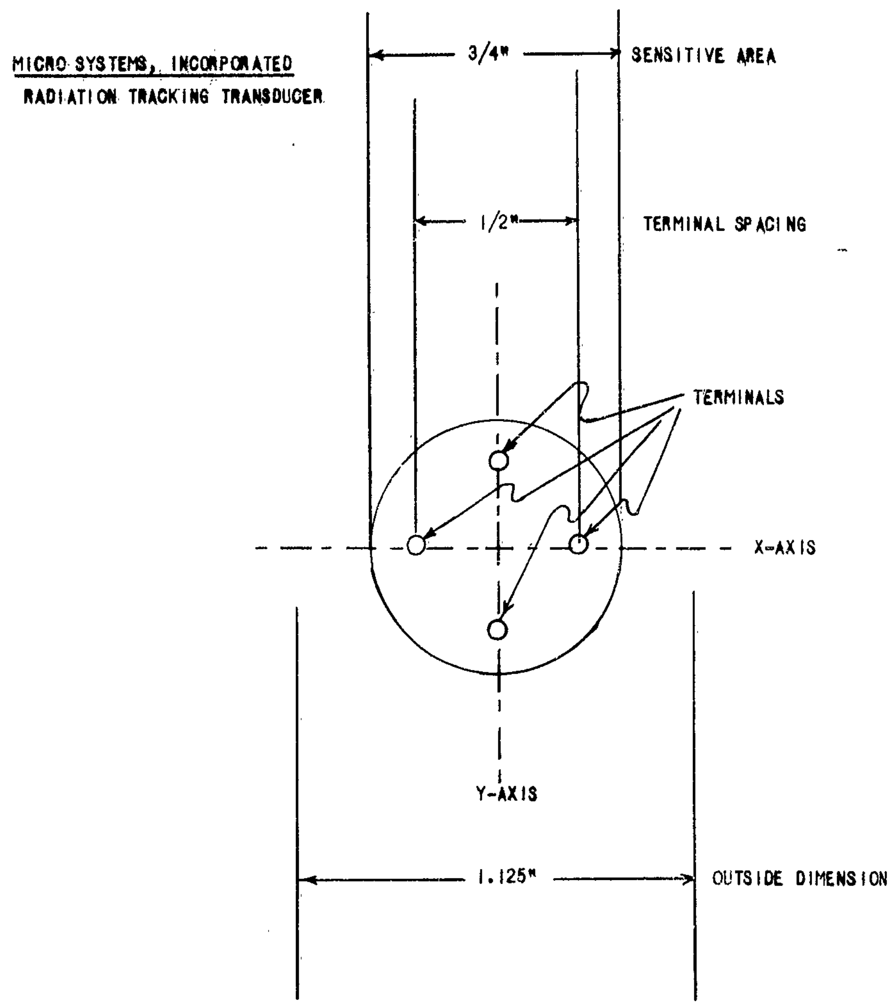


FIGURE 30

DISPLACEMENT TERMINAL LOCATION -- RADIATION TRACKING TRANSDUCER
SHOWING 2 PAIRS OF DISPLACEMENT SENSING TERMINALS

The next section describes a scheme devised to overcome this difficulty.

4.2 Rotating Grating

In the diffusion chopper discussed above, the diffusive element smeared the power at each point in the detector plane over the surrounding area. Consider a one-dimensional diffuser which smears the power at a point symmetrically over a line through that point. The angle between the line of smear and one axis in the detector plane is determined by the angular orientation of the one-dimensional diffuser. Rotating the diffusing element will rotate the direction of the smear line. Assuming, as with the diffusion chopper, that the background contains primarily low space frequencies while the correlation peak contains the highs, the rotating diffuser will change the peak into a rotating line but not significantly affect the background.

When using the RTT area detector, the length of the correlation smear line must be greater than the diameter of the RTT in order to generate useful signals. Assuming the peak to have been located at point (a, b) relative to the center of the detector before processing, after insertion of the rotating one-dimensional diffuser, the center of power would appear to be rotating around a circle one of whose diameters runs from (a, b) to (0, 0), the center of the detector. This is illustrated in Figure 31. The center of the signals from the RTT are processed by synchronous demodulators keyed in quadrature at twice the diffuser rate, a pair of dc voltages proportional to a and b, respectively, will be generated. When the original correlation peak position is at the center of the RTT, these voltages are nulled.

Several types of one-dimensional diffuser could be used. One type is a cylindrical lens which would "defocus" the intensity distribution in the detector plane in one dimension. Another one-dimensional diffuser is a fine line diffraction grating. The intensity at each point in the detector plane would be smeared along a line orthogonal to the lines of the grating. The smearing from each point would resemble the Fraunhofer diffraction pattern for that grating. A more complete description of one-dimensional correlators is to be found in Reference 2.

