21-75c

THE PHOTOBATHYMETRIC PROGRAM
ESTABLISHED AT N.O.A.A.

by R.A. Langford

1975

ABSTRACT

The study of the Photobathymetry Program is being carried out by the N.O.A.A. offices in Rockville, Maryland and Norfolk, Virginia. The basic formulae used are based on a number of technical papers as published in the Photogrammetric Engineering Journal. The separate papers each deal with a specific correction which must be applied to the overall adjustment to give accurate reliable depths and contours.

## CONTENTS

## INTRODUCTION

The field of photobathymetry was opened to a usable degree by the appearance of colour aerial photography on the sales market, in addition, the use of infrared photography has further simplified the process. The original theory for the exact value of the scale factor for the true depths was equated by Mr. G.C. Tewinkel of the U.S. Coast and Geodetic Survey, Washington, D.C.

Mr. Tewinkel's theories have been proven and are that the depth of water observed in a plotter needs to be multiplied by a factor in the range from 1.4 to 1.5, depending on relative location in the stereo model.

The value of the factor is also dependent on photography scale and base altitude ratio; the horizontal location of the bottom features are plotted correctly.

The effect of refraction having no direct effect on horizontal position was questioned by Mr. M.C. Van Wijk of the National Research Council, and proved that horizontal displacement is a maximum of the .06 h.; h being the apparent depth of the water such that it would be insignificant and unplottable at most scales.

? The tilt of the camera has no direct significance on the accuracy of the work, so long as it is not too great or the aircraft is not flying at a very low altitude.

A further refinement in the process was established by W.O.J. Groeneveld Meijer Phd. Groeneveld Meijer developed a series of formulae from Tewinkel's original formula and simplified the overall process. The equations used determine a fine grid network of refraction factors to allow elliptical curves to be drawn through points of equal value. The function of this graph is to allow more accurate scaling of the apparent depths observed in the stereo model. The values and amount of change in the scale factor is dependent on the amount of overlap between successive photographs and the plotting scale of the instrument.

Thus far, the basic mathematics and theory of the system have been discussed, it has been a quick scan across the data since to delve deeply into it would require a great deal of time, and the fact that all the persons involved have published papers makes it simpler to read their published papers.

In 1974, Martin Keller of the Photogrammetric Research Branch, Coastal Mapping Division, published a paper dealing specifically with the aspect of photobathymetry and covering the basic field of topics. This paper covers the film types used, an example of the planning of the field operation, the aircraft requirements and laboratory processing. Included are the actual features that are to be shown, the delineation of shoreline and significant features. Along with these topics are a series of other related fields that this type of work is used to obtain.

TABLE 1. PHOTOGRAMMETRIC REFRACTION IN MICRORADIANS FOR A RAY AT 45° WITH THE VERTICAL IN THE U. S. STANDARD ATMOSPHERE, 1962

| *Flying height above sea level* | *Photogrammetric refraction for ground heights of* | | | | *Flying height above sea level* | *Photogrammetric refraction for ground heights of* | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *0.0 km.* | *1.0 km.* | *2.0 km.* | *4.0 km.* | | *0.0 km.* | *0.1 km.* | *2.0 km* | *4.0 km.* |
| 0.5 km. | 6.5 | | | | 23 km. | 85.8 | 78.3 | 71.2 | 58.4 |
| 1.0 | 12.6 | 0.0 | | | 24 | 84.0 | 76.7 | 69.8 | 57.2 |
| 1.5 | 18.5 | 6.0 | | | 25 | 82.2 | 75.0 | 68.2 | 56.0 |
| 2.0 | 24.1 | 11.7 | 0.0 | | 26 | 80.3 | 73.3 | 66.7 | 54.8 |
| 2.5 | 29.3 | 17.1 | 5.6 | | 27 | 78.4 | 71.6 | 65.1 | 53.5 |
| 3.0 | 34.3 | 22.3 | 10.9 | | 28 | 76.6 | 69.8 | 63.6 | 52.2 |
| 3.5 | 39.0 | 27.1 | 15.9 | | 29 | 74.7 | 68.2 | 62.0 | 50.9 |
| 4.0 | 43.5 | 31.7 | 20.6 | 0.0 | 30 | 72.9 | 66.5 | 60.5 | 49.6 |
| 4.5 | 47.7 | 36.1 | 25.1 | 4.8 | 31 | 71.2 | 64.8 | 59.0 | 48.3 |
| 5.0 | 51.6 | 40.2 | 29.3 | 9.2 | 32 | 69.4 | 63.3 | 57.5 | 47.1 |
| 5.5 | 55.3 | 44.0 | 33.3 | 13.5 | 34 | 66.1 | 60.2 | 54.7 | 44.8 |
| 6.0 | 58.8 | 47.6 | 37.0 | 17.5 | 36 | 63.0 | 57.4 | 52.1 | 42.6 |
| 6.5 | 62.1 | 51.0 | 40.6 | 21.3 | 38 | 60.1 | 54.7 | 49.6 | 40.5 |
| 7.0 | 65.1 | 54.2 | 43.9 | 24.8 | 40 | 57.4 | 52.2 | 47.3 | 38.8 |
| 7.5 | 67.9 | 57.2 | 47.0 | 28.2 | 42 | 54.9 | 49.8 | 45.1 | 36.7 |
| 8.0 | 70.6 | 59.9 | 49.8 | 31.3 | 44 | 52.6 | 47.7 | 43.1 | 35.0 |
| 8.5 | 73.0 | 62.5 | 52.5 | 34.2 | 46 | 50.4 | 45.7 | 41.3 | 33.5 |
| 9.0 | 75.2 | 64.9 | 55.0 | 37.0 | 48 | 48.4 | 43.8 | 39.6 | 32.1 |
| 9.5 | 77.3 | 67.1 | 57.3 | 39.5 | 50 | 46.5 | 42.1 | 38.0 | 30.7 |
| 10.0 | 79.2 | 69.1 | 59.5 | 41.9 | 52 | 44.8 | 40.5 | 36.5 | 29.5 |
| 10.5 | 80.9 | 70.9 | 61.5 | 44.1 | 54 | 43.2 | 39.0 | 35.2 | 28.4 |
| 11.0 | 82.5 | 72.6 | 63.3 | 46.1 | 56 | 41.7 | 37.6 | 33.9 | 27.3 |
| 11.5 | 85.0 | 75.2 | 66.0 | 49.0 | 58 | 40.3 | 36.3 | 32.7 | 26.3 |
| 12.0 | 87.1 | 77.4 | 68.3 | 51.5 | 60 | 38.9 | 35.1 | 31.6 | 25.4 |
| 12.5 | 88.8 | 79.2 | 70.2 | 53.7 | 62 | 37.7 | 34.0 | 30.6 | 24.5 |
| 13.0 | 90.2 | 80.8 | 71.8 | 55.5 | 64 | 36.5 | 32.9 | 29.6 | 23.7 |
| 13.5 | 91.3 | 82.0 | 73.2 | 57.0 | 66 | 35.4 | 31.9 | 28.7 | 23.0 |
| 14.0 | 92.2 | 83.0 | 74.2 | 58.2 | 68 | 34.4 | 31.0 | 27.8 | 22.2 |
| 14.5 | 92.8 | 83.7 | 75.1 | 59.2 | 70 | 33.4 | 30.1 | 27.0 | 21.6 |
| 15.0 | 93.3 | 84.2 | 75.7 | 60.1 | 72 | 32.5 | 29.2 | 26.2 | 21.0 |
| 15.5 | 93.5 | 84.6 | 76.2 | 60.7 | 74 | 31.6 | 28.4 | 25.5 | 20.4 |
| 16.0 | 93.6 | 84.8 | 76.5 | 61.2 | 76 | 30.8 | 27.7 | 24.8 | 19.8 |
| 16.5 | 93.6 | 84.9 | 76.6 | 61.5 | 78 | 30.0 | 27.0 | 24.2 | 19.3 |
| 17.0 | 93.4 | 84.8 | 76.6 | 61.7 | 80 | 29.2 | 26.3 | 23.6 | 18.8 |
| 17.5 | 93.2 | 84.6 | 76.5 | 61.8 | 82 | 28.5 | 25.6 | 23.0 | 18.3 |
| 18.0 | 92.8 | 84.3 | 76.4 | 61.8 | 84 | 27.9 | 25.0 | 22.4 | 17.8 |
| 18.5 | 92.3 | 84.0 | 76.1 | 61.7 | 86 | 27.2 | 24.4 | 21.9 | 17.4 |
| 19.0 | 91.8 | 83.5 | 75.7 | 61.5 | 88 | 26.6 | 23.9 | 21.4 | 17.0 |
| 19.5 | 91.2 | 83.0 | 75.3 | 61.3 | 90 | 26.0 | 23.3 | 20.9 | 16.6 |
| 20.0 | 90.5 | 82.4 | 74.8 | 61.0 | | | | | |
| 21.0 | 89.1 | 81.2 | 73.8 | 60.3 | $Z>90$ | $\frac{2{,}340}{Z}$ | $\frac{2{,}076}{Z-1}$ | $\frac{1{,}837}{Z-2}$ | $\frac{1{,}426}{Z-4}$ |
| 22.0 | 87.5 | 79.8 | 72.6 | 59.4 | | | | | |

