Version: October 14, 1994

CLAS NOTE 94-018

The Region 1 Drift Chamber Endplates: Procurement History & Inspection Results

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CLAS Note Dated: October 12, 1994

Abstract

This report covers two aspects of the construction of the Region 1 Drift Chamber, a 30,000 wire detector which will be used in the CLAS spectrometer at the Continuous Electron Beam Accelerator Facility (CEBAF). First it summarizes the main steps in the recently completed procurement procedure. It also presents data on the quality of the endplates, as inferred from measurements made at the manufacturing company prior to delivery, as well as checks made after delivery of the plates to Carnegie Mellon University (CMU). Our conclusion is that these plates are acceptable for incorporation in the final Region 1 Detector for use in CLAS.

Procurement Procedures.

Procurement of the endplates was handled by Carnegie Mellon University under contract to CEBAF. The design of the endplates was finalized in the early 1994. Drawings for the two kinds of endplates ("near" and "far"), were submitted to CEBAF for review. The written detailed design specifications are included in this report as Appendix A. The bidding process began with letters sent out to vendors on March 14, 1994, with a one-month response time. Six vendors were approached; all were large shops with known capabilities for making large, precise parts. Four vendors submitted bids. Of these, plant trips were made by CMU, University of Pittsburgh, and CEBAF physicists and engineers to those shops whose capabilities were not yet well known to us. After a combined technical and cost review, the contract for making the plates was awarded on May 27th to Ideal Tool and Manufacturing Company, Chicago, Ill. The total price was $50,000. The final shop drawings, CAD diskettes and specification were sent to the company on June 8th. The

CMU procurement office issued the purchase order by June 17th. One subsequent visit was made to Ideal Tool by CMU personnel to check on progress of the job, on August 8th. At that time the first plate had been finished and the second plate (of twelve) was being fabricated. At this point it was found that the agreed-upon procedures were being followed by the company, and the only unexpected development was a small systematic deviation of the vertical coordinates of the holes near the middle of the plates (see discussion below). It was decided that manufacturing could continue using essentially the same procedure. All endplates were finished by September 9th. Delivery was delayed for about one week because Ideal Tool said they wanted to clean the holes more thoroughly. A crate containing the parts arrived at the CMU Medium Energy Group's laboratory on September 29th, 1994. Thus, the whole procurement process took six and 1/2 months. According to our contract with CEBAF this was on time and below budget.

Inspection of the Endplates

There are twelve endplates in total, six identical "Near" endplates and six identical "Far" endplates. They differ in their feedthrough hole patterns, due to the stereo wires, in the countersinking of holes for the struts, and in the layout of tapped holes for the circuit boards.

Upon uncrating the plates we made the following observations:
Surface quality was good, 25 micro-inch finish was marred by occasional scratches. Dowel and strut holes all accepted the appropriate gauge pins. Many holes were still showing signs of greasy dirt, despite the company's claim to have cleaned them all. The holes were mostly deburred; this was evidently a hand process, because in some areas the hole edges looked ragged. Surface oxidation and/or etching was visible in a number of places, typically where the cooling agent used during cutting had apparently dried. A number of etched-in fingerprints also were visible against the otherwise shiny surface. More specifically:
NS-1 (Near side plate #1): the first plate made by the company. No sign of the broken 4-40 tap we say while visiting the company in August.
FS-1 (Far side plate #1): the worst plate; a total of 27 holes were plugged and redrilled. They occurred in a row of 10 at the extreme upstream end of the plate in the stereo layers, and a row of 17 more near the middle in the axial layers. Only this plate had plugged holes, and the problem had been known to us previously. The plugs were flush to the surface, although a few were slightly pitted below the surface. Also in the same areas, rows of small dimples are found at precise offsets from the 'good' holes. The plugs and the dimples cause only cosmetic defects in this plate.

FS-2: This plate has a dent next to a strut hole near the notch. It would be consistent with a blow from a large ball peen hammer. This dent will have to be filled with epoxy, not for strength but to ensure that the gas seal on the bolt for the strut is tight.

We have inspection reports for the all endplates. See Figure 1 for a sample of the first page of one such report. These inspection reports were generated by Ideal Tool, and entailed the measurements of approximately 200 holes which were selected by us. The hole positions and diameters were measured using a coordinate measuring machine (CMM) located in the Ideal Tool shop. One of the six endplates, NS-1, was measured twice. This gave us the opportunity to check the reproducibility of the Ideal Tool CMM numbers.

The information was transmitted to CMU in the form of hardcopy and ASCII files. Rich Magahiz converted the information into an exhaustive set of histograms, a sampling of which is attached. Looking at the numbers and the graphs, we report the following findings:

1) Hole locations for struts and feedthroughs: Our specified true position tolerance was 5 mils, that is, we allowed a 2.5 mil radius deviation from the desired location. Roughly 50% of the holes did not meet this spec. All the plates showed the same systematic Y position error of -3 ± 1 mil near the center of the X dimension, with decreasing error near X=0 and X=80". If we "allow" this, many more of the holes would be considered acceptable.

This is illustrated in Figure 2, which shows the plate profile and typical Y and X position errors as a function of X. The dark boxes indicate the Y position errors. To make these measurements the first dowel hole near the downstream corner of the Near plates was used to locate the origin of the coordinates. The first upstream dowel hole was used to set the angle of the plate to its nominal (i.e. computed) value, and all other measurements where then made relative to this coordinate system. Hence the holes near (0,0) always came out near their nominal positions. Figures 2, 3, and 4, show the data for the Near plate strut holes. We present only strut hole data because these holes are evenly distributed; the feedthrough hole and dowel hole data follow the trends of the strut holes.

The position errors in X tended to increase monotonically from X=0 to X=80". Some plates had errors that suggested the plate was "too large" (numbers NS-2, NS-5, and NS-6, for example), while others are "too small" (number NS-1, when remeasured) or "just right" (numbers NS-1, first measurement, and NS-6). Since NS-1 changed from one measurement to the next, we had good evidence that we were seeing temperature changes which caused the size to change. This is shown in Figure 4. The two NS-1 measurements were consistent with a 1.5^{0}F temperature difference between the measurements. Note that we expected this kind of temperature sensitivity from the outset of the project.

Figures 5 and 6 show the analogous information for the Far plates. The same qualitative behavior is seen, only now the coordinate axis runs the opposite way; the origin of the measurements was still set such the holes near (0,0) are closest to their nominal positions.

The same data is presented in another way in Figures 7 and 8. Here the strut hole position deviations are plotted on polar graphs, on which one could draw 5 mil true position ellipses (with semi-major and semi-minor axes of 2.5 mils). One sees again the same systematic deviations we observed above. In Appendix C we attempt to parameterize these deviations for possible inclusion in the decoding software for the drift chamber.

2) Hole diameter for the feedthroughs: The nominal spec was 0.156 + 0.002 - 0.000" (5/32 inched). About 95% of all holes tested met the spec. Most were .0005 over the minimum size, and a single hole on NS-6 was 0.001 over the minimum. There were no holes larger than the upper limit. The few undersize holes were too small by less than or equal to .0005". Remeasurement of NS-1 showed that the reproducibility of the diameter measurements was ±0.0001". Also, the single undersize hole from the first NS-1 measurement "grew" by half a mil, indicating that the initial undersize measurement was probably due to some dirt in the hole. Since Ideal Tool supposedly put a gauge pin in every single hole, undersize measurements were probably the result of dirt.

