PROGRESS REPORT

J.N. GREEN

ARCG GRANT A77/15780

Investigation of 17th Century Shipbuilding Techniques and methods of recording these ship structures

Report - Department of Maritime Archaeology, Western Australian Museum, No. 16

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Maritime Archaeology
Western Australian Museum
FREMANTLE WA 6160
March 1980

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A. INTRODUCTION

The objectives of this study are, firstly to investigate existing 17th century ship structures in order to learn more about the methods, techniques and properties of such structures, and secondly, to develop methods of recording such structures underwater. This report is divided into two parts dealing with these two separate studies.

The investigation of ship structures has been most successful. Four major 17th century ship structures have been recorded to date: the V.O.C. (Dutch East India Company) ship Batavia, lost off the Western Australian coast in 1629; the Portuguese ship Santo Antonio de Tanna, lost in Mombasa Harbour (Kenya) in 1697; the Kedelhaven ship E81, lost in the Iselmeerpolder, Holland, in the mid 17th century; and the Sweedish warship Wasa, lost in Stockholm Harbour in 1629.

The analysis of the records of these ships are in varying stages of progress. In the Batavia study, a 1:10 scale model is under construction, all the structure has been recorded, catalogued and drawn up, and detailed plans are about to be produced. The Santo Antonio de Tanna plans are almost complete, and should be ready for publication later this year. Detailed analysis of the Kedelhaven ship and the Wasa await study, which will be undertaken as time permits.

In the investigation of recording ship structure two separate methods have been developed, one based on classical surveying techniques, the other on photogrammetry. The classical surveying technique utilises cross sectional profiles of the structure, which are then transformed into the three major naval architectural projections of sheer plan, half-breadth plan and body plan. The two former plans are faired, and then transferred to a new body plan. This technique has been used on the Santo Antonio de Tanna quite successfully.

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PROGRESS OR FINAL REPORT

Chief Investigator(s) (1) J.N. GREEN

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Department MARITIME ARCHAEOLOGY

Institution WESTERN AUSTRALIAN MUSEUM

Project title

RESEARCH INTO 17TH CENTURY SHIPBUILDING TECHNIQUES

Indicate the years of A.R.G.C. support for this project 1978, 1979, 1980

Do you intend applying for a grant for this project next year? YES/~~NO~~

Have you previously supplied a progress report of this form ~~YES~~/NO Year

	Year	Personnel	Equipment	Computer Charges	Maintenance	Travel	Total
		$	$	$	$	$	$
Summary of A.R.G.C. support granted for the period covered by this report.	19 78	nil	3050	nil	1998	7400	12448
	19 79	6000	nil	nil	900	6400	13300
	19 80	5000	7000	nil	600	nil	12600

INSTRUCTIONS FOR THE COMPLETION OF THIS REPORT

A) Enter the information sought in the above sections of this form.

B) The information requested under the headings set out below should be provided on the following pages of this form; *your report should be set out in sections, numbered to correspond with these headings.* Copies of any publications arising from the project, which have not previously been forwarded to the Committee, should be attached to this report.

1. What were the original aims of the project? How far have they been achieved? How long will it take to complete the project? In what ways, if any, have the aims been modified as the project proceeded?
2. Discuss any difficulties which have been encountered in carrying out the project. Have they been overcome?
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When completed this form should be sent as soon as practicable to the Secretary, Australian Research Grants Committee, Department of Science and the Environment, P.O. Box 449, Woden, A.C.T., 2606. If you intend applying for a grant for this project for the coming year this form should be attached to your application and the information supplied in this report need not be repeated in the application.

TK 39
Jan 79

Supply in the space provided below and on the following pages, the information sought in section B of the instructions on page 1.

NOTE TO ASSESSORS The Committee requires that applications for the fourth year of support must be accompanied by a Progress Report so that they can be assessed in time for the beginning of the fourth year. You should therefore bear in mind, when assessing this Report, that it is based upon only a little more than *two years* work.

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(1) .... Date ....
Signature of Chief Investigators (2) .... Date ....
(3) .... Date ....

on each photograph, it is possible, on a computer, to determine the orientation parameters of the two cameras. With this information, using a standard and quite simple analytical approach, three dimensional coordinates of features in the photographs can be obtained. The computer program is in a development stage, but $\pm$2.5% accuracy has been achieved so far. These are exceedingly promising results.

The second approach utilises a stereo tower and stereo bar. In this case the orientations of the cameras are aligned, in such a way as to give the optimum results. This, together with a rigid tower, gives a fixed and constant height, allowing a variety of simple analytical approaches, and reduces errors due to orientation distortions. The system has been tested with known test objects and has given results in the order of $\pm$0.1% for heights and $\pm$0.02% for horizontal distances in a Wild B8 stereo plotter. These results indicate that the accuracy limitation is in the plotting instrument rather than the camera system. Plans are underway to produce a stereotope or stereocoordinator, linked to a small computer to operate in field conditions.

As part of this project, a number of other techniques have been developed which are discussed below.

B. SHIP STRUCTURES

1. Batavia

From 1973 to 1976 a total of four expeditions were mounted to the site of the V.O.C. ship Batavia. During the excavation about one third of one side of the ship was recovered; this consisted of half of the stern and about 10m of the side of the ship. Due to the conditions on the site, it was not possible to record the structure of the ship *in situ*. Therefore tracings of the timbers, together with photographs were used as the prime method of recording structure. These plans have served two purposes. They provide a series of profiles of the structure, obtained from the curvature of the outer surface of the frames. It is planned to produce a body plan for these frames and then project the sheer-and half-bredth plans. This part of the project is just about to start. It is unclear exactly how successfuly this approach will be, but results are expected within the next month. The second approach is via a model. Here timber plans are used to construct 1:10 models of each individual piece of timber. These are then fitted together to produce a scale model of the whole structure. An initial pilot model was constructed by Mr R. Steffy of the Institute for Nautical Archaeology, at College Station, Texas. This author visited the institution in 1979 as part of a study leave project, sponsored by the Western Australian Museum. There, techniques and methods of model construction were studied. The pilot model was brought back to the Museum for further work , (Fig. 1). A second research model is now under construction, using more detailed information. It is hoped that this model will give a more exact plan of the structure, and can be compared with the lines plan as a cross check. A third model is also under construction, this is a full 1:10 model of the whole ship , (Fig. 2) The model is based on the information available from the remains of the Batavia, together with information of missing areas from contemporary sources and the Wasa. The ship will be fully planked on one side and open framed on the other so that the inside of the ship may be seen.

