PHOTOGRAMMETRY

EXTRACTS FROM AN EVALUATION STUDY

BY

R.K. STEVENS AND T. SMITH
(*Design Division Portsmouth Dockyard*)

> When you can measure what you are talking about and express it in numbers you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind. It may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the stage of science, whatever the matter may be.
>
> LORD KELVIN OF LARGS

Introduction

Photogrammetry is briefly defined as the science or art of obtaining reliable measurements from photography to determine geometric characteristics such as size, form and position of the photographed object. The technique has been in use since the inception of photography some hundred years ago, influenced largely by the surveying or 'topographical' application—as an aid in terrain mapping. This predominance together with aerial photography gave little scope for its use in industrial and engineering metrology but in recent years photogrammetry has become more appreciated as a general method of physical measurement. To this purpose, major optical instrument manufacturers, particularly German, Swiss, and Italian, have produced cameras and plotting instruments capable of presenting information either as conventional drawings (graphical) or in analytical form.

The cost of the equipment naturally relates to the accuracy available and in photogrammetric terms a third order plotter and camera was obtained in 1973 for an evaluation study at Portsmouth Naval Base. This question of accuracy was veiled in such expressions as 'being well within shipbuilding practice', or between one five thousandth to one ten thousandth of the taking distance. Under ideal conditions a few microns discrepancy was offered. Ideal conditions in shipwork can soon be dismissed but in many close range exercises 0·2 mm was proven possible. To the expert photogrammetrist, operating with first order equipment, this would represent gross error but to the evaluation team was well within shipbuilding practice.

The Cameras

Initially the major proportion of projects was directed to MOD(N) shipbuilding work, particularly for the production of 'as-fitted' and working drawings, and the camera selected was of a close-range type (see FIG. 1). Other cameras were borrowed to conduct long range exercises (see FIG. 2). Broadly the types of cameras for terrestrial work fall into three categories:

(*a*) Stereoscopic cameras in fixed mountings 400 mm apart with range 1·5 to 10 metres (Evaluation model SMK 40, wide angle 71°, nominal focal length 56 mm, cost in 1973 £3000.)

(*b*) Similar to (*a*), fixed mountings 1200 mm apart with range 5 to 30 metres (SMK 120).

(*c*) Single camera used stereoscopically in two positions to suit subject with range 3·6 metres to infinity (e.g. UMK, P31 and TMK6).

Items (*a*) and (*b*) are simpler to operate as the left and right cameras are on a

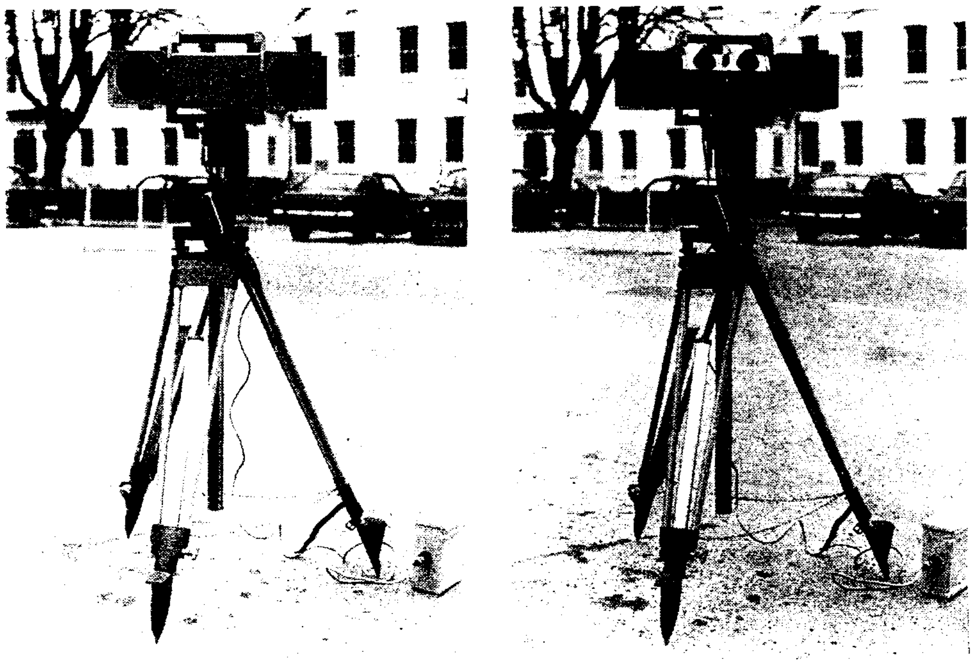


FIG. 1—SMK 40 CAMERA VIEWED FROM FRONT AND REAR

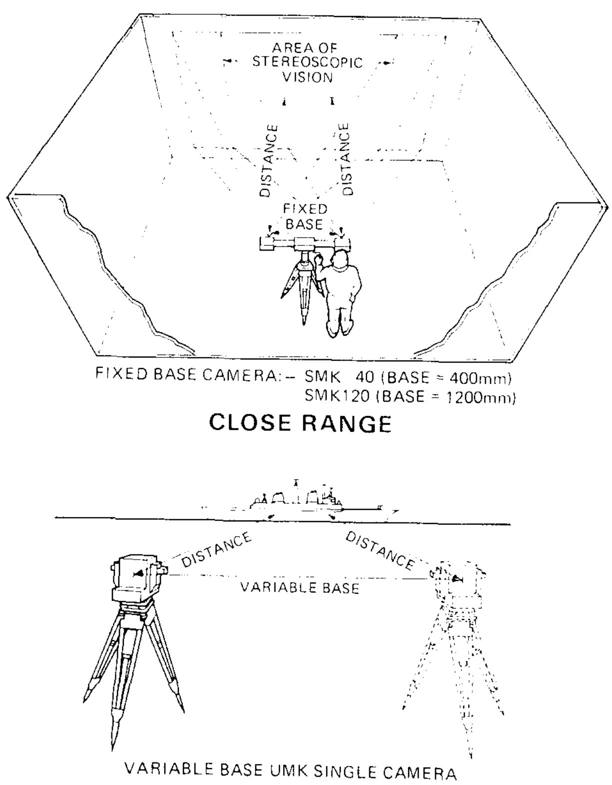


FIG. 2—DIAGRAM SHOWING CAMERA ARRANGEMENTS FOR CLOSE RANGE AND LONG RANGE STEREOSCOPIC PHOTOGRAPHY

fixed base with the axes at right angles to the base line; the cameras being levelled, simultaneously, with inbuilt accurate levels. This obviates tip and tilt of the stereopairs and tedious rectification when plotting.

It is worth noting at this point that the double image or stereoscopic principle is used. (Freely translated *stereoscopic* = seeing solid). There are other photogrammetry procedures, including the complementary colour (anaglyph) 3D process or in certain aspects the use of single photographs.

Members of the evaluation team (two from Design Division and one from the Photographic Unit) in their daily routine accepted three dimensional viewing as a natural process. However, constant use of optical equipment and examination of photographs, taken with an enlarged base, emphasized the ability to observe first monocularly and then binocularly, establishing an appreciation of depth—a giant's eye view compared to the normal visual images registered with eyes approximately $2\frac{1}{2}$ in apart. The greater the distance between points of view the more the observer is hypersensitive to depth but the less the field of three-dimension. This stereo-perception or 'art of seeing' is exploited in the plotting machines by making use of the horizontal parallax 'X', i.e. the distance between corresponding points in the photographs from their photo-centres; and the appreciation of depth.