3) Dowel holes: The diameters were consistent within each plate, but varied from plate to plate, from +0.00025 (NS-2) to +0.002 (NS-1). On NS-4 there is one hole which is 4 mils oversize. The X position deviations track the systematic behavior of the other holes on the endplates.

4) Material Strength and Composition: The endplates were specified to be made of 5/16" = 0.3125" Alca-Plus Cast Tooling Plate. This material is reputed to have excellent flatness and low internal stresses. The exact composition seems to be something of a trade secret, since we had no success finding the chemical composition listed in any engineering handbook. Alcoa would not tell us the composition. From Eric Sund, President of Ideal Tool, we obtained a copy of a "Certificate of Conformity" from the supplier of the material, which gives the actual elemental composition of the lot containing our material. It is included as Appendix B. The main admixtures to the aluminum are 4% copper and 1% zinc.

Tests were conducted to determine the modulus of elasticity (Young's Modulus) of the material of the plates. Sample pieces were cut from scrap stock and subjected to bending under controlled conditions. One end of the pieces were "rigidly" clamped to a table edge, and weights in the range of one kilogram were hung from the cantilevered end at a distance of roughly 65 cm. Deflections were measured with a machinists "dial-indicator." Using standard mechanical engineering formulae for the bending on beams we measured the modulus of elasticity of the endplate material to be 9.5±.2 million psi. A second measurement on a shorter piece yielded 8.0 ± .5 million psi. This was compared to the handbook value of most kinds of aluminum of 10.3 million psi. The disagreement between our two measurements is not understood, but we believe it is due to less than ideal clamping of the plates, resulting in a "too soft" plate. A third measurement, of a piece of conventional 6061 aluminum stock of the same length as the first measurement, yielded a value of 9.5±.2 million psi, also below the handbook value, but exactly the same as the first measurement on Alca Plus plate. Our conclusion was that our measurement technique and/or the formula we are using resulted in systematic underestimates of the modulus, but that since the known aluminum bar and the test piece from the endplates yielded identical results, the endplates are made of essentially "standard strength" aluminum.

5) **Overall fit:** Upon arriving at CMU the plates were matched into pairs to ensure that neighboring plates would indeed fit together, without straining dowel pins. No problems were encountered.

6) **Thickness and Flatness:** We found that all the plates were flat to the extent that they conformed to the benchtop upon which they were placed. Note that the struts and post eventually would dominate any forces causing small deviations from flatness, even if there were any. The uniformity of the thickness was measured on all plates at nine points each. All plates were within five mils of their nominal thickness of 5/16" = .3125". The average thickness of each of the plates are given as follows:

NS1	.312±.001"	FS1	.313±.001"
NS2	.316±.001"	FS2	.311±.001"
NS3	.311±.001"	FS3	.311±.001"
NS4	.316±.001"	FS4	.311±.001"
NS4	.313±.001"	FS5	.314±.001"
NS6	.312±.001"	FS6	.311±.001"

To test for overall warping the plates were stacked together on edge and lightly clamped together. Any significant warping would have been evident as gaps between the plates. No such gaps were detected, so that the plates appeared flat well within the specified tolerance of 15 mils.

Appendix A
CLAS Region 1 Drift Chamber Endplate Specifications

(attached)

Carnegie Mellon University

CLAS Region I Drift Chamber Endplate Specifications

Richard Magahiz

May 24, 1994

I. Introduction

The Continuous Electron Beam Accelerator Facility (CEBAF) is a basic physics research laboratory built by the Department of Energy in Newport News, Virginia. Three experimental halls will be instrumented with equipment to do experiments; Hall B will house the CEBAF Large Acceptance Spectrometer (CLAS) detector. One of the many different components to this detector, in the critical innermost region, is the Region I Drift Chamber. This document specifies the construction of what are termed "endplates" which belong to this drift chamber. The Region I Drift Chamber Endplates (hereafter referred to as "the endplates") are extremely high-precision mounting devices for tens of thousands of very thin wires. The design of the Region I Drift Chamber is a collaborative effort between the University of Pittsburgh and Carnegie Mellon University.

This document describes a total of twelve endplates of identical outer shape. The endplates will be made out of aluminum alloy and are approximately eight feet by three feet by 5/16″ in dimensions (precise specifications follow). Each will have several thousand 0.156″ holes (hereafter referred to as "feedthrough holes"; holes "6A" in all accompanying drawings), drilled at precise locations and with precise diameters. There are two distinct feedthrough hole patterns, the "near" (six endplates) and the "far" (six endplates). A number of other auxiliary holes (2A, 2B, ...; 3A, 3B, ...; 5A, 5B, ..., 7A, 7B, ...; 10A, 10B, ...) are also specified. Seven precision dowel holes (holes 4A, 4B,...) are to provide a locational clearance fit (Class LC3) for 0.2502″ diameter dowel pins attached to the endplate mounting structure. The electronics and gas manifold mounting holes (10A, 10B, ..., 5A, 5B, ...) shall receive a 4-40 thread and some of the strut holes (among the 2A, 2B, ... series) are to be countersunk on one side. All holes penetrate through the endplates completely.

There is a basic feedthrough hole pattern for the endplates: a hexagon of holes with one additional hole in the center. The hole in the center of the hexagon is referred to as the "sense wire" hole, while the surrounding holes are referred to as the "field wire" holes. In addition, there are "guard wire" holes and "tension measuring holes" which occur at the edges of the overall hole pattern. The exact dimensions of the hexagon vary with position along the plate and therefore a CNC machine is the only possible option, with the hole pattern being communicated to the vendor by means of computer storage media in a mutually agreeable format. Each of these holes is to provide a locational clearance fit (ANSI B4.1 Class LC3) to a metal and plastic feedthrough which will be produced by an insert molding process.

There are two tolerances in the specification which are particularly restrictive; these constraints come from basic design considerations. The feedthrough hole location tolerance on the endplates is 0.005″ absolute true position. The dowel hole location tolerance is 0.003" absolute true position.

The flatness tolerance (after machining) is specified as ±0.015″ over the entire length of the endplate.

In the following are included the vendor's responsibilities, a list of the accompanying drawings, and a summary of the specifications of the dimensional tolerances which must be met. We also mention specific issues of quality control which are known to us to be critical to successful completion of the work, and we require that the vendor address these issues.

II. Vendor's Responsibility

The vendor shall furnish all labor, material, equipment, and facilities to fabricate, inspect, and deliver the aluminum endplates. They are to be machined in strict accordance with this specification and accompanying drawings.

III. Accompanying Drawings

The following two drawings are part of this specification:

1) Drilled Plate, Near, Rev. 1, dated 05-18-94; CADD ID \a3\dwg\r1fin03.dwg
2) Drilled Plate, Far, Rev. 1, dated 05-18-94; CADD ID \a3\dwg\r1fin13.dwg

In case of conflict, the specifications given explicitly within this document supersede those indicated on the drawings.