2. The Santo Antonio de Tanna

The chief investigator completed the survey of the Santo Antonio de Tanna during the 1979 season in Mombasa. The work here was assisted by the new part-time ARGC appointment, Mr B. Richards, who processed the photographic information and produced a photomosaic , (Fig. 3). Strip mosaics have also been produced for use with the profiles. The profiles have been redrawn and work has progressed on fairing the lines. The sheer, half-breadth and body plans have been drawn. Horizontal and vertical elevations, showing ceiling planking are being produced at this moment,(Fig.4). Once these plans have been produced, a comparison series will be constructed using the stereo photogrammetric coverage. It is hoped that this work will proceed following the development of the stereotope or stereocoordinator.

3. The Wasa and Kedelhaven ship

As mentioned above, no analytical work has been carried out on the photographic coverage of these two structures, (Fig. 5). However a scaled up lines drawing has been produced of the Wasa hull, for comparison with the Batavia. These plans were taken from the Ritning published by the Wasa Museum for model makers.

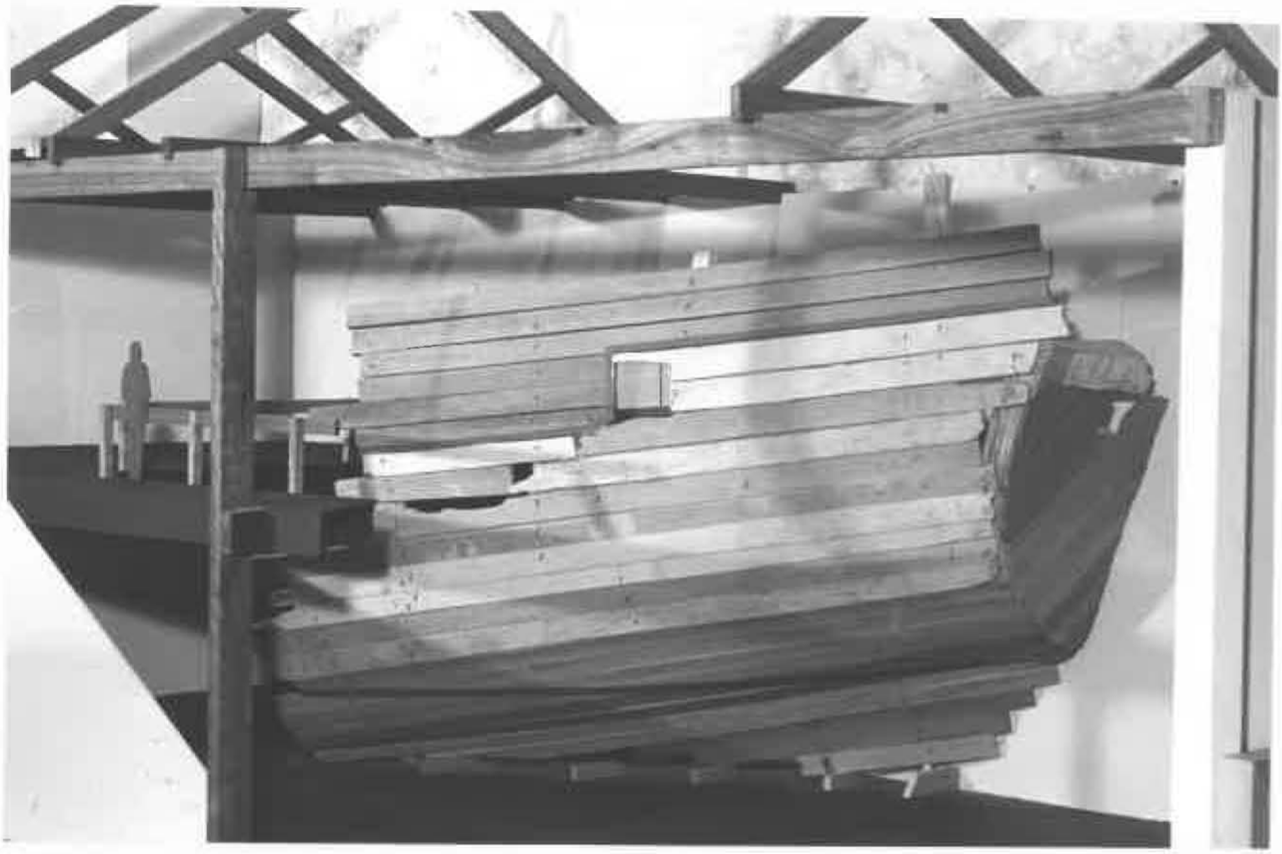

Fig. 1 The first Batavia research model built at the Institute of Nautical Archaeology, College Station, Texas, and reconstructed at Western Australian Maritime Museum. Model is shown in the Batavia Gallery showing proposed structural arrangements. Note scale of figure standing at left on upper gallery.

Fig. 2 Third model, full 1:10 reconstruction of Batavia. Work in progress on transom. Note Batavia facade in background.