When setting-up the cameras on site, at least one known accurate horizontal (X) measurement is required within the image. In most close range projects this was a 2 metre batten or a known calibrated feature such as the distance between fine points on ship equipment or structure. This measurement enables a check when selecting a plotting scale. A range in depth is also noted, not necessarily with great accuracy, to accommodate points near and far from the camera (Z near and Z far). For visual comfort and interpretation, a camera base to range ratio of not greater and preferably less than 1 : 25 is required (e.g. SMK 40 cm/10 metres is at its limit).

FIG. 3—PLOTTING MACHINE—TECHNOCART

FIG. 4—PLOTTING TABLE

The Plotting Machine and Table

The Plotting machine selected for use in conjunction with the SMK camera was the Technocart (see FIG. 3). It relies on the production of photopairs with a perfect constancy of the elements of orientation, and is not designed to rectify errors introduced by camera misalignment (tip and tilt causing vertical parallax Y). Together with the drawing table (FIG. 4), the cost was £14 000 in 1973. Basically the plotter comprises left and right analogue computers which solve the optical formulae for measurements within the stereoscopic pictures and converts the results to a drawn picture in plans and elevations on the table. Alternatively, numerical readouts may be taken and spatial co-ordinates identified (X Y Z). The glass plated negatives or stereo pairs have to be set up in the plotter to the camera characteristics so that they can be viewed through binoculars (magnification 6 to 1) as an enlarged three dimensional picture.

The machine plotting scale, controlled by the original near and far depth situation, camera base distance and photo scale, is selected to traverse the image in the normal geometric planes X Y Z. Drawing scales as required are arranged by gear wheel combination, and the drawing is made by following the 3D picture with a measuring mark (a micro-light or dot). Travel control of the dot in each plane is by two handwheels and one foot wheel and the movements are transferred by transmission shafts to the drawing table. Refinements can be added to these plotters to give digital plots of the subjects in numerical form either on punched tape, punched cards, or magnetic tape.

Projects

The following few extracts from the large number of projects undertaken, hopefully, indicate the variety of application in MOD(N) shipbuilding work:

No. 2 Basin Caisson (see FIGS. 5 to 9)

This project was undertaken in 1975, in two parts. Firstly, an SMK 120 camera (on loan from the manufacturers) was used to record the size and form of the caisson as a check against Mould Loft offsets. These offsets were required in order to undertake the repair of the greenheart stem keel seal. The photography, consisting of three overlapping photopairs of the whole of the north face of the caisson, was accomplished in less than 2 hours. After processing, an outline of the caisson was drawn to a scale of 1 : 24, highlighting the critical areas required. A series of offsets was also produced and comparison with the originals was extremely good. The whole process, including photography, processing, plotting and numerical reading of offsets, took only three man-days compared with a possible fourteen man-days by conventional methods.

Several months later the Unit was requested to obtain the true shape of the curved corners of the keel for future renewal of the rubber seals. Four photopairs—one for each corner of the caisson—were taken with the SMK 40. The shapes of the corners were plotted to a scale of 1 : 20 and the bolt positions indicated. Mean readings were taken and the co-ordinates tabulated as offsets and buttocks. In this instance, time and labour commitments did not permit normal measurement methods and the 'as-fitted' information would not have been recorded without the use of photogrammetry.

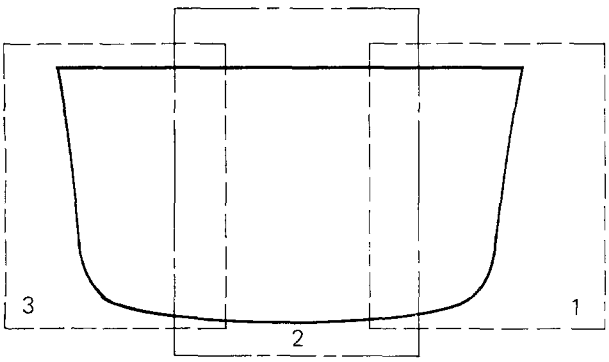


FIG. 5—DIAGRAM SHOWING OVERLAP IN SEQUENCE OF PHOTOGRAPHY

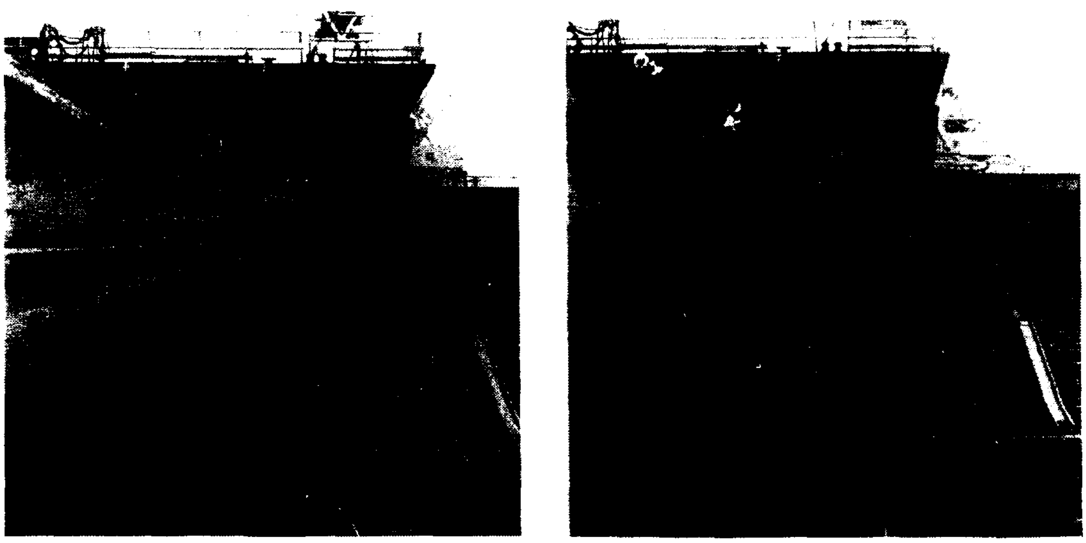
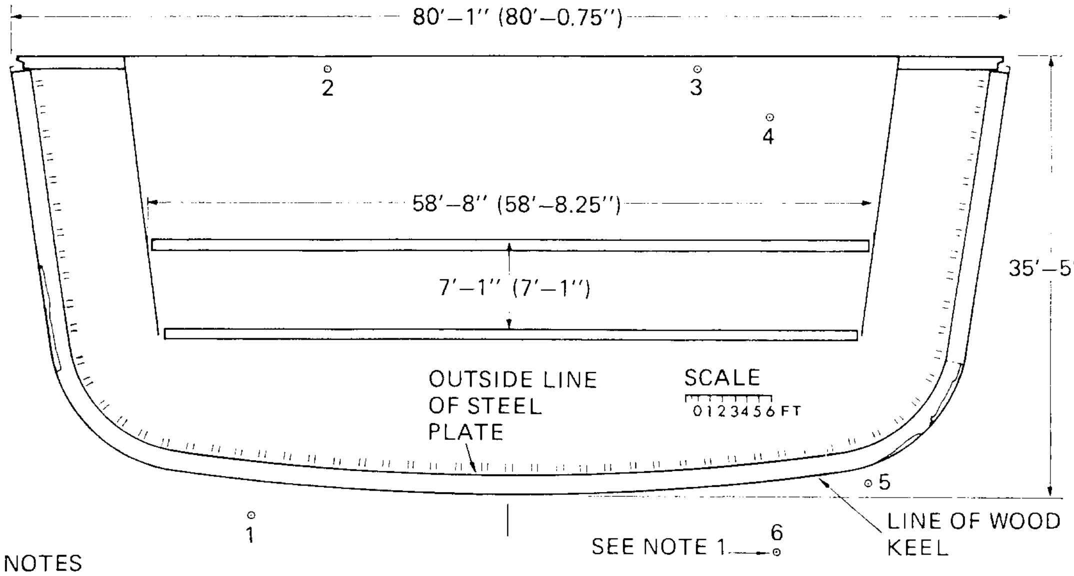


