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Donald F. Menne

RDT & E Project No. 1M222901A215
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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ABSTRACT

The performance of a skyscreen system using an electrical analogue computer was demonstrated in a series of laboratory tests. The computer was developed at the Franklin Institute Laboratories under contract* with the Ballistic Research Laboratories. Inputs for the computer are continuous analogue presentations of unrestricted azimuth and elevations angles to the target and the output is the positioning of a skyscreen aperture at the focal plane of the camera. The criterion for evaluating the performance of the system was the difference between the observed position of the skyscreen aperture and its corresponding theoretical position for selected inputs. The mean of the differences for all tests was 0.38mm. Test results indicate the acceptability of an electrical analogue computer as a component of a skyscreen system.

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* The Franklin Institute contract (DA-36-034-509-ORD-3241RD) was partially supported by White Sands Proving Ground funds.

LIST OF ILLUSTRATIONS

INTRODUCTION

Research and development in the field of precision photogrammetry at the Ballistic Research Laboratories has consisted of extensive theoretical and experimental programs, resulting in a rigorous analytical treatment of data and a high precision instrumentation system.[1,2]

This instrumentation, commonly known as the BC-4 system, has evolved from a series of developments beginning in 1951. Early investigations of methods to obtain simultaneous exposures with several cameras were made with Askania phototheodolites.[3] Later, a system was developed specifically for the Wild BC-4 ballistic cameras.[4] A synchronization system based on the BRL developments was made for the Army Ballistic Missile Agency and is currently being used by the National Aeronautics and Space Administration. Likewise, a satellite tracking system has been developed for the Coast and Geodetic Survey Agency. Other agencies have employed the principles of the BRL developments to make ballistic camera systems for their specific requirements.

A feasibility study of methods to enhance the daylight capability of the BC-4 camera has resulted in the adoption of a skyscreen system. A skyscreen at the focal plane of the camera masks the photographic plate except in the area of the image. The skyscreen may be thought of as two focal plane shutters with independent control of the slot positions (Figure 1). An aperture is formed at the intersection of the two slots. Thus, it is necessary to position the skyscreen aperture at the area where the image is being formed. An auxiliary tracking instrument provides the input data to control the position of the aperture. A computer is used to convert the angular coordinates of the tracker's direction to corresponding orthogonal coordinates in the camera's focal plane.

Both a mechanical analogue computer and an electrical analogue computer have been considered for the skyscreen system. A prototype mechanical analogue computer has been made at the Ballistic Research Laboratories.[5] The Franklin Institute under contract with the BRL developed an electrical analogue computer for the skyscreen system.[6] Laboratory tests were made with a skyscreen system using the Franklin Institute computer. A description of the tests and their results are presented in this report.

ELECTRICAL ANALOGUE COMPUTER

The function of the electrical analogue computer is to transform the angular coordinates (azimuth and elevation) of a tracking instrument to orthogonal coordinates in the focal plane of the camera. If the distance between the tracking instrument and the ballistic camera is sufficiently small in comparison with the distance from the ballistic camera to the target, the effect of parallax on the determination of the orthogonal coordinates is negligible. A parallax computer may be inserted between tracking instruments and the electrical analogue computer when the effect of parallax is significant.

Figure 2 shows the skyscreen computer together with the Wild BC-4 camera body and skyscreen assembly. The major components of the computer are (1) remote resolvers, (2) computer console, and (3) servo package. A 100 ft. cable connects the resolvers with the computer console and another 100 ft. cable links the computer console to the servo package.

The general requirements concerning the computer's performance may be specified in terms of its outputs to the camera for corresponding error free inputs from a tracking instrument. In addition, some measure of flexibility is required in order that the computer be compatible for use with ballistic cameras of different focal lengths.

Inputs to the computer will therefore be of two types: (1) fixed inputs manually set into the computer to specify the focal length and the orientation of the ballistic camera, and (2) continuously varying inputs, supplied by a remote tracking instrument, which specify the direction to the target to be photographed. The orientation of the ballistic camera may be used in an elevation range between -5° and $+90^{\circ}$ (measured from horizontal) but unrestricted (360°) in azimuth. Focal length compatibility will be restricted to four ranges corresponding to $\pm 3\%$ deviation from each of four nominal focal lengths: 304, 210, 115 and 68mm. A remote tracker is capable of providing useful input information through unlimited azimuth and elevation ranges; however, the tracker has a practical lower limit of approximately -5° on elevation.

Fixed input information concerning the focal length of the ballistic camera is inserted into the computer by manually setting a four-position selector switch. Each switch position corresponds to a nominal focal length and it is possible to compensate for any deviation between this and the actual camera focal length by setting two precision potentiometers in accordance with calibration charts. The fixed elevation angle of the camera is introduced into the computer by the setting of two resolvers. Variable input information from the remote tracker is supplied to the computer through a pair of resolvers whose shafts are mechanically coupled to the tracker.

The output of the computer consists of two separate servo motor shafts, each coupled through a gear train to a shaft controlling a skyscreen curtain. Individual closed loop servo systems thus control the position of the aperture in the camera's focal plane. Should the tracker follow the target beyond the field of view of the ballistic camera, the aperture of the skyscreen is always located at a position along the perimeter of the focal plane such that it will be in the proper location when the target re-enters the field of view.

SYSTEM TESTS

The performance of the skyscreen system was demonstrated in a series of laboratory tests using the Wild BC-4 Aviogon camera body, serial number 235, and the prototype electrical analogue computer developed under the Franklin Institute contract. The computer consisted of (1) remote resolvers for introducing the azimuth and elevation of the target, (2) a computer console with provision for manually introducing the focal length and elevation of the ballistic camera, (3) the servo package for controlling the position of the skyscreen aperture, and (4) two 100 ft. cables, one cable between the remote resolver and the computer console and the other cable between the computer console and the servo package on the ballistic camera. A complete skyscreen system was tested under conditions approximating the intended usage with the following exception: discrete azimuth and elevation angles to the target were introduced rather than continuously varying angles.

The position of the skyscreen aperture was measured for various combinations of the input parameters. Differences between the observed positions and the corresponding theoretical positions were the criterion for evaluating the performance of the skyscreen system.

The skyscreen system was prepared for the tests in accordance with the operation manual for the electrical analogue computer.[7] Each remote resolver was coupled to the azimuth circle of a Wild T2 theodolite. Input angles to the remote resolvers were considered free of error for the purpose of these tests. A cathetometer was used to determine the position of the skyscreen aperture. Position measurements were determined to an accuracy of ± 0.025mm.

Azimuth to the target, A_t, elevation to the target, E_t, elevation of the ballistic camera, E_p, and focal length of the ballistic camera, FL, were the input parameters.

During each test, the variable parameter(s) consisted of either one or both of the target tracker angles, E_t and A_t. Six determinations of the aperture position were made for each discrete set of the variable parameters. Setting of the variable parameters was approached from different directions for each determination. For example, when E_t was the variable parameter, three determinations were made as E_t was approached from one direction and three determinations were made as E_t was approached from the opposite direction. The presentations of the data show the spread in measurements as well as their mean value for each setting. A mean value of the six readings was used as the best representative value to compare with the theoretical value at each setting. Comparisons between tests were made with mean values.

Table I lists the tests and the figures which show the data.

Test results shown in Figures 3 through 10 illustrate the system performance for some of the simplest possible arrangements of input parameters. The skyscreen aperture moves in only one coordinate direction. In instances where $A_t = 0^\circ$ and E_t is varied, for example, the y-curtain is stationary and the x-curtain moves an amount which is proportional to the tangent of the E_t angle. Hence, these "on-axis" tests manifest the performance of each curtain independently. Odd numbered tests and corresponding figures refer to x-curtain performance; even numbered tests and figures refer to y-curtain performance. Non-zero E_p angles are included among the input conditions for the tests results shown in Figures 11 through 14. For the 12 tests, the average value of the differences was 0.34mm for the x-curtain and 0.21mm for the y-curtain.

TABLE I - TESTS

Figure No.	E_p In Degrees	A_t In Degrees	E_t In Degrees	FL In MM
3	0	0	Var.	67.613
4	0	Var.	0	67.613
5	0	0	Var.	114.829
6	0	Var.	0	114.829
7	0	0	Var.	211.382
8	0	Var.	0	211.382
9	0	0	Var.	305.68
10	0	Var.	0	305.68
11	45	0	Var.	67.613
12	45	Var.	45	67.613
13	45	0	Var.	305.68
14	45	Var.	45	305.68
15	0	0	Var.	112.500
16	* 0	0	Var.	114.829
17	0	0	Var.	117.000
19 & 20	45	Var.	Var.	67.613

* The two E_p resolvers were electrically nulled for these tests. The E_p dial settings at electrical null were 359°56' and 359°46', respectively.

Examination of the data in the odd numbered figures shows a preponderance of negative differences in the x-curtain response. This would indicate that perhaps the setting of the focal length trim pots produces an analogue focal length that is too short. It is possible to find a focal length which will "fit" the observed data better; that is, it is possible to reduce the arithmetic sum of the differences to zero for an "indicated focal length." This technique was employed in the three instances whose results appear in Figures 15, 16 and 17. The mean of the differences was reduced 37% from 0.38mm to 0.24mm in these three instances when the "indicated focal length" was used to compute the differences. If a sufficient number of such tests were made, it would also be possible to optimize the computer response by plotting empirical curves to determine an effective focal length for each trim pot setting. However, it is clear that only part of the observed differences can be attributed directly to errors in the focal length circuitry and this technique would thus be somewhat artificial.

To illustrate this point, Figure 18 has been drawn to show the effects on curtain response when two error sources are considered. Curve (1) in Figure 18 is a typical representation of curtain response showing the differences as the curtain position changes, when no errors are introduced by the computer itself. Errors are inherent and are due to the non-linearity of curtain movement induced by wrapping of the curtain material on its shaft.[5] Curve (2) shows the effect of an error introduced by an incorrect focal length setting. The resultant of these two separate error curves yields the curve labeled (3) in Figure 18. This curve has characteristics similar to curve (4) in Figure 18 which is a plot of an actual test ($A_t = 0^\circ$; $E_p = 0^\circ$ - vary E_t).

A test was made with $E_p = 45^\circ$, while random values of the other input parameters, A_t and E_t, were selected to provide simultaneous movement of both curtains. The difference between the observed position and the theoretical position was calculated for each set of input conditions. Figure 19 shows the distribution of magnitudes of the differences for 118 discrete sets of input conditions. The mean value of these differences is 0.38mm; the maximum difference is 1.59mm. Figure 20 shows a contour plot of the differences over the entire focal plane. This plot shows that systematic errors are larger than random errors.

A series of tests were performed to determine the maximum tracking rates that the computer could accommodate. Tracking rate is expressed in terms of curtain velocity because maximum curtain velocity is independent of focal length. The time required for the curtain to travel from one edge of the focal plane to the opposite edge was measured for inputs causing large error signals.