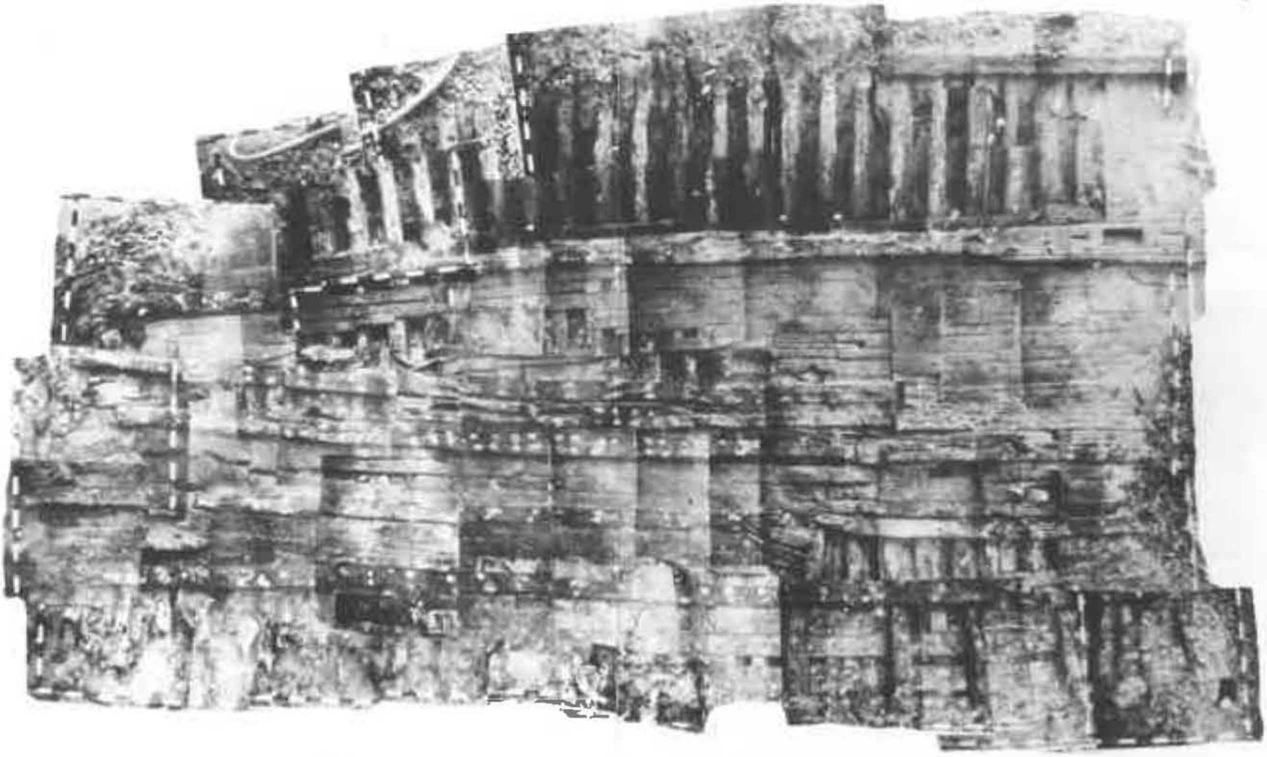

Fig. 3 Photomosaic of Santo Antonio de Tanna produced by Mr B. Richards.

Santo António de Tanná BODY PLAN

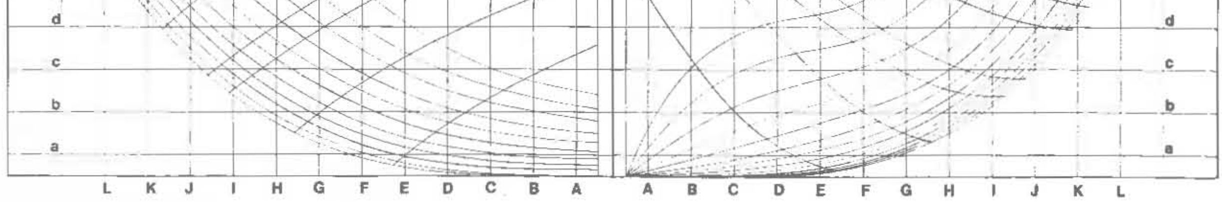

Fig. 4A Body Plans of Santo Antonio de Tanna

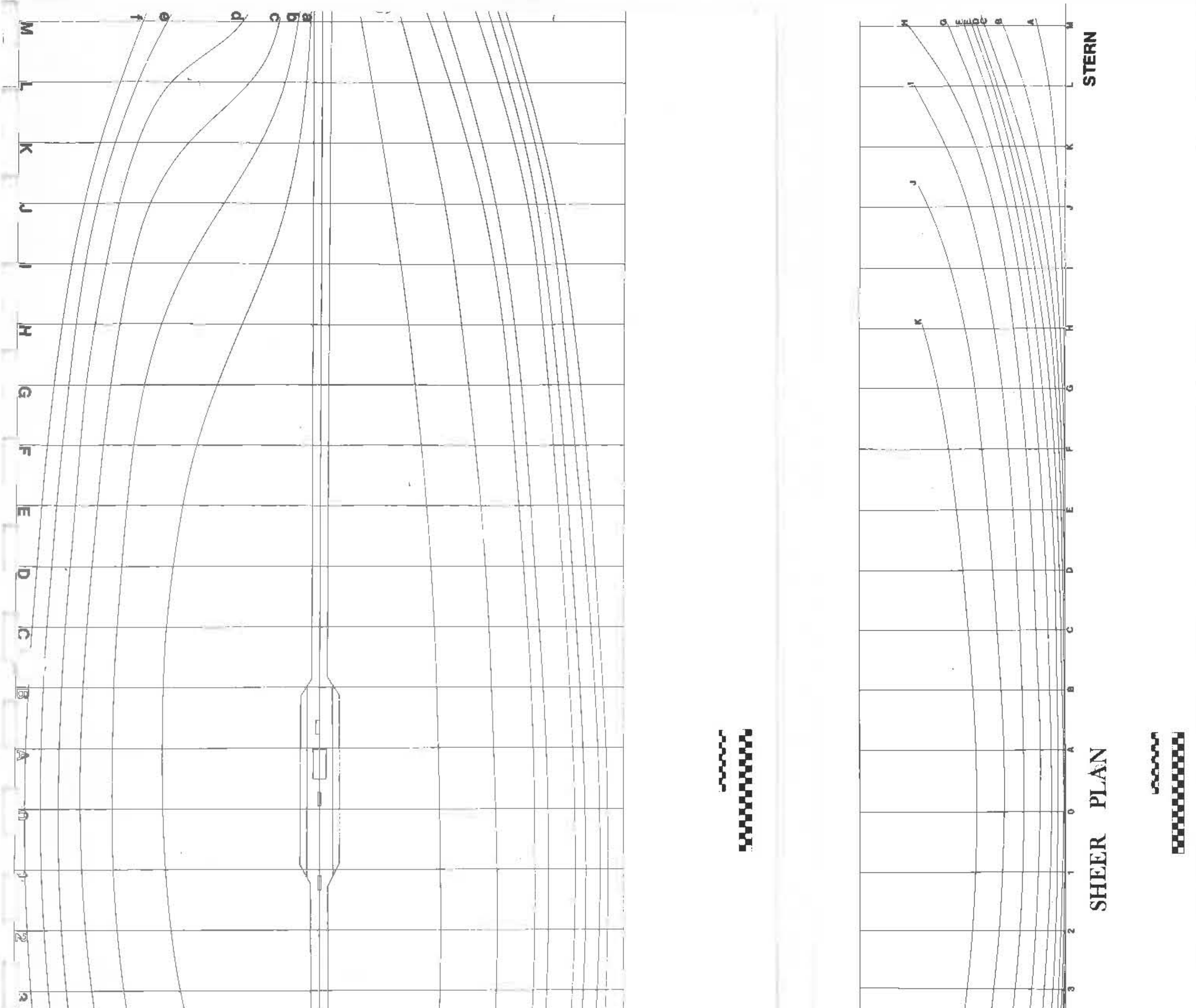

Fig. 4B Sheer and half-breadth plan of Santo Antonio de Tanna

Fig. 5 Stereo recording system in use on board the _Wasa_.