IV. Computer Files

The following files are being provided to the vendor on a 3.5" high-density floppy disk (IBM format). All dimensions are in inches, using the coordinate system specified on the drawings. Additional information is available on request.

NAME	SIZE	DATE	TIME	# HOLES	DESCRIPTION
NSENSE1.TXT	31268	5-24-94	4:03pm	1855	Sense and guard wires, near, *ASCII*
FSENSE1.TXT	33019	5-24-94	4:03pm	1855	Sense and guard wires, far, *ASCII*
FFWDF1.TXT	21827	5-24-94	4:03pm	1247	Field wires, far, forward, *ASCII*
FMIDF1.TXT	16020	5-24-94	4:03pm	890	Field wires, far, middle, *ASCII*
FUPSF1.TXT	18180	5-24-94	4:03pm	1010	Field wires, far, upstream, *ASCII*
NFWDF1.TXT	12845	5-24-94	4:03pm	782	Field wires, near, forward, *ASCII*
NMIDF1.TXT	19890	5-24-94	4:03pm	1170	Field wires, near, middle, *ASCII*
NUPSF1.TXT	20315	5-24-94	4:03pm	1195	Field wires, near, upstream, *ASCII*
NFEED1.TXT	84888	5-24-94	4:03pm	5036	All wires, near, *ASCII*
FFEED1.TXT	89646	5-24-94	4:03pm	5036	All wires, far, *ASCII*
NTENS1.TXT	570	5-24-94	4:15pm	34	Tension wires, near, *ASCII*
FTENS1.TXT	600	5-24-94	4:03pm	34	Tension wires, far, *ASCII*
NFIN2.DWG	142772	5-24-94	4:04pm	-	Near endplate, AutoCAD Rel. 12 drawing
FFIN2.DWG	141931	5-24-94	4:04pm	-	Far endplate, AutoCAD Rel. 12 drawing

V. Specifications

1) All of the endplates are to be made of nonmagnetic aluminum alloy; cast aluminum tooling plate is recommended. The vendor must clearly identify which alloy will be used.
2) Feedthrough holes are to be located to an absolute true position tolerance of 0.005″ on all endplates.
3) Feedthrough hole diameters are 0.156″ (+0.002″, -0.000″).
4) Dowel holes are located to an absolute true position tolerance of 0.003″ on all endplates.
5) Dowel hole diameters are 0.252″ (+0.002″, -0.000″).
6) Auxiliary holes are to be located to an absolute true position tolerance of 0.005″, except for the electronics and gas manifold mounting holes, which can have a tolerance of 0.012″.
7) The absolute positioning of the outer contour of the endplates is to be ±0.010″.
8) The thickness of the endplates is to be 0.3125″ ±0.005″.
9) All endplates are to be flat to within ±0.015″ over their entire length in the free state. Surface finish (roughness) must be 63 microinch or finer.
10) All edges shall be deburred.
11) A portion of the strut holes (as designated on the drawings) is to receive a 100° countersink. The drawings are oriented such that each endplate is being viewed from the countersink side (note that near and far endplates are countersunk on opposite faces). The depth of the countersink shall be sufficient to ensure that a flat-head 1/4-20 machine screw not protrude above the surface of the endplate.
12) The electronics and gas manifold mounting holes (5A, 5B, ..., 10A, 10B, ...) shall be tapped through with a 4-40 thread.
13) Each endplate shall be stamped with a unique identifying mark on edge EDL11, 0.5" from the corner with edge EDL12, to associate it with the corresponding Quality Assurance Reports provided by the vendor.

VI. Procedures

1) The vendor is invited to discuss fabrication controls that will be implemented to meet the required dimensional tolerances. Examples of issues which might be addressed are: control of temperature fluctuations; how the workpiece will be clamped and held; whether the workpiece will be moved at any point during the machining process; how the drill speed selections will be accomplished; how many operations there will be per feedthrough hole; and how the tolerance on feedthrough diameters will be monitored during the course of fabrication.
2) The vendor must describe the equipment which will be used to drill and shape the plates.

3) The vendor shall demonstrate that a Quality Assurance Program will be effective in all phases of the project. This shall include design, procurement, manufacturing, inspection, and testing. Specifically, this activity must include procedures for verification of dimensions and tolerances. Verification of the feedthrough holes' position location may be on a sampling basis. The vendor shall demonstrate that purchased items will be procured such that they comply with specifications necessary to assure performance of the complete endplates. A list of approximately one hundred feedthrough hole locations to be checked on each endplate will be provided to the vendor after drilling is completed; the vendor is expected to return a list of the measured hole locations and diameters for the same holes. All strut, upstream mounting, and dowel holes (labeled 2A, 2B..., 3A, 3B..., and 4A, 4B... in accompanying drawings) shall be measured on each endplate.
4) The vendor is responsible for the safe delivery of the endplates to Carnegie Mellon University, Central Receiving, 6701 Fifth Ave., Pittsburgh, PA 15208.
5) The vendor shall describe procedures to insure that the endplates be received free of all oils, fluids, or debris introduced during the course of fabrication.
6) Final acceptance of the endplates shall follow delivery and inspection of the endplates at Carnegie Mellon University by designated personnel.
7) Designated personnel from Carnegie Mellon University shall have the right to make unscheduled visits to the vendor's facilities. Prior to contract award, we reserve the right to inspect those facilities the vendor has identified as being used for the fabrication of the endplates.
8) The vendor shall identify all subcontractors and identify their role in the fabrication of the endplates.
9) The vendor shall provide and adhere to a delivery schedule.

Appendix B
Endplate Material Metallurgical Analysis

(attached)

CERTIFICATE OF CONFORMITY

Meier
METAL SERVICENTERS

Purchaser Ideal Tool
Address
City & State Chicago, Illinois

JOB #7953

Purchaser's Order No. 30286

Specification

INVOICE NO.	QUANTITY SHIPPED	DESCRIPTION OF MATERIAL
w/o282295	1354#	Cast Alum Plate 5/16 x 48 x 144

CHEMICAL COMPOSITION	MECHANICAL PROPERTIES
Zn - .50-1.00% Cu - 3.00-4.00% Mg - .30- .70% Si - 1.10-1.35% Cr - .15 max Ti - .15 max Fe - 1.00 max Mn - .50 max Al - Bal.	Tensile Strength P.S.I. 24,000 Min. Yield Strength P.S.I. 19,000 Min. Elong. % in 2 in. 1.5 Min. From E. Sund, [illegible] [illegible]

☒ We hereby certify that to the best of our knowledge and belief, the chemical composition and mechanical properties of the material furnished above are within the limits specified.

☐ We hereby certify that the producer has on file Inspection and Test Certificates for the above material.

☐ We hereby certify that we have on file, available for inspection, copies of chemical and mechanical test reports certifying that the above material conforms to the standards specified. Chemical and Mechanical properties are within the limits shown above.