Both curtains were driven in both directions and each test was repeated five times. The average curtain velocity for all tests was 50mm/sec with a standard deviation of less than 3mm/sec. Further dynamic testing is recommended for applications requiring large accelerations.

SUMMARY AND CONCLUSIONS

The skyscreen system is the latest contribution to a series of developments culminating in a complete, precision photogrammetric instrumentation system based on the Wild BC-4 camera series. An electrical analogue computer developed at the Franklin Institute Laboratories was used in the skyscreen system for a series of laboratory tests.

The computer transforms the angular coordinates of a tracking instrument to orthogonal coordinates in the focal plane of the camera. This computer accommodates cameras with nominal focal lengths of 68, 115, 210 and 304mm. Unrestricted tracker and camera orientations are accepted by the computer to the extent that the skyscreen aperture is continually positioned along the edge of the focal plane when the target is out of the camera's field of view and is in the proper location when the target re-enters the field of view.

The criterion for evaluating the accuracy of the coordinate transformation was the difference between the observed positive of the aperture and its corresponding theoretical position. Results of laboratory tests are presented in this report. The mean value of the differences from all the tests was 0.38mm with a standard deviation of 0.24mm.

Even though the electrical analogue computer is a prototype model, it more than satisfies the general requirements of a skyscreen system.

