CERN/TC/NBC 65-3
5.3.1965

ADAPTATION OF THRESH TO BRITISH NATIONAL HYDROGEN BUBBLE CHAMBER

I. Introduction

Lens distortions and tilt of film plane with respect to the glass plane of the chamber made it necessary to envisage an additional treatment of IEP measurements. The tilt is certainly present in film taken prior to January 1965. After that date the tilt coefficients are expected to be different, since new film holders are mounted. The description falls into two parts, the search for the correction coefficients, and their application in Thresh. Extensive work on this subject has also been done by J.W. Burren, N.I.R.N.S.

II. Finding of the coefficients

Three sets of film have been used, taken at

Temp.	Chamber
$293^{\circ}K$	empty, called warm
$60^{\circ}K$	empty, called cold empty
$27^{\circ}K$	filled with H_2, called cold full.

In these sets consistent sets of correction coefficients were found. The step (warm $\rightarrow$ cold empty) verifies the assumption that the relative position of the glasses does not change when cooling down. The step (cold empty $\rightarrow$ cold full) determines the refractive index of the H_2, no contraction being considered between $60^{\circ}K$ and $27^{\circ}K$.

The position of the cameras had to be found independently, since the corrections are applied with respect to the camera axes. Here one enters a vicious circle since proper manipulation of measurements, as required by the camera reconstruction programme (T.C. program library), requires the knowledge of these coefficients.

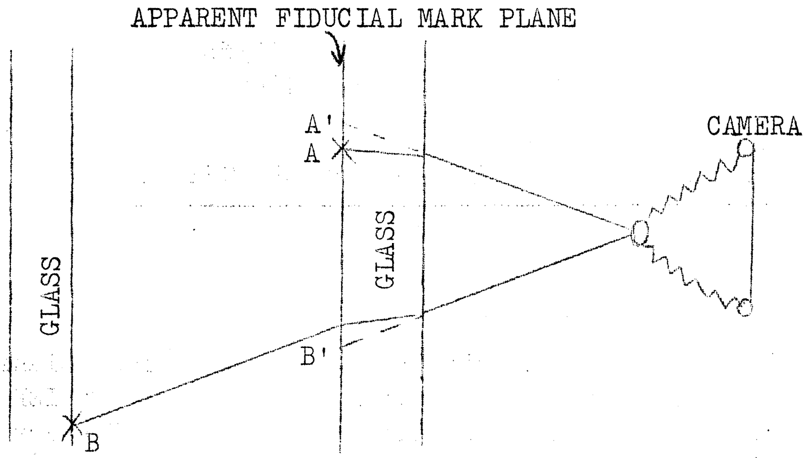
A sufficient, accurate approximation in X and Y was found by running the programme for one camera at a time and using only fiducial marks near around the optical axis. A starting value for the Z position of the camera is also found; this value can be adjusted by the reprojection method (see below).

The method employed to find the correction coefficients is the following :

1. Find the apparent fiducial mark positions of all fiducial marks. This requires the knowledge of X_{cam}, Y_{cam}, Z_{cam}, and of course the Chamber constants and fiducial mark positions.

   A, B fiducial mark; A', B' apparent fiducial mark.

PS/4822/mhg



Simple geometry requires that the measurements of the fiducial marks x_A, y_A are related to the apparent fiducial marks A' through a rotation, a translation and a magnification. Therefore,

2. Solve for a set of fiducial marks A, B..., the equations (in α)

$$X_{A'} = \alpha_1 + \alpha_2 \; x_A + \alpha_3 \; y_A \tag{1a}$$

$$X_{B'} = \alpha_1 + \alpha_2 \; x_B + \alpha_3 \; y_B \tag{1b}$$

Etc...

3. Find the position of the optical axis on the film in film measurement units (P, Q). This is done using the α's found from equations (1a), (1b), etc. The α's transform from film to apparent fiducial mark plane. The back transformation from apparent fiducial mark plane to the film plane is then also known. Here we have entered another vicious circle. It was verified that the uncertainty introduced by the inaccuracy in P and Q does not affect the result.

4. Correct the measured quantities (x_A, y_A), etc., according to

$$x_A^{rel} = x_A - P \tag{2a}$$

$$y_A^{rel} = y_A - Q \tag{2b}$$

$$r_A^{rel} = \sqrt{(x_A - P)^2 + (y_A - Q)^2} \tag{2c}$$

$$x'_A = x_A^{rel} \left[1 + c_1 \, x_A^{rel} + c_2 \, y_A^{rel} + c_3 \, (r_A^{rel})^2 + c_4 \, (r_A^{rel})^4\right] \tag{2d}$$

$$y'_A = y_A^{rel} \left[1 + c_1 \, x_A^{rel} + c_2 \, y_A^{rel} + c_3 \, (r_A^{rel})^2 + c_4 \, (r_A^{rel})^4\right] \tag{2e}$$

Now the measured quantities (x_A, y_A) are transformed in the corrected ones (x'_A, y'_A). The origin of the system has been changed.