FIG. 6—PAIR OF STEREOSCOPIC PHOTOGRAPHS OF NO. 2 BASIN CAISSON



NOTES
1 CONTROL POINTS, USED TO ALIGN OVERLAPPING PHOTOPAIRS SHOWN ⊙
2 MEASUREMENTS IN BRACKETS TAKEN FROM CAISSON

FIG. 7—REPRODUCTION OF DRAWING BY PHOTOGRAMMETRY OF NO. 2 BASIN CAISSON DRAWN FROM THREE PAIRS OF OVERLAPPING STEREOSCOPIC PHOTOGRAPHS

Dimensions as obtained from technocart plotting machine:

Offsets

Ht. above baseline	LHS Wood edge	LHS Steel edge	RHS Wood edge	RHS Steel edge
2′–0″	27′–10·26″	13′–8·33″	28′–2·5″	13′–4·9″
4′–0″	32′–5·6″	29′–6·36″	32′–7·2″	29′–4·9″
6′–0″	34′–6·6″	32′–6·72″	34′–7·4″	32′–7·32″
8′–0″	35′–9·18″	34′–0·78″	35′–10·9″	34′–2·35″
10′–0″	36′–6·2″	35′–0·084″	36′–9·3″	35′–1·89″
12′–0″	37′–0·7″	35′–6·98″	37′–4″	35′–9·3″
14′–0″	37′–5·2″	35′–11·4″	37′–8·21″	36′–1·9″
16′–0″	37′–8·5″	36′–2·66″	37′–11·5″	36′–4·8″
18′–0″	37′–11·24″	36′–5·5″	38′–2·37″	36′–7·35″
20′–0″	38′–2·16″	36′–8·44″	38′–5·21″	36′–10·03″
22′–0″	38′–5·05″	36′–11·3″	38′–7·96″	37′–0·75″
24′–0″	38′–8·125″	37′–2·089″	38′–10·7″	37′–3·97″
26′–0″	38′–11·15″	37′–5·01″	39′–1·37″	37′–6·5″
28′–0″	39′–2·35″	37′–7·9″	39′–4·3″	37′–9″
30′–0″	39′–5·5″	37′–10·87″	39′–7·056″	37′–11·79″
32′–0″	39′–8·6″	38′–1·7″	39′–9·96″	38′–2·47″
34′–0″	39′–11·7″	38′–4·5″	40′–0·78″	38′–4·8″

Buttock lines

Dist. from centre	LHS Wood edge	LHS Steel edge	RHS Wood edge	RHS Steel edge
2′–0″	0′–0·59″	1′–6·86″	0′–0·36″	1′–6·54″
4′–0″	0′–1·03″	1′–7·15″	0′–0·68″	1′–6·85″
6′–0″	0′–1·68″	1′–7·8″	0′–1·324″	1′–7·6″
8′–0″	0′–2·38″	1′–8·27″	0′–2·138″	1′–8·52″
10′–0″	0′–3·46″	1′–9·65″	0′–3·25″	1′–9·64″
12′–0″	0′–4·54″	1′–10·74″	0′–4·53″	1′–10·89″
14′–0″	0′–5·96″	2′–0·25″	0′–6·045″	2′–0·12″
16′–0″	0′–7·57″	2′–1·91″	0′–7·8″	2′–2″
18′–0″	0′–9·66″	2′–3·62″	0′–9·36″	2′–3·95″
20′–0″	0′–11·68″	2′–5·67″	0′–11·125″	2′–6″
22′–0″	1′–1·86″	2′–7·99″	1′–1·29″	2′–8·35″
24′–0″	1′–4·5″	2′–10·8″	1′–4·01″	2′–11·2″
26′–0″	1′–7·85″	3′–1·9″	1′–7·33″	3′–2·5″
28′–0″	2′–0·46″	3′–6·25″	1′–11·46″	3′–6·72″
30′–0″	2′–7·68″	4′–2·4″	2′–6·76″	4′–2·83″
32′–0″	3′–8·05″	5′–6·175″	3′–6·92″	5′–5·4″
34′–0″	5′–4·36″	7′–10·56″	5′–3·17″	7′–8·35″
36′–0″	8′–6·24″	14′–0·4″	8′–1·4″	12′–11·7″
38′–0″	18′–6·0″	30′–9·12″	16′–4·2″	30′–2·2″
40′–0″	34′–1·48″	———	33′–5·48″	———

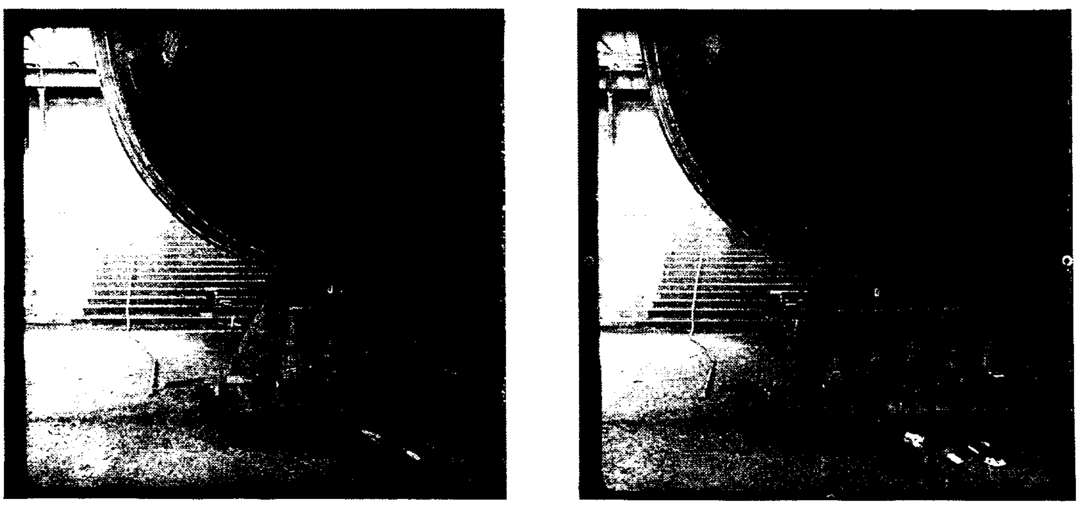


FIG. 8—PAIR OF STEREOSCOPIC PHOTOGRAPHS OF TYPICAL CORNER OF CAISSON

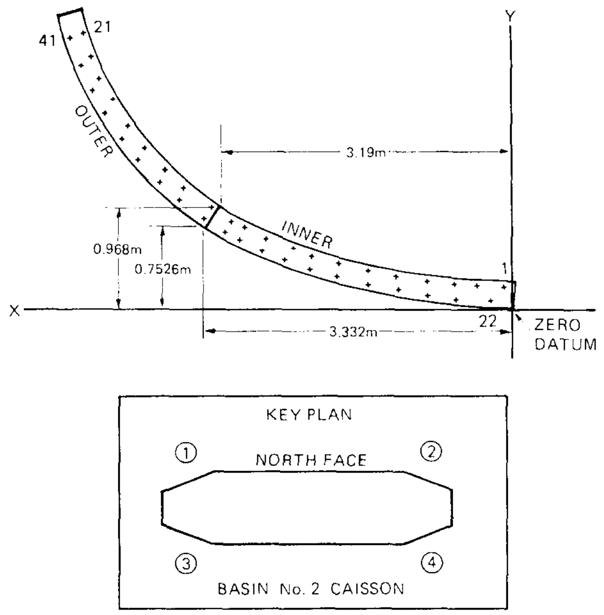


FIG. 9—DIAGRAM OF CORNER POSITION (NO. 3) OF CAISSON

Dimensions as obtained from technocart plotting machine:

Bolt positions

Inner			Outer		
Position	X metres	Y metres	Position	X metres	Y metres
1	0·0706	0·2144	23	0·5374	0·0962
2	0·3388	0·2406	24	0·8588	0·129
3	0·601	0·2652	25	1·184	0·1646
4	0·9048	0·2966	26	1·5092	0·2052
5	1·2106	0·3326	27	1·8328	0·251
6	1·5182	0·3686	28	2·1532	0·314
7	1·8228	0·415	29	2·461	0·403
8	2·1224	0·4748	30	2·7178	0·49
9	2·34	0·5342	31	2·9456	0·588
10	2·6328	0·6328	32	3·096	0·6628
11	2·874	0·7388	33	3·36	0·8212
12	3·0188	0·801	34	3·6108	1·0114
13	3·2792	0·966	35	3·835	1·2172
14	3·521	1·157	36	4·0334	1·448
15	3·74	1·364	37	4·2148	1·691
16	3·9432	1·5948	38	4·382	1·9474
17	4·1192	1·8382	39	4·528	2·217
18	4·28	2·0994	40	4·652	2·4914
19	4·4212	2·3698	41	4·751	2·7832
20	4·523	2·598			
21	4·6048	2·831			
22	0·2168	0·0676			

Offsets

Y Intervals *metres*	Outer X *metres*	Inner X *metres*
0·05	0·521	
0·1	1·028	
0·2	1·766	
0·252		−0·0122
0·3	2·273	0·469
0·4	2·584	1·352
0·5	2·837	2·003
0·6	3·056	2·381
0·7	3·244	2·651
0·8	3·401	2·891
0·9	3·534	3·086
1·0	3·654	3·240
1·1	3·769	3·377
1·2	3·869	3·499
1·3	3·966	3·609
1·4	4·053	3·710
1·5	4·130	3·8016
1·6	4·203	3·888
1·7	4·274	3·965
1·8	4·338	4·030
1·9	4·398	4·101
2·0	4·456	4·164
2·1	4·508	4·223
2·2	4·560	4·278
2·3	4·608	4·329
2·4	4·649	4·376
2·5	4·692	4·419
2·6	4·732	4·461
2·7	4·767	4·501
2·8	4·802	4·539
2·9	4·838	4·573
3·0	4·870	4·606
3·0158	4 874	
3·0852		4·631

Buttocks

X Intervals *metres*	Outer Y *metres*	Inner Y *metres*
0·2	0·0210	0·275
0·4	0·0385	0·293
0·6	0·0560	0·313
0·8	0·0758	0·333
1·0	0·0960	0·352
1·2	0·1214	0·378
1·4	0·1495	0·407
1·6	0·1760	0·434
1·8	0·2050	0·465
2·0	0·242	0·498
2·1	0·261	0·524
2·2	0·282	0·548
2·3	0·308	0·576
2·4	0·339	0·606
2·5	0·371	0·642
2·6	0·4066	0·679
2·7	0·445	0·718
2·8	0·483	0·759
2·9	0·525	0·803
3·0	0·572	0·852
3·1	0·624	0·908
3·2	0·674	0·973
3·3	0·731	1·042
3·4	0·798	1·116
3·5	0·875	1·200
3·6	0·952	1·288
3·7	1·037	1·389
3·8	1·129	1·496
3·9	1·226	1·613
4·0	1·338	1·750
4·1	1·455	1·896
4·2	1·592	2·056
4·3	1·738	2·243
4·4	1·899	2·457
4·5	2·082	2·699
4·6	2·281	2·986
4·6336		3·086
4·7	2·811	
4·8	2·783	
4·8746	3·018	

FIG. 10—PAIR OF STEREOSCOPIC PHOTOGRAPHS OF S.C.O.T. RADAR DISPLAY ROOM LOOKING FROM FORWARD BULKHEAD

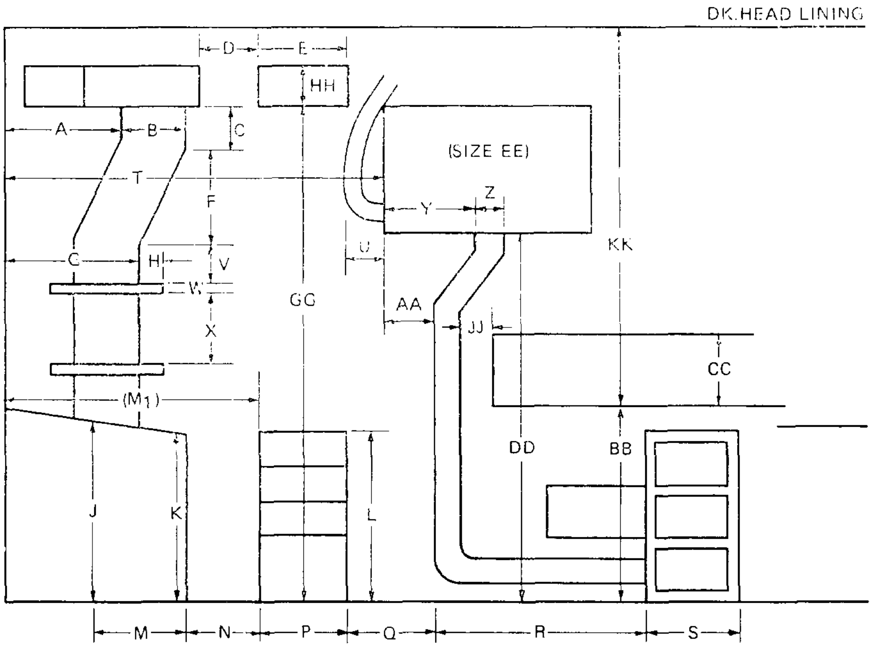


FIG. 11—SKETCH OF S.C.O.T. RADAR DISPLAY ROOM WITH RECORD OF DIMENSIONS TAKEN BY TECHNOCART PLOTTING MACHINE

	metres		metres
A	0·199	U	0·118
B	0·235	V	0·027
C	0·181	W	0·101
D	0·260	X	0·248
E	0·306	Y	0·176
F	0·271	Z	0·107
G	0·301	AA	0·144
H	0·0575	BB	0·836
J	0·787	CC	0·409
K	0·754	DD	1·534
L	0·761	EE	x = 0·758, y = 0·671,
M	0·320		z = 0·134, (z bulkd. = 0·322)
N	0·122	GG	2·144
P	0·355	HH	0·147
Q	0·139	JJ	0·0875
R	0·396	M1	0·733
S	0·315	KK	1·600
T	1·135		

Limited Availability of Ship (see FIGS. 10 and 11)

In many instances sufficient information may be required from a ship (whose availability to the dockyard is restricted) in order to progress certain drawings during its absence. In this temporal situation photogrammetry again proves its worth. With known 'customer' requirements the Unit can quickly record adequate details of structure and compartments so as to provide information to the draughtsman subsequent to the ship leaving the Naval Base. This information is often given in analytical form, i.e. upon request for particular measurements the photopairs are set up on the plotting machine and numerical read-outs given—as in the case of a large ship's R.D.R. Stereo prints are also supplied to enable the draughtsman, using a mirror stereoscope, to have a three-dimensional pictorial reference.