4. Study related to ship's structure

Copies have been obtained of most of the major 17th century Dutch and English shipbuilding publications. However some important reference works still need to be obtained. These works are being used to help fill in details in the 1:10 scale model of the Batavia, for which we have no structural remains.

C. SHIP STRUCTURE RECORDING

1. Surveying underwater profiles

In this approach, profiles of the internal structure of the ship are made. These profiles then act as the starting point in a fairing process. The profiles are recorded underwater, using a distance and angle measurements. Two methods were used on the Santo Antonio de Tanna, one method used a protractor with diameter about 300mm, this proved to be too small and consequently the angle measurements were not accurate enough. Subsequently, a second approach used a rigid triangular framework which acted as an angle measuring device; the framework doubled the accuracy of angle measurement but still had accuracy problems. The final drawn-up profiles were extremely uneven, and it is fortunate that the bilge thick stuff and shelf clamps could be used to fair the lines and adjust the sections. Having faired the lines, the result is a theoretical reconstruction of the shape of the hull as it would have been. If a plan is required of the hull, as it exists on the seabed, the lines need not be faired, and the resultant plan will show the distorted form of the hull. There are a number of shortcomings with this approach, mainly because the recording is being made of the inside of the hull. Thus it is impossible in some cases to determine the depth of the deadwood and thus determine moulded dimensions. Until more analysis of present results can be carried out, it is difficult to anticipate the best approach here.

2. Three dimensional trilateration

In this approach, measurements are made from three fixed points, at known distances appart and in mutually perpendicular directions, to the point required to be located. By solving the triangles it is possible to determine the coordinates of the point. This approach has been rather unsuccessful, mainly because of the errors compounded in the equations.

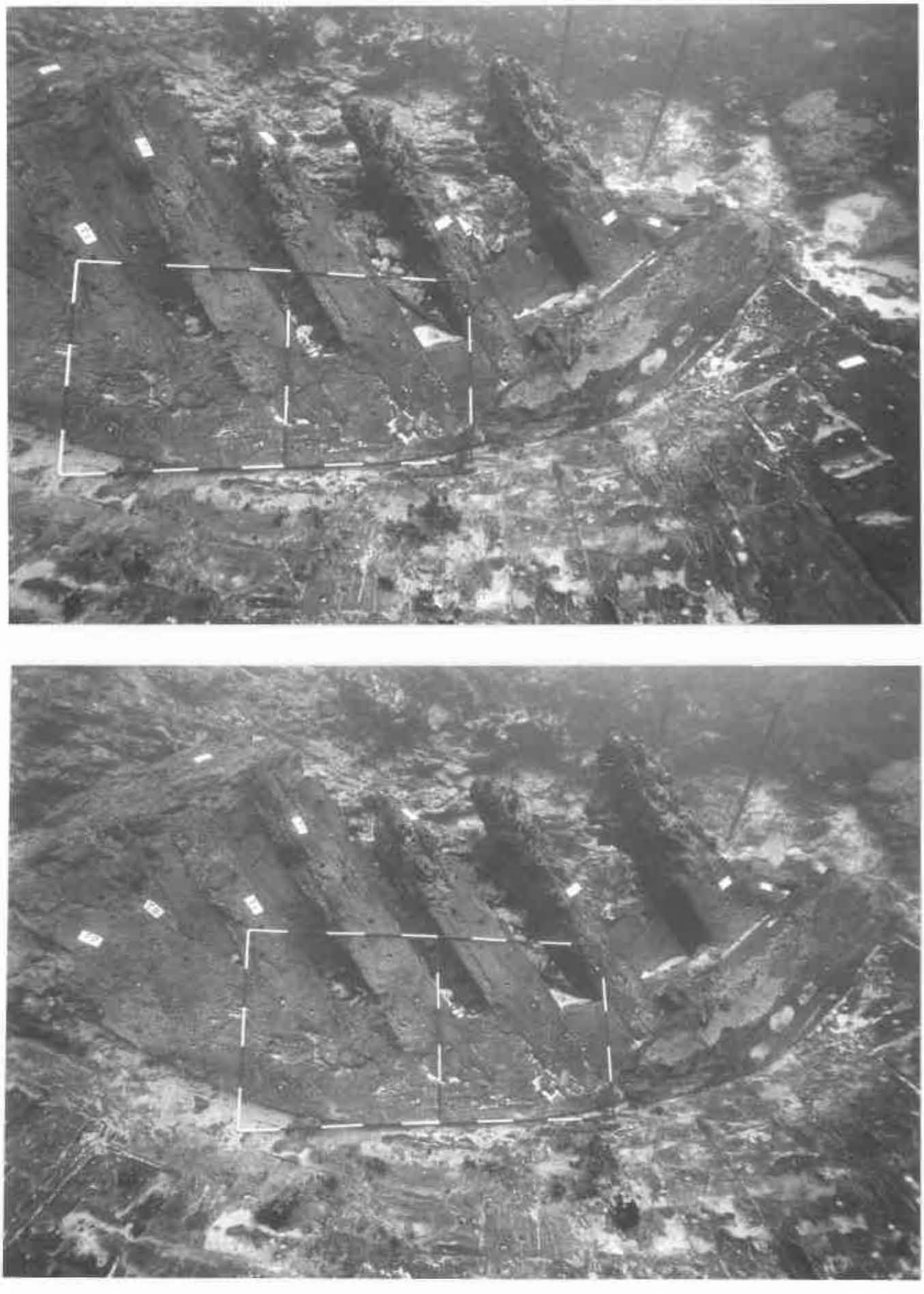

Fig. 6 Left-hand (above) and right-hand (below) stereo pair of transom of <u>Batavia</u>, scale 1 x 2 m.

It is still hoped to carry out further investigations of this method but it would seem unlikely to hold any great promise of high accuracy, although perhaps being a cheap and cheerful method when more elaborate equipment is not available.