Sworn to before me, a Notary Public,
this 25th day of May 19 94
State of Illinois County of Cook

"OFFICIAL SEAL"
TONY ZAPOTOCKY
NOTARY PUBLIC, STATE OF ILLINOIS
MY COMMISSION EXPIRES 3/30/97

Notary Public

My Commission Expires

MEIER METAL SERVICENTERS
Per Merle Planeta
Merle Planeta

ALUMINUM • BRASS • COPPER • BRONZE • STAINLESS STEEL • ROD • BAR

Appendix C

Parameterization of Y Position Error Data

As a possible software correction to the nominal positions of the feedthrough holes in the Region 1 endplates, the data in Figures 2 through 6 can be parameterized as follows. Ignore the X variations since these are temperature dependent. A temperature correction may be appropriate at some future time if and when we know the temperature distribution in the spectrometer. The Y systematic error can be corrected. The correction can get as large a 5 mils, or 125 microns. This is still fairly small compared to the ultimate resolution of the chamber, which we expect will be 200 microns per layer if all goes well. Also, for particles heading normally out of the detector, the deviation is mostly in the non-bend direction, and so is less important in momentum reconstruction. We parameterize the Y deviations using a parabolic function with only one free parameter, namely the "height" of the deviation. Ignore the apparent skewing of the deviations for some endplates.

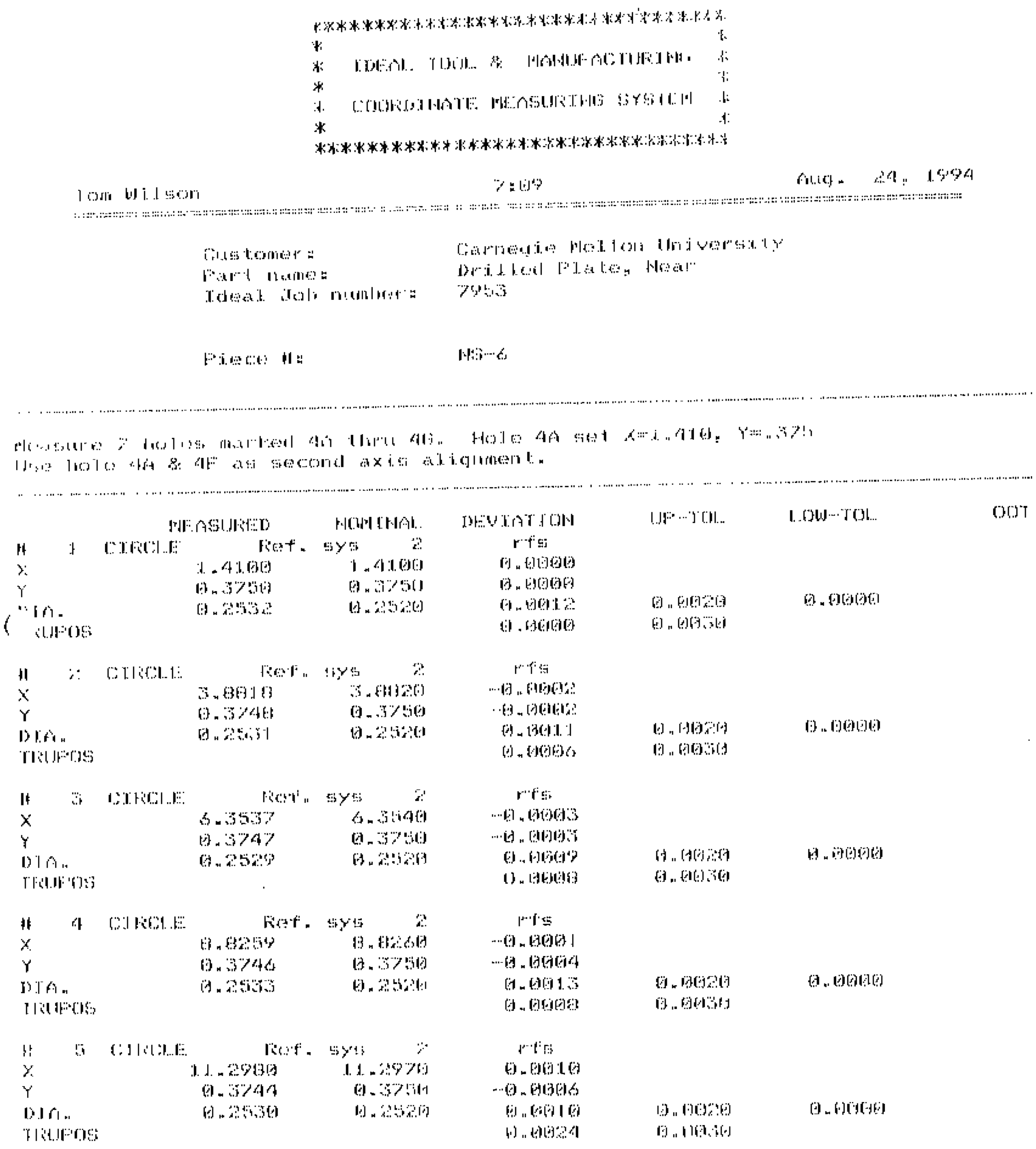
L = length of endplate pattern (L = 90 inches)
y = vertical position error from nominal hole location (mils)
y_0 = maximum deviation for a given endplate (less than 0, in mils)

We want y = 0 at x = 0 and x = L, so $a = -4y_0/L^2$. Then we can write

$$y = 4\, y_0 \left(\frac{x}{L} - \left(\frac{x}{L}\right)^2 \right)$$

From the CMM data displayed in the Figures we estimate the magnitudes of the offsets. Assuming the plates are joined NS-1 to FS-1, etc., we also give the average y_0 parameter for each sector. These values are for the systematic deviation in the plane of the endplates. With respect to the detector midplanes the effect is reduced by a factor of cos(30°). The resulting values are given in the last column, also in mils.

Endplate	y_0 (mils)	Endplate	y_0 (mils)	Sector average (mils)	Midplane average (mils)
NS-1	−3.5	FS-1	−3.0	−3.25	−2.8
NS-2	−3.0	FS-2	−1.5	−2.25	−1.9
NS-3	−2.3	FS-3	−3.0	−2.65	−2.3
NS-4	−2.5	FS-4	−2.5	−2.50	−2.2
NS-5	−2.0	FS-5	−3.5	−2.75	−2.4
NS-6	−1.8	FS-6	−5.0	−3.40	−2.9



```
                    ********************************
                    *                              *
                    *  IDEAL TOOL & MANUFACTURING  *
                    *                              *
                    *  COORDINATE MEASURING SYSTEM *
                    *                              *
                    ********************************
Tom Wilson                         7:09                      Aug. 24, 1994
--------------------------------------------------------------------------

          Customer:               Carnegie Mellon University
          Part name:              Drilled Plate, Near
          Ideal Job number:       7953


          Piece #:                NS-6
------------------------------------------------------------------------------

Measure 7 holes marked 4A thru 4G.  Hole 4A set X=1.410, Y=.375
Use hole 4A & 4F as second axis alignment.
------------------------------------------------------------------------------

                MEASURED     NOMINAL     DEVIATION      UP-TOL      LOW-TOL        OOT
#    1  CIRCLE       Ref. sys      2        rfs
X               1.4100       1.4100       0.0000
Y               0.3750       0.3750       0.0000
DIA.            0.2532       0.2520       0.0012      0.0020      0.0000
TRUPOS                                    0.0000      0.0030

#    2  CIRCLE       Ref. sys      2        rfs
X               3.8018       3.8020      -0.0002
Y               0.3748       0.3750      -0.0002
DIA.            0.2531       0.2520       0.0011      0.0020      0.0000
TRUPOS                                    0.0006      0.0030

#    3  CIRCLE       Ref. sys      2        rfs
X               6.3537       6.3540      -0.0003
Y               0.3747       0.3750      -0.0003
DIA.            0.2529       0.2520       0.0009      0.0020      0.0000
TRUPOS                                    0.0008      0.0030

#    4  CIRCLE       Ref. sys      2        rfs
X               8.8259       8.8260      -0.0001
Y               0.3746       0.3750      -0.0004
DIA.            0.2533       0.2520       0.0013      0.0020      0.0000
TRUPOS                                    0.0008      0.0030

#    5  CIRCLE       Ref. sys      2        rfs
X              11.2980      11.2970       0.0010
Y               0.3744       0.3750      -0.0006
DIA.            0.2530       0.2520       0.0010      0.0020      0.0000
TRUPOS                                    0.0024      0.0030
```