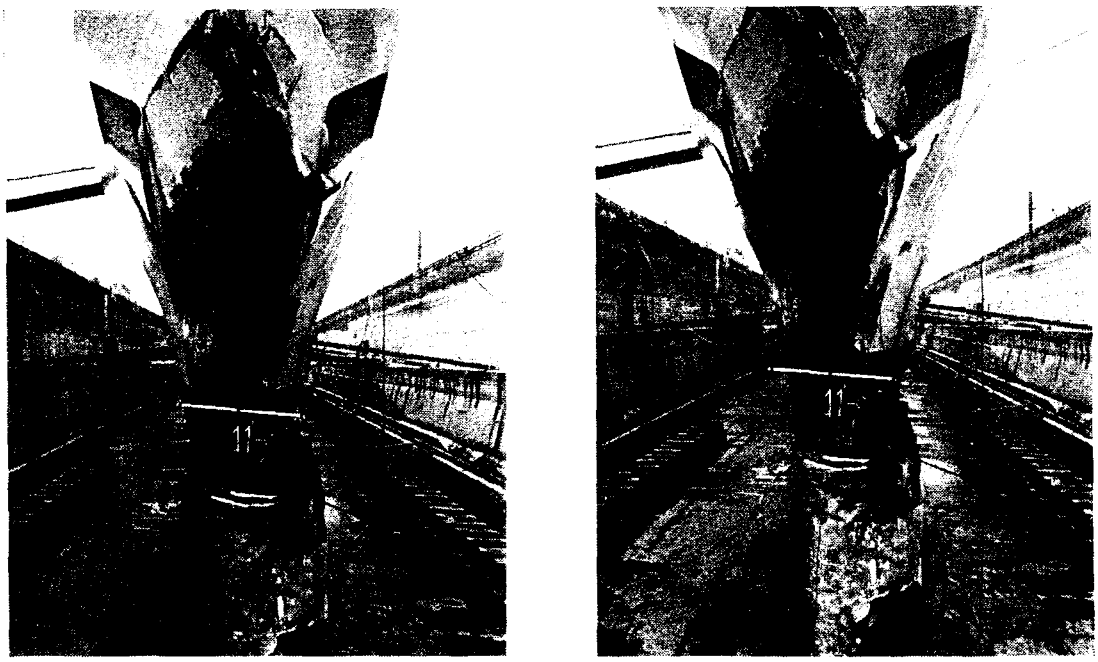


FIG. 12—PAIR OF STEREOSCOPIC PHOTOGRAPHS OF DAMAGED BOWS OF A FRIGATE LOOKING FROM FORWARD

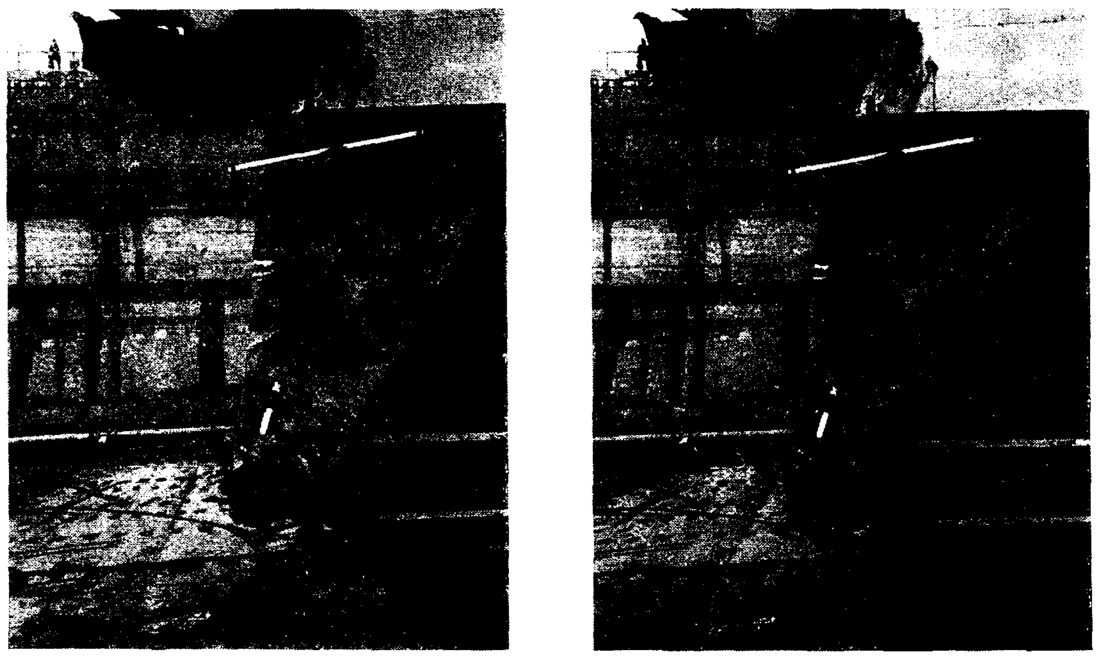


FIG. 13—PAIR OF STEREOSCOPIC PHOTOGRAPHS OF DAMAGED BOWS OF SAME FRIGATE LOOKING FROM PORT SIDE

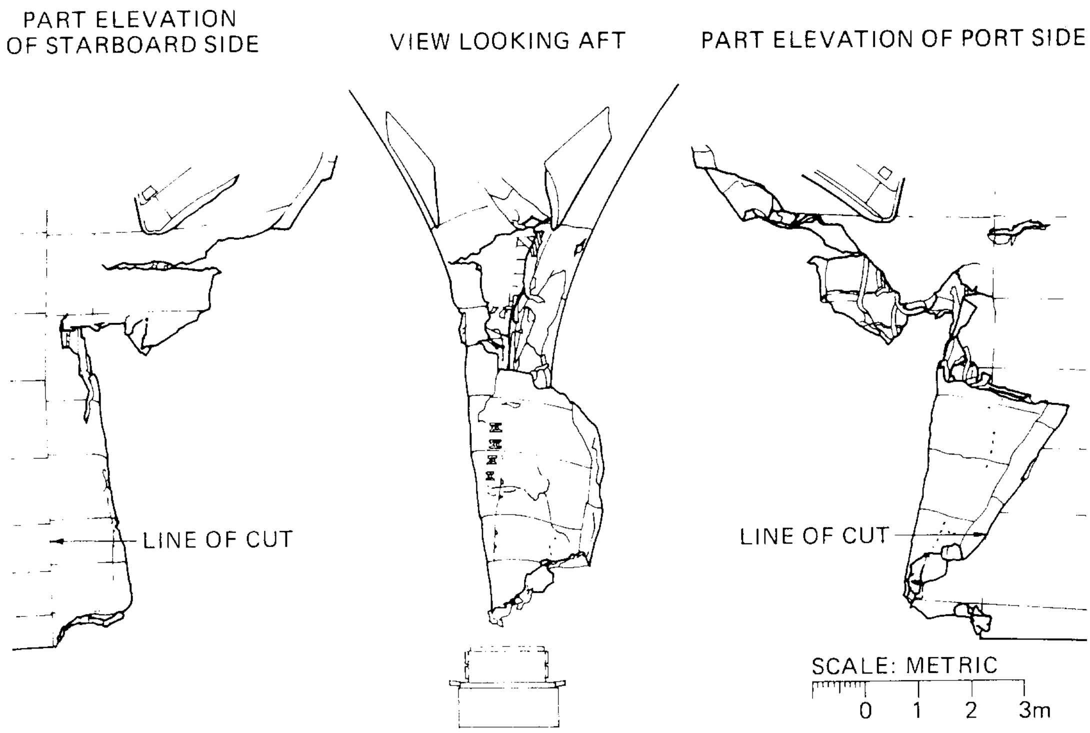
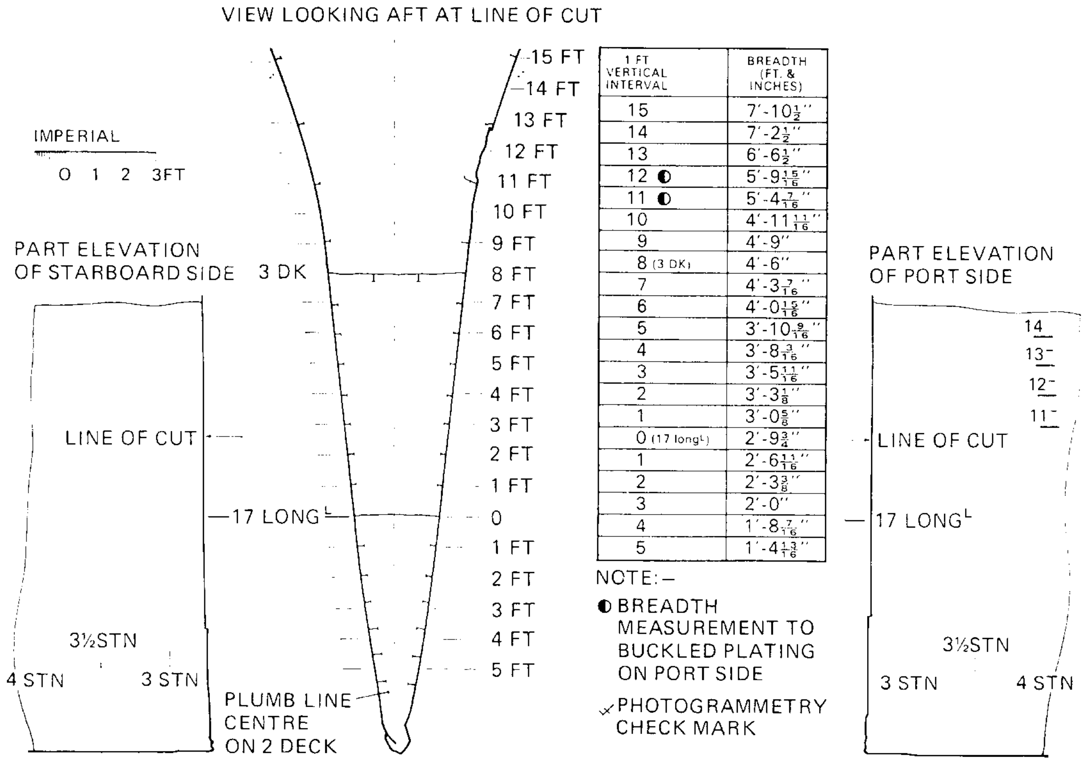
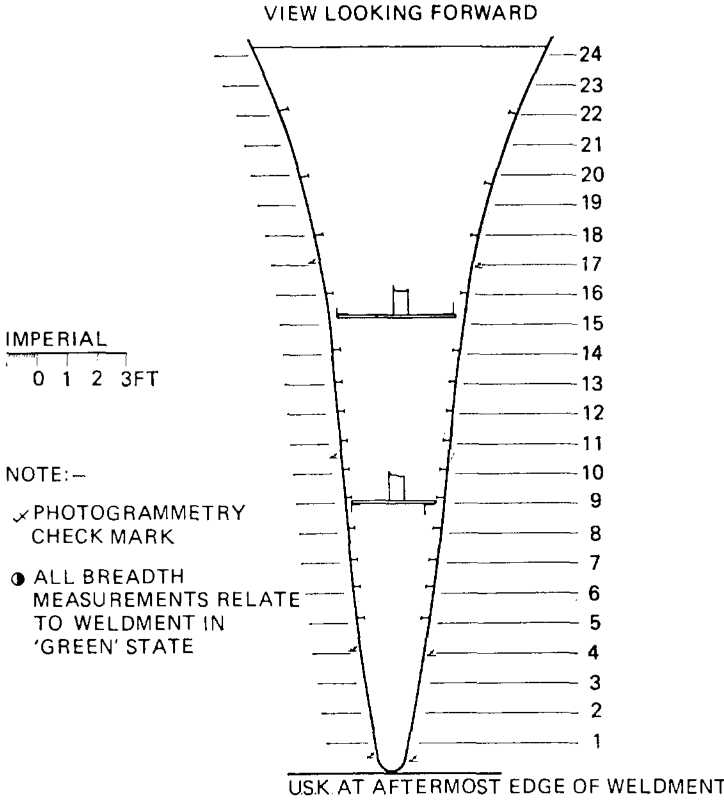


FIG. 14—REPRODUCTION OF DRAWING BY PHOTOGRAMMETRY OF DAMAGED BOWS OF FRIGATE



1 FT VERTICAL INTERVAL	BREADTH (FT. & INCHES)
15	7′-10½″
14	7′-2½″
13	6′-6½″
12 ◐	5′-9 15/16″
11 ◐	5′-4 7/16″
10	4′-11 11/16″
9	4′-9″
8 (3 DK)	4′-6″
7	4′-3 7/16″
6	4′-0 15/16″
5	3′-10 9/16″
4	3′-8 3/16″
3	3′-5 11/16″
2	3′-3⅛″
1	3′-0⅝″
0 (17 long^{L})	2′-9¾″
1	2′-6 11/16″
2	2′-3⅜″
3	2′-0″
4	1′-8 7/16″
5	1′-4 13/16″

FIG. 15—REPRODUCTION OF DRAWING BY PHOTOGRAMMETRY OF BOWS OF FRIGATE AFTER DAMAGED PART HAS BEEN CUT AWAY



1 FT VERTICAL INTERVAL	BREADTH ◑ (FT. & INCHES)
24	9′-8$\frac{5}{8}$″
23	8′-10$\frac{1}{8}$″