5. Apply again the set of equations (1a), (1b), etc., but with (x_A, y_A) replaced by (x'_A, y'_A), etc.

   The condition for the coefficients c's is that the average distance between the apparent fiducial marks $(X_{A'}, Y_{A'})$ and the corresponding quantities deduced from the corrected measurements is a minimum.

   The optimum condition for the c's can be compared to the case when the c's are set to zero. Whereas for the optimum condition the average distance from the reprojection of the measured fiducial mark and the apparent fiducial mark is around 0.15 mm, for the case when c = 0, the average is .5 mm (in the apparent fiducial mark plane).

   The distance between a measured and reprojected fiducial mark and the apparent fiducial mark is (for all c = 0) strongly dependent on the distance to the optical axes; for the farthest crosses this distance climbs to 5.0 mm.

6. Repeat the cycle for some Z_{cam} values. The minimum condition mentioned above fixes the best Z_{cam} value when fiducial marks on both glasses are used.

7. Repeat the cycle 1 - 6 for all the cameras.

Some remarks should be made :

Apart from the set of equations (1a), (1b), a corresponding set with $Y_{A'}$, etc. were used. With the 34 fiducial marks available, the Y set is less sensitive for the c's than the X set.

The quantity C_4 was really not determined. C_3 and C_4 are the distortion terms, C_1 and C_2 the tilt terms. They all have dimensions. We worked with CERN IEP fringes (2.5 μm). The signs of the terms C_1 and C_2 are sensitive to the actual orientation of the x and y axis of the measuring device.

Considering measuring errors, it was found that with the 34 crosses available, C_1 and C_3 could be determined with ~ 20 °/o accuracy, C_2 with ~50 % accuracy.

III. Application of the coefficients in Thresh

Once the coefficients are found, the following modifications were made to Thresh. In title 1 the reading Misc (13) is used as a marker to indicate the need for a correction cycle. The marker indicates the number of cards to be read at the end of the deck, where for each camera the c's are stored (FORMAT 4E 10.5). The c's are kept in a new subroutine CORREC. Depending on Misc(13), the subroutine GEOM2 calls BNHBC. Here the optical axes for the correction formula are determined and then all the measured values are corrected using the set of formulae (2a), (2b), etc. The optical axis is found using the uncorrected measurements of the fiducial marks and transforming the apparent fiducial marks back to them. The same set of transformation coefficients is used to find the optical axis on the film plane. Numerical values show that this does not introduce a detectable error. Thresh then continues to work as before, using the corrected measurements.

When fiducial marks are reconstructed as points in an otherwise normal scheme of measurements, the deviations in the X, Y plane are maximally .2 mm, in the Z direction they can rise to 1.5 mm.

Appendix I shows an example of a title 1. The units of C_1 and C_2 are $(2.5\ \mu m)^{-1}$, of C_3 $(2.5\ \mu m)^{-2}$ and of C_4 $(2.5\ \mu m)^{-4}$.

Appendix II shows the positions of the fiducial marks.

A.-M. Cnops
B. Jongejans

APPENDIX I

EXAMPLE OF TITLE 1 FOR THRESH (FORTRAN 2 VERSION)

THE NEW ITEMS ARE PUT BETWEEN LINES

```
TITLE1     BNHBC COLD FULL RECONSTRUCTION OF FIRST SET OF EVENTS
   80                                                          1
   2    3    3    7    0
     0.5      40.0       1.0 100000.                  0.0002
   1           3                               R
 24.417   22.485 142.2
-23.548 - 1.620 141.7
 24.558 -25.525 141.9
     1.0     1.523    1.092
122.27   19.63    46.41
-39.9599   0.0839   0.
0.         0.         0.
 39.9599 -0.0839   0.
-39.5485-19.6362-46.4100
-39.9710 18.1379-46.4100
  0.2878-19.6649-46.4100
  0.2351 -0.6136-46.4100
  0.1583 18.5455-46.4100
 40.2544-19.3625-46.4100
 40.1634 18.2814-46.4100
 0.22 E-06-0.15 E-06 0.18 E-10 0.00 E-30
 0.29 E-06 0.00 E-06 0.15 E-10 0.00 E-30
 0.22 E-06 0.10 E-06 0.08 E-10 0.00 E-30
777777
*      END
```