Donald F. Menne

DONALD F. MENNE

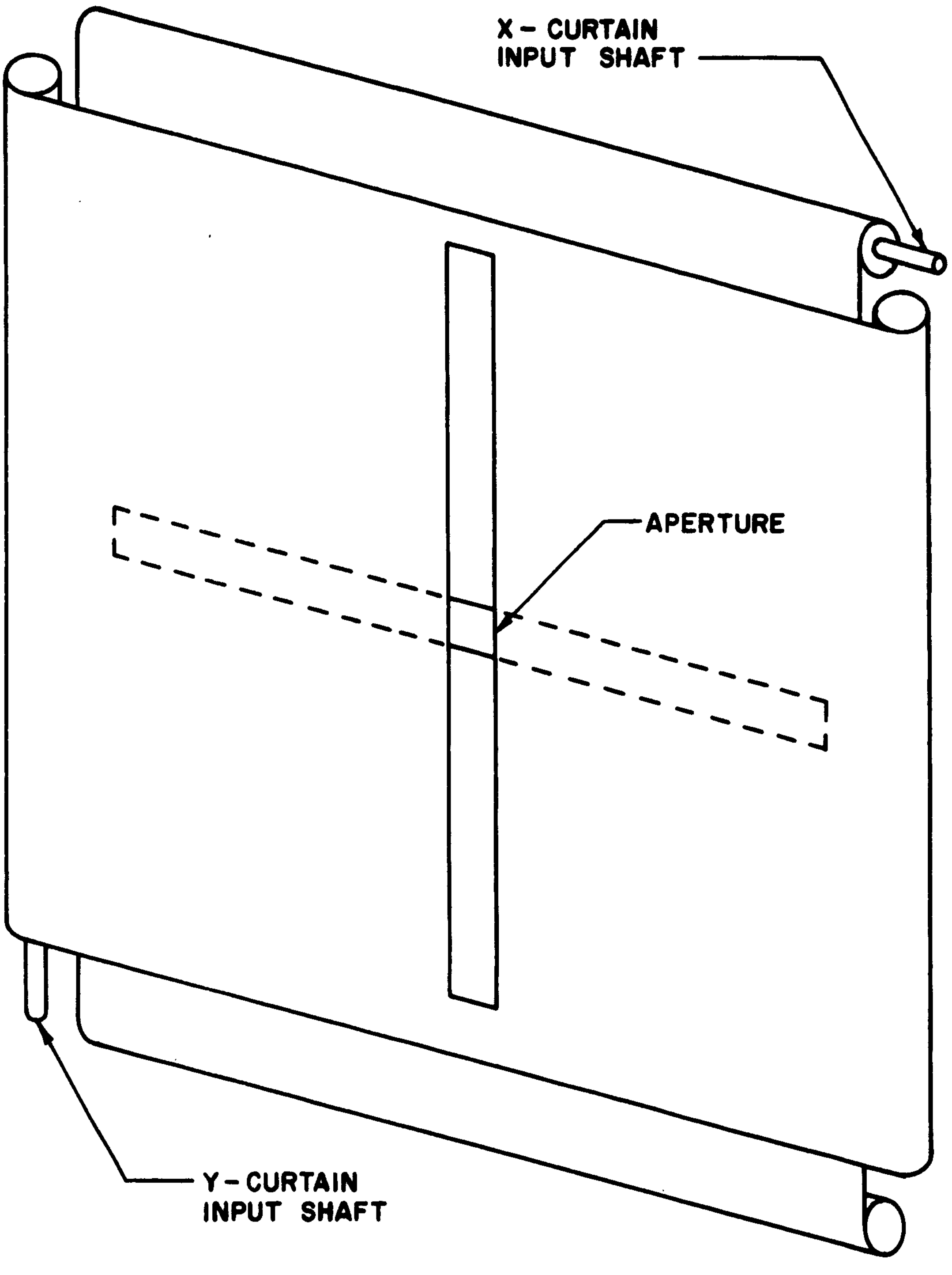

FIGURE 1 - SKYSCREEN SCHEMATIC

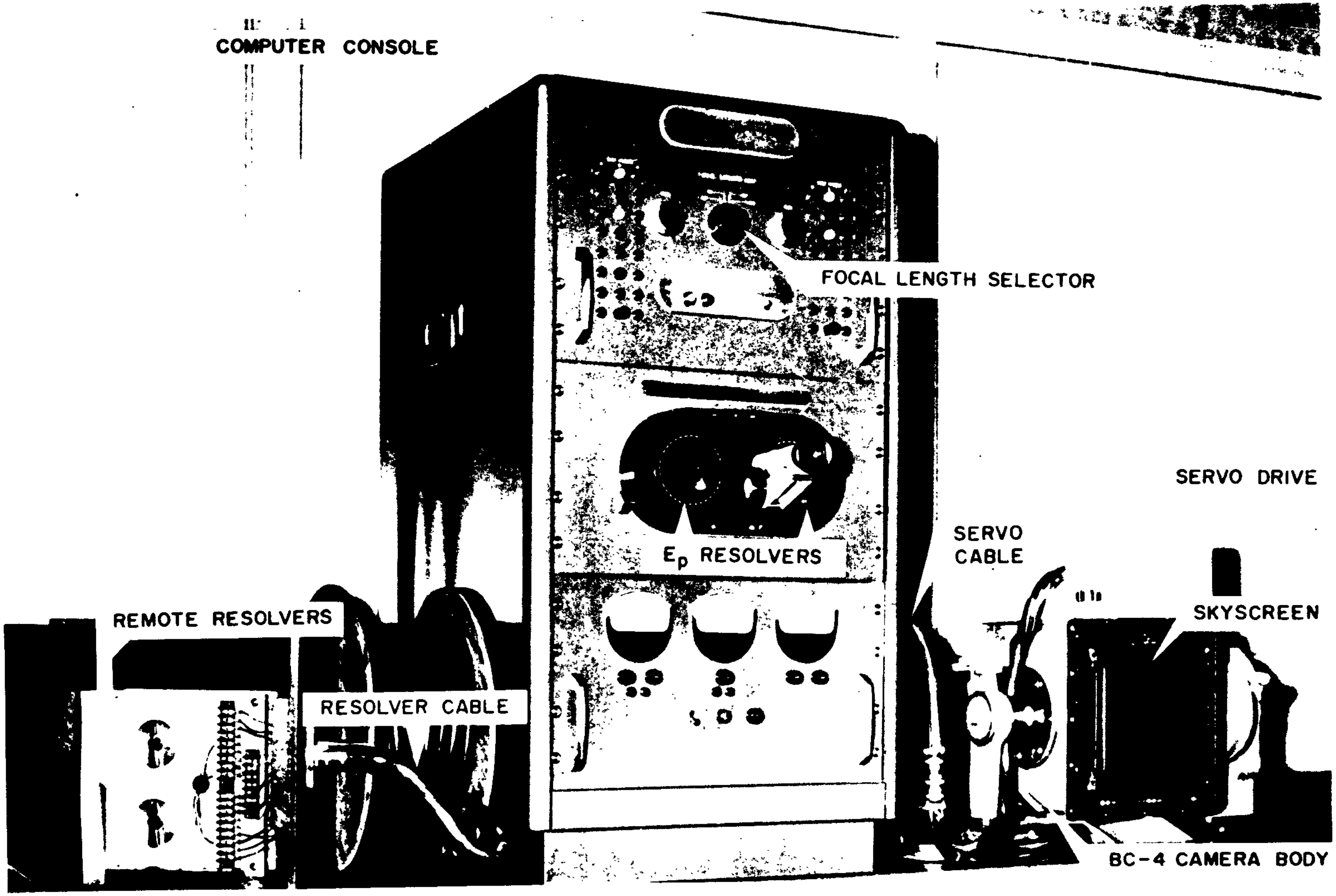

FIGURE 2 - SKYSCREEN COMPUTER

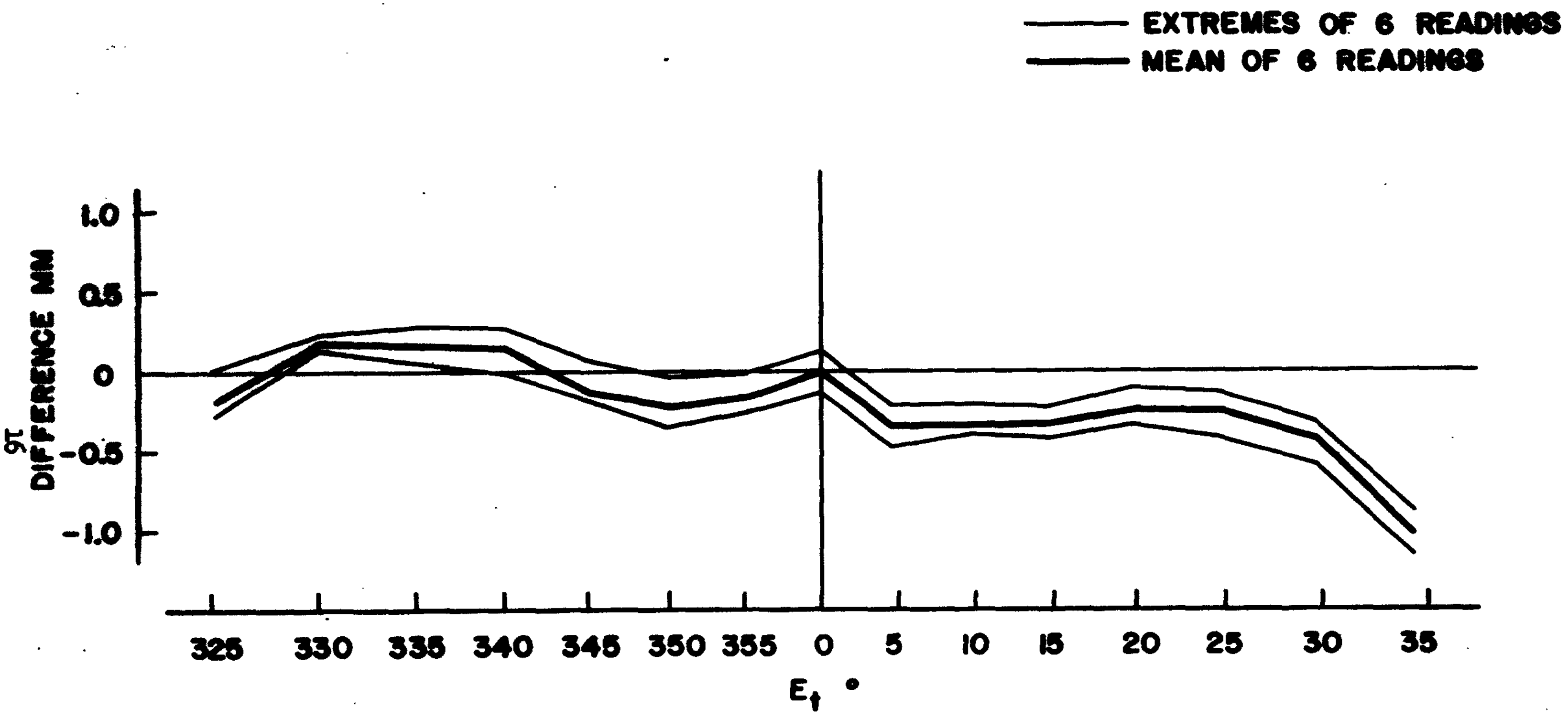

FIGURE 3 – FOCAL LENGTH = 67.613 MM, $E_p = 0°$, $A_t = 0°$

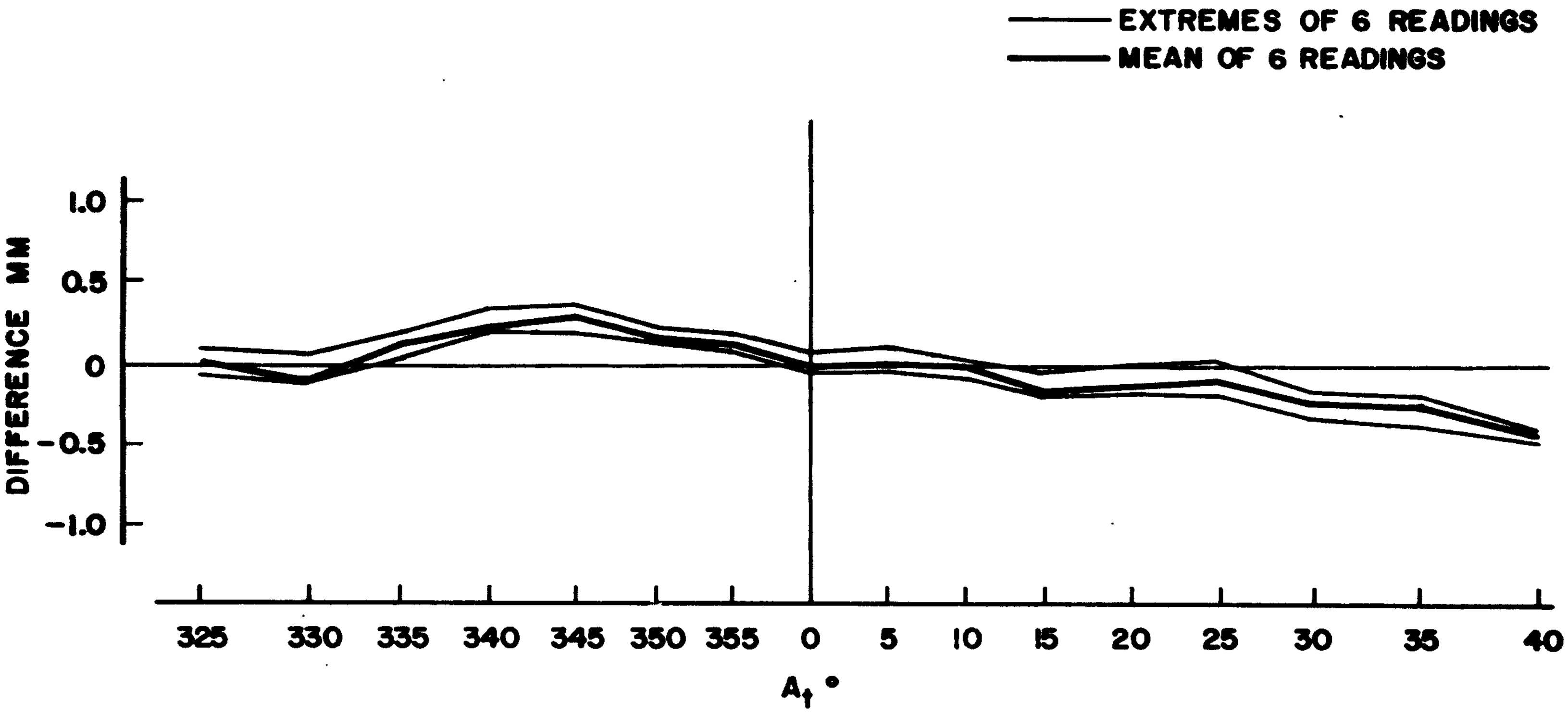