22	7′-11$\frac{3}{4}$″
21	7′-3$\frac{1}{8}$″
20	6′-7$\frac{1}{4}$″
19	6′-0$\frac{13}{16}$″
18	5′-6$\frac{13}{16}$″
17	5′-1$\frac{13}{16}$″
16	4′-9$\frac{13}{16}$″
15	4′-6$\frac{1}{4}$″
14	4′-3$\frac{3}{4}$″
13	4′-0$\frac{3}{4}$″
12	3′-10$\frac{13}{16}$″
11	3′-8$\frac{7}{16}$″
10	3′-6$\frac{5}{8}$″
9	3′-4$\frac{1}{16}$″
8	3′-1$\frac{1}{16}$″
7	2′-10$\frac{7}{16}$″
6	2′-7$\frac{9}{16}$″
5	2′-4$\frac{9}{16}$″
4	2′-0$\frac{15}{16}$″
3	1′-9$\frac{3}{4}$″
2	1′-5$\frac{3}{16}$″
1	1′-0$\frac{3}{4}$″

FIG. 16—REPRODUCTION OF DRAWING BY PHOTOGRAMMETRY OF NEW BOW WELDMENT

FIG. 17—PHOTOGRAPH OF NEW BOW WELDMENT IN CRADLE

Collision Damage

(see FIGS. 12 to 17)

Another interesting aspect of photogrammertry in Portsmouth Dockyard has been its involvement in two cases of collision damage. The first, dealt with here, was in 1976 when H.M.S. *Falmouth* encountered an Icelandic gunboat during the Cod War, and the second was in 1977 when H.M.S. *Ardent* was involved in a collision with the grain carrier *Friso*.