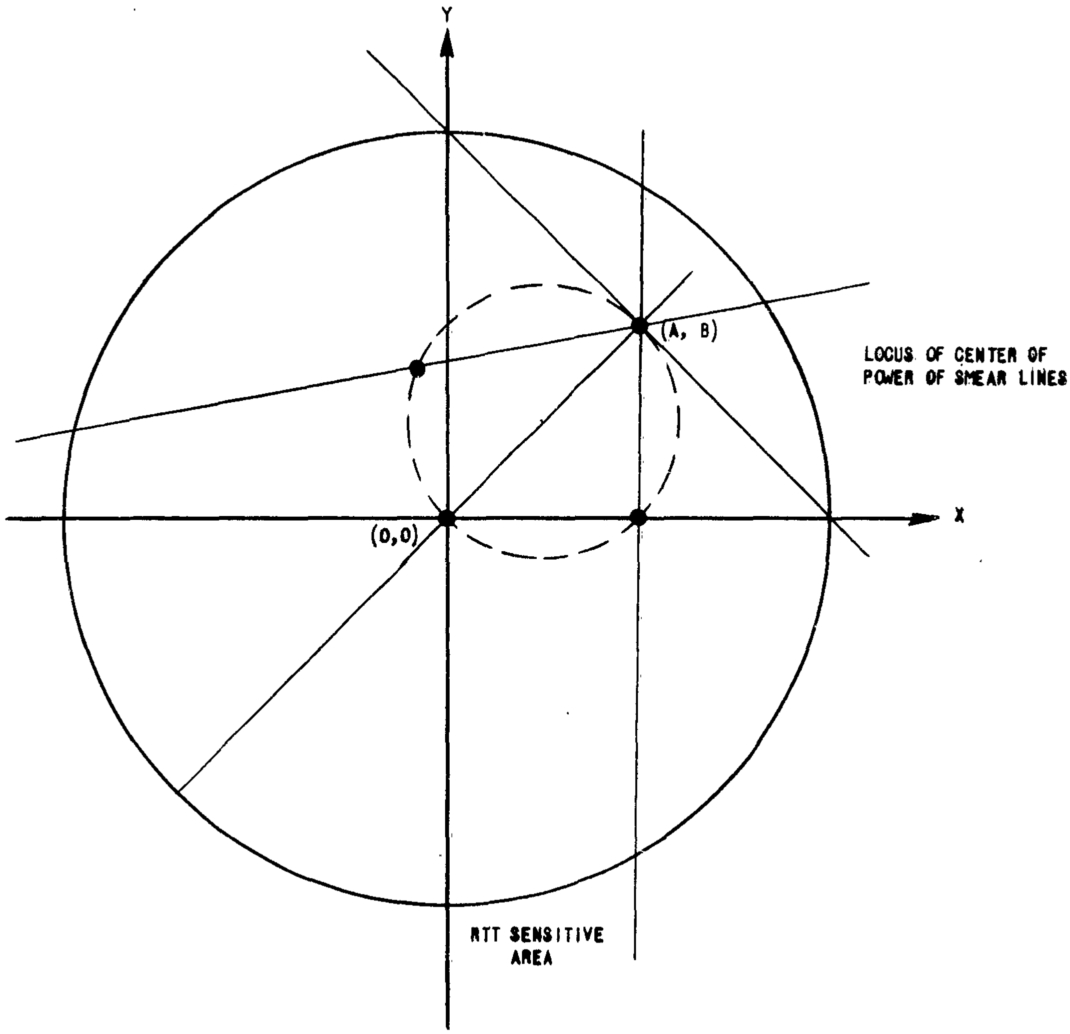


FIGURE 31

ILLUSTRATION OF ROTATION OF SMEAR LINE ON RTT

A rotating grating was chosen for the diffusion correlator experiments. The grating was on a film transparency and, therefore, much easier to rotate than a cylindrical lens. An additional advantage of a grating is that it does not have an optic axis which has to be centered in the rotating mechanism.

4.2.1 Rotation Grating Experiments

The one-dimensional diffuser, a 980 line per inch Ronchi Ruling, was made photographically from a commercially available 133 line per inch glass plate master. The grating was tested to determine the amount of smearing to a point image in the detector plane. A collimated beam of coherent green light was directed at the lens used in the basic correlator assembly. The lens converged the beam to a point in the detector plane (the focal plane of the lens). When the grating was placed between the collimated light source and the lens, the single point image was spread into a set of point images on a line, as predicted by Fraunhofer diffraction. The line of points was perpendicular to the lines of the Ronchi Ruling. Figure 32a is a plot of the light intensity as a function of position along the line of smear. A scan made at right angles to the direction of smear, plotted in Figure 32b showed no smearing in this direction.

The basic experimental correlator assembly was altered for the rotating grating experiments. The modified assembly is shown in Figure 33. The point detector was replaced by an area detector (RTT) stopped down to a quarter-inch diameter sensitive area. The iris assembly in the stereo correlator was replaced by a new unit. This unit held the grating in contact with the system aperture and had bearings in it which allowed the grating to be rotated. The axis of rotation was through the center of the system aperture. A synchronous motor was used to drive the rotating assembly. The RTT and the rotating machinery were, optically, the only deviations from the basic correlator assembly.

The associated electronics in the rotating grating measurements consisted of a low noise preamplifier, a synchronous detector, a dc amplifier and a pen recorder (all shown in Figure 33). The output of the area detector was first amplified in the preamplifier and was then fed into the synchronous detector (a switch which periodically shorted the signal to ground). The frequency and phase of the synchronous switching was derived from the 115 volt