FIGURE 4 – FOCAL LENGTH = 67.613 MM , $E_p = 0°$, $E_t = 0°$

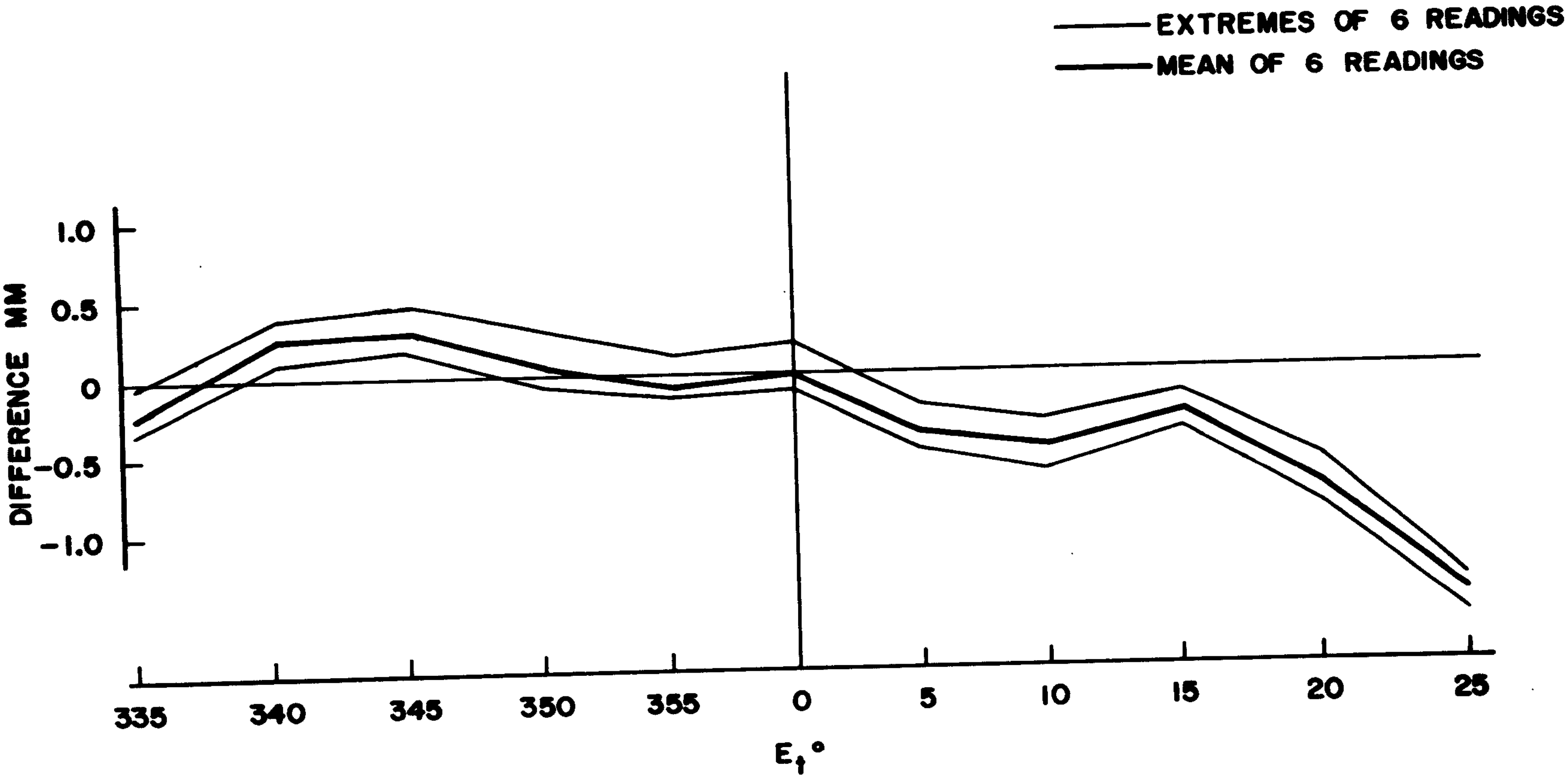

FIGURE 5 – FOCAL LENGTH = 114.829 MM , E_p = 0° , A_t = 0°

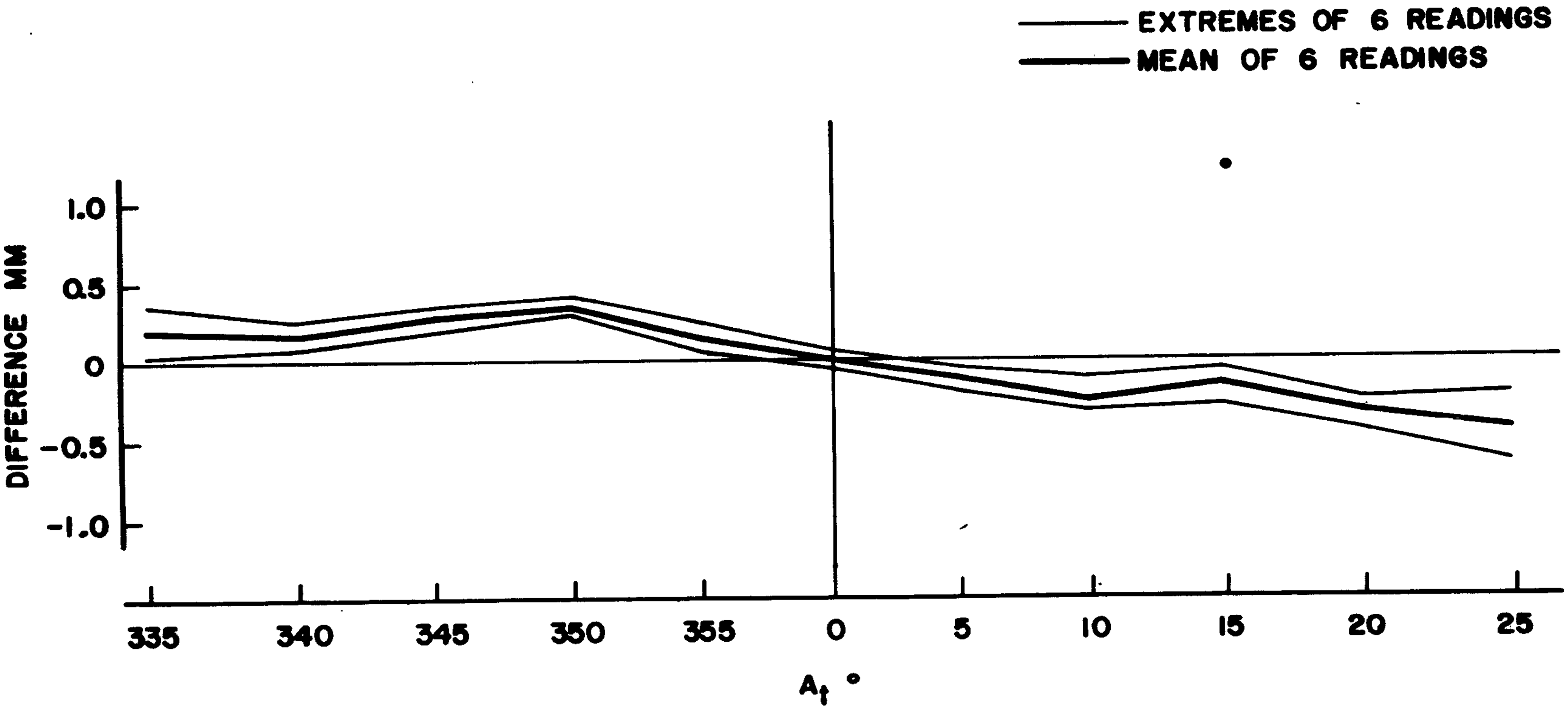

FIGURE 6 - FOCAL LENGTH = 114.829 MM , E_p = 0° , E_t = 0°

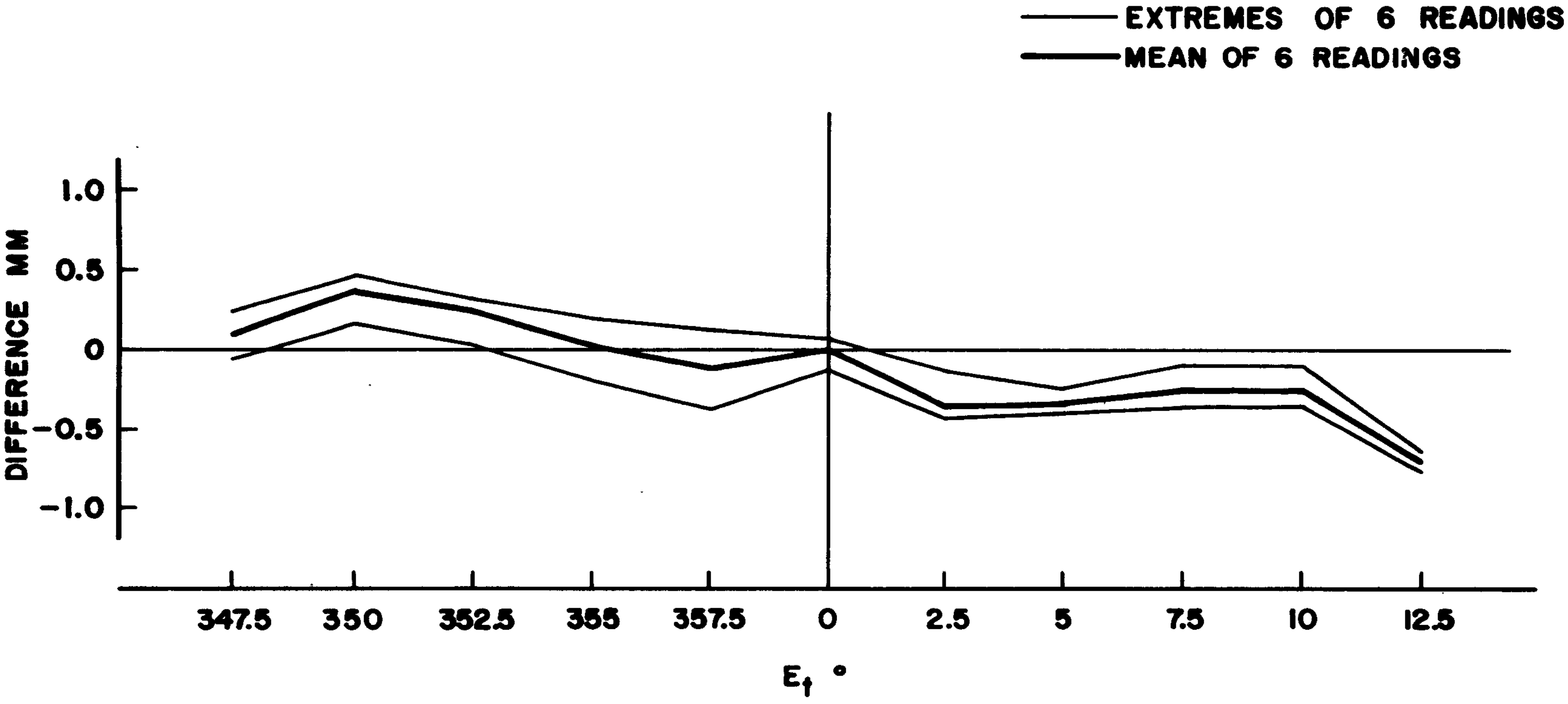

FIGURE 7 – FOCAL LENGTH = 211.382 MM, $E_p = 0°$, $A_t = 0°$