Figure 1

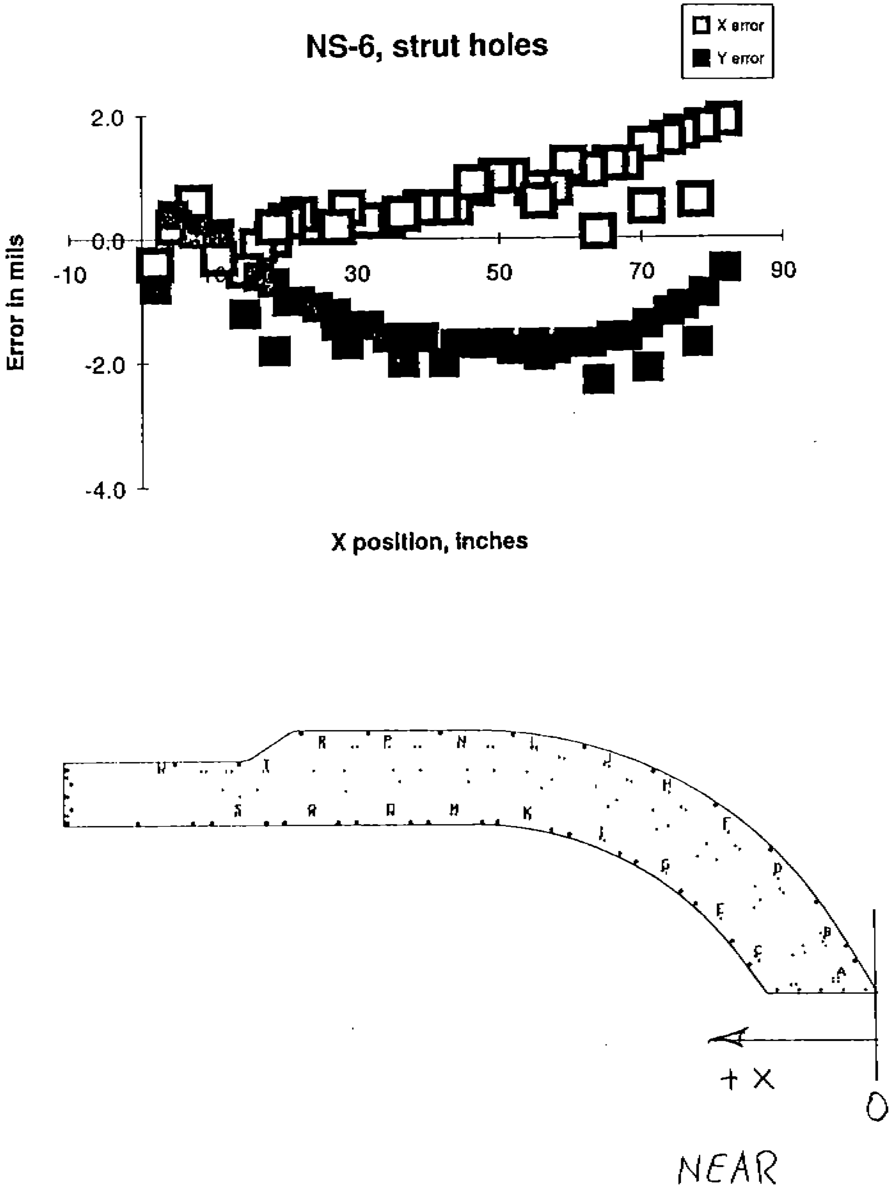
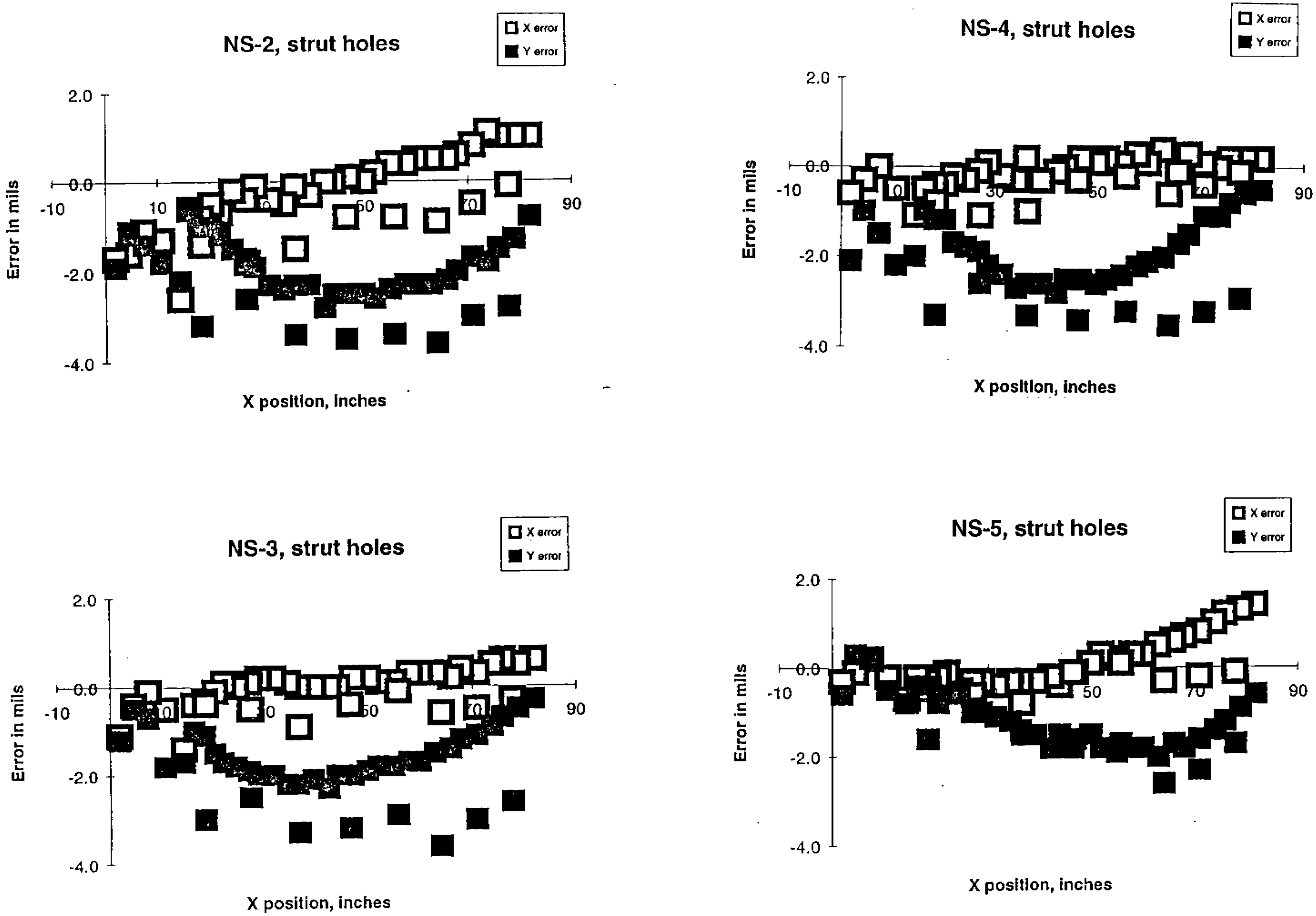