SIMPLIFIED REFRACTIVE INDICES FORMULA

$$F = \frac{\dfrac{b}{h + h_a}}{\dfrac{s}{\sqrt{(n^2 - 1)d_1^2 + (h + h_a)^2 n^2}} + \dfrac{t}{\sqrt{(n^2 - 1)d_2^2 + (h + h_a)^2 n^2}}}$$

$\frac{B}{H-h} = \frac{9(1-e)}{f}$

### NUMERICAL EXAMPLES

Examples have been calculated for the following conditions:

| | |
|---|---|
| Flight altitude | h=2,500′ |
| Photographic lens | $f$=6″ |
| Forward overlap | 70% |
| Negative size | 9″×9″ |
| Negative scale | 1/5,000 |
| Photographic base: | $b$=1,126′ |
| Side overlap | 40%, 50% |

$\frac{B}{2500} = \frac{9(1-.7)}{6}$

$B = 2500\left(\frac{2.7}{6}\right)$

$B = 1125$

$\frac{B}{2500} = \frac{\text{Photoformat Size }(1-\text{Overlap})}{\text{Lens Length}} = \frac{9'(1-.7)}{6''}$ ∴ $B = 2500'\left(\frac{2.7''}{6''}\right) = 1126'$



TABLE 1

EFFECTIVE INDICES OF REFRACTION $F$ CALCULATED FOR VARIOUS APPARENT DEPTHS $h_a$ AND LOCATIONS ON STEREO MODEL ($d_1$, $d_2$, $s$, $t$)

| *Location on Stereo Model* | | | | *Effective Index of Refraction F Apparent Depth $h_a$* | | | | |
|---|---|---|---|---|---|---|---|---|
| $d_1$ | $d_2$ | $s$ | $t$ | 0′ | 10′ | 25′ | 50′ | 100′ |
| 563′ | 563′ | 563′ | 563′ | 1.3652 | 1.3653 | 1.3651 | 1.3647 | 1.3642 |
| 600 | 600 | 563 | 563 | 1.3676 | 1.3673 | 1.3671 | 1.3667 | 1.3661 |
| 800 | 800 | 563 | 563 | 1.3808 | 1.3804 | 1.3802 | 1.3796 | 1.3785 |
| 1,000 | 1,000 | 563 | 563 | 1.3980 | 1.3976 | 1.3968 | 1.3961 | 1.3942 |
| 1,200 | 1,200 | 563 | 563 | 1.4184 | 1.4179 | 1.4170 | 1.4157 | 1.4135 |
| 1,251 | 1,251 | 563 | 563 | 1.4244 | 1.4235 | 1.4226 | 1.4212 | 1.4188 |
| 0 | 1,126 | 0 | 1,126 | 1.4104 | 1.4100 | 1.4091 | 1.4082 | 1.4062 |
| 400 | 1,200 | 0 | 1,126 | 1.4181 | 1.4179 | 1.4170 | 1.4157 | 1.4135 |
| 800 | 1,400 | 0 | 1,126 | 1.4424 | 1.4418 | 1.4408 | 1.4388 | 1.4358 |
| 1,126 | 1,600 | 0 | 1,126 | 1.4696 | 1.4685 | 1.4673 | 1.4651 | 1.4608 |
| 200 | 1,000 | 144 | 982 | 1.3920 | 1.3916 | 1.3908 | 1.3904 | 1.3887 |
| 400 | 1,000 | 192 | 934 | 1.3909 | 1.3906 | 1.3899 | 1.3895 | 1.3879 |
| 400 | 800 | 346 | 780 | 1.3736 | 1.3734 | 1.3731 | 1.3729 | 1.3720 |
| 600 | 1,200 | 83 | 1,043 | 1.4145 | 1.4141 | 1.4131 | 1.4120 | 1.4099 |
| 600 | 1,000 | 284 | 842 | 1.3903 | 1.3898 | 1.3891 | 1.3886 | 1.3872 |
| 600 | 800 | 438 | 688 | 1.3756 | 1.3753 | 1.3750 | 1.3746 | 1.3738 |
| 800 | 1,200 | 213 | 913 | 1.4112 | 1.4107 | 1.4098 | 1.4088 | 1.4068 |
| 800 | 1,000 | 409 | 717 | 1.3917 | 1.3913 | 1.3906 | 1.3902 | 1.3835 |
| 1,000 | 1,400 | 142 | 984 | 1.4366 | 1.4361 | 1.4350 | 1.4334 | 1.4305 |
| 1,000 | 1,200 | 367 | 759 | 1.4117 | 1.4112 | 1.4103 | 1.4093 | 1.4072 |
| 326 | 800 | 326 | 800 | 1.3730 | 1.3730 | 1.3728 | 1.3725 | 1.3716 |
| 1,159 | 1,400 | 300 | 826 | 1.4348 | 1.4342 | 1.4331 | 1.4315 | 1.4287 |

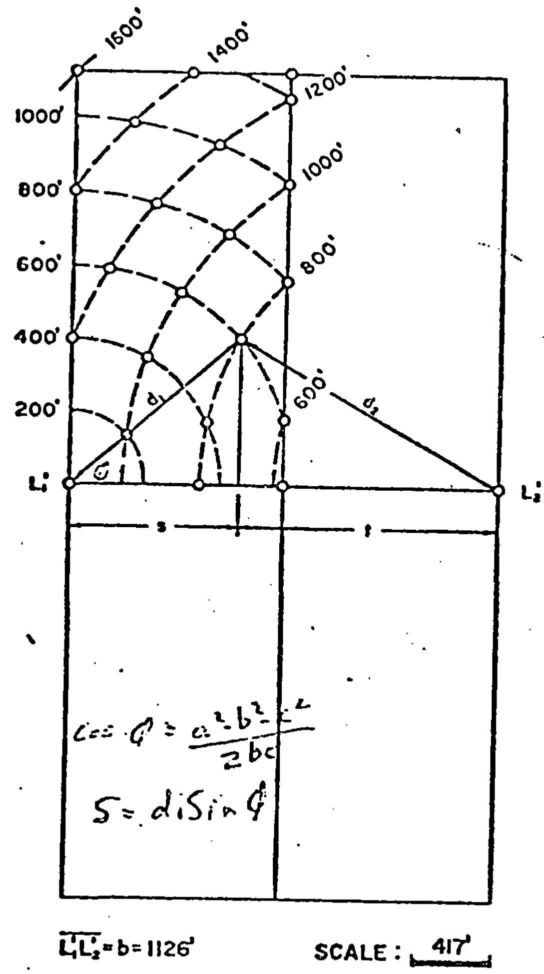



FIG. 3. Location of points on stereo model for which effective index of refraction $F$ is calculated.

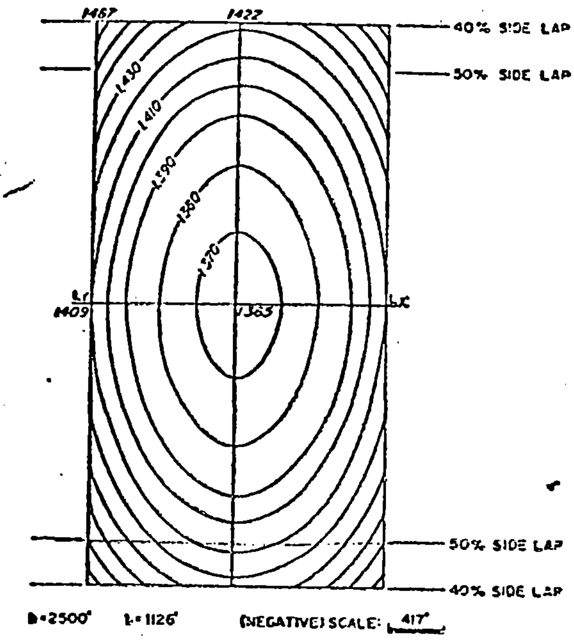



FIG. 4. Variation of effective index of refraction $F_{23}$ over stereo model.



**TABLE 3**

**DISTRIBUTION OF DEPARTURES OVER AREA OF STEREO MODEL**

| *Contour* | *h'(feet)* | Δ*(feet)* | Δ(%) |
|---|---|---|---|
| 1.467 | 36.68 | 1.43 | 4.1 |
| 1.460 | 36.50 | 1.25 | 3.5 |
| 1.450 | 36.25 | 1.00 | 2.8 |
| 1.440 | 36.00 | 0.75 | 2.1 |
| 1.430 | 35.75 | 0.50 | 1.4 |
| 1.420 | 35.50 | 0.25 | 0.7 |
| 1.410 | 35.25 | 0.00 | 0.0 |
| 1.400 | 35.00 | −0.25 | −0.7 |
| 1.390 | 34.75 | −0.50 | −1.4 |
| 1.380 | 34.50 | −0.75 | −2.1 |
| 1.370 | 34.25 | −1.00 | −2.8 |
| 1.365 | 34.13 | −1.22 | −3.5 |

Systematic departures of up to ±4% may be incurred if a single, median value for the effect. index of refraction is used for the whole stereo model.