3. Photogrammetry using collinearity

A pair of photographs, taken of a particular object, but from different viewpoints, may be used to obtain measurement of the object provided adequate control is provided. In the application studied here, for underwater work, there are a number of considerations which make this approach far more simple than in normal terrestrial work. Firstly, and importantly, since it is extremely difficult to obtain accurate plans underwater because of the lack of accurate measuring devices, a far lower degree of accuracy is acceptable underwater than on land. Secondly a photogrammetric approach is more attractive underwater, because at the speed that photographs may be taken, and that the lengthy analysis can be carried out on dry land at a later date, cutting costly time underwater. Provided a rigid grid square is inserted in the view and is common to both photographs, the orientation parameters can be determined, (Fig. 6). The process is as follows: the coordintes of the corners of the grid square in the photograph in relationship to the axis of the photographic print are measured; the coordinates of the corners of the grid square are nominated or known; and the focal length of the camera is determined. This information is entered into the computer, which carries out the following process:

1. it calculates the coordinates on the photograph of the vanishing points of opposite sides of the grid square,

2. it calculates the equation of the horizon line,

3. it calculates the azimuth A of the tilt of the photograph in relationship to the axis of the print,

4. it calculates the value of the angle of tilt Ø of the photograph,

5. it then calculates the perpendicular height H of the optical centre of the camera above the of the grid,

Fig. 7 Stereotope, mounted for operation.

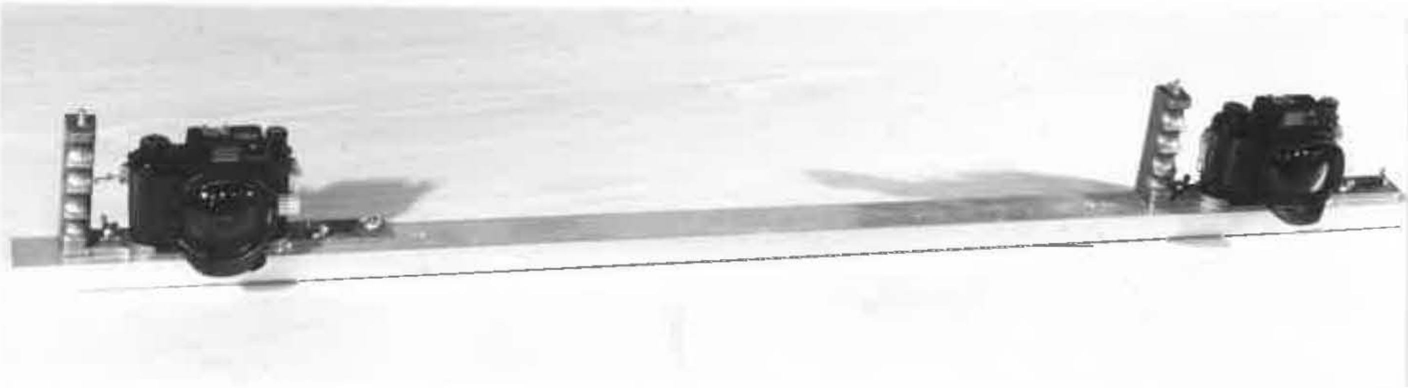

Fig. 8 Stereo bar with two Nikonos cameras with 15mm water corrected lenses. Camera separation 1 m.

Fig. 9 Photographic tower with stereo bar in place, just prior to swimming pool trials.

6. the coordinates of the intersection of the optical axis of the camera with the grid frame, Xc, Yc is determined and the azimuth of the grid frame to the optical axis B is obtained.
(See Appendix 1 for the complete Basic program and Formula)

Having determined the orientation parameters for the two photographs, if the coordinates of any point on the two photographs are measured, the XYZ coordinates relative to the grid frame can be determined. This system has been used on randomly orientated photographs, and whilst the programme is still in the pilot stage, results indicate an accuracy around $\pm 2.5\%$.

4. Photogrammetric using a stereo bar and tower

From time to time it has been possible to borrow a Zeiss Stereotope from the Royal Melbourne Institute of Technology. This instrument has,(Fig.7), been used in conjunction with a photo tower and stereo bar to produce plans. Since the instrument cannot tolerate large angles of relative orientation, in other words the optical axis of the cameras need to be reasonably co-parallel, the research developed along a slightly different approach. Firstly a stero bar was constructed onto which the two cameras were mounted,(Fig.8). The cameras were optically aligned with a simple parallax system,utilising a mirror. The stereo bar was mounted on a tripod, and levelled using a spirit level. A second test bar was set up same distance (c10m) away and set to the same height and levelled. Two targets exactly 1m apart were set up on the test bar, this separation was exactly the same as the camera separation. Plane glass mirrors were mounted in the lens mounts of the two cameras. The two bars were first set parallel to each other, by observing no-parallax conditions between two plane mirrors clamped to the opposing surfaces of the two bars. The cameras were then aligned by observing through a small hole in the centre of the target the reflection of the targets in the mirrors on the camera. The orientations of the cameras are adjusted until they appear exactly in the centre of the mirrors. With the cameras set co-parallel on the bar, they can then be locked in position with locating tags, so that they may be demounted from the bar, and later re-installed in the same position. The stereo bar was then mounted on the tower so that the cameras were symmetrical about the grid frame. The tower (Fig.9), was built out of square section with steel tube,

Fig. 10 Photo tower with grid square and calibrated bricks. Diver in process of taking a stereophotograph.