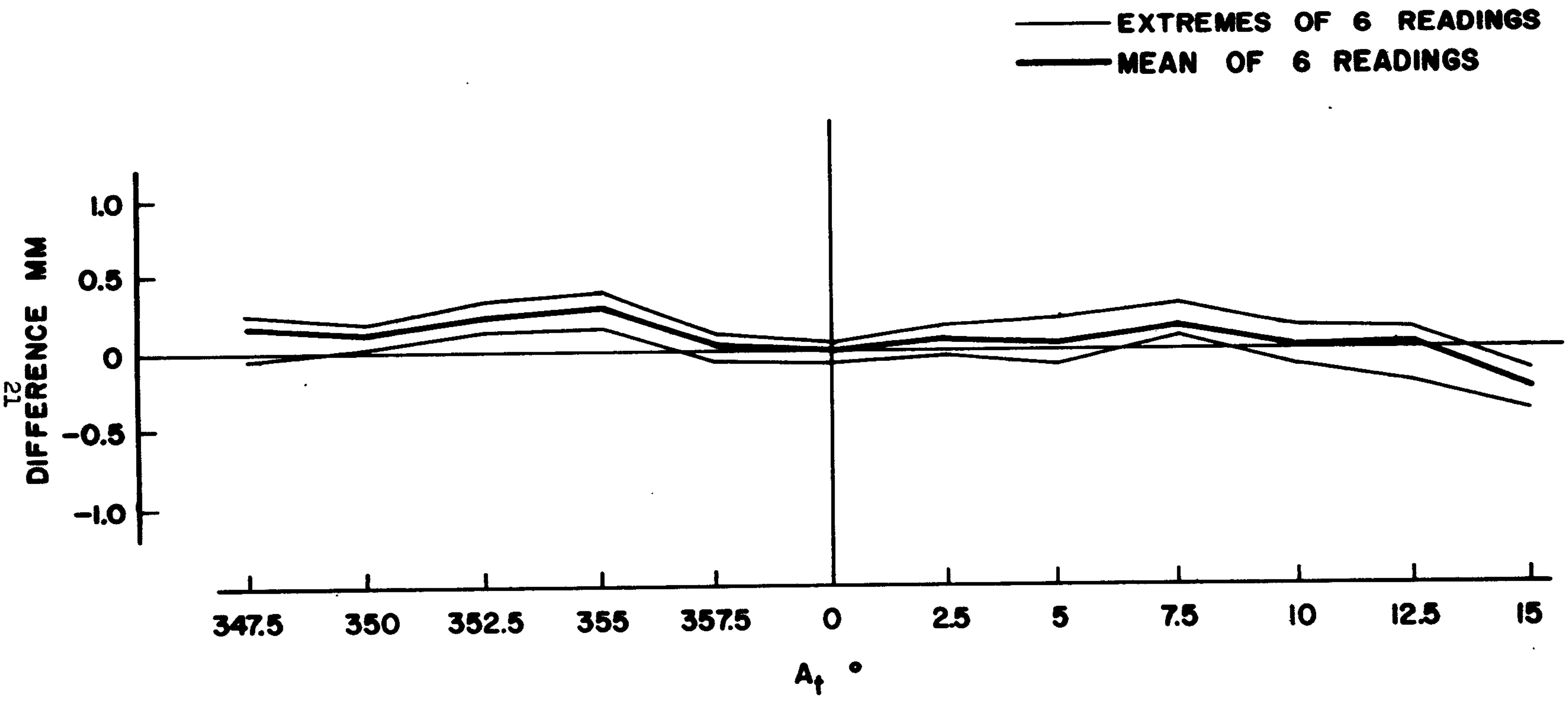

FIGURE 8 - FOCAL LENGTH = 211.382 MM, $E_p = 0°$, $E_t = 0°$

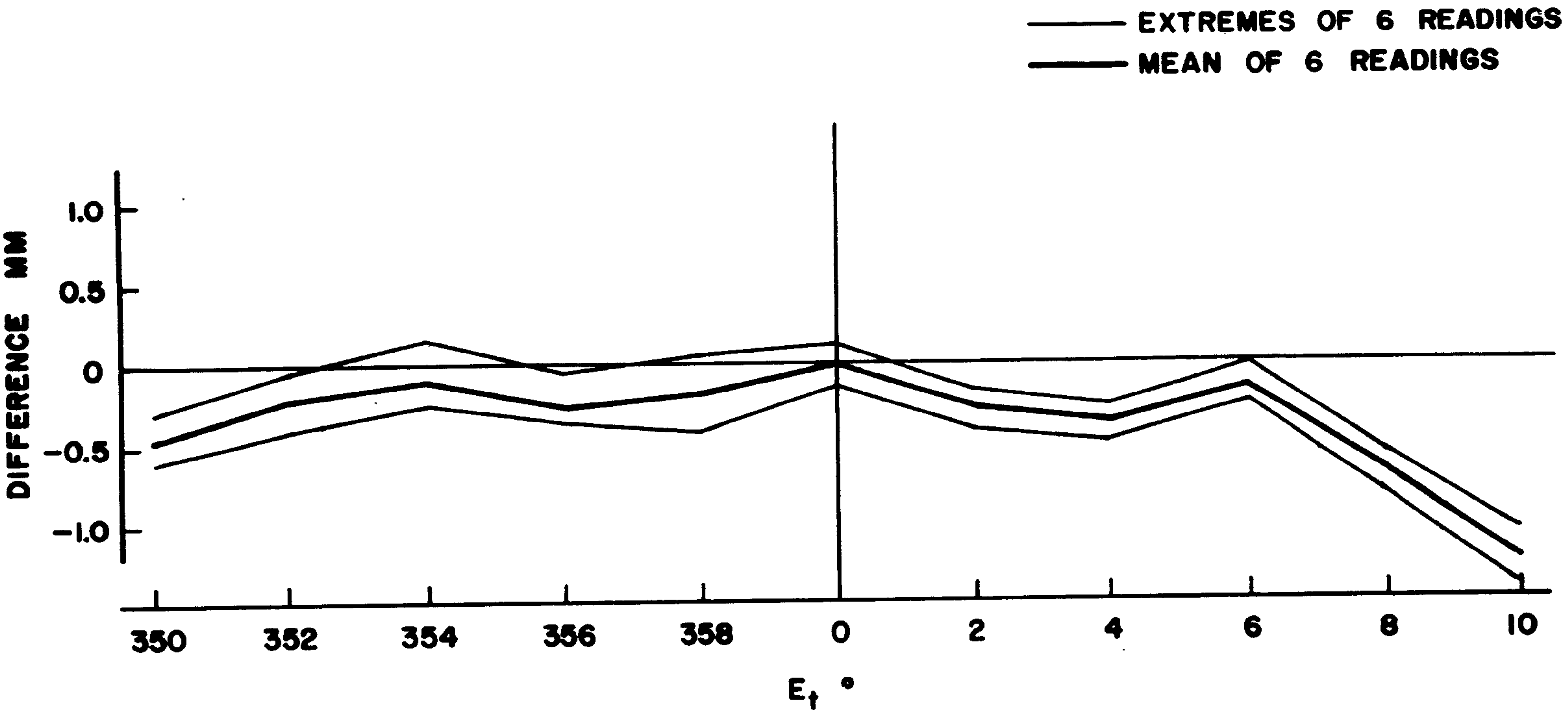

FIGURE 9 – FOCAL LENGTH = 305.68 MM , $E_p = 0°$, $A_t = 0°$

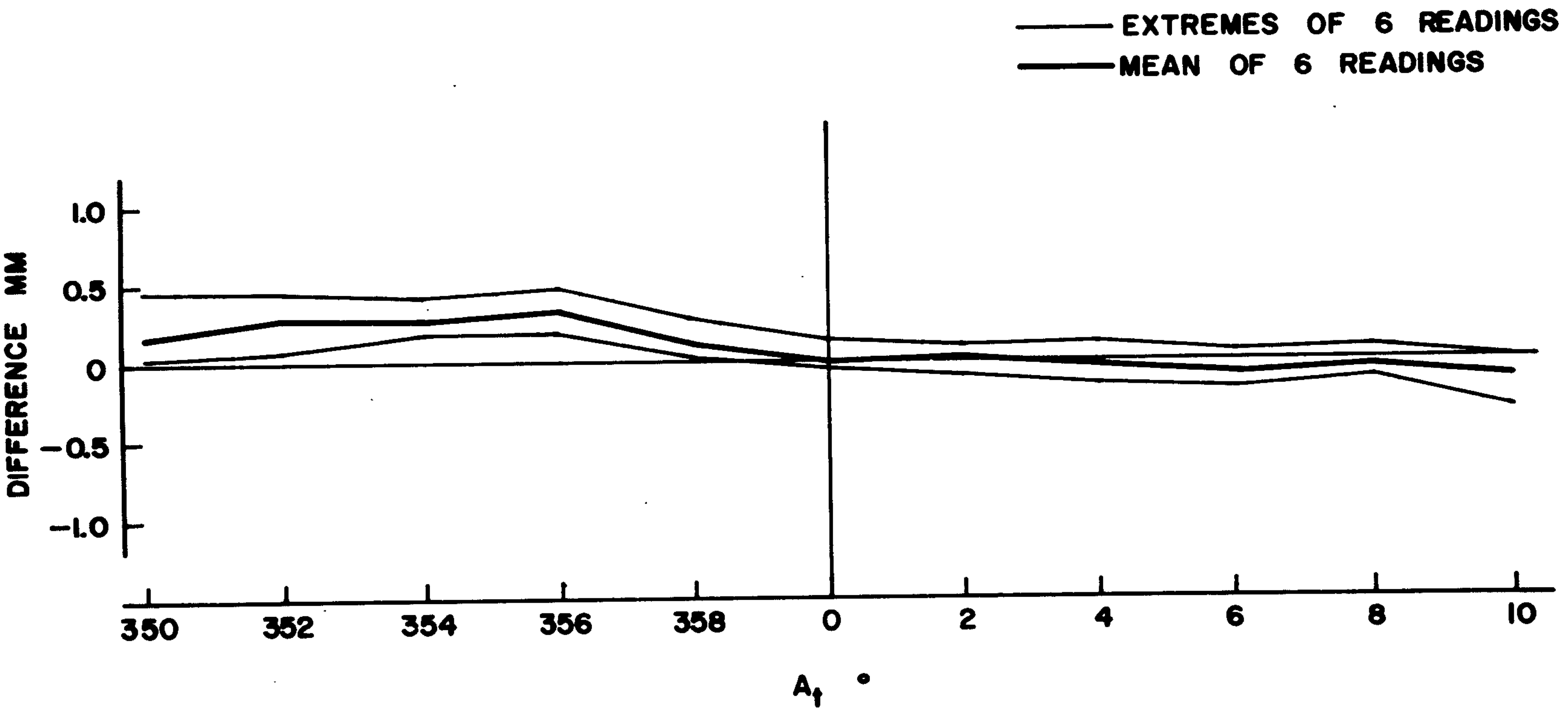

FIGURE 10 - FOCAL LENGTH = 305.68 MM, E_p = 0°, E_t = 0°

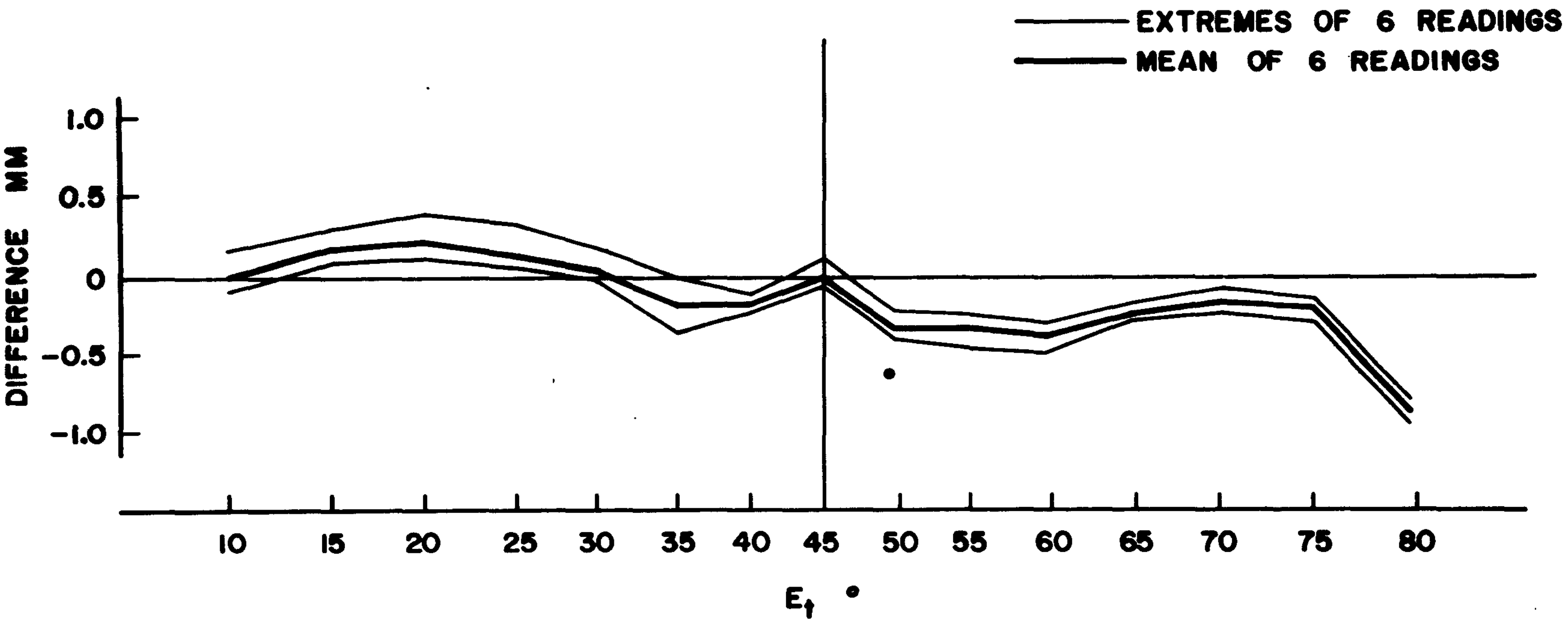