Figure 2



NS-2, strut holes

NS-4, strut holes

NS-3, strut holes

NS-5, strut holes

Figure 3

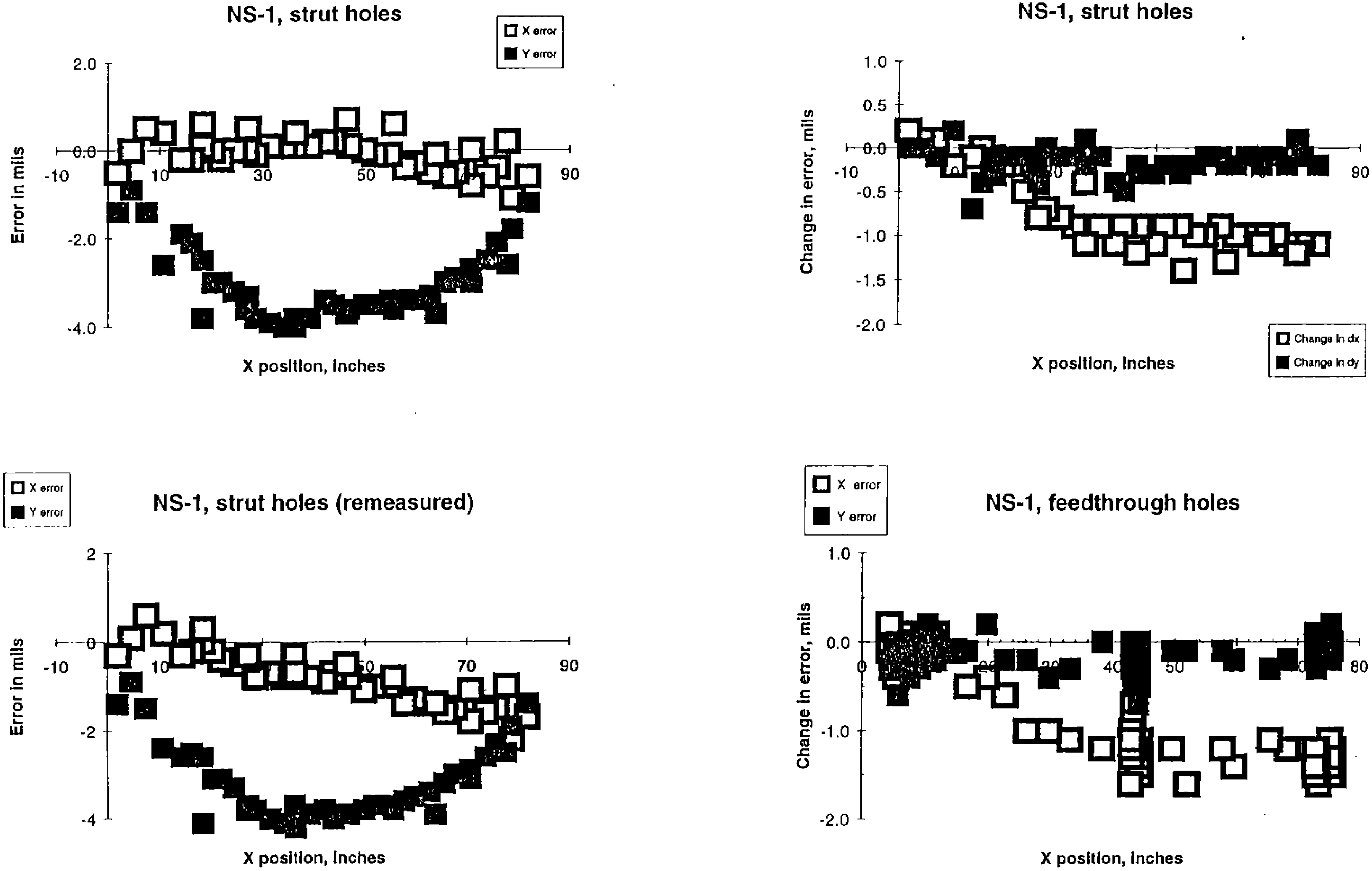


Figure 4

ΔT ~1.5°F

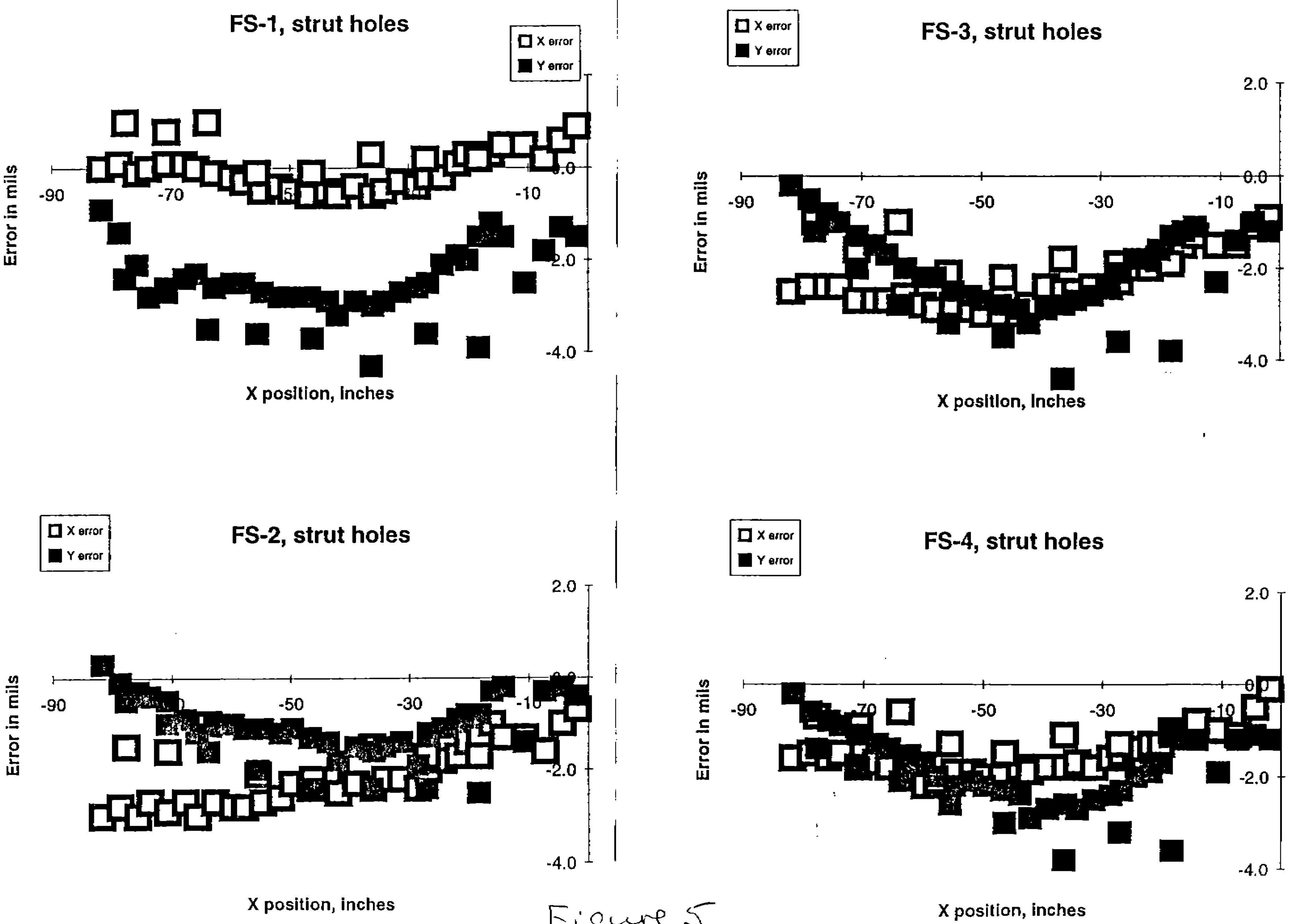
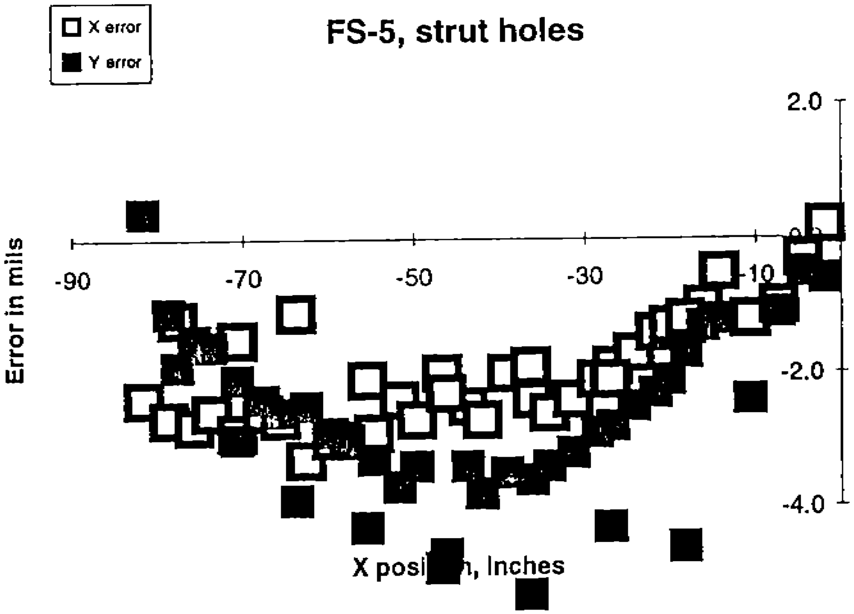

FS-1, strut holes
X error
Y error
Error in mils
-90
-70
-50
-10
0.0
-2.0
-4.0
X position, inches
FS-3, strut holes
X error
Y error
2.0
0.0
-2.0
-4.0
Error in mils
-90
-70
-50
-30