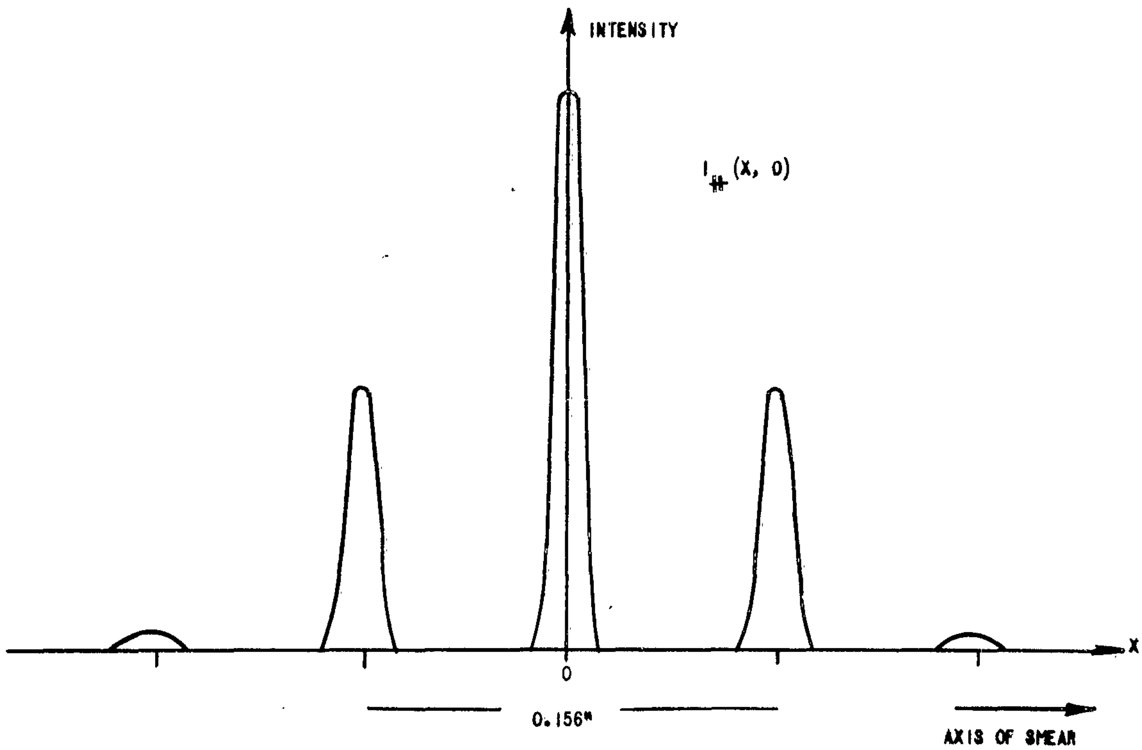
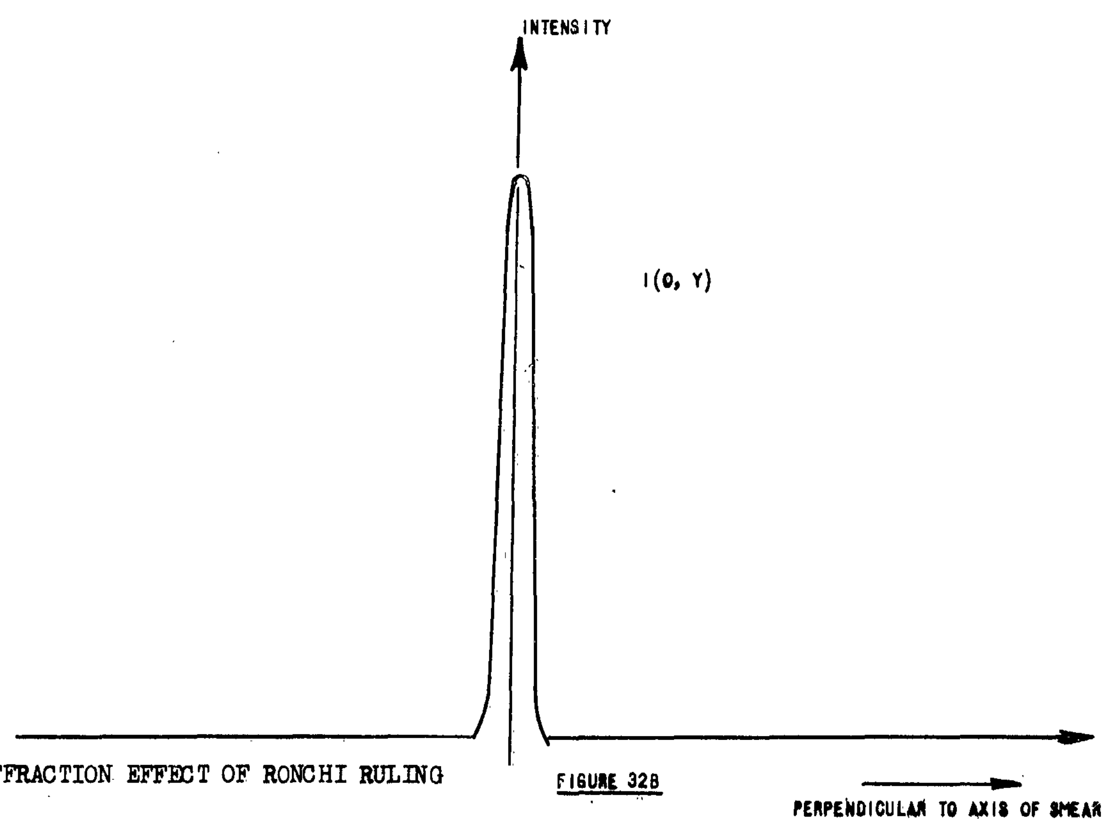