FIGURE 11 - FOCAL LENGTH = 67.613 MM , $E_p = 45°$, $A_t = 0°$

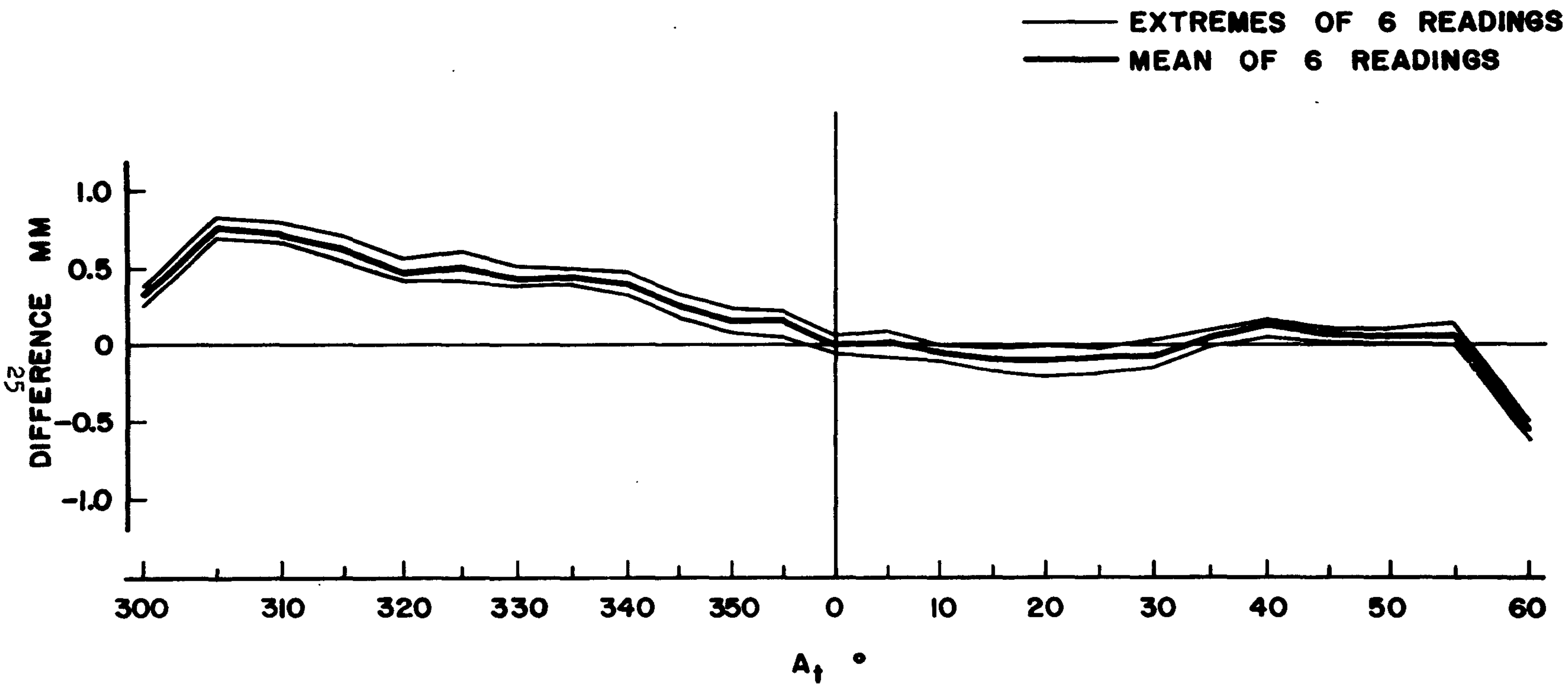

FIGURE 12 – FOCAL LENGTH = 67.613 MM , E_p = 45° , E_t = 45°

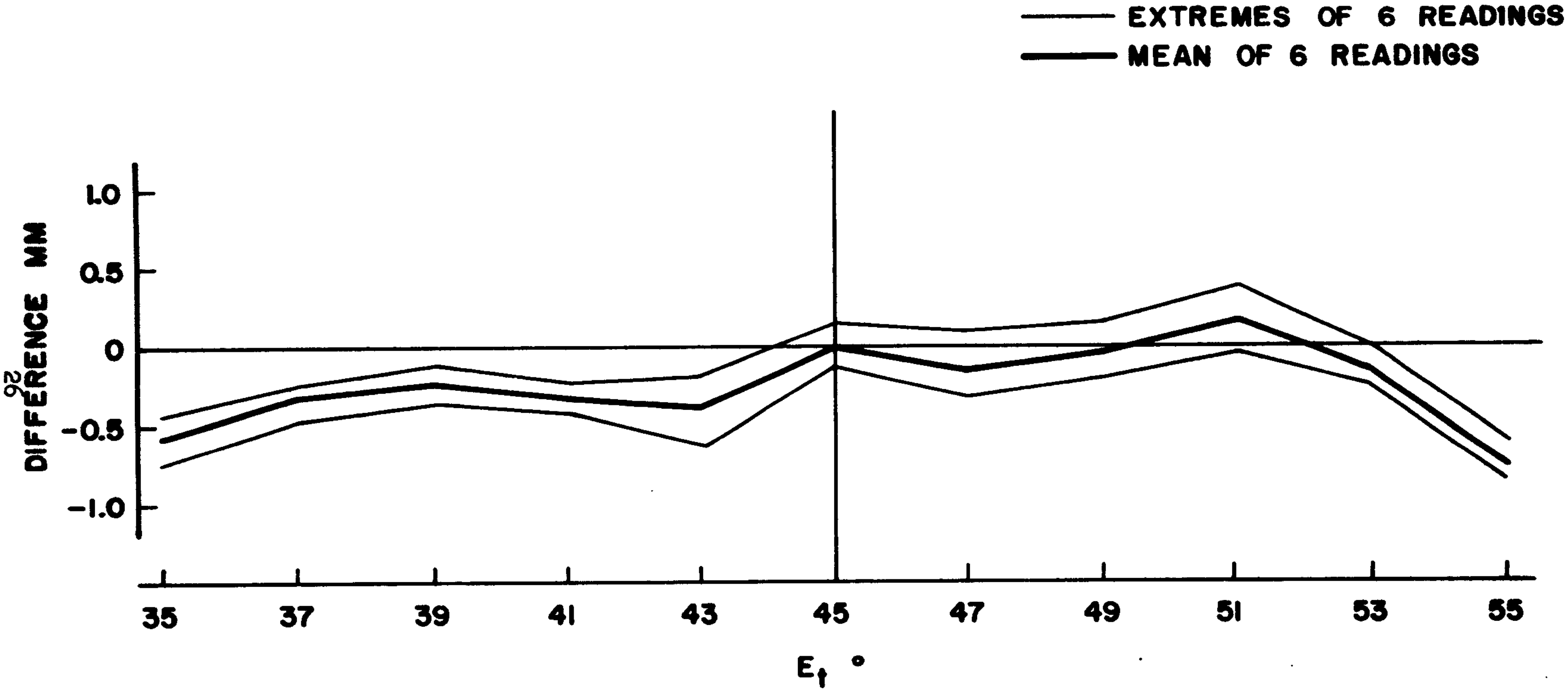

FIGURE 13 - FOCAL LENGTH = 305.68 MM , $E_p = 45°$, $A_t = 0°$

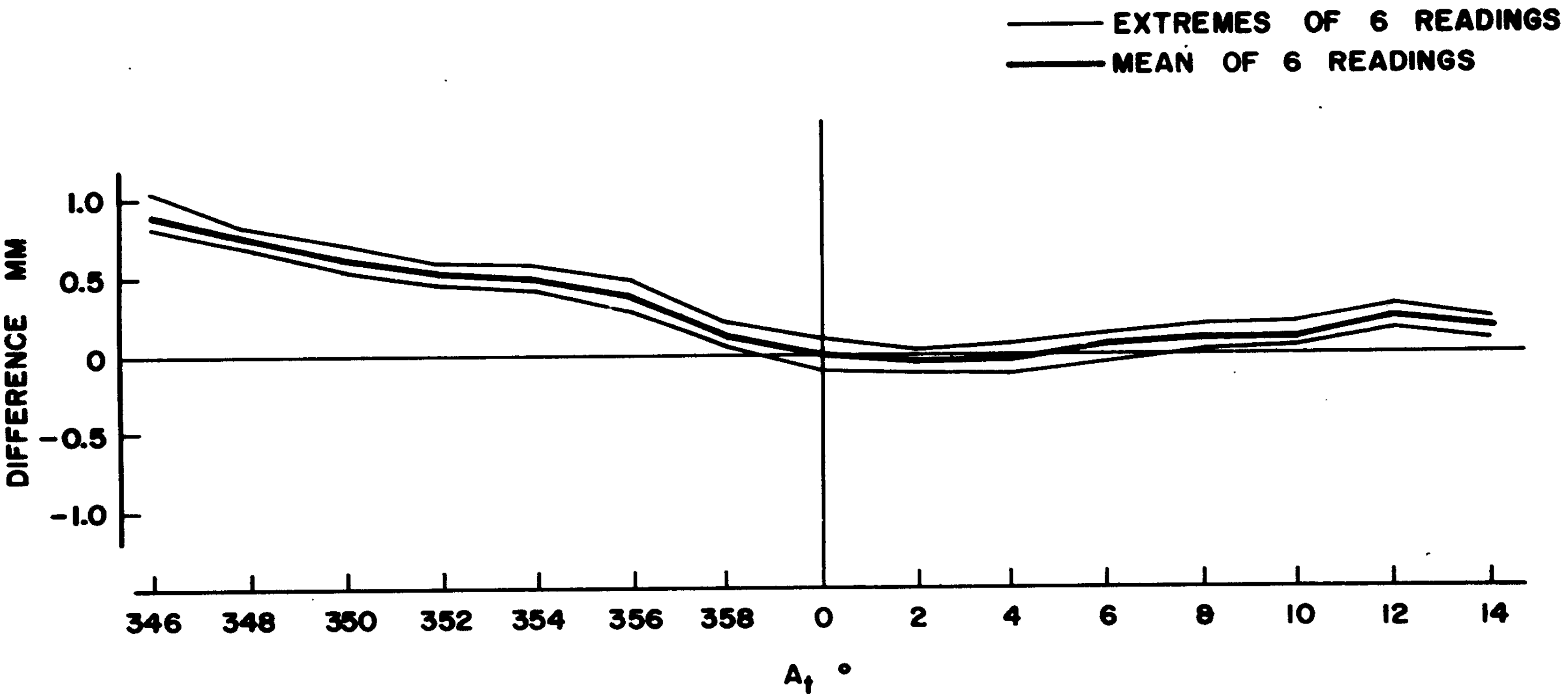

FIGURE 14 – FOCAL LENGTH = 305.68 MM, E_p = 45°, E_t = 45°