**TABLE 4**

**SELECTED INDICES OF REFRACTION OF PURE WATER AND OCEAN WATER**

| | *0°C.* | *15°C.* | *25°C.* |
|---|---|---|---|
| pure water | 1.33402 | 1.33340 | 1.33250 |
| 1.477% Cl | 1.33453 | 1.33388 | 1.33299 |
| 10.476% Cl | 1.33774 | 1.33692 | 1.33595 |
| 19.227% Cl* | 1.34082 | 1.33985 | 1.33881 |
| 21.381% | 1.34158 | 1.34055 | 1.33949 |

* Average ocean water.

..ISSION

The process of photobathymetry uses aerial photography in stereo ..dels to facilitate the accurate plotting of the low water line, high water line, contours or spot elevations of land features, the delineation of navigable channels and random spot soundings and, where possible, the actual contours of the bottom. The final product is then combined with field hydrography to produce a nautical chart, and if the photobathymetry was compiled prior to field work, it is checked in sample areas for accuracy.

The basic breakdown of the complete process is in three segments, namely, flight planning and the flying of photography; aero triangulation of the flight lines; and finally, the actual plotting of the area using a stereo plotter. Omitted from these segments is the establishing and targeting of control, both horizontal and vertical.

All control must be targeted and if there is a definite lack of control, then it must be established and targeted prior to flying the photography. As usual, there are the field checking of data and the office quality control checks.

## FLIGHT PLANNING

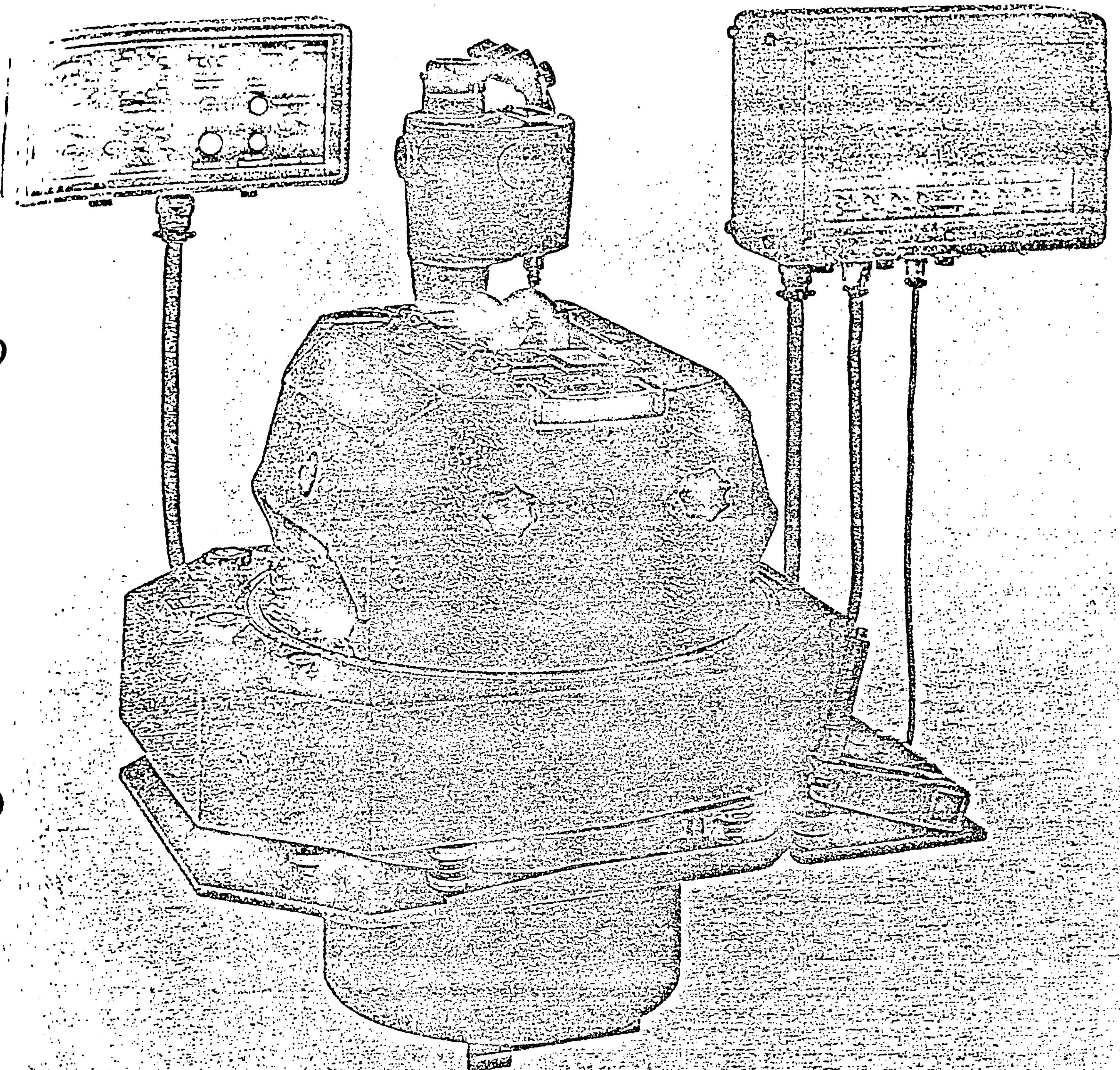
The primary purpose of the flight planners is to set up a series of flight lines over the work area such that there will be more than ample photography in the area to allow for stereo plotting. Standard topographic photography is flown at 60% forward overlap and 20% overlap between flight lines, which is more than sufficient to facilitate compilation. For photobathymetry, the requirements are greater, so that the forward overlap is usually at 80% and sometimes 90% with the side overlap at 60%. The need for this redundant photography is to be able to pick and choose photography to by-pass areas of sun spots on the water surface. Another special feature used is to have pin-point photography taken such that in the planning stage it is possible to have sufficient objects in the photography to allow good relative and absolute orientation of the stereo models.

The type of film to be used in the area is also specified at this time, if colour photography is to be used, then black and white infrared photography must also be taken concurrent with the colour photography. When false colour infrared film is used it does not need any supplementary photography as the processing laboratories can produce a black and white sliced photograph to show the water level.

The slicing process of the photography is such that a minus blue filter is used and this filter cuts off all water penetration in the reproduced photography.

Before the photography can be flown, there has to be a tidal study in the area to allow for the photography to be tide-related. The manner in which the photography is controlled is to have all the tide gauges manned and having radio contact with the aircraft to tell the pilot when he can fly the photography in each area, either to obtain the high water line or the low water line. In this manner, it is possible to know the tide level in the area such that the person plotting the stereo model knows what depth he is actually observing.

WILD RC10 UNIVERSAL FILM CAMERA



A special feature is the computation of the sun spot position relative to the photograph. The reason for this is to obtain photography with the best sunlight possible and the least amount of sun glare from the water.

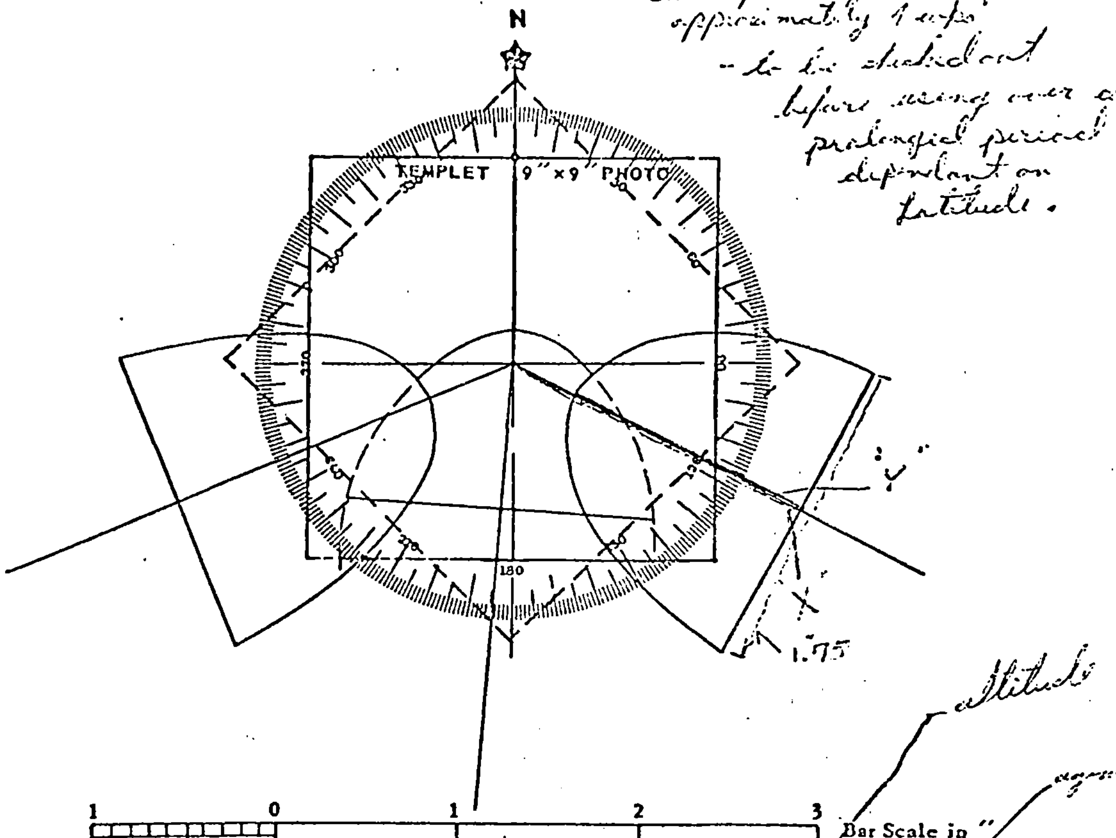
In conjunction with the sun problem, the stage of tide is critical in such a way that the photography can only be flown at the time of the month when the tide is low or high, as desired, and the sun's glare is minimal. Sometimes, it might be necessary to postpone flying for one or two weeks before ideal conditions exist.