FIGURE 32A



DIFFRACTION EFFECT OF RONCHI RULING

FIGURE 32B

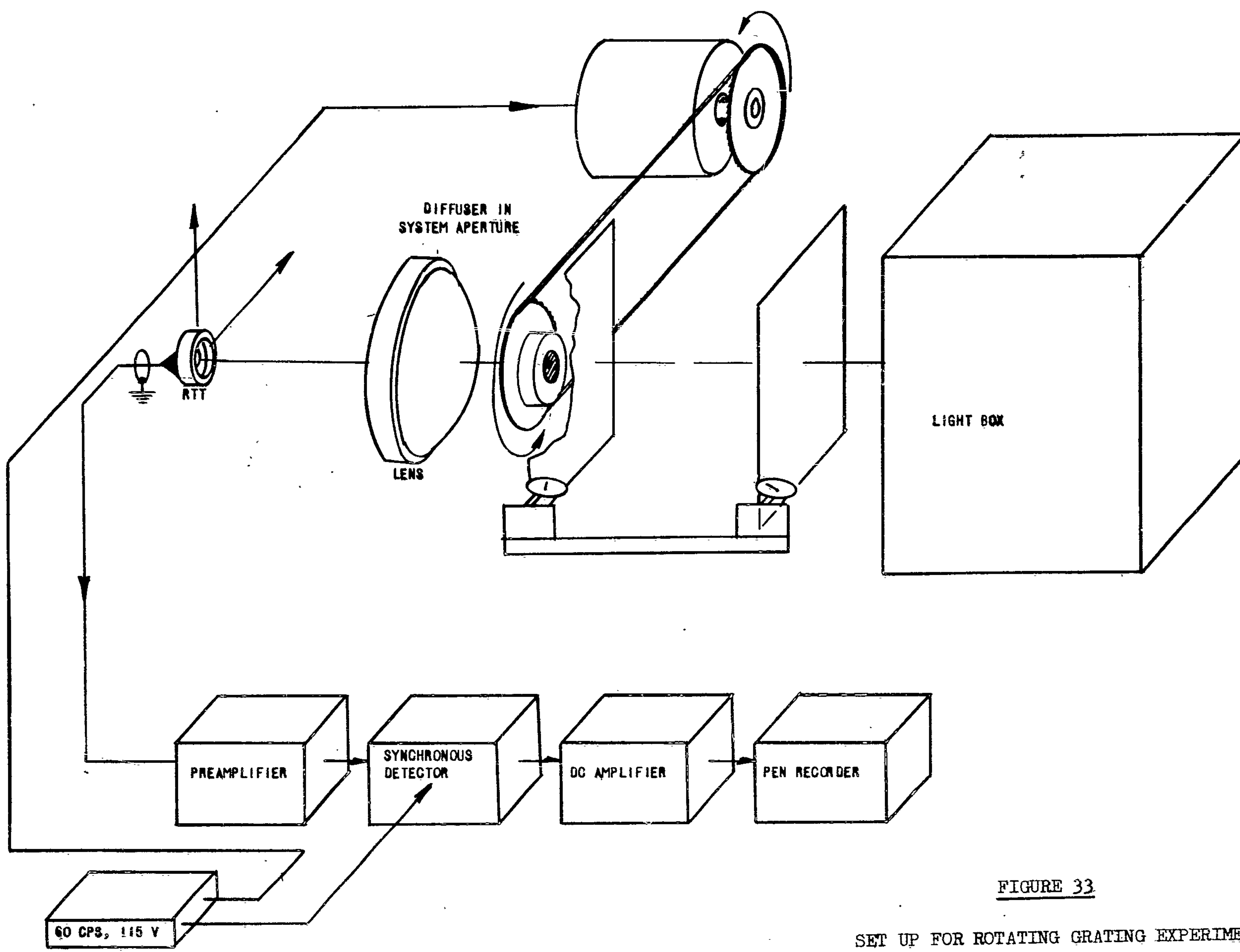


FIGURE 33

SET UP FOR ROTATING GRATING EXPERIMENTS

60 cps line which was also used to drive the synchronous motor. Since the synchronous motor drove the spinning mechanism at a fixed phase and at half of the frequency of the power line, the synchronous detector was chopping at the signal frequency. The chopped signal was averaged and amplified in a dc amplifier, which in turn drove the pen recorder. The expected signal from the RTT was of the form: $v(t) = A \cos (\omega t + n\pi)$. After passing through the associated electronics, this signal was to be read on the pen recorder as $KA \cos (n\pi)$. The amplitude A is a function of the separation of the unsmeared peak from the detector center.

As a preliminary test, the collimated beam of coherent light was directed at the grating, the motor was energized and the smeared image rotated about its center at the motor frequency. The RTT area detector was scanned in the detector plane on a line through the center of the smear. The output had the form shown in Figure 34, showing the expected discriminator characteristic.

The stereo pair from the tilted plane tests (shown in Figure 5) was then mounted in the diffusion correlator assembly and all of the apparatus was turned on. The area being correlated was flat so there were no stereo sources of error. A scan was made through the center of the rotating smeared correlation peak. There were several spurious error signals, but none would behave in a predictable manner.

The absence of useable error signals precipitated an investigation of the optical pattern falling on the RTT. The intensity distribution in the detector plane was raster scanned by the point detector with the grating fixed as four different angles. The measured light intensity, as a function of x and y in the detector plane, is plotted in Figures 35, 36, 37, and 38. The direction of the smear axis relative to the x axis is indicated by an arrow and noted as an angle in the upper left hand corner of each of the figures. Another raster scan was made with the grating removed from the system. This scan, representative of the correlation function including the peak, is shown in Figure 39.

Figures 35 through 39 indicate that the background was being modulated almost as strongly as the peak. The desired signal apparently did