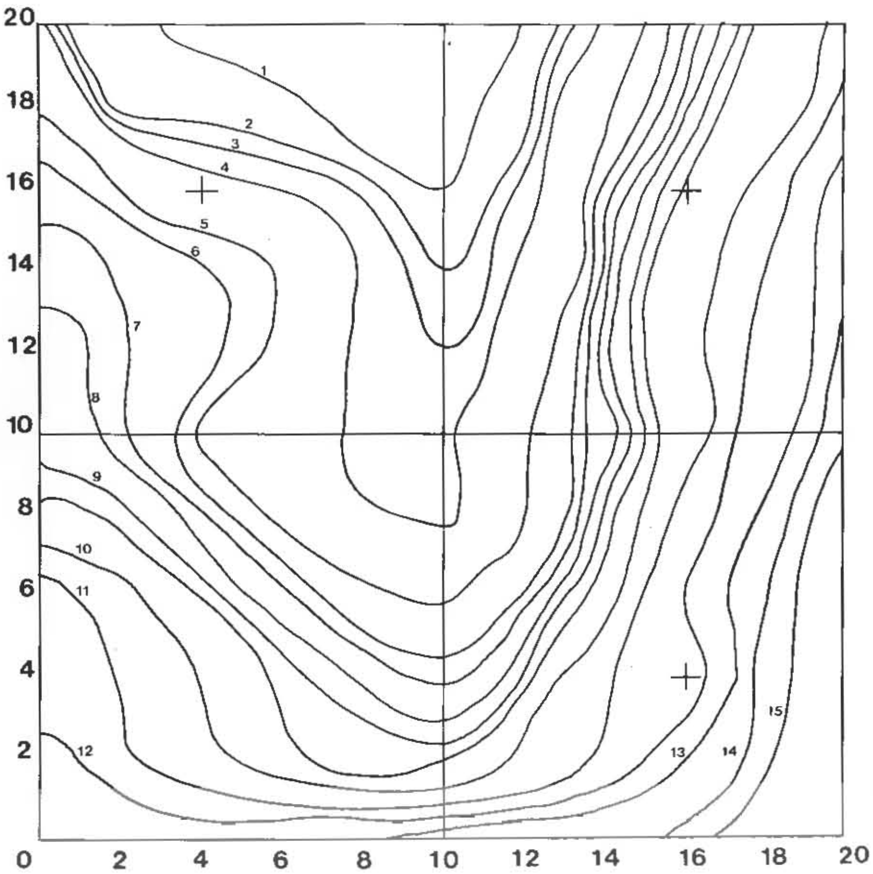

Fig. 11 Contour diagram of surface of grid frame, contour intervals 10 mm.

galvanized and the 2m square grid marked at 200mm intervals; the tower weighed 46 kg. The height of the camera above the grid frame, was set at 2.70m, this gave a good overlap of the grid frame.

The first test of the system was to determine the distortion caused by using non-sterometric lenses. A string grid was set up over the grid frame; the string being stretched between corresponding opposing grid marks. Thus there are strings intersecting at 200mm intervals across the whole of the grid frame, giving 81 intersections. A pair of stereo photographs were taken of this grid and the results analysed in the Wild B8 Aeroplot belonging to the Department of Surveying at the Western Australian Institute of Technology. The results were inconclusive since they tended to indicate that the strings of the grid were at different levels. A second test was conducted using a flat aluminium sheet, with a 200mm grid drawn on the surface. To test the height measurements, three calibrated bricks were placed on the plane surface, (Fig.10). The results indicated that there was a "U" shaped trough depression in the plane, at a depth of about 5mm, it was still not clear if this is a distortion caused by the sheet bending to the shape of the bottom of the pool, or a distortion caused by the camera lens enlarger system. Tests are underway at present to resolve this problem although it seems most likely to be a real effect caused by a distortion of the plane by the bottom of the swimming pool. The results of determining the spot heights of the bricks gave an accuracy of about $\pm 0.5\%$ which is extremely accurate. There was no noticeable pincushion or barrel distortion of the grid, indicating that the system gives excellent rectilinearity, (Fig. 11).

5. The Stereotope

The same data has been analysed in the stereotope by Mr Richards, and this has given slightly less accurate results, indicating again, that it is the machine that limits the accuracy, rather than the system. The project has now developed into the two separate photogrammetric approaches, both of which have important applications. Present developments indicate that the stereotope should be modified to suit the system. Thus design is in progress to produce a stereocoordinator (stereotope), where the coordinates, instead of utilising a mechanical computer to convert the perspective and orientation distortions as in the stereotope, are converted by a computer. The design is basically a moving plattern, where the X and Y coordinates are determined from an analogue distance from a potentiometer running off a rack and pinion drive. At present the interface is being investigated, and design has progressed to a general concept, see Appendix 2.

6. Peripheral projects

The Department Challenger C2P Computer is being widely used for computing data from the Wild B8. Several analytical programs are in an advanced state. A simple program has been developed for the Tl 59 with the PC 200 to determine the azimuth and tilt of the tilted photographs. This is of particular use when rectifying tilted photographs.

A Coordinate Transform program is being carried out on the data from the survey of the James Matthews hull. Here three dimensional coordinates relative to an arbitrary framework must be converted to the coordinates of a new coordinate system corresponding to the major axis of the vessel. Thus the Eulerian angles must be calculated, and utilised to transform the coordinates.

D. CONCLUSIONS

The project has progressed well in most areas, and it may be stated that the level of knowledge in this field has improved considerably. In the 17th Century shipbuilding study, a large amount of new information will be available before the end of this year. It is hoped to have completed the Santo Antonio de Tanna study and have the material ready for publication by 1981. The Batavia plans should be finished by the end of the year, and the design of the supporting framework underway. The model of the remaining structure should be finished, but the full scale model will take a lot longer. The development and construction of the stereorecorder, is hoped to be underway later this year, possibly in commission in 1981 and then ready for processing the Wasa and Kedelhaven ship then. There is a great deal of work and development still to do, but this author is optimistic that this should progress reasonably smoothly.

The research has indicated that in terms of underwater recording there is little alternative apart from photogrammetry for accuracy. In some cases however standard measuring techniques may be more practical, either in terms of problems with visibility or availability of equipment. The profile recording system on the Santo Antonio de Tanna is an example of a situation where time is limited, the conditions are not ideal, both in regards to visibility and current, and as a result poor results were obtained. Clearly in some situations, with optimum conditions, there would be time to make elaborate and accurate distance measurements to the accuracy of about ±1%. In other cases time may be exceptionally limited precluding all but the briefest recording time. One suggested development would be an underwater laser distance measuring device (ULDMD). Such an instrument could be used to make accurate underwater measurements (±0.01% which would make the three dimensional trilateration more feasible. An investigation into the problems of developing an ULDMD is being considered.

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The East India Companies of 17th and 18th century.
In Atlas for Maritime Archaeology gen. edit. K. Muchelroy (In press).