-10
X position, inches
FS-2, strut holes
X error
Y error
2.0
0.0
-2.0
-4.0
Error in mils
-90
-50
-30
-10
X position, inches
FS-4, strut holes
X error
Y error
2.0
0.0
-2.0
-4.0
Error in mils
-90
-70
-50
-30
-10
X position, inches

Figure 5


FS-5, strut holes
X error
Y error
Error in mils
X posi n, Inches
2.0
0.0
-2.0
-4.0
-90
-70
-50
-30
-10

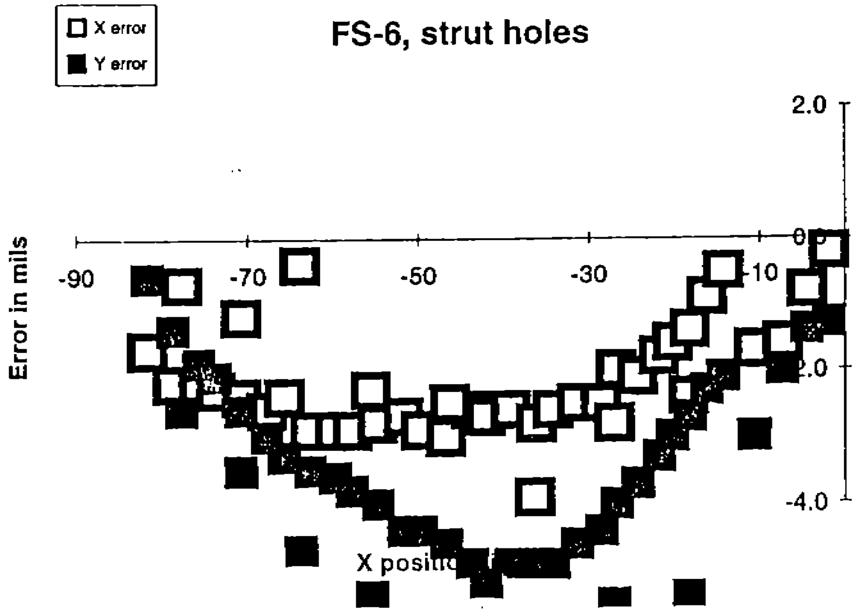
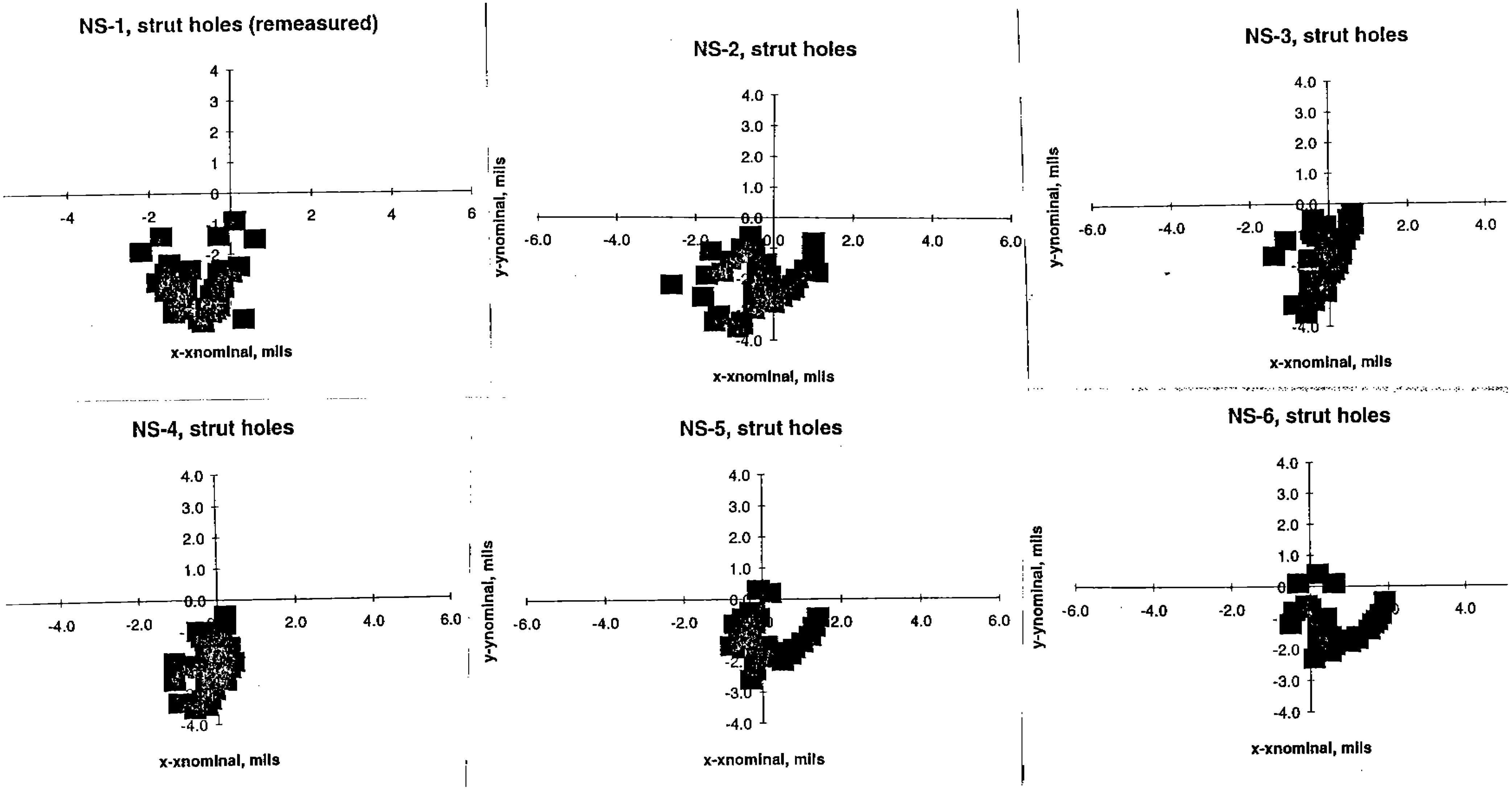