H.M.S. *Falmouth* suffered damage to her bow section and it was decided to construct the more streamlined type of bow being fitted to LEANDER and WHITBY Class frigates. Subsequently, a request was made by Production to use stereo photography to obtain dimensions of the cut back section, required as a check to the interface of the new bow weldment under construction in the heavy plate shop.

Using the SMK 40 camera the following information was recorded:

(*a*) Collision damage —Stereoscopic pairs taken on 22 May

(*b*) 'Cleaned up' section—Following the removal of damaged plating and 'cleaning up' of structure, further photopairs were taken at ship showing the cut-back section

(*c*) Final Weldment On 16 July photopairs were taken of the new bow before it was jacked into position

For both (*a*) and (*b*), a Simon platform was used for access to secure the necessary base/distance ratio essential for accurate photo-interpretation and plotting. Because of Production arrangements, i.e. the hoisting of the new bow into the cradle position, it was decided not to involve the platform in the dock for phase (*c*). This meant siting the camera at and beyond its limit of 10 metres.

The total 'on location' time for all the photography amounted to $4\frac{3}{4}$ hours. All drawings and relevant dimensions were obtained in a total of $4\frac{1}{2}$ days by one draughtsman on the Technocart plotter (the 'line-of-cut' drawing, being the most urgent, was completed in one day) and it can be seen from this that where large interface detail is required, e.g. 'dressing' of existing or new ship's structure, photogrammetry can be used to provide quickly dimensions without frequent recourse to design information or physical measurement. Apart from this functional purpose, a comprehensive record will always be available in photographic form from which analytical and graphical information—certainly useful to the professional in determining facts and figures allied to shipbuilding practice —can be produced at any time.

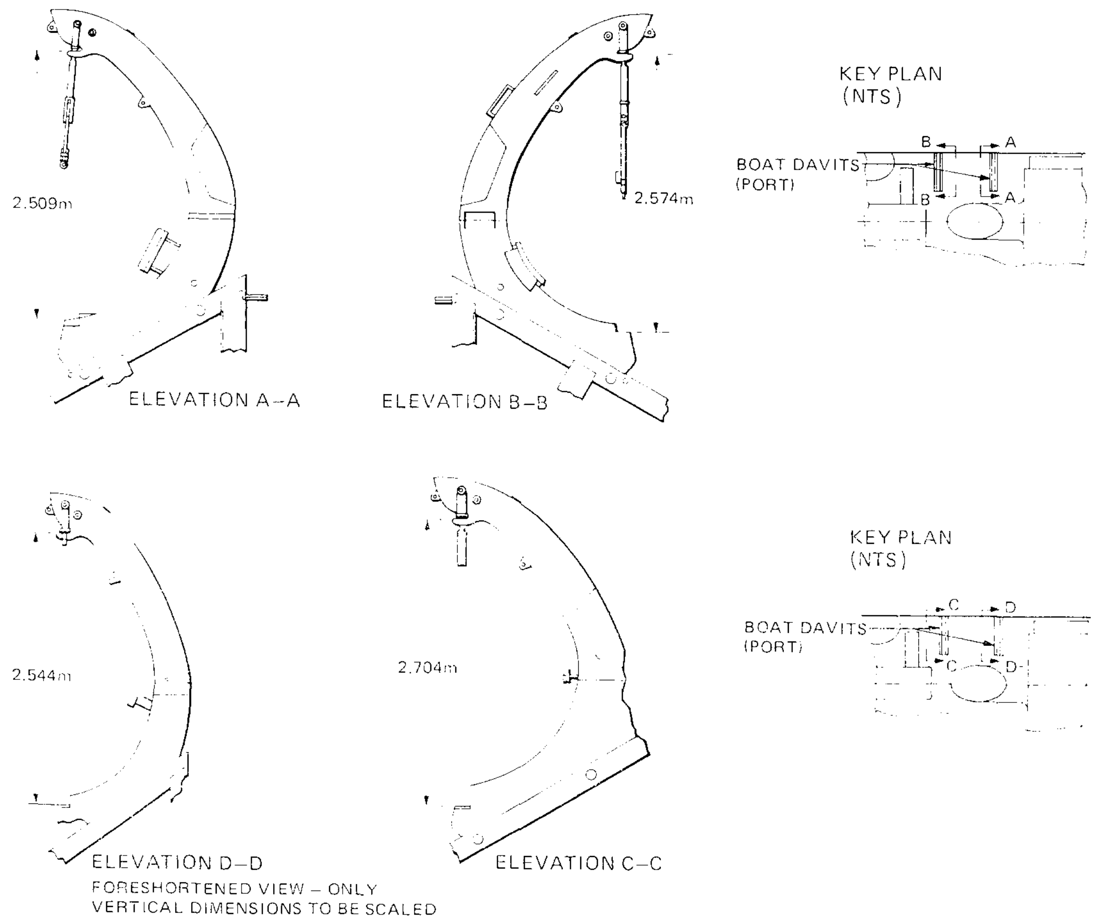


FIG. 18—REPRODUCTION OF DRAWING BY PHOTOGRAMMETRY COMPARING BOAT DAVITS OF TWO FRIGATES

Boat Davits (see FIG. 18)

Difficulty in fitting 'Cheverton' boats on two frigates was reported and scale drawings of the davits were requested from the Photogrammetry Unit. Four in number stereopairs were taken on one day (the time was dependent on one ship being available a.m. and the other p.m.). A drawing of the four davits was completed in one day and the shapes and details of davits compared. The awkward shape would have required two to three weeks of drawing work, including the manufacture of moulds and transfer of information. It would have been very difficult to take off measurements by normal methods with the boats in position as was the case with one frigate.