The most important requirement is to have very calm water conditions, meaning very little or no wind, and preferably at least 12 hours after a rain to allow the land to dry off and any sediment to settle. In the case of dry land, the infrared photography will not show features that are water covered, even if it is only a coating of rain water.

| DATE | FORM C&GS-6317 (8-62) | U.S. DEPARTMENT OF COMMERCE COAST AND GEODETIC SURVEY |
|---|---|---|
| 20th Sept. 1962 | | |
| LOCALITY | | **SUN SPOT COMPUTATION** |
| Mississippi Delta | | |

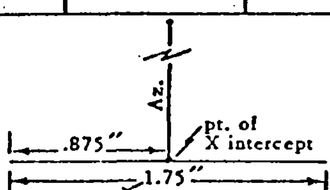
REMARKS:

- all periods are relatively the same for a period of approximately 1 wk.
- to be checked out before using over a prolonged period dependent on latitude.




| ST | ST $^{+W}_{-\not E}$ (zone diff) GMT | Nautical (or Air) Almanac GHA (Sun) | Dec. N/~~S~~ | Sight Reduction Tables H.O. Pub. No. 249 GHA $^{-W}_{+\not E}$ (Long.) LHA | $H_c$ | $Z_n$ | Formulae $X=1.5 \cot H_c$ | $Y=\frac{.875}{\sin H_c}$ |
|---|---|---|---|---|---|---|---|---|
| h | h | ° | ° | ° | ° | ° | " | " |
| 0900 | 1500 | 47 | 01 | 317 | 40 | 117 | 1.8 | 1.4 |
| 1200 | 1800 | 92 | 01 | 02 | 62 | 184 | 0.8 | 1.0 |
| 1500 | 2100 | 137 | 01 | 47 | 37 | 247 | 2.0 | 1.5 |
| | | | | | | | | |
| | | | | | | | | |

| Standard meridians | Zone diff |
|---|---|
| E.S.T. - 75° W | $5^h$ |
| C.S.T. - 90° W | $6^h$ |
| M.S.T. - 105° W | $7^h$ |
| P.S.T. - 120° W | $8^h$ |




| Location of photography | |
|---|---|
| Longitude | Latitude |
| 90° W/~~E~~ | 29° N/~~S~~ |

Notes: 1. X - gives distance in inches to X intercept.
2. Y - gives distance in inches from X intercept to Y intercept.

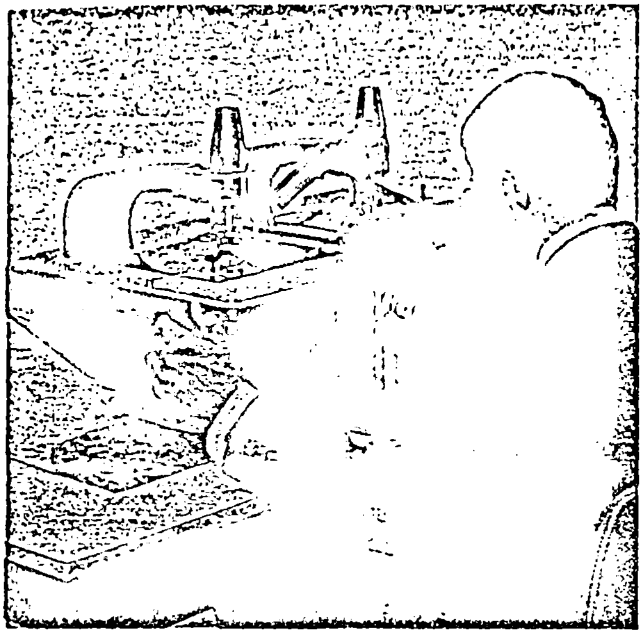
## TRIANGULATION

The purpose of this section is the selection of usable photography for the area, and establishing control points in each photograph to allow precise levelling and scaling of the stereo models.

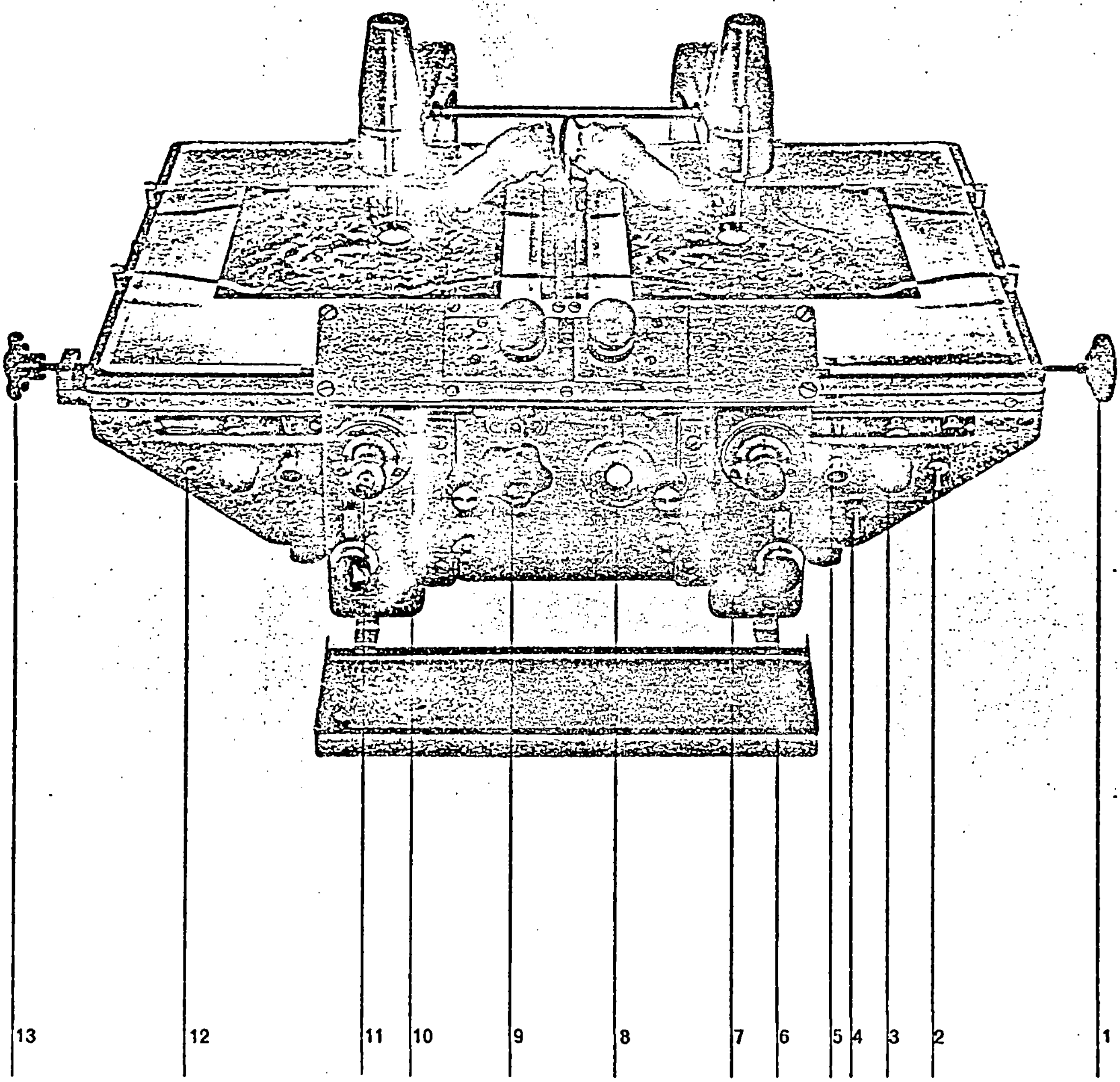
Each photograph used in the job must contain three pass points that are visible in three consecutive photographs, along with shoreline points, horizontal and vertical positions if they appear on the photography. Any control point appearing in the central area of the photograph is marked permanently on the diapositive, along with a coloured mark and code number on the contact print. The manner in which these marks are made is by drilling a small hole in the emulsion of the diapositive; the drill is approximately 6 microns in diameter. The instrument used to make these drill holes is used so that the operator is looking at a stereo model. Through manipulation of the instrument, he is able to put the floating point of the instrument on the surface in the 3 dimensional sense. Having placed the floating point mark on the surface the drill is activated and in this way the hole is made.

When the photographs have been selected and the control points have been drilled on the diapositive the next step is to obtain the relative positions of these points in a stereo-comparator. A stereo model is set in the instrument and the position of each control point is determined precisely and the values are recorded on a teletype. The data is also punched out on computer cards. After the control points are obtained, the four or eight fiducial marks of the photographs are measured and recorded.