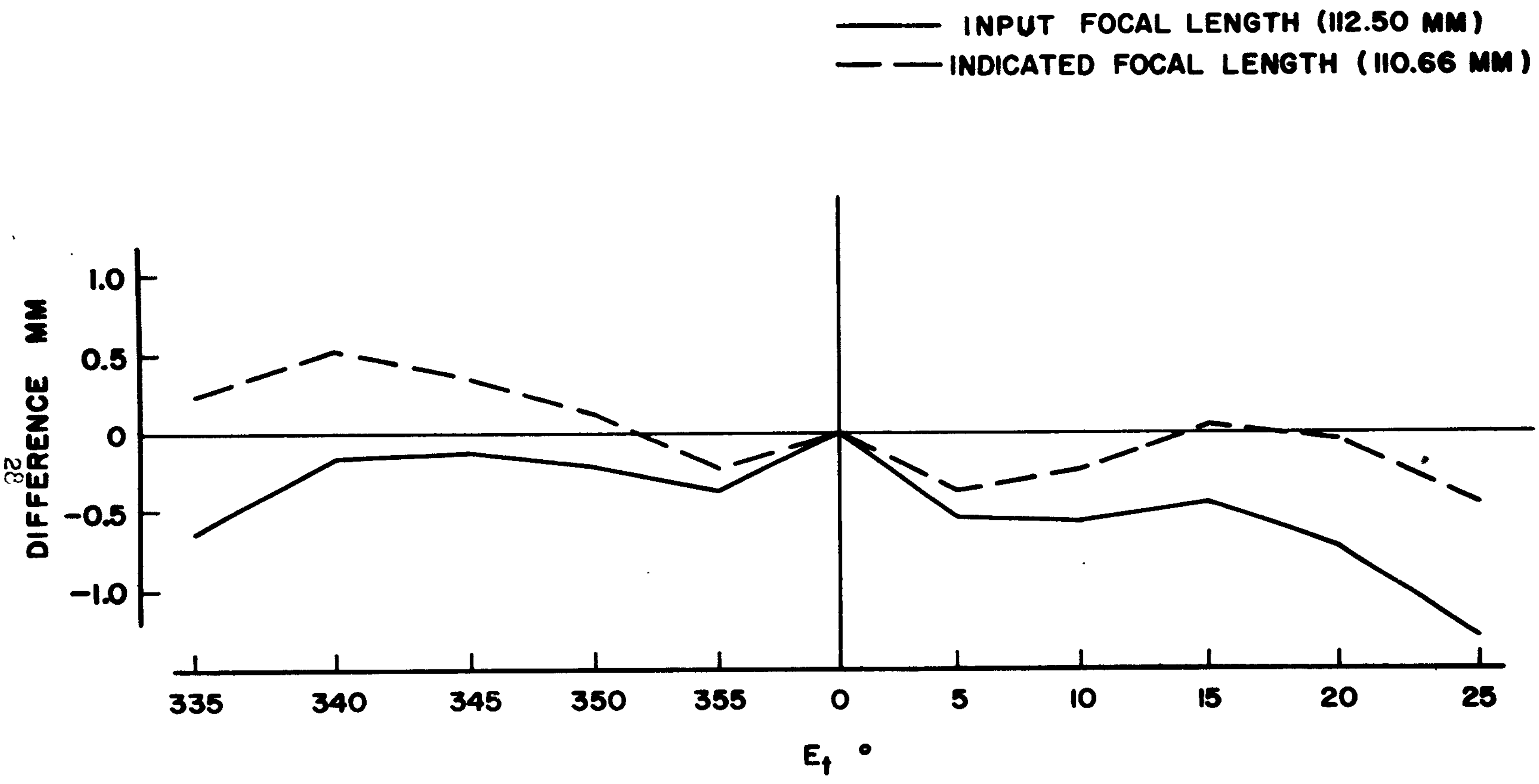

FIGURE 15 — FOCAL LENGTH = 112.50 MM , $E_p = 0°$, $A_t = 0°$

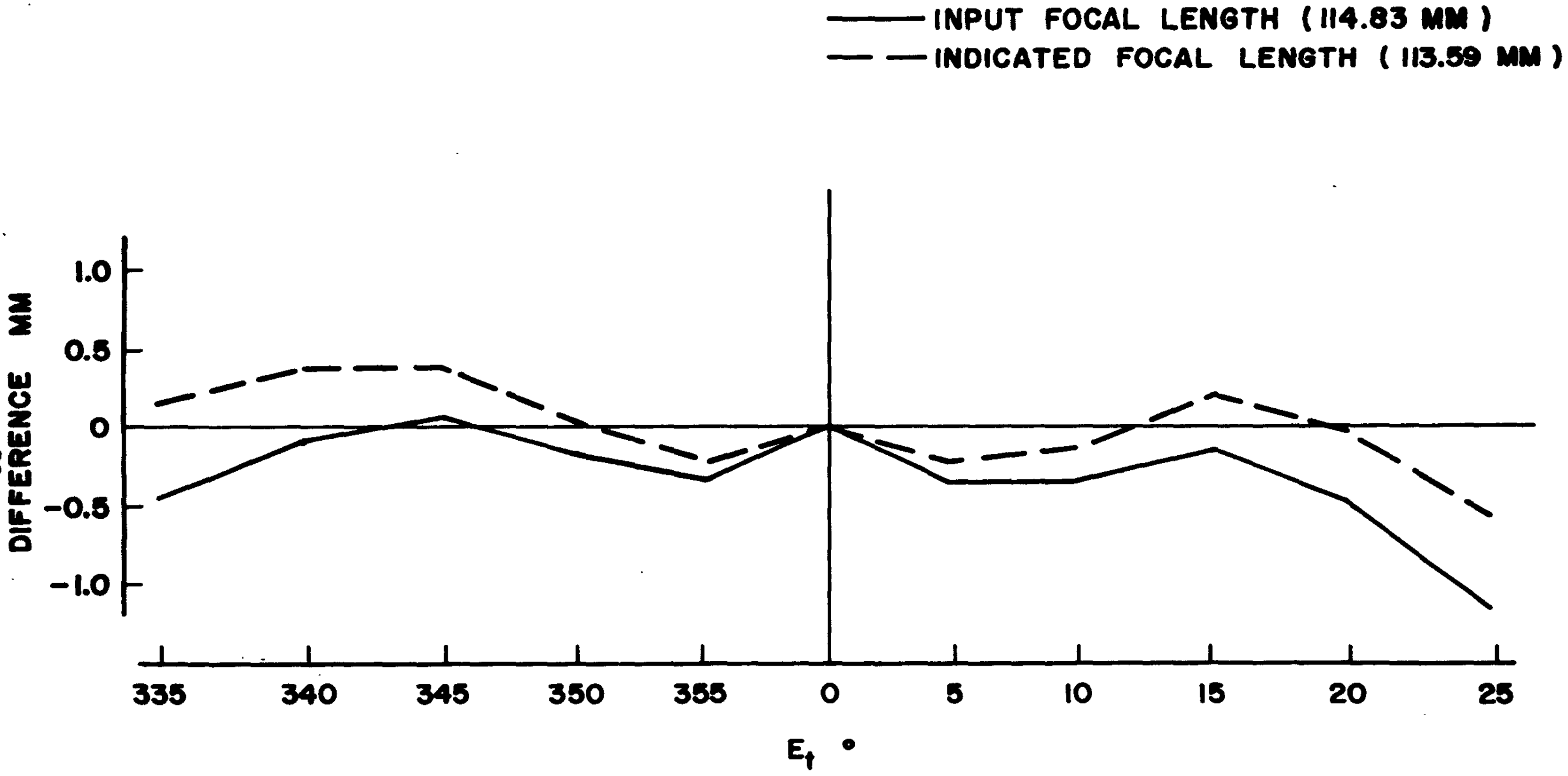

FIGURE 16 — FOCAL LENGTH = 114.83 MM., $E_p = 0°$, $A_t = 0°$

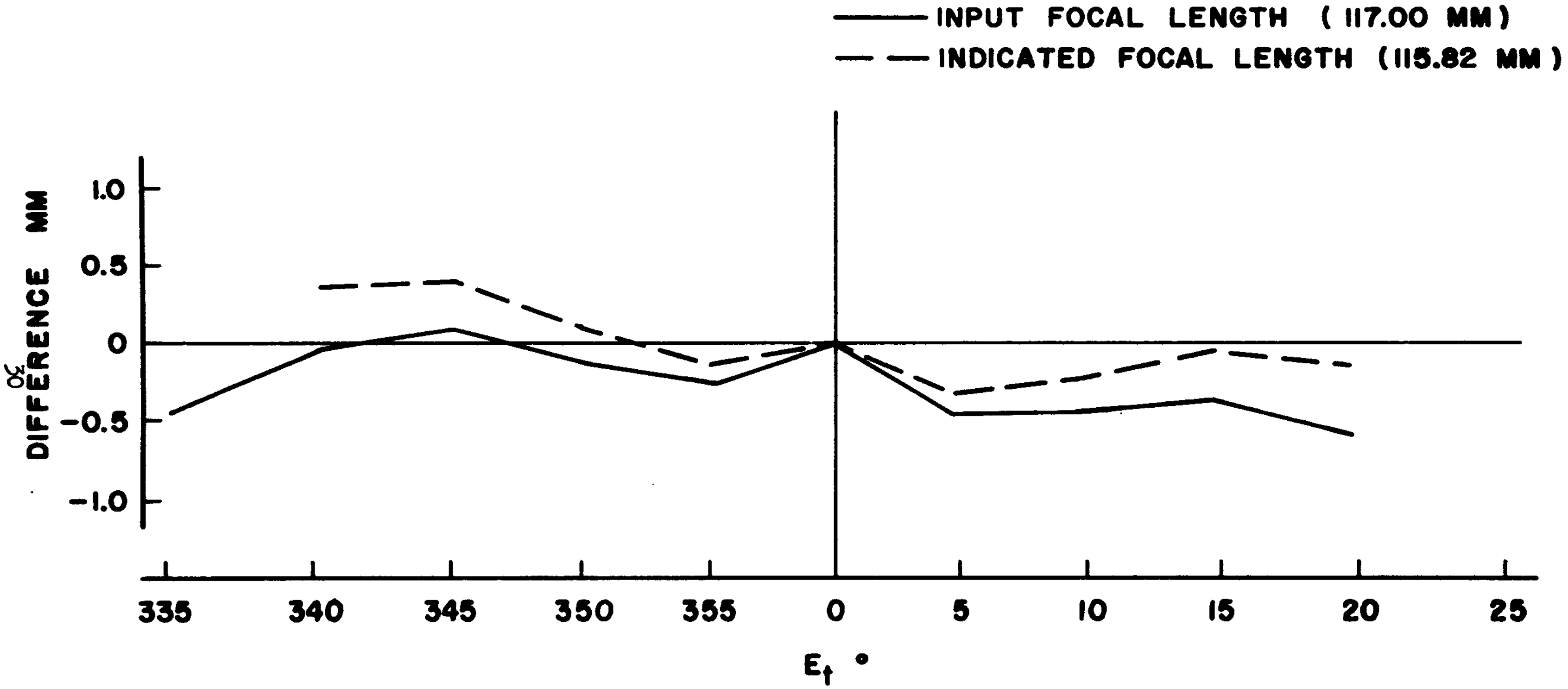

FIGURE 17 — FOCAL LENGTH = 117.00 MM , $E_p = 0°$, $A_t = 0°$

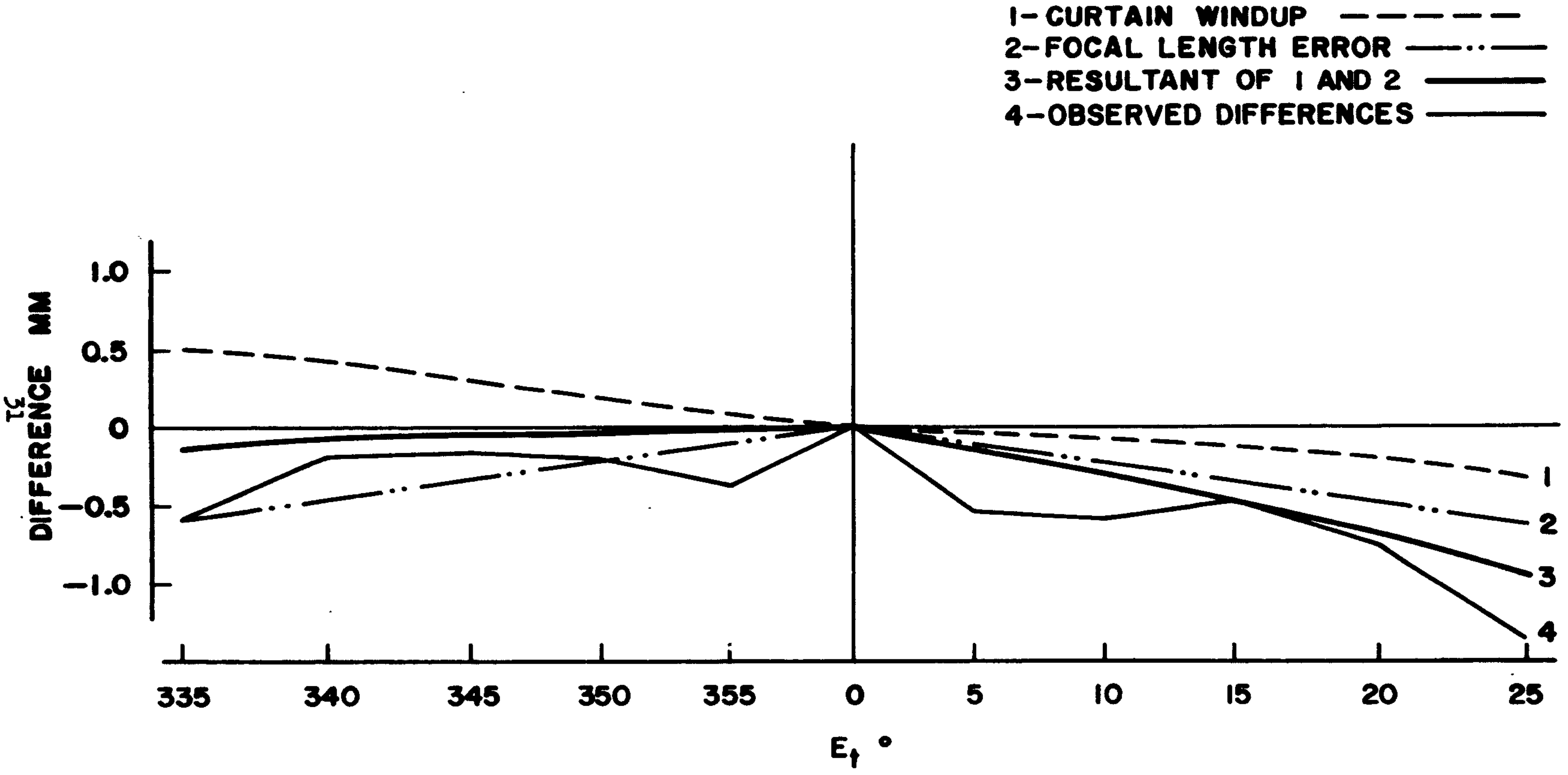