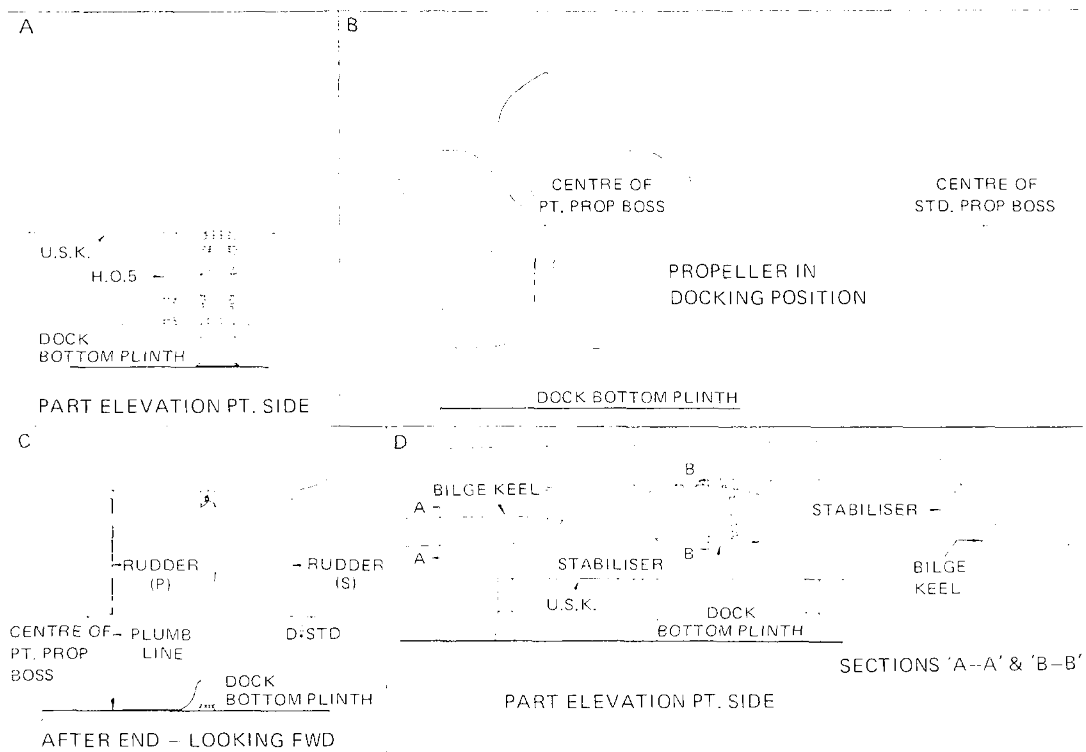


FIG. 19—REPRODUCTION OF DRAWING BY PHOTOGRAMMETRY SHOWING FRIGATE UNDERWATER FITTINGS

Underwater Fittings (see FIG. 19)

A request was made to undertake an independent check of the exterior 'as-fitted' of a frigate. Two half days on site resulted in twenty-one pairs of photographs giving extensive coverage of the hull. Three days on the 'Technocart' plotter produced drawings of rudders, sweep of propellers, draught marks, bilge keel and stabilizer, shape of bow, and hull outfit. In particular, the checking of the sweep of propellers was made easy. Using photogrammetry the sweep can be checked with the propeller in any position. Also in this time several measurements, including sonar fittings, etc., related to forward perpendicular as a datum were provided. Photogrammetry established its advantage because of the non-intrusive factor, speed of recording information and no requirement for scaffolding.

Part Profile of Frigate (see FIGS. 20 and 21)

This illustrates the use of the larger based SMK 120 camera and the additional detail that can be measured. (Big brother to the evaluated SMK 40). An overlap technique may be applied using triangulation of the common points of detail of related photographs (control points) and four or five camera sitings will include the overall length of a small frigate. The exercise was a forerunner to a more

FIG. 20—PAIR OF STEREOSCOPIC PHOTOGRAPHS OF PART PROFILE OF A FRIGATE

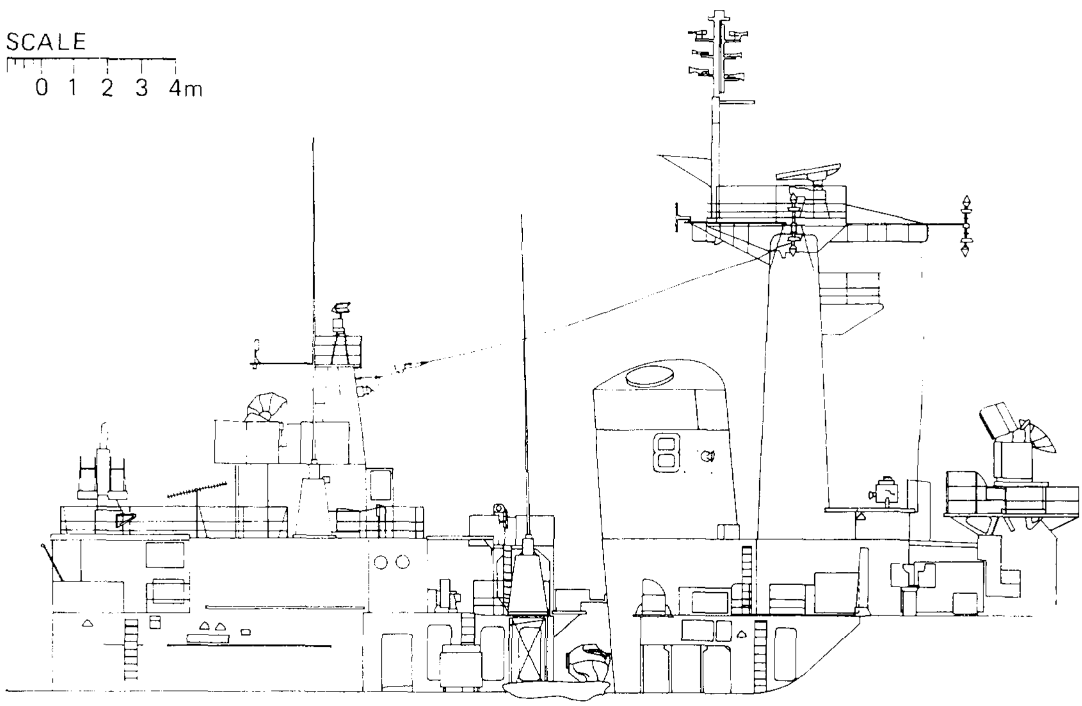


FIG. 21—REPRODUCTION OF PART PROFILE DRAWN BY PHOTOGRAMMETRY OF FRIGATE (FIG. 20)

ambitious attempt to record the 'Arcs of Fire' obstruction ordinates of another frigate in a state of refit. In this instance, the limitations of the SMK 40 were obvious and more suitable and expensive equipment was borrowed—UMK Camera and the Stecometer, which is a plotter consisting of a stereo comparator, a control console and an automatic recorder for recording measurements.

Specific information moves to a higher security classification, but principally two conditions led to unsatisfactory results:

(*a*) The ship state—in which many of the points required were obscured by awnings, temporary staging and scaffolding.

(*b*) The ship's position relative to camera stations—here the failure to record accepted tolerances of those points which did register was attributed solely to difficult geometry. The berth was trapezoidal.

Understandably the question is posed: Why not select better conditions? To select conditions within a Dockyard programme is one thing, but to expect such conditions to remain constant is another. The near ideal conditions on which the project was based did indeed change, which stresses the point made in the introduction to this article. The merit of the attempt was to highlight the requirement for controlled conditions, perhaps 'window dressing', and this to a higher authority constituted a disadvantage. Nevertheless, sufficient information was obtained to enable the specializations concerned with 'Arcs of Fire' to progress investigations.

Conclusions

From the three major reports submitted to Headquarters, covering many ship work applications, some of the following conclusions have been offered but not necessarily accepted.

(*a*) Photogrammetry is an excellent supplementary technique for recording detailed information particularly when time commitment is critical. This 'back-up' service can be included in routine 'as-fitted' photography.

(*b*) To produce drawings of complete layouts, it is sometimes necessary to obtain conventional measurements. In congested compartments there are blind (photographic) spots where the technique cannot be applied and siting the camera is difficult.

(*c*) For the analysis of awkward shapes, photogrammetry is an excellent method. It has the advantage of being virtually a non-contact procedure and can record safely in what may normally be considered a hazard situation.

(*d*) The storage facility is well proven. Hundreds of photopairs are stored in a space 60 cm × 25 cm × 14 cm. This could be further improved if film was used.

(*e*) The initial concept and consequent purchase of the close range equipment, allied to the production of 'as-fitted' drawings, proved to be restrictive to the more diversified applications of photogrammetry within shipbuilding work.