When the strip of photography has been finished, the punched card data along with the known positions also on punched cards are run in a computer program and an adjustment is made to best fit the existing known control. When the print-out is returned, it is possible to see where the control is bad or the control marker has been moved, which does happen. For a good adjustment, the variance of the measured to actual positions is generally to less than one foot both horizontally and vertically.



1 Δx-motion, right
2 Switch for illumination of the diapositives for fine setting and drilling
3 Potentiometer for variable illumination
4 Main switch
5 Drilling button
6 Enlargement
7 Focussing
8 Δy-motion, right
9 y-motion
10 Optical image centring
11 Dove prism control
12 Switch for illumination of the diapositives for initial orientation
13 x-motion






WILD PUG 4 POINT TRANSFER DEVICE

The central positions need not be on land, if it is possible to see and define points on the bottom these can be used to extend control in the area. At present, there is a job in the Florida Keys being processed where the majority of the control being used in the photography is underwater.

After all the photography has been bridged by aerotriangulation, the positional data is used to produce a field sheet showing all the control positions that are now known. These plots are used to control the separate stereo models in the orientation to allow accurate plotting of shoreline, prominent features, depths and contours of the bottom.

# POINT NUMBERING FOR AEROTRIANGULATION

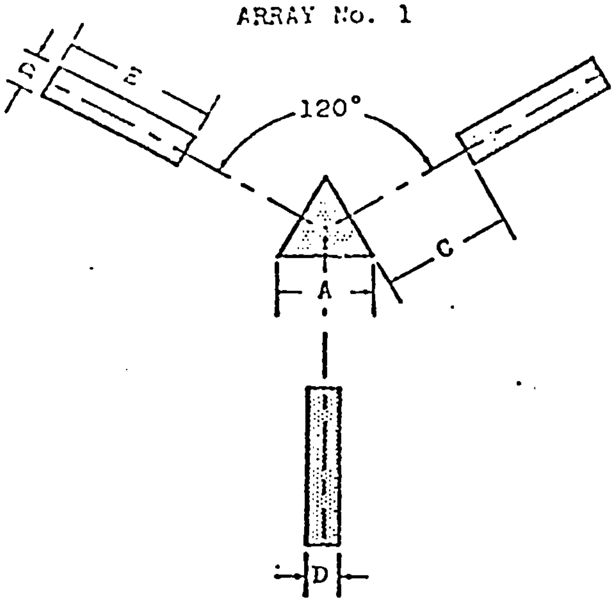
## GENERAL

| | |
|---|---|
| 100 | Horizontal Control Points |
| 200 | Vertical Control Points |
| 300 | Pass Points |
| 400, 500 | Points to be located for position, e.g. Landmarks and Aids |
| 600 | Points for ordering ratio prints |
| 800 | Tie Points between strips |
| 900 | Points established for setting models |

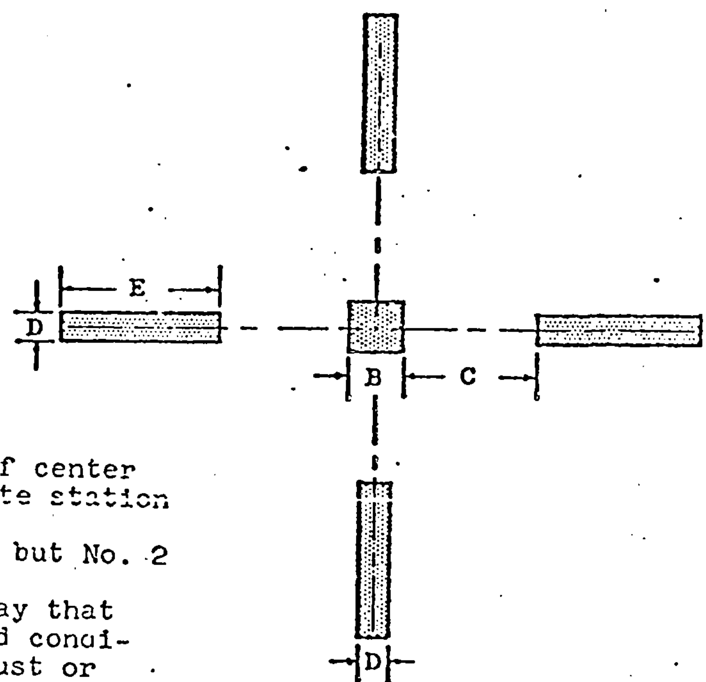
| TYPE | SYMBOL | NUMERICAL CODE |
|---|---|---|
| **Bridge Points** | | |
| Wing Points | □ | — — — 310, 311; 320, 321 |
| Center Point | □ | — — 330, 331 |
| Supplemental | □ | — — 312, 322, 332, etc. |
| Photo Center | ◎ | — — 300 |
| Tie Points | ⬡ | — — 801-up |
| **Horizontal Control** | | |
| Field | | |
| Home Station | △ | — — 100 |
| Substation | △ | — — 101-109 |
| Office Identified | △ | — — 110-up |
| **Vertical Control** | | |
| Field | ⊕ | — — 201-9 |
| Office | ⊕ | — — 211-9 |
| Non-identifiable | ○ | — — 211-9 |
| **All Other Points** | ○ | — — 01-up |

NOTE: The first two digits of the Point Number are the last two digits of the Photo Number; the center of which is nearest the point. In this case, the Point Number is a five digit number. When necessary, to avoid confusion or duplication of numbers, photos are re-numbered in the bridge. In rare cases, where the number of photos exceeds 100 in a project, the Photo Number is increased to a six digit number.

ARRAY No. 1




ARRAY No. 2




NOTE:
1. The dimensions and centering of center panel over station or substitute station are critical.
2. Panel array No. 1 is preferred but No. 2 is acceptable.
3. Chief of party will select array that makes best application of field conditions and is authorized to adjust or omit one of the recognition panels if terrain is not suitable for placement of entire array.
4. Recommendations for target materials to be used for various terrain and photographic conditions are given in Photogrammetry Instructions No. 22, Revision 3.

PANEL AND SPACE DIMENSIONS

(in meters)

| Photo Scale | A | B | C | D | E |
|---|---|---|---|---|---|
| 1:10,000 | 0.5 | 0.3 | 1.3 | 0.2 | 0.9 |
| 1:20,000 | 1.1 | 0.7 | 2.6 | 0.4 | 1.8 |
| 1:30,000 | 1.6 | 1.0 | 3.9 | 0.5 | 2.7 |
| 1:40,000 | 2.2 | 1.3 | 5.2 | 0.7 | 3.6 |
| 1:50,000 | 2.7 | 1.6 | 6.5 | 0.9 | 4.5 |
| 1:60,000 | 3.2 | 2.0 | 7.8 | 1.1 | 5.4 |
| 1:70,000 | 3.8 | 2.3 | 9.1 | 1.3 | 6.3 |
| 1:80,000 | 4.4 | 2.6 | 10.4 | 1.4 | 7.2 |

STEREO PLOTTING

The job of plotting the data from the stereo model is the final step to the actual finished field sheet for the area under study.

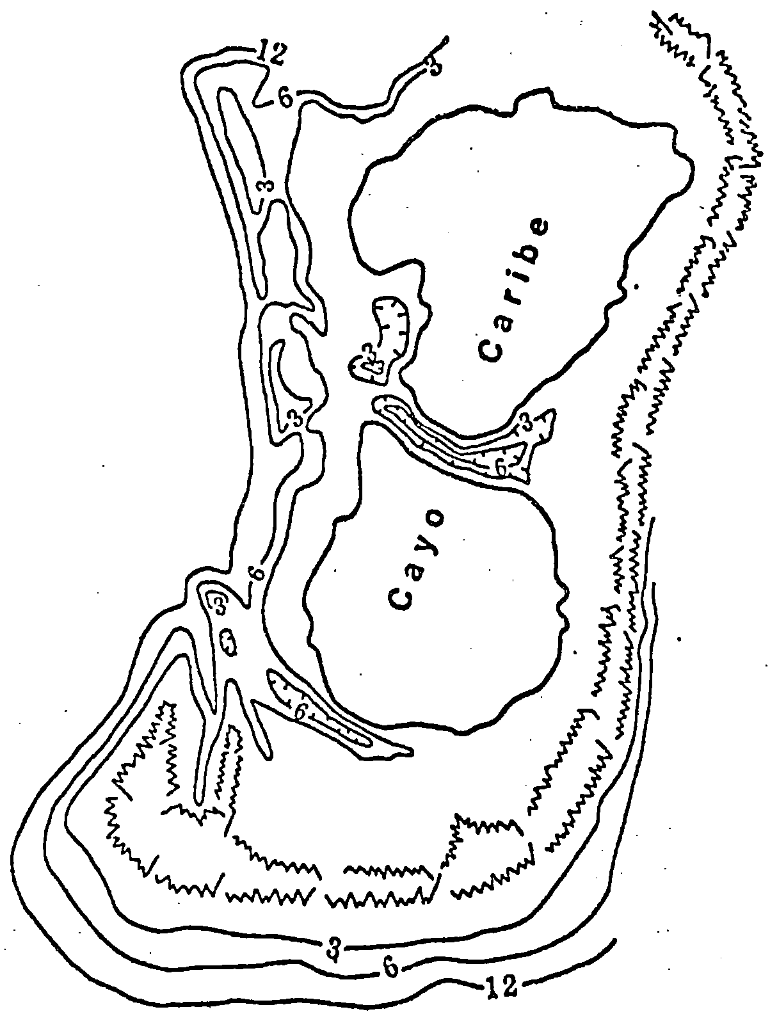
Basically, it is the same as the topographic plotting that is carried out to produce shoreline for field sheets or to produce topographical maps. Depending upon Project Instructions, the amount of data shown on land will vary; as to show the shoreline and high points, it is possible to go as far as showing relief of the area with contours and random spot elevations. Once this has been accomplished from the stereo model, the work of showing the depths begins.