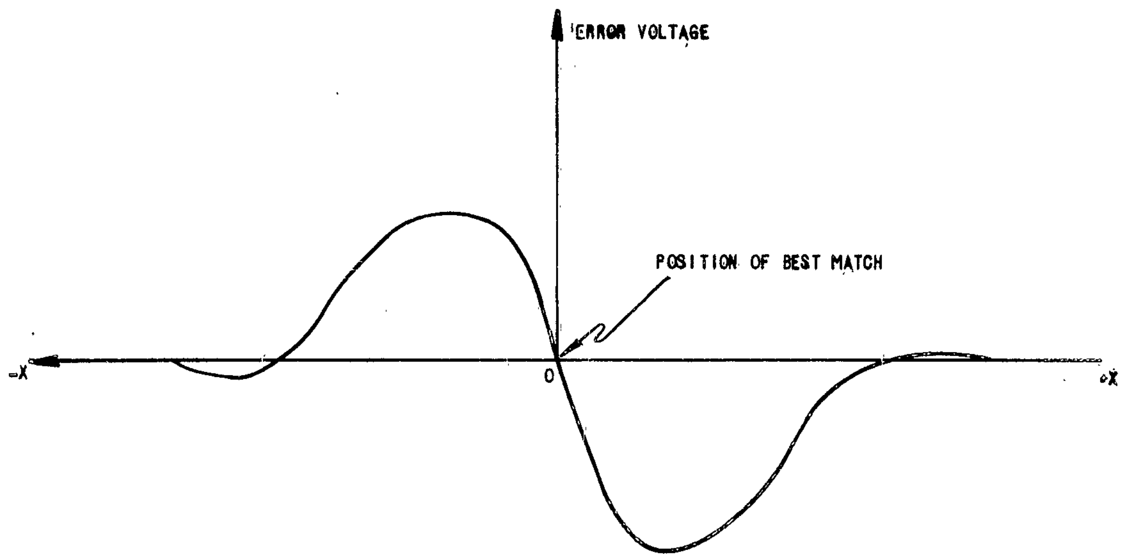


FIGURE 34

DISCRIMINATION CURVE FOR ROTATING GRATING

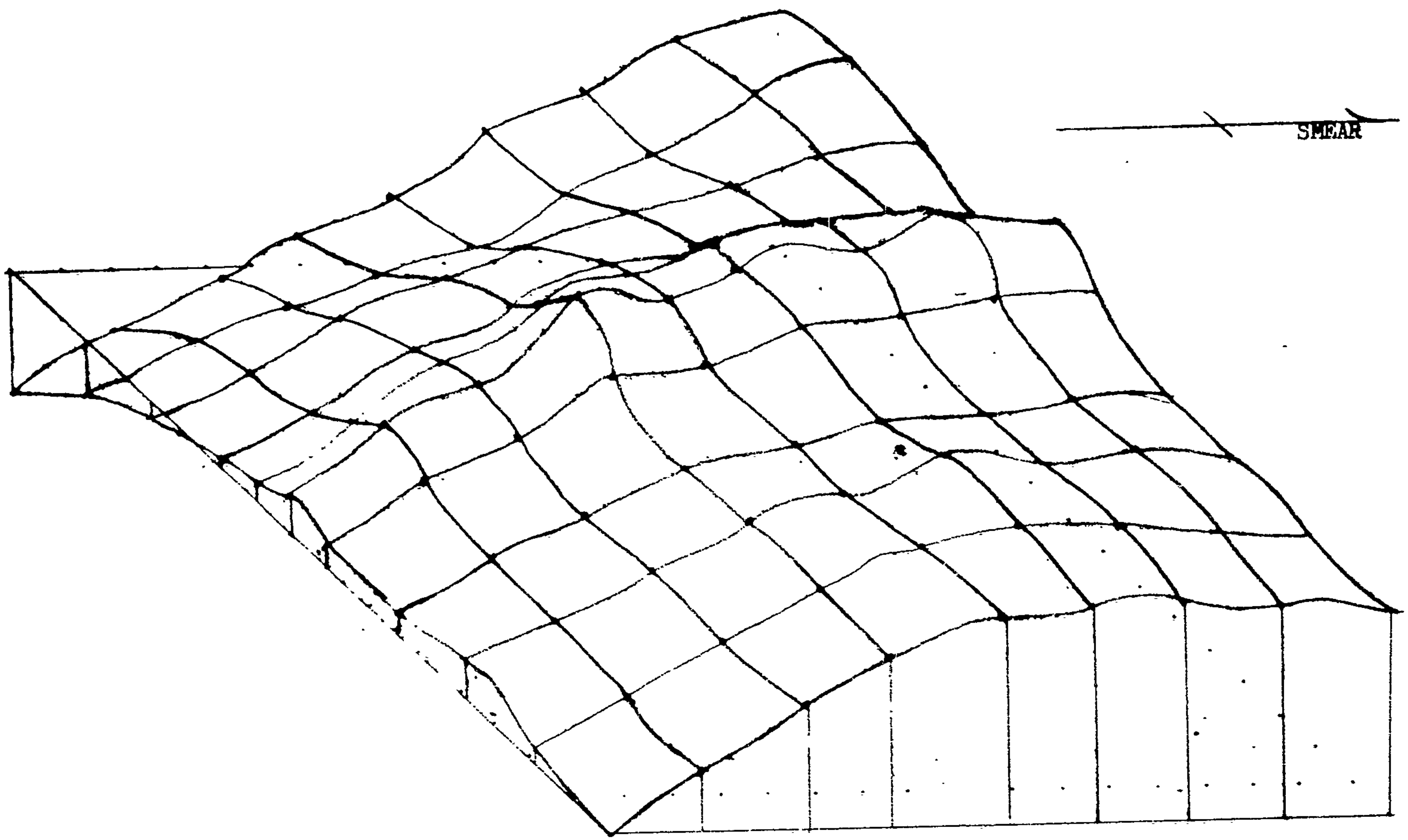


FIGURE 35

CORRELATION SURFACE SMEARED BY LINE GRATING

0°

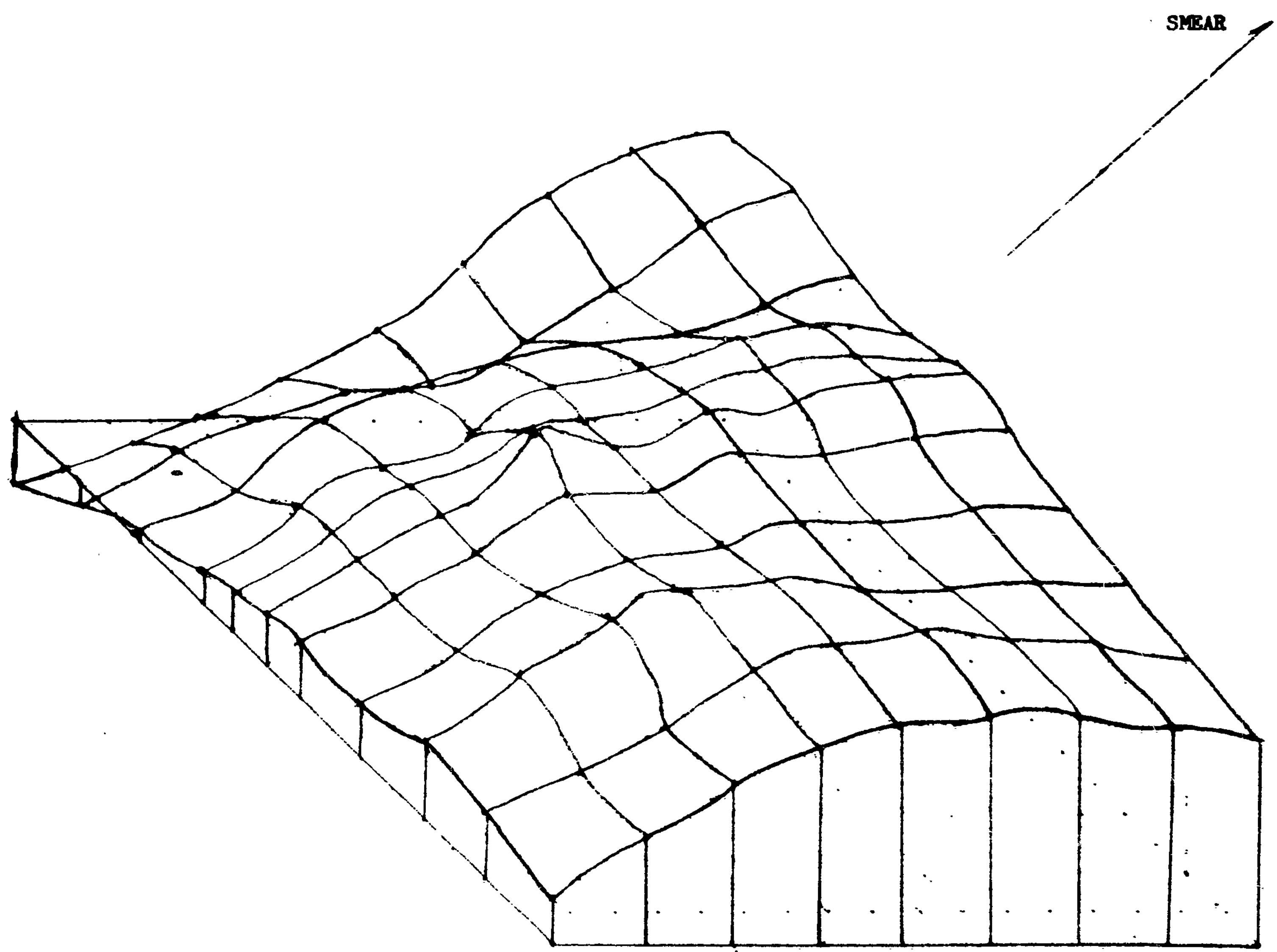


FIGURE 36

CORRELATION SURFACE SMEARED BY LINE GRATING

30°

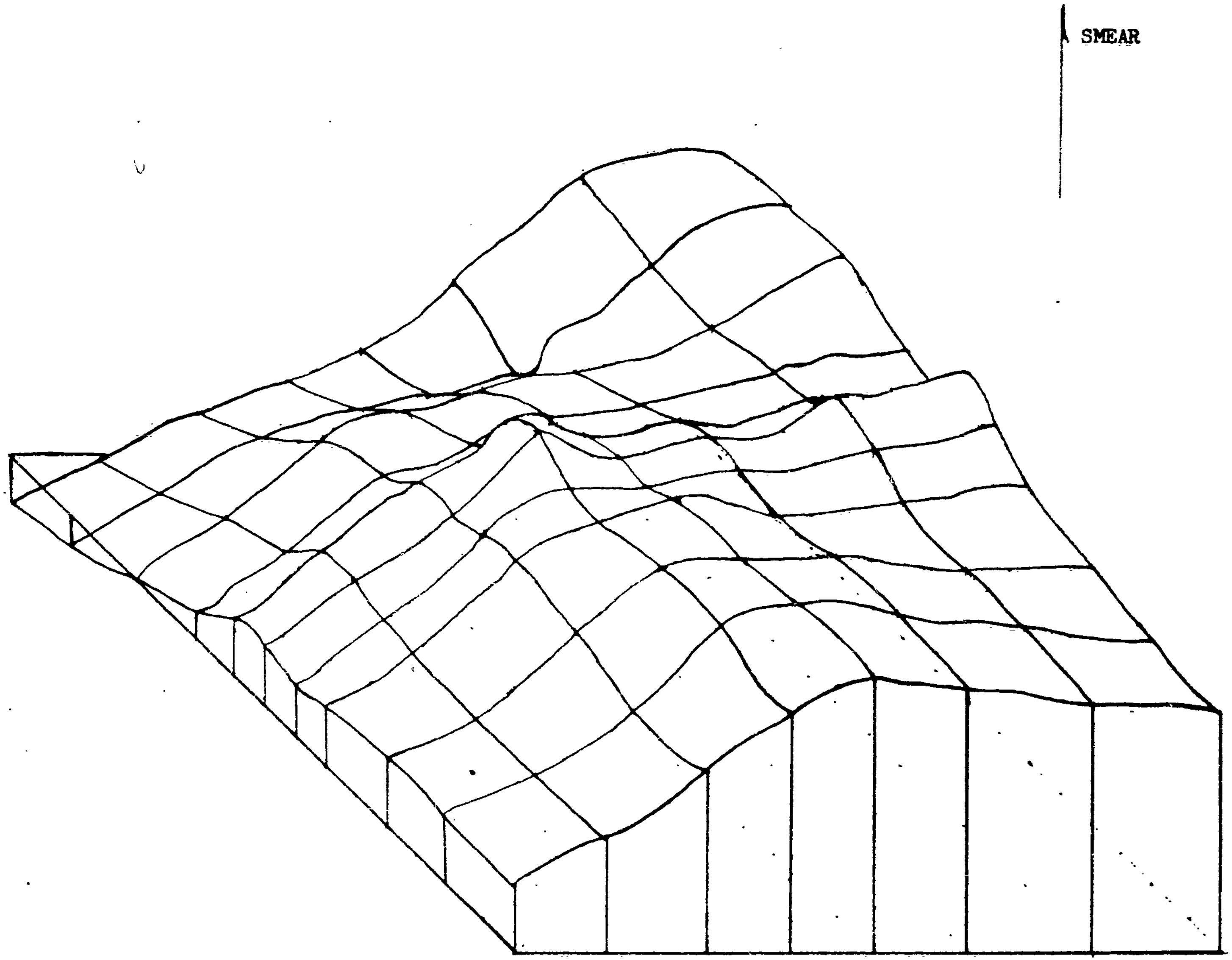


FIGURE 37

CORRELATION SURFACE SMEARED BY LINE GRATING

60°

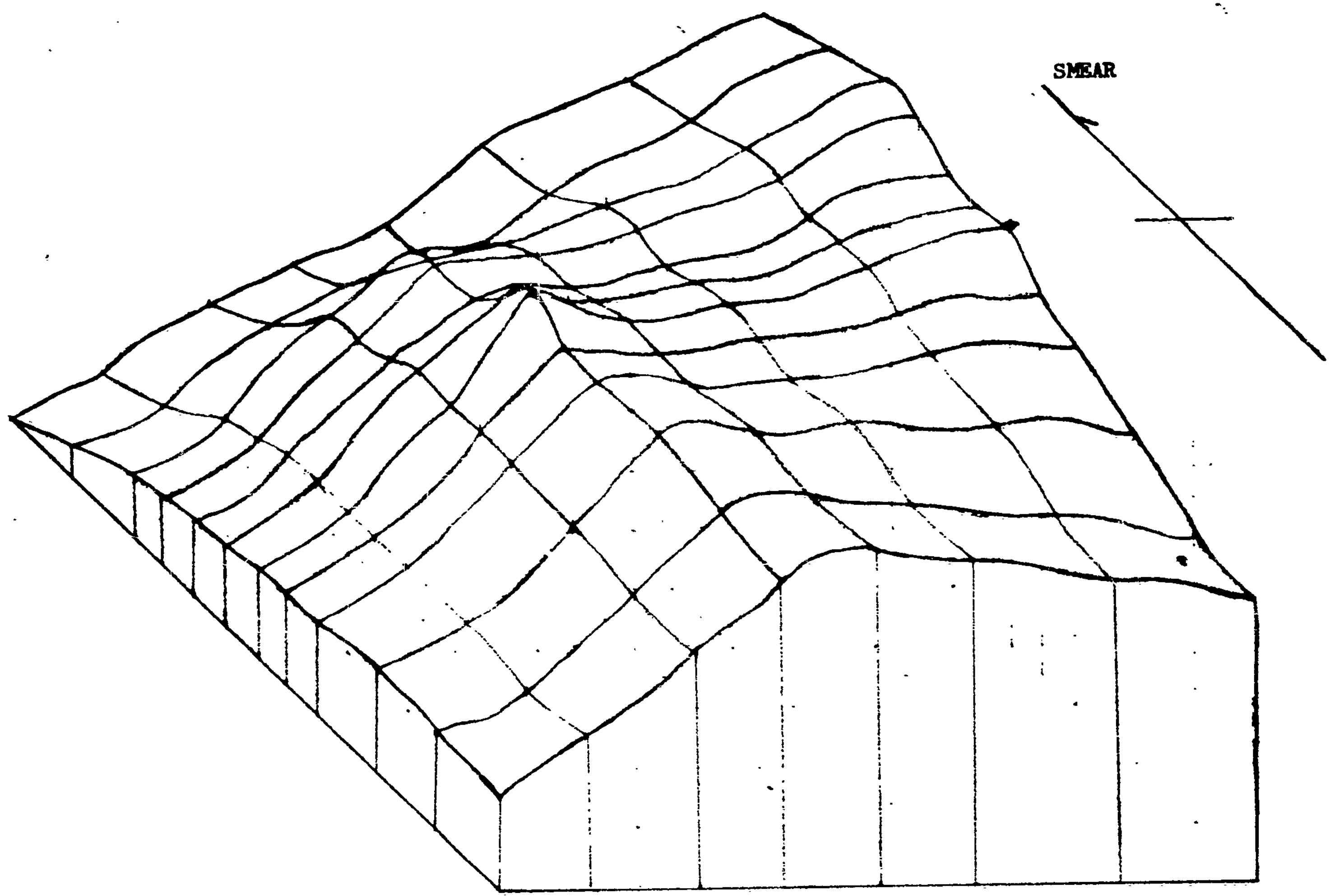


FIGURE 38

CORRELATION SURFACE SMEARED BY LINE GRATING

90°

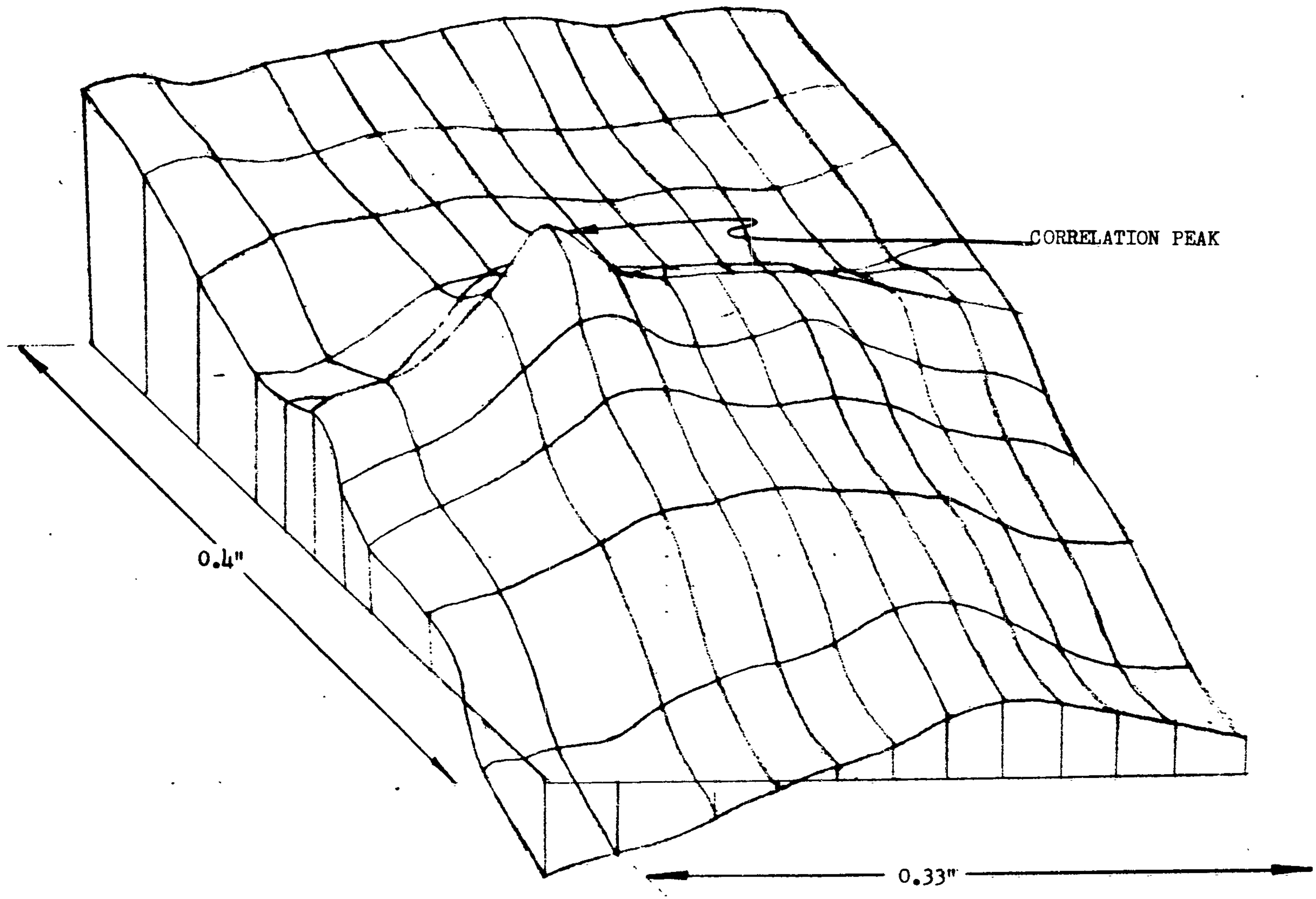


FIGURE 39

CORRELATION SURFACE SMEARED BY LINE GRATING
NO DIFFUSER

not behave properly because it could not be separated from the background modulation. The exact causes of this difficulty have not been ascertained. However, it is felt that a displacement between the system aperture and the reference may have helped to degrade the correlation statistics.

4.2.2 Discussion of Experimental Results

The experimental apparatus and the rotating grating appear to have been working properly. A number of modifications have suggested themselves, including greatly reducing the separation between the system aperture and the reference transparency (permitted to facilitate assembly on the optical bench). These could not, however, be explored within the time and funding limitations of the contract. Hence, it must be stated that these experiments have yielded only inconclusive results with regard to the rotating grating technique. It is