FS-6, strut holes
X error
Y error
Error in mils
X positio
2.0
0.0
-2.0
-4.0
-90
-70
-50
-30
-10

Figure 6


NS-1, strut holes (remeasured)

NS-2, strut holes

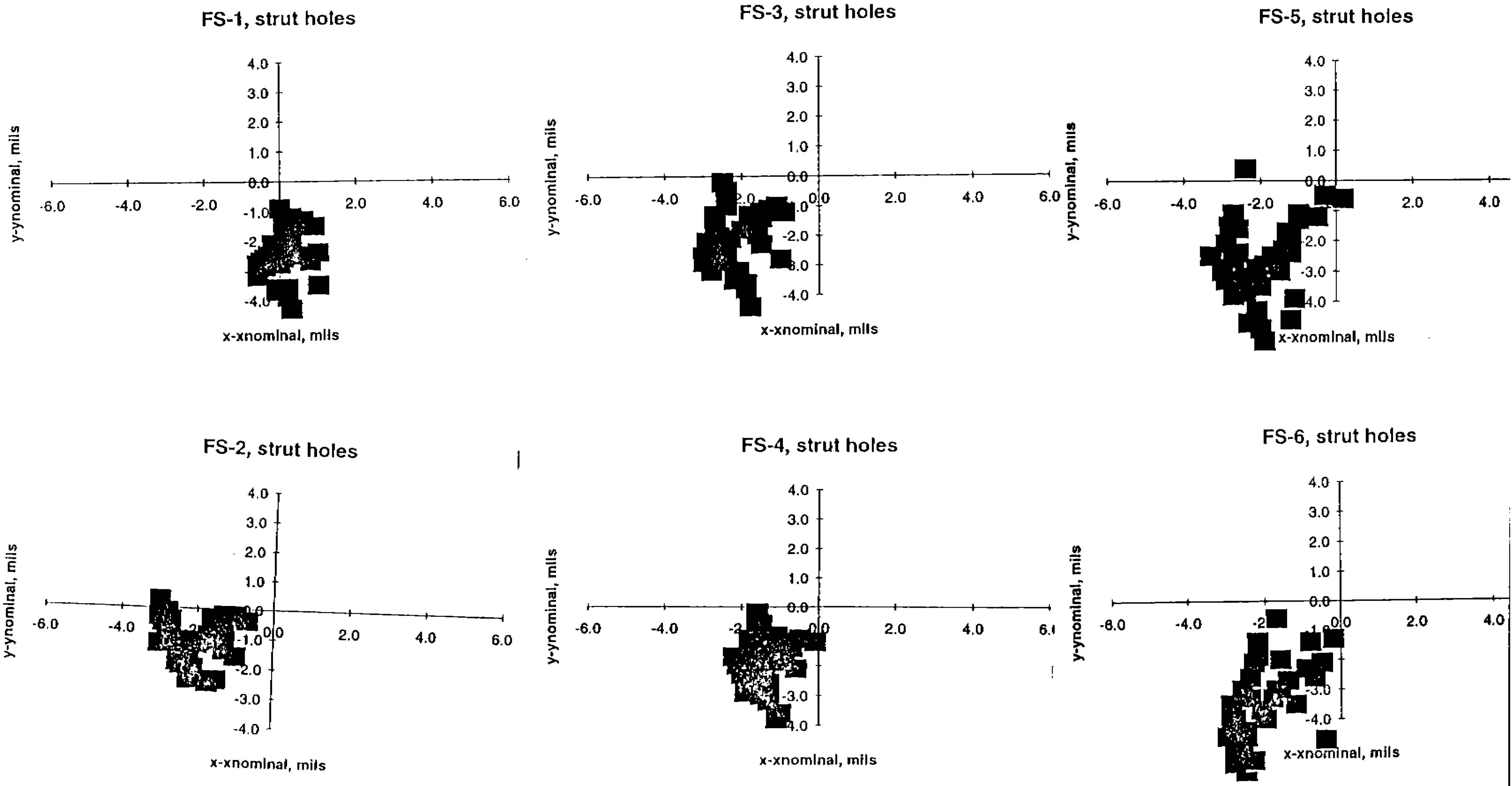
NS-3, strut holes

NS-4, strut holes

NS-5, strut holes

NS-6, strut holes

Figure 7



FS-1, strut holes

FS-3, strut holes

FS-5, strut holes

FS-2, strut holes

FS-4, strut holes

FS-6, strut holes

Figure 8