To give an accurate depth from the photography, it is necessary to read the apparent depth of the position to the closest decimetre, then multiply this value by the correction factor of refraction. Another factor to be applied is the actual correction to elevation read which is obtained from the calibration graph for the plotter being used. If the refraction factor is close to being constant throughout the model, it is possible to use the plotter to draw the actual contours of the bottom.

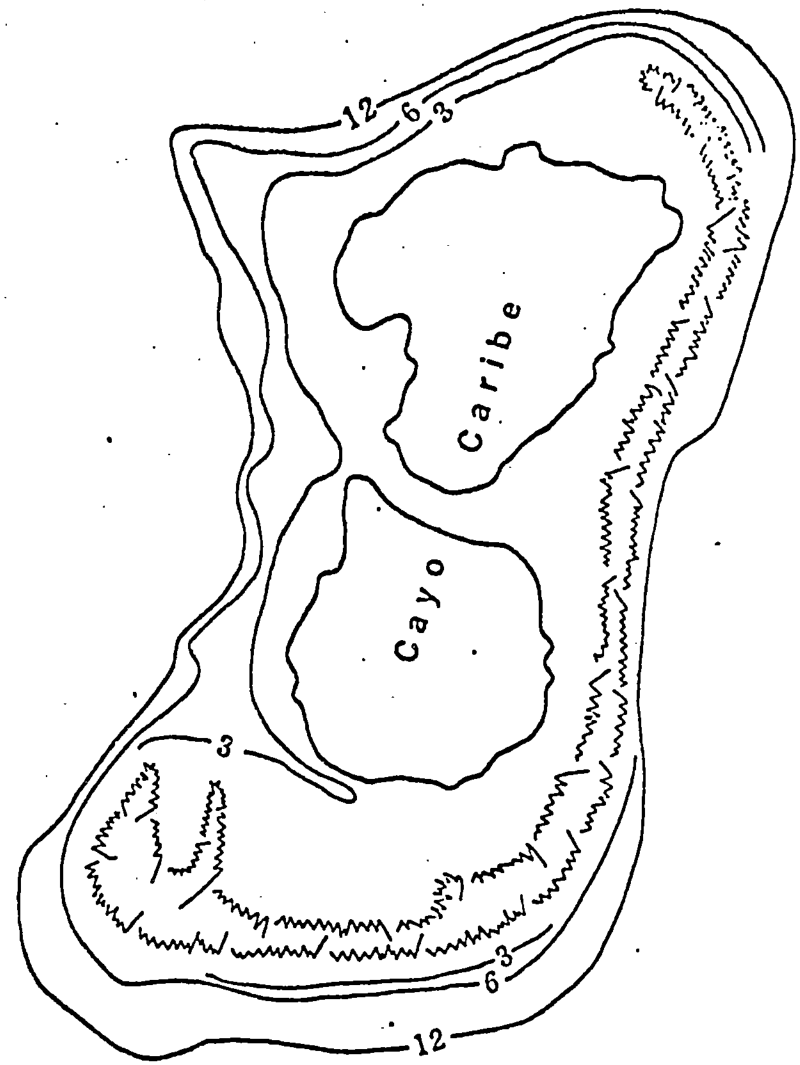
While doing the underwater work, the hardest areas in which to obtain accurate depth readings are gently sloping areas where there is a lack of colour tone variations or any object actually on the bottom. Under this criteria, it is impossible to read depths on a flat area whether it be sand or mud so long as there are no objects or differences in tone of the bottom to give depth-perception.

Thus far, there have been specific areas omitted to give an easy breakdown of the type of work required to produce an accurate final manuscript.

The photographic principles used in processing the film; being the contact prints and diapositives; are very critical as a film that is poorly developed is useless and of no value. The diapositives used must be perfectly developed because if there is any emulsion shift on the plate it is absolutely useless for plotting. The black and white infrared photography must be developed in such a way as to give a clear hard line between the water surface