felt, nonetheless, that an appropriate modification of the rotating grating or diffusion chopper techniques will make it possible to locate the correlation peak with improved accuracy and without scanning, thereby paving the way toward simple automatic operation.

5. CONCLUSION

The principal result of the studies presented in this report is that the techniques of optical area correlation are suitable for the measurement of parallactic displacement on stereo photographs. Some of the problems involved in achieving precision in the measurements have been explored and, in particular, it has been shown that the use of a cylindrical lens suitably mounted in the correlator can be used to compensate for average terrain slope (Section 3.2.3.3). Comparative tests made with a Fairchild Stereocomparagraph and with the cylindrical lens modified correlator showed that higher precision by a factor of two was available with the latter when working with the test photographs of Figure 13. It is felt that the techniques employed in the modified correlator will compensate for the average slope and ultimately yield high precision over any terrain. In connection with the question of precision, the various techniques reported in Section 4 for imparting a modulation signature to the correlation peak warrant considerable further study. Similar techniques have been successfully instrumented on a correlator built for the Air Force [Reference 1] and the concepts appear quite promising.

Some thought has been devoted to the larger question of the utility of any correlation scheme for stereo measurements. It appears that a skilled operator, possessing good visual stereo perception and working with currently available plotters (such as the Kelsh plotter) can measure relief with higher precision than is possible by presently used stereo correlators. However, the process is tedious and long drawn out at best. The precision attainable depends strongly on the skill of the operator, achieved only after a substantial training period, and on the quality of his eyesight. This is certainly not a satisfactory situation in cases where contour or profile maps are needed in large quantities, where only short delays can be tolerated and only untrained personnel are available. For such cases, automatic photogrammetric instruments based on the correlation technique are a necessity. In this connection, it is felt that optical stereo correlators will ultimately prove superior to electronic versions in terms of size, speed, and complexity. The reason behind this conjecture is the fact that in an optical stereo correlator, the bulk of the computation would be accomplished in parallel in the compact optical front end of the device.

The work performed under the present contract represents a first step toward achieving a useable optical stereo correlator. Much remains to be done in order to realize the ultimate potential of this technique.

6. REFERENCES