BASIC PROGRAMME FOR COLLINEARITY

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1.      PHOTOGRAMMETRY PROGRAMME
10      P1 = 3.1410
100     READ  F0
110     FOR  N= 1 TO 4
120     READ X(N), Y(N), E(N), F(N)
130     NEXT N
140     GO SUB 1000
150     LH = H
160     LAZ = AZ1
170     LPH = PH1
180     LGZ = GAZ
190     LD =  D0
200     LC =  C0
210     LE = NEA
220     LF = NFA
230     FOR N = 1 TO 4
240     READ X(N), Y(N), E(N), F(N)
250     NEXT
260     GO SUB 1000
270     RH = H
280     RAZ = AZ1
290     PPH = PH1
300     RGZ = GAZ
310     RD =  D0
320     RC =  C0
330     RE = NEA
340     RF = NFA
350     PRINT TAB(20)'LEFT'; TAB(40)'RIGHT'
360     PRINT 'HEIGHT'; TAB(20) LH; TAB(40)RH
370     PRINT 'AZIMUTH'; TAB(20) LAZ; TAB(40)RAZ
380     PRINT 'TILT'; TAB(20)LPH; TAB(40)RPH
390     PRINT 'ROTATION; TAB(20)LGZ; TAB(40)RGZ
400     PRINT 'C CENTRE'; TAB(20)LC; TAB(40)RC
410     PRINT 'D CENTRE'; TAB(20)LD; TAB(40)RD
420     PRINT 'ENADIA'; TAB(20)LE; TAB(40)RE
430     PRINT 'FNADIA'; TAB(20)LF; TAB(40)RF
500     PRINT "ENTRE DATA ON POINT"
510     PRINT "LEFT PRINT X COORDINATE"
520     INPUT X
530     PRINT "LEFT PRINT Y COORDINATE"
540     INPUT Y
560     A=X * COS(LAZ) + Y * SIN(LAZ)
570     B=Y * COS(LAZ) - X * SIN(LAZ)
580     C = LH/(COS(LPH)  * (COS(LPH) * F0/A-SIN(LPH)))
590     D = LH * B * (C/LH + TAN(LPH))/(F0 * TAN(LPH)+A)
600     FL = ((D-LD) * COS(LGZ)-(C-LC) * SIN(LGZ))
610     EL = ((C-LC) * COS(LGZ) + (D-LD) * SIN(LGZ))
620     PRINT "RIGHT PRINT X COORDINATE"
630     INPUT X
640     PRINT "LEFT PRINT Y COORDINATE"
650     INPUT Y
660     A = X * COS(RAZ) + Y * SIN(RAZ)
670     B = Y * COS(RAZ) - X * SIN(RAZ)
680     C = RH/(COS(RPH) * (COS(RPH) * F0/A-SIN(RPH)))
690     D = RH * B(C/RH + TAN(RPH))/(F0 * TAN(RPH)+A)
700     FR = ((D-RD) * COS(RGZ)-(C-RC) * SIN(RGZ))
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710    ER = ((C-RC) * COS(RGZ) + (D-RD) * SIN(RGZ) )
750    LM = (LF-FL) 1(LE-EC)
760    LK = LF-LM * LE
770    RM = (RF-FR)/(RE-ER)
780    RK = RF-RM * RE
790    E = (LK-RK)/(RM-LM)
800    F = E * LM + LK
810    HL = LH/(SQR((LE-EL)Λ2 + (LF-FL)Λ2)) * (SQR((EL-E)Λ2 +(FL-F)Λ2))
820    HR = RH/(SQR((RE-ER)Λ2 + (RF-FR)Λ2)) * (SQR(ER-E)Λ+(FR-F)Λ2))
830    PRINT "COORDINATE E", E
840    PRINT "COORDINATE F", F
850    PRINT "HEIGHT L", HL
800    PRINT "HEIGHT R", HR
900    END
1000   REM SUBROUTINE
1010   X(5) = X(1)
1015   Y(5) = Y(1)
1020   C(5) = C(1)
1025   D(5) = D(1)
1030   E(5) = E(1)
1035   F(5) = F(1)
1040   V(5) = V(1)
1045   W(5) = W(1)
1060   FOR N = 1 TO 4
1070   M(N) = (Y(N+L) - Y(N))/CX(NH) - X(N))
1080   K(N) = Y(N) - M(N) * X(N)
1090   NEXT N
1100   XL = (K(1) - K(3))/(M(3)-M(1))
1110   YL = XL * M(1) + K(1)
1120   SR = (K(2) - K(4))/(M(4)-M(2))
1130   YR = XR * M(2) + K(2)
1140   MH = (YR-YL)/(XR-XL)
1150   KH = YR-XR * MH
1160   AZ1 = ATN(-1/MH)
1170   XH = -KH * MH/(MHΛ2 +1)
1180   YH = KH/(MHΛ2 + 1)
1190   HP = XH * COS(AZ1) + YH * SIN(AZ1)
1200   PHI = ATN(F0/HP)
1210   FOR N = 1 TO 4
1220   A(N) = X(N) * COS(AZ1) + Y(N) * SIN(AZ1)
1230   B(N) = Y(N) * COS(AZ1)- X(N) * SIN(AZ1)
1250   V(N) = 1/(COS(PH1) * COS(PH1) * F0/A(N) - SIN(PH1)))
1260   W(N) = B(N) * (TAN(PH1) + V(N))/(F0 * TAN(PH1) + A(N))
1270   NEXT N
1275   H = 0:E=0
1280   FOR N = 1 TO 4
1290   H(N) = SQR((E(N)-E(N+1))Λ2 + (F(N)-F(N+L))Λ2)
1300   H(N) = H(N)/(SQR((V(N)-V(N+L))Λ2 + (N(N)-W(N+1))Λ2))
1310   H = H + H(N)
1320   E =  +H(N)Λ2
1330   NEXT N
1340   H = H/4
1350   E = E/4
1390   FOR N = 1 TO 2
1400   M(N) = (Y(N) - Y(N+2))/(X(N)-X(N+2))
1410   K(N) = Y(N)-X(N) * M(N)
1470   NEXT N
1430   X0 = (K(2)-K(1))/(M(1)-M(2))
1440   Y0 = M(1) * X0 + K(1)
1450   A0 = X0 * COS(AZ1) + Y0 * SIN(AZ1)
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1460    B0 = Y0 * COS(AZ1) - X0 * SIN(AZ1)
1470    C0 = H/(COS(PH1) * (COS(PH1) * F0/A0 - SIN(PH1)))
1480    D0 = H * B0 *(TAN(PH1) + C0/H)/(F0 * TAN(PH1) + A0)
1490    G0 : EG = 0
1500    FOR N = 1 TO 4
1510    C(N) = H*V(N)
1520    D(N) = H * W(N)
1530    NEXT N
1540    FOR N = 1 TO 4
1550    G(N) = (((D(N)-D0)/F(M))-((C(N)-C0)/E(N)))
1560    G(N) = G(N)/(((DCN)-D0)/E(N)) + ((C(N)-C0)/F(N)))
1570    IF G(N)<0 AND C(1)<C(2) THEN GAZ = ATN(ABS(G(N)))+P1/2
1580    IF G(N)<0 AND C(1)>C(2) THEN GAZ = ATN (ABS(G)N))
1590    IF G(N)>0 AND C(1)<C(2) THEN GAZ = ATN(G(N))+P1
1600    IF G(N)>  AND C(1)>C(2) THEN GAZ = ATN(G(N))
1610    G = G+GAZ
1620    EG = EG+(GAZ )^2
1630    NEXT N
1640    GAZ = G/4
1650    EG = EG/4
1660    NFA = -D0 * COS(GAZ) - (H * TAN(PH1)+C0)*SIN(GAZ)
1670    NEA = -D0 * SIN(GAZ) + (H * TAN(PH1)+C0)*COS(GAZ)
2000    RETURN
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GENERAL CONCEPT OF STEREOPLOTTING SYSTEM