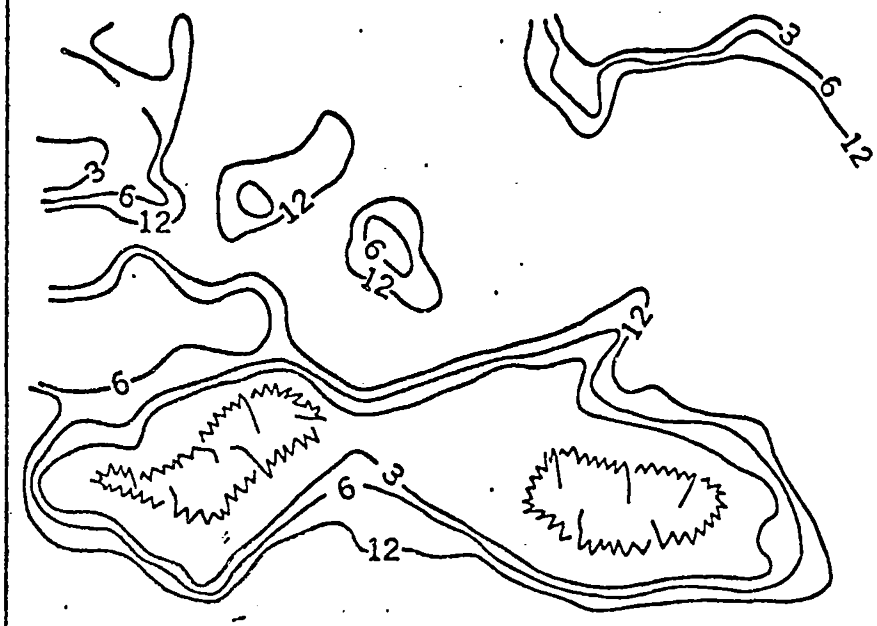



DEPTH CURVES BY PHOTOGRAMMETRIC METHODS




DEPTH CURVES BY CONVENTIONAL METHODS


DEPTH CURVES BY PHOTOGRAMMETRIC METHODS

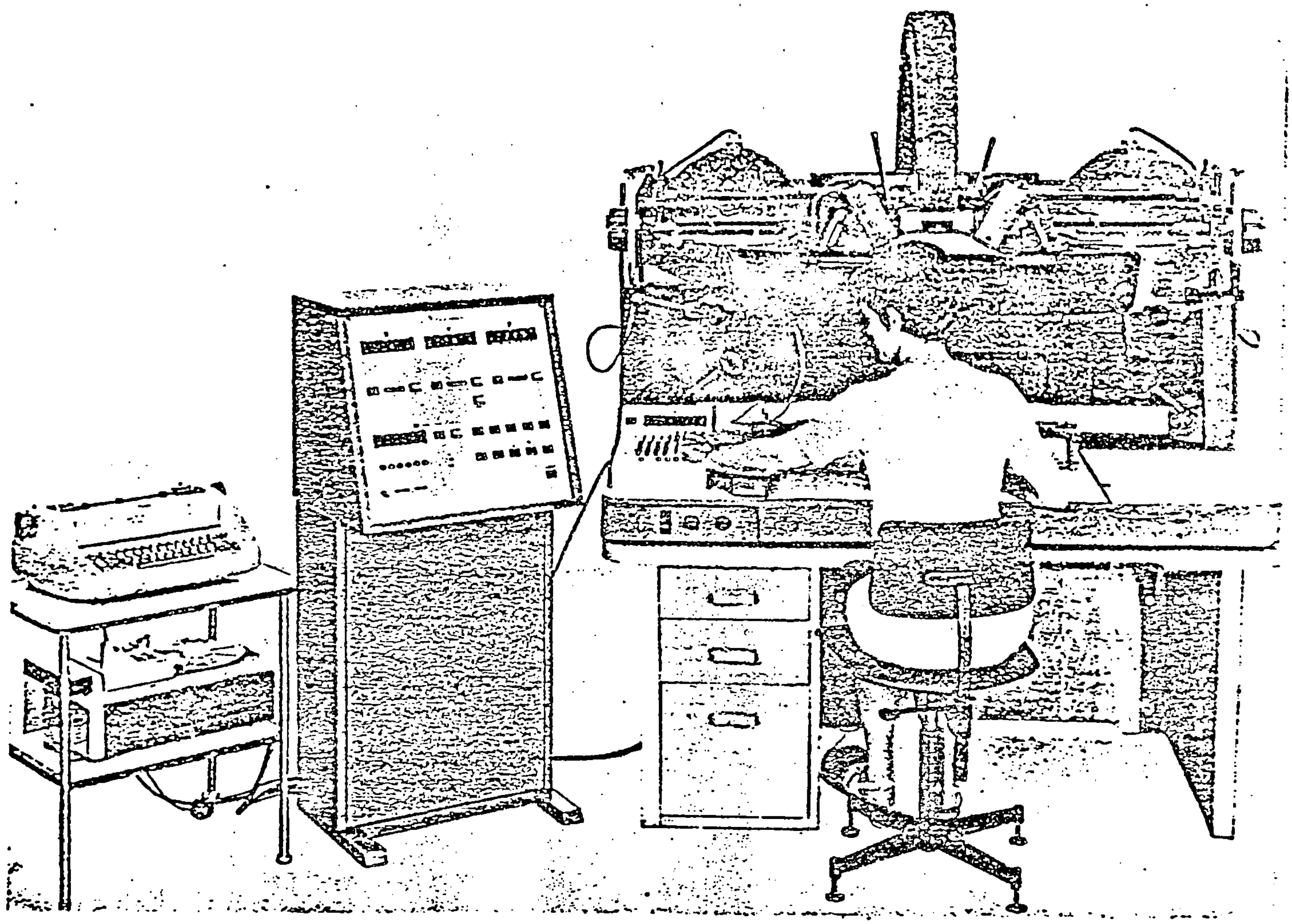



DEPTH CURVES BY CONVENTIONAL METHODS

and the shore to allow for an accurate drying line to be shown. Ratio prints must be very close to the desired scale as they are used to check the final product - the shallow water field sheet.

Regarding the exact procedures used in the developing process, these are similar to all places where photography is processed, except for the slicing of photography to blank out all water penetration.

*Wild B8S Aviograph with Wild EK8 Coordinate Recording System, tape punch and IBM typewriter.*



## CALIBRATIONS

The most important part of the whole procedure of photobathymetry is to know the calibration values of every instrument used in the work.

The aerial cameras used are very accurately calibrated to ±1 micron; the values that N.O.A.A. use are the three asymetrical values for the camera and the focal length of the lens, including the distortion values of the lens. The actual values of the distortion are measured every millimetre from the optical center of the camera to the corner, it was then decided that between these values the curve was assumed to be linear.

The stereo comparators are calibrated using a grid plate whose values are known to 2 microns. The calibration of a stereo comparator is a long process where the values for each point on the grid plate are observed at least four times in four separate rotations by at least two operators. In this manner, the error of the human element is hopefully compensated for in the random errors of pointing.

With the calibration of the camera and stereo plotter, it is possible to obtain accurate results from the aerotriangulation of the photography.

The stereo plotter is also calibrated for each focal length that will be used for production work. The principle used is to observe two grid plates in stereo and read the elevation of a series of grid intersections five times. From the data recorded it is possible to mathematically level the plates and from the resultant values derive a graph that shows the error of the observed elevations. The values derived are then checked to determine the accuracy of the plotter at plate scale.

Once the calibration has been proven good, a plot is made at the scale of the instrument plotting table so that when the elevations are read it is possible to apply the elevation correction at the same time as the refraction correction.

```
C
C      CAMERA CONSTANTS-1968 NEW FIDUCIAL COORDINATES ADOPTED JULY 72
C
       DATA                     (CAMCON=+1.0,0.0,0.0,+0.15271,
      11.,+.10599868,+.10600075,         2.,+.10600070,-.10599814,
      13.,-.10599607,-.10599814,         4.,-.10600755,+.10599898,
      15.,-.00001476,+.11000200,         6.,+.11000461,-.00001125,
      17.,+.00000905,-.11000889,         8.,-.11001294,+.00000566,
      1 -150.0, -150.0, -150.0, -150.0, -150.0, -150.0, -150.0, -150.0,
      1 -150.0, -150.0, -150.0, -150.0, -150.0, -150.0, -150.0, -150.0,
      1 -150.0, -150.0, -150.0, -150.0, -150.0, -150.0, -150.0, -150.0,
      1 -147.9, -148.0, -148.1, -146.3, -146.4, -144.8, -145.0, -143.5,
      1 -143.8, -142.4, -141.2, -141.4, -140.3, -139.2, -138.2, -135.9,
      1 -133.8, -131.7, -128.6, -125.6, -122.7, -118.9, -115.2, -111.7,
      1 -108.3, -105.1, -101.0,  -97.1,  -93.3,  -89.6,  -86.1,  -82.7,
      1  -79.5,  -75.4,  -72.4,  -69.5,  -65.8,  -62.3,  -59.7,  -56.3,
      1  -52.3,  -50.0,  -46.2,  -42.5,  -39.7,  -36.2,  -32.9,  -30.3,
      1  -27.1,  -24.0,  -20.9,  -18.0,  -15.1,  -12.3,   -9.6,   -7.0,
      1   -4.4,   -1.9,    1.2,    3.6,    6.0,    7.6,    9.5,   12.1,
      1   14.2,   15.7,   17.8,   19.8,   21.7,   23.7,   25.0,   26.8,
      1   26.1,   29.9,   31.1,   32.8,   34.0,   35.1,   36.3,   37.4,
      1   38.5,   39.0,   39.6,   40.2,   40.7,   40.8,   40.9,   41.0)
       DATA(CAMCO1 =
      1   40.6,   40.3,   39.9,   39.1,   38.4,   37.2,   36.0,   34.9,
      1   33.3,   32.2,   30.7,   29.7,   28.2,   26.8,   25.4,   24.0,
      1   22.5,   20.5,   19.2,   17.2,   14.6,   12.4,    9.7,    7.0,
      1    4.0,    1.1,   -2.5,   -6.5,  -10.7,  -14.9,  -21.1,  -27.6,
      1  -34.7,  -42.4,  -50.0,  -59.9,  -70.9,  -83.2,  -94.0,
```

Shown above are the

- 3 camera constants, and the camera focal length.
- the positions of the eight fiducial marks in the camera.
- the 151 values for the radial distortion correction.

This data is shown as it is listed in the aero-triangulation adjustment program.

```
                    COMPARATOR NUMBER  3 CALIBRATION
                         OPERATOR NUMBER  1
                     DATE OF MEASUREMENT 7/17/72
                     GRID AND CASE NUMBER   1320
                         CALIBRATION SUMMARY
          ANALYSIS OF VARIANCE
  X      Y
2.355  2.620  2.491 = ROOT MEAN SQUARE ERROR OF A SINGLE OBSERVATION OF UNIT WEIGHT BEFORE CALIBRATION

1.481   .978  1.255 = STANDARD ERROR OF A SINGLE OBSERVATION OF UNIT WEIGHT AFTER LINEAR ADJUSTMENT

 .934   .935   .935 = STANDARD ERROR OF A SINGLE OBSERVATION OF UNIT WEIGHT AFTER LINEAR AND NON-LINEAR ADJUSTMENTS

 .339   .297   .319 = STANDARD ERROR OF MEAN POINTING MEASUREMENTS

               .249 = A PRIORI STANDARD ERROR OF MASTER GRID 1320

               .228 = COMPUTED UNBIASED STANDARD ERROR OF MASTER GRID 1320

              2.151 = STANDARD ERROR OF SYSTEMATIC LINEAR ERRORS

               .837 = STANDARD ERROR OF SYSTEMATIC NON-LINEAR ERRORS

               .843 = STANDARD ERROR OF RANDOM (IRREGULAR) COMPARATOR ERRORS


       ADJUSTED COMPARATOR CALIBRATION PARAMETERS FROM THE SIMULTANEOUS SOLUTION OF  4 CASES

                              LINEAR PARAMETERS

                   PARAMETER VALUE        SIGMA                          VARIANCE-COVARIANCE MATRIX
            SCALER X =  9.9999522E-01   1.77563146E-06        SCALER X          SCALER Y            ALPHA
            SCALER Y =  9.9997765F-01   1.77558250E-06     3.15286707E-12    2.66515238E-20     4.13617816E-16
NON-ORTHOG. ANGLE ALPHA =   0  0 10.210    0  0    .5180                        3.15269323E-12     4.13610068E-16
   SCALER RATIO SX/SY =  1.0000176E+00                                                             6.30568105E-12

                 SCALERS IN MICRONS/METER
            SCALER X =      -4.7809          1.7756
            SCALER Y =     -22.3478          1.7756
               SX/SY =      17.5674


                              NON-LINEAR PARAMETERS
     NON-LINEAR CORRECTION COEFFICIENTS FOR X

     A               B               C               D               E               F               G               H               J
1.16561736F-02-3.91230146E-03-4.73651214E-03 2.49033847E-03 7.76495331F-04-5.02147551E-04-7.25123955F-05 3.34591998F-05 1.94338808F-06

     NON-LINEAR CORRECTION COEFFICIENTS FOR Y

     A               B               C               D               E               F               G               H               J
-5.59099411F-03-5.97474242F-03 2.22254828E-03 3.34345790F-03-1.87751317F-04-6.27374361E-04-8.29255365F-06 4.47734009E-05-3.14622986F-07
```

FIGURE 30. – Output summary of a complete comparator calibration.



OUTPUT FROM STEREO-COMPATATOR CALIBRATIONS

these values are used in the aero-triangulation program to reduce error.