[1] "Second Quarterly Technical Note on a Study of Automatic Position Fixing - Infrared - Optical Correlator," L. I. Goldfischer, January 1962, GPL Report A26-2. SECRET.

[2] "First Interim Technical Report on Automatic Stereo Perception of Aerial Photography by Means of Optical Correlation," S. Belchis, July 1962, GPL Report A27-1.

THE PRINCIPAL RESULT IS THAT OPTICAL CORRELATION IS SUITABLE FOR STEREO MEASUREMENTS. IT IS FELT THAT OPTICAL STEREO CORRELATORS WILL ULTIMATELY PROVE SUPERIOR TO ELECTRONIC VERSIONS BECAUSE THE BULK OF THE COMPUTATION IS PERFORMED IN THE COMPACT OPTICAL FRONT END.	UNCLASSIFIED REPORT UNCLASSIFIED REPORT	THE PRINCIPAL RESULT IS THAT OPTICAL CORRELATION IS SUITABLE FOR STEREO MEASUREMENTS. IT IS FELT THAT OPTICAL STEREO CORRELATORS WILL ULTIMATELY PROVE SUPERIOR TO ELECTRONIC VERSIONS BECAUSE THE BULK OF THE COMPUTATION IS PERFORMED IN THE COMPACT OPTICAL FRONT END.	UNCLASSIFIED REPORT UNCLASSIFIED REPORT
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THIS IS THE FINAL TECHNICAL REPORT ON A STUDY OF AUTOMATIC STEREO PERCEPTION OF AERIAL PHOTOGRAPHY BY OPTICAL CORRELATION. IT INCLUDES A DISCUSSION OF THE PRINCIPLES OF OPTICAL CORRELATION AND THE APPLICATION TO STEREO MEASUREMENTS; A DESCRIPTION OF SOME POTENTIAL STEREO CORRELATOR INSTRUMENTATIONS; A STUDY OF THE BEHAVIOR OF THE AUTO-CORRELATION FUNCTION AS THE SAMPLE SIZE IS REDUCED; A COMPARISON OF STEREO MEASUREMENTS UNDER THREE DIFFERENT CONDITIONS; AND AN INVESTIGATION OF IMPROVED CONFIGURATIONS.

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