FIGURE 18 ERROR ANALYSIS

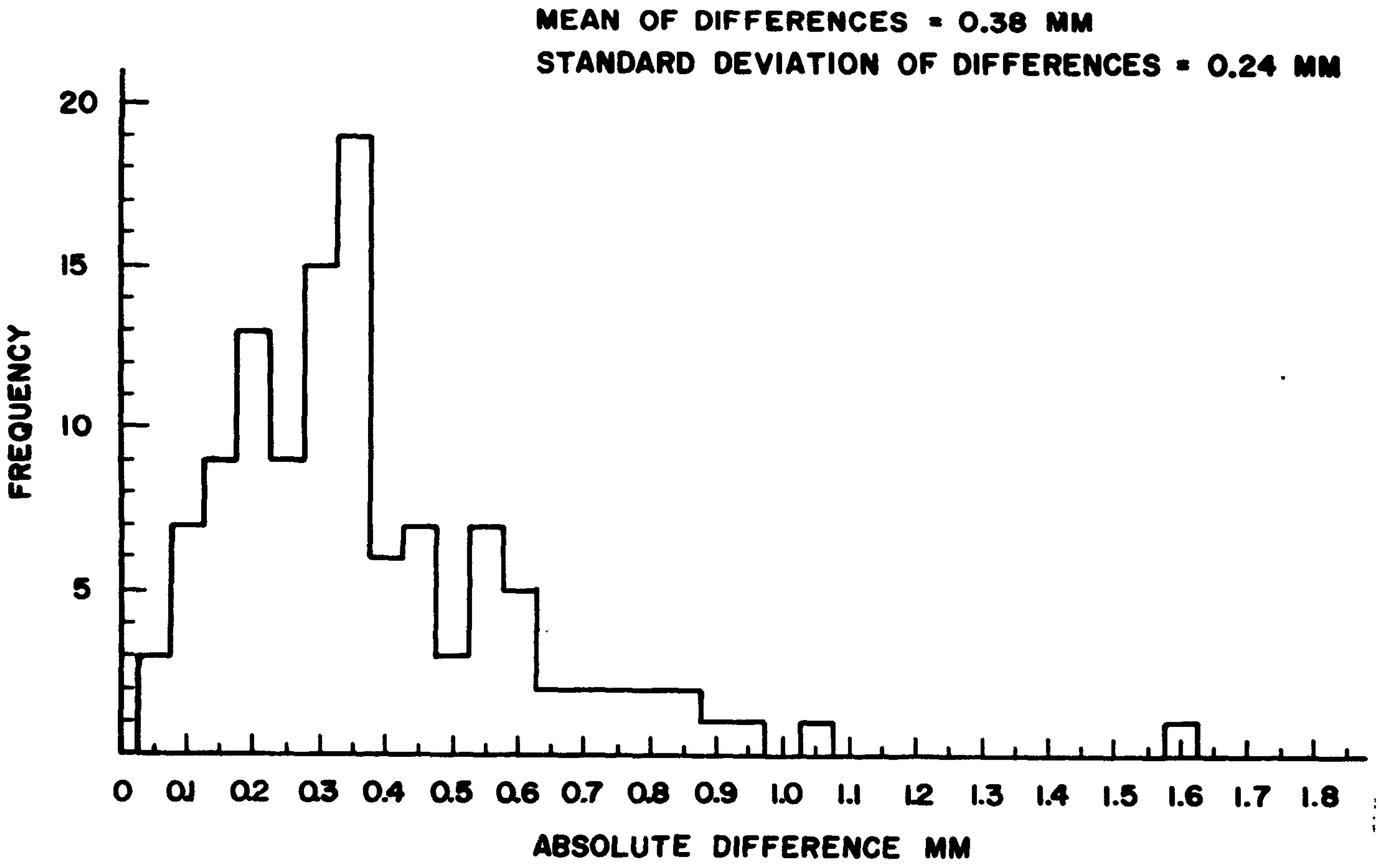
MEAN OF DIFFERENCES = 0.38 MM
STANDARD DEVIATION OF DIFFERENCES = 0.24 MM

FIGURE 19 - DISTRIBUTION OF DIFFERENCES

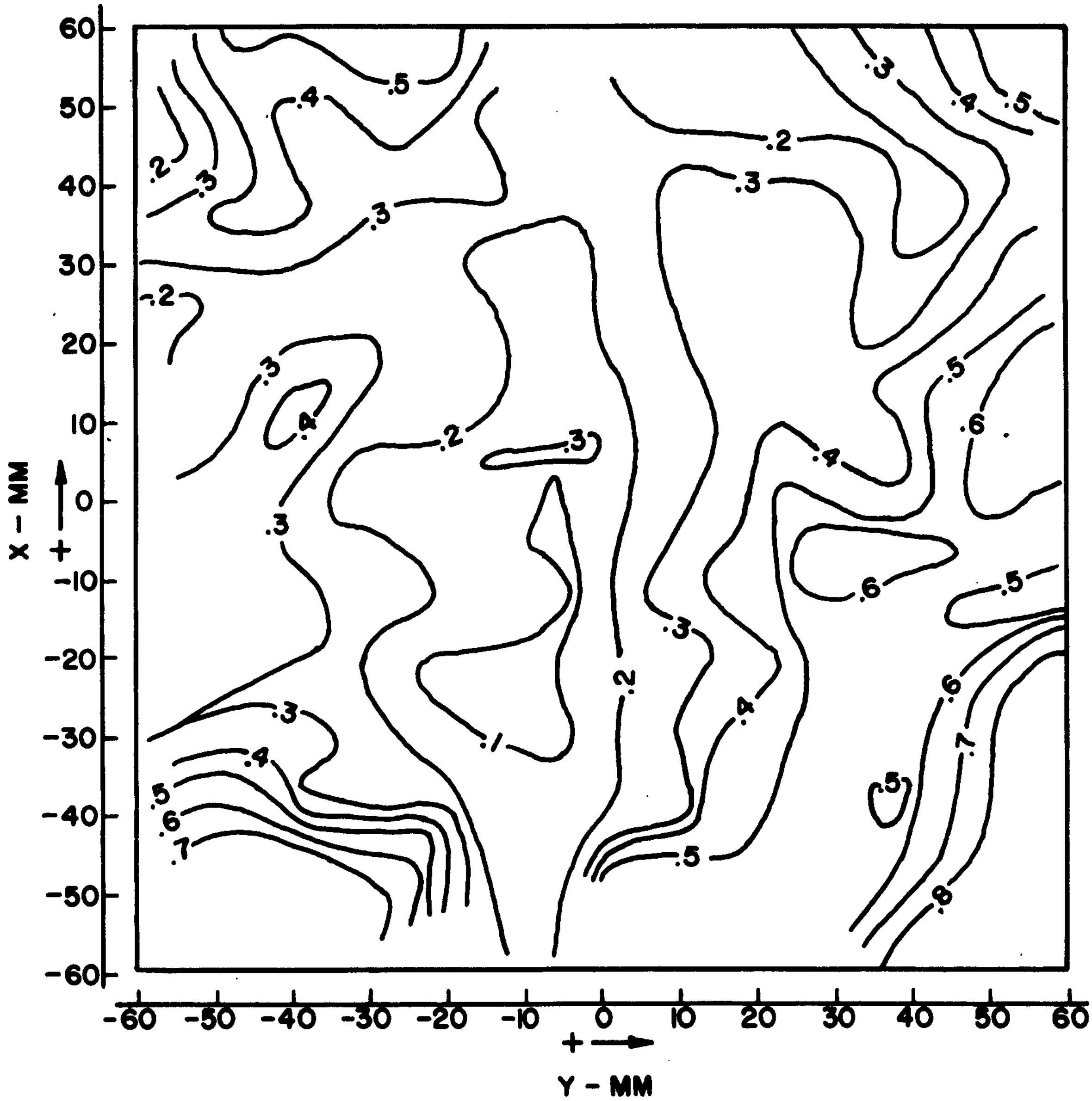

FIGURE 20 — CONTOUR PLOT OF DIFFERENCES (MM)
FOCAL LENGTH = 67.613 MM , E_p = 45°

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