# MODEL DEFORMATION TEST

Plotter 1132

Operator Fromm

Date 2/19/75

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 100.1 | 100.1 | 100.0 | 100.0 | 100.0 | |
| 2 | 100.0 | 100.0 | 100.0 | 99.9 | 99.9 | |
| 3 | 100.0 | 100.0 | 99.9 | 99.9 | 99.9 | |
| 4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | |
| 5 | 100.0 | 99.9 | 100.0 | 100.0 | 100.0 | |
| 6 | 100.1 | 100.0 | 100.0 | 100.1 | 100.1 | |
| 7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | |
| 8 | 100.0 | 99.9 | 99.9 | 100.0 | 99.9 | |
| 9 | 100.1 | 100.0 | 100.0 | 100.0 | 100.1 | |
| 10 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | |
| 11 | 100.0 | 100.0 | 100.0 | 100.1 | 100.0 | |
| 12 | 100.1 | 100.0 | 100.0 | 100.0 | 100.0 | |
| 13 | 100.0 | 99.9 | 100.0 | 100.0 | 100.0 | |
| 14 | 100.0 | 100.0 | 100.1 | 100.0 | 100.0 | |
| 15 | 100.0 | 100.0 | 100.0 | 99.9 | 100.0 | |
| 16 | 100.0 | 100.0 | 100.0 | 100.0 | 100.1 | |
| 17 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | |
| 18 | 100.0 | 100.0 | 100.0 | 99.9 | 100.0 | |
| 19 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | |
| 20 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | |
| 21 | 99.9 | 99.9 | 99.9 | 99.9 | 99.9 | |
| 22 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | |
| 23 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | |

Datum Warpage
1-3-(21-23)

1-21-(3-23)

Line
1-Mean of 5 readings

2-Level correction ⊥ to line of flight and along the line of flight

3-$\omega$ correction
a-Translate corner elevations to 3=0
b-$\omega = \frac{1}{4}(21-1-23)$
c-Add $2\omega$ to 1 and 23
d-Points along diagonal 3-21 receive no correction. Other points receive a correction according to distance from the diagonal 3-21

4-Lens distortion correction if needed. If real photography is used, then an earth curvature correction is needed.

5-Sum lines 1 thru 4

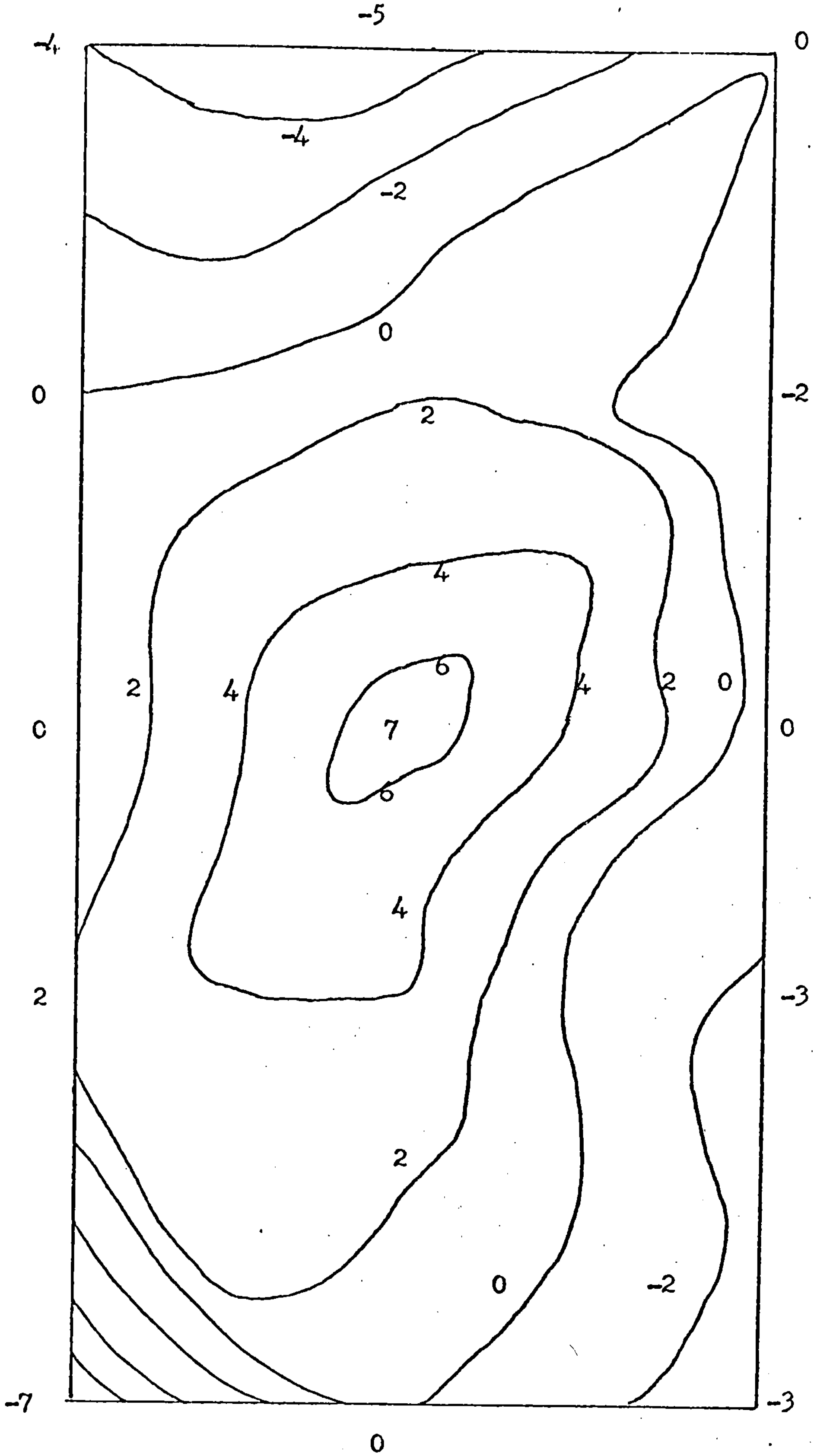
6-Common plane = $\Sigma$ line 5/23
C.P. =
Deviation from C.P. equals line 6

$$\sigma = \sqrt{\frac{\text{error}^2}{22}} = \sqrt{\frac{\qquad}{22}}$$

$\sigma_m$ = .003 mm. @ model scale

$\sigma_p$ = .001 mm. @ plate scale

$\sigma_p/f = 1/$




Sample of Calibration Graph for a B 8 plotter
Values derived from Model Deformation Test

## SYNOPSIS

The field of photobathymetry is as yet a new field with all the advancements being made within the last five years. The advantage of this program is that there are continuing improvements in the process all the time. The N.O.A.A. office in Rockville is starting to approach the plotting corrections under the possibility of having digitized plotters and automatic computer corrections to the data.

The future of this type of work is unlimited so long as there is depth penetration into the water. It may be feasible to compile large areas and have a minimum of Hydrographic work in the area. If it could be possible to have enough time before a Hydrographic party started work in an area, the shoreline and all the photobathymetry could be plotted and ready for the field party. This being possible it would be unnecessary to have the launches going into the shallow areas. The amount of lost time due to launch damage and the problems of surveying the shallow areas would be at a minimum.

With this program it is possible to compile accurate data for other applied fields with reference to Aquatic Affairs. Two major fields have had studies done to ascertain the usefulness of this system.

One example of the work is the ability to compile current information in an area using floating markers and having the aerial photography. Using this technique would require the aircraft to be flown over the study area at specific increments of time. The clock in the camera can give the time of exposure, and the stereo model will give accurate horizontal positions.

A second example of an applied field is the use of aerial photography for the study of waste dispersal in water. A case where this was accomplished was in the area off New York Harbour where chemical wastes were dumped at sea. The study was carried out by having two ships in the area to give positions to the photographs. A series of photographs were taken at set time intervals over the area. Produced from this photography was a series of overlays delineating the extent of the dispersion of the waste materials. Using this principle, it would be possible to determine any adverse effects in the local vicinity.

The present program of Photobathymetry is actually in its infancy. The applied uses for this program are expanding as the mathematical formulae are being derived and proven.

When the system was first comprehended, it advanced at a very slow rate of progress, until the operators actually began to understand the process. Modifications to the computer programs are being made to improve and speed up the actual computations. As more theories are applied to the program, it could be possible to set the system such that there will be a minimum of physical operator time to produce a maximum of output.

The usefulness of this system is relative to the type or specific character of the work to be compiled as such in stereo models. The most apparent application is to produce a field sheet showing all the shallow water areas and hazards to navigation that are visible in the photography. If an area was to be surveyed to produce a chart that would be used only by shallow draft vessels, tourist trade, it could be possible to delineate all shallow areas to an extent to facilitate the safe navigation of shallow draft vessels throughout the area.

Establishing a section, similar to the N.O.A.A. Photobathymetric Section, could prove beneficial over a period of time for the production of shallow water field sheets. The production of these sheets can be accomplished year round so long as there is adequate photography readily available. The second stage - the actual hydrographic survey - could then be accomplished in a shorter period of time, with the possibility of saving repair costs to the survey launches.

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| | |
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