Two stereo photographs are mounted on a moveable platten. The photographs are viewed under a stereoscope with a fixed separation stereobar. The photographs can be rotated, so that their photographic base lines up. The separation may be adjusted to give a stereo view with the marks lying on the surface of the model. Three potentiometers give analogue readings of the X, Y and Parallax measurements. These are fed into a A-D converter and then into the C2P computer via an input interface.

The program is written so that the first measurements are made on the left photograph. Readings of X and Y for the four corners of photograph are taken, and then for the four corners of the grid square. This enables the left hand orientation parameters to be determined. In the same way the orientation parameters for the right hand photograph are determined. Once the orientation parameters are known, it is then possible to plot. The operator guides the plattern so that the dots follow a ship's structure feature. The parallax being continuously adjusted so that the spot maintains contact with the model. The proposed system would work as follows, whilst tracing, since the computer can calculate in real time, an X-Y plotter may be used to produce plan. Linked to a foot switch, the coordinates of selected points can be recorded on floppy disk storage and printed for hard copy.

When the plan within the grid square is completed, the next adjacent stereopairs are inspected and three common points on both sets of pairs are photo identified. The X Y and Z coordinates of these three points are recorded on the first stereo pair. After the second stereo pair has been set up and the orientation parameters determined, the same set of coordinates are measured. The program then determines the relative orientation of the two sets of axis of the two plans, and subsequently plots all results reduced to the original plane. Thus inspite of the fact that the planes of the photo tower may vary across the site, each individual plan may be reduced to a common plane, which would preferably be the axis of the ship.

For general outline of comparator see Fig. 12.

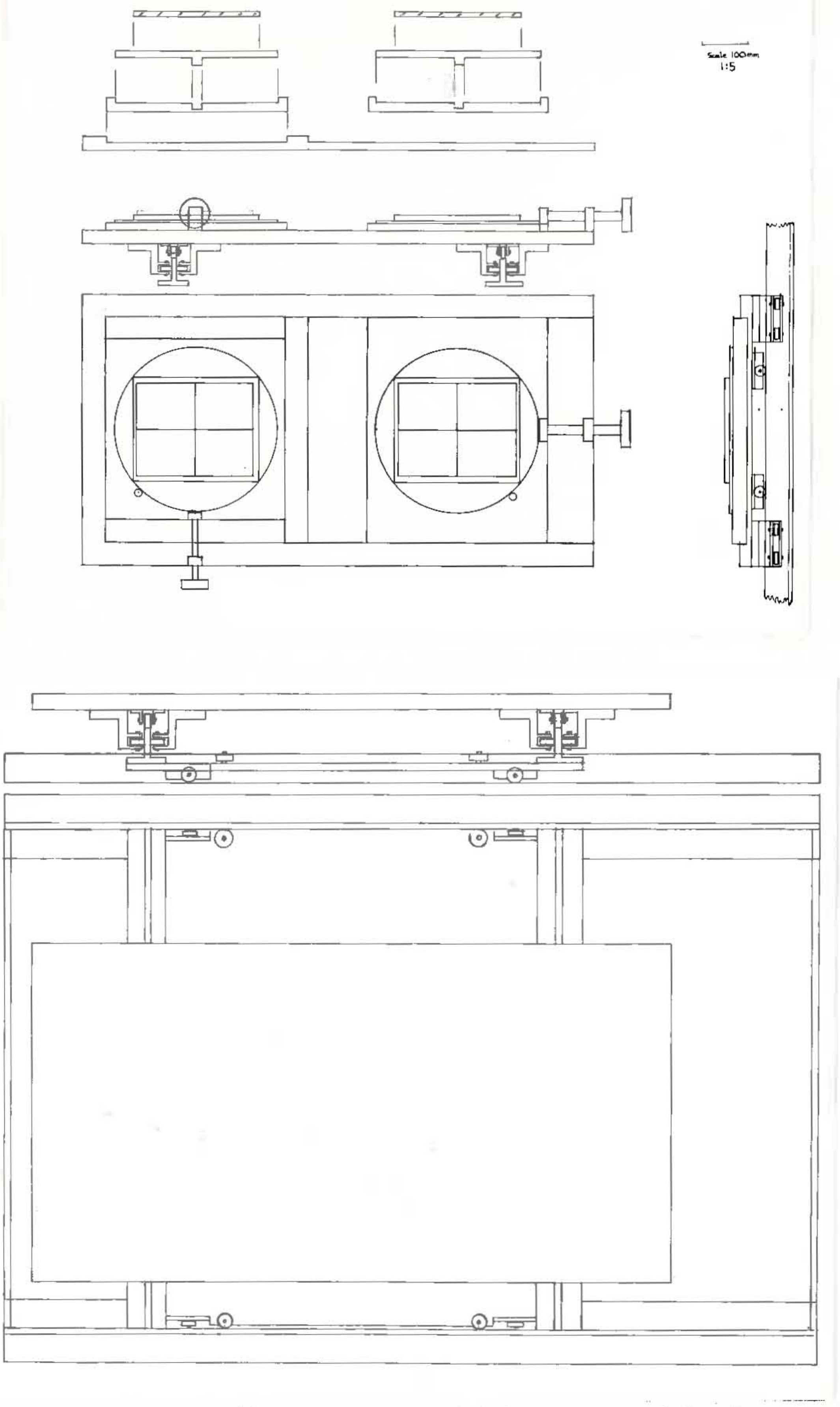

Fig. 12 Stereocoordinator plans in initial stages of development.