*** THIS JOB 000025 LINES

APPENDIX II

FIDUCIAL MARK POSITION IN B.N.H.B.C. FALL 1965

FIRST MARK 1 UP TO AND INCLUDING 17
THEN MARK 21 UP TO AND INCLUDING 37

-39.9710	18.1379	-46.4100
-19.7616	18.3515	-46.4100
0.1583	18.5455	-46.4100
20.2016	18.3834	-46.4100
40.1634	18.2814	-46.4100
-59.7048	-0.6615	-46.4100
-39.7248	-0.6455	-46.4100
-19.7449	-0.6295	-46.4100
0.2351	-0.6136	-46.4100
20.2151	-0.5976	-46.4100
40.1950	-0.5816	-46.4100
60.1750	-0.5656	-46.4100
-39.5485	-19.6362	-46.4100
-19.7297	-19.6104	-46.4100
0.2878	-19.6649	-46.4100
20.2303	-19.5785	-46.4100
40.2544	-19.3625	-46.4100
-39.7703	18.6451	0.
-19.9412	19.0230	0.
0.2031	18.6443	0.
20.0205	18.9390	0.
39.9340	18.5273	0.
-59.9399	0.1259	0.
-39.9599	0.0839	0.
-19.9800	0.0420	0.
-0.0000	0.0000	0.
19.9799	-0.0420	0.
39.9599	-0.0839	0.
59.9399	-0.1259	0.
-40.0125	-19.0102	0.
-20.0199	-18.9389	0.
-0.0393	-19.0113	0.
19.9400	-19.0229	0.
39.9506	-19.0045	0.

*** THIS JOB 000034 LINES

APPENDIX I

EXAMPLE OF TITLE 1 FOR THRESH
(FORTRAN 2 VERSION)

THE NEW ITEMS ARE PUT BETWEEN LINES

```
TITLE1    BNHBC COLD FULL RECONSTRUCTION OF FIRST SET OF EVENTS
   80                                                            1
   2    3    3    7    0
     0.5     40.0      1.0 100000.                         0.0002
   1          3                                  R
 24.417  22.485 142.2
-23.548 - 1.620 141.7
 24.558 -25.525 141.9
     1.0     1.523    1.092
122.27   19.63    46.41
-39.9599   0.0839   0.
0.        0.         0.
 39.9599 -0.0839   0.
-39.5455-19.6352-46.4100
-39.9710 19.1379-46.4100
  0.2878-19.6649-46.4100
  0.2351 -0.6136-46.4100
  0.1583 19.5455-46.4100
 40.2544-19.3625-46.4100
 40.1634 18.2814-46.4100
 0.22 E-06-0.15 E-06 0.18 E-10 0.00 E-30
 0.20 E-06 0.00 E-06 0.15 E-10 0.00 E-30
 0.22 E-06 0.10 E-06 0.08 E-10 0.00 E-30
777777
*       END

                                   *** THIS JOB 000025 LINES
```

APPENDIX II

FIDUCIAL MARK POSITION IN B.N.H.B.C. FALL 1965

FIRST MARK 1 UP TO AND INCLUDING 17
THEN MARK 21 UP TO AND INCLUDING 37

-39.9710	18.1379	-46.4100
-19.7616	18.3515	-46.4100
0.1583	18.5455	-46.4100
20.2016	18.3834	-46.4100
40.1634	18.2814	-46.4100
-59.7048	-0.6615	-46.4100
-39.7248	-0.6455	-46.4100
-19.7449	-0.6295	-46.4100
0.2351	-0.6136	-46.4100
20.2151	-0.5976	-46.4100
40.1950	-0.5816	-46.4100
60.1750	-0.5656	-46.4100
-39.5485	-19.6362	-46.4100
-19.7297	-19.6104	-46.4100
0.2878	-19.6649	-46.4100
20.2303	-19.5785	-46.4100
40.2544	-19.3625	-46.4100
-39.7703	18.6451	0.
-19.9412	19.0230	0.
0.2031	18.6443	0.
20.0205	18.9390	0.
39.9340	18.5273	0.
-59.9399	0.1259	0.
-39.9599	0.0839	0.
-19.9800	0.0420	0.
-0.0000	0.0000	0.
19.9799	-0.0420	0.
39.9599	-0.0839	0.
59.9399	-0.1259	0.
-40.0125	-19.0102	0.
-20.0199	-18.9389	0.
-0.0393	-19.0113	0.
19.9400	-19.0229	0.
39.9506	-19.0045	0.

*** THIS JOB 000034 LINES