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Report on Benthic Bio-Sledge Model Trials

Alan Packwood (Hydrodynamicist)
Bob Aldred (Project Originator)
Geoff Lodge (Designer)
Alan Gray (Model Maker)

Internal Document No. 132

April 1981

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Wormley, Godalming,
Surrey GU8 5UB
(042-879-4141)

(Director: Dr. A. S. Laughton)

Bidston Observatory,
Birkenhead,
Merseyside L43 7RA
(051-653-8633)
(Assistant Director: Dr. D. E. Cartwright)

Crossway,
Taunton,
Somerset TA1 2DW
(0823-86211)
(Assistant Director: M. J. Tucker)

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BENTHIC BIO-SLEDGE MODEL TRIALS

DEPLOYMENT AND MID-WATER STABILITY

1. STATEMENT OF THE PROBLEM

A requirement was received for the design and development of an improved benthic sledge for fishing on the ocean bed. The original version (See fig. 1) had performed its bottom fishing function acceptably but on deployment was on occasions found to roll over into an upside down position from which it did not recover. This meant that the device had to be brought back inboard and redeployed. This trial and error method was unsatisfactory and any improved version should therefore have more positive roll stability and ideally should be fully self-righting in the event of it being perturbed sufficiently to invert it, by the ship's propeller wake say.

The main structure of the new sledge would incorporate many features of the original. Major changes to the framework to accomplish the improved stability would therefore be undesirable as this might change the already proven fishing ability of the original frame. Small changes, either by adding lead weights or buoyancy or some hydrodynamic device to give roll correction were therefore envisaged and the scope of these trials was therefore constrained to work within these restrictions. A general arrangement drawing of the new proposed framework giving relevant dimensions is shown in fig. 2. During deployment all of the nets are closed, the bottom nets by a blind, the top net by closing the net mouth and collapsing the net. The nets are opened automatically by skids that are retracted when the frame reaches the sea floor. The design towing speed is 1.5 kts and the nets operate in depths of 400 - 4000 m. The wire speed during deployment (paying out) and retrieval (hauling in) is 0.5 m/s. To reduce the amount of wire out and the time for the sledge to reach bottom it is advantageous to maintain a drag to weight ratio for the sledge of less than one. Thus any form of drag device to give a righting moment is likely to reduce the efficiency of operation. A further point to be considered is the emergency retrieval system in the event of the sledge becoming snagged on the bottom. If this occurs, a weak link in the bridle breaks and the cable picks up on two auxiliary bridles attached to the rear of the frame. These bridles roll the frame over, hopefully freeing it from the obstruction and tow it along the bottom upside down. This triggers an acoustic signal which indicates that the frame needs rapid recovery. Any self-righting mechanism must be capable of withstanding this sort of treatment without loss.

In view of a lack of data on the towing attitude and stability characteristics of the Mark 1 sledge, it was decided that a series of model tests on the new version should be undertaken on which a number of self-righting mechanisms could be investigated.

2. MODEL SCALING

Due to the physical constraints of the cross sectional size of the towing tank facility, a model length scale of $\frac{1}{8}$ full scale was decided upon. Thus the weights of the frame and its various components would be scaled by volume such that model weight is $\frac{1}{512}$ of full scale weight. The scale model frame was constructed of $\frac{1}{8}$ in. diameter steel welding rod, the bottom runners and net opening skids of thin mild steel sheet and the steel netting on the lower part of the frame was modelled with a stiff fine plastic netting of 2 mm mesh size. It was evident that it would be difficult to realistically model the fishing nets but since during deployment all nets are closed, this was not thought to be a grave problem. A fine, soft, knotless 1 mm mesh net material was found that was approximately $\frac{1}{6}$ scale of the finest full-scale net material used and this was used to model all of the nets.

Full scale weights in air (lb)		Scaled model weight (gm)
Odometer wheel	22	
Acoustic net monitor	40	
Camera	18	
Flash unit	10	
Nets and fittings	50	
4 lead weights @ 40 lb	160	140 @ 35 gm each
Steel frame (guess)	550	
	850 lb	750 gm

The actual model weight fully assembled was 835 gm with the four 35 gm lead weights on the bottom runners. The model was thus some 85 gm over weight due to the frame being made of solid round section unlike the lighter angle section of the original. The four 35 gm lead weights were removed and replaced with smaller ones to give the model weight in air 750 gm. In water this configuration weighed 570 gm corresponding to a full scale fully immersed weight of 640 lb. Exact figures for the weight in water of the original sledge are not available so these figures can only be taken as rough approximations.

To model the motion of the model, the correct similarity criteria have to be obeyed. Consider first the Reynolds number of the full-scale sledge.

$$R_e = \frac{\text{inertia force}}{\text{viscous force}} = \frac{lV}{\nu} \simeq 1.6 \times 10^6$$

The Reynolds number is high, indicating that viscous forces are small compared to inertia forces. Next consider the Froude number of the sledge.

$$F_r = \frac{\text{inertia force}}{\text{gravitational force}} = \frac{V}{\sqrt{gl}} \simeq 0.05$$

i.e. the gravitational force dominates the inertia forces. It will be impossible for the $\frac{1}{8}$ scale model in water to meet both Reynolds number and Froude number similarity criteria but since the gravitational force is so very much more important than the viscous forces in this situation, Froude number scaling will be used. Since the model length scale has been fixed, this fixes the model velocity scale.

$$F_r = \frac{V}{\sqrt{gl}} \quad \therefore \quad \frac{V_m}{V} = \sqrt{\frac{l_m}{l}} = \sqrt{\frac{1}{8}}$$

$$\text{i.e. } V_m = \frac{V}{2.8} \tag{1}$$

Froude number scaling has the added benefit that the drag forces are scaled in just the same way as the weight. If the full-scale drag D is given by

$$D = \tfrac{1}{2}\rho V^2 S \, C_D \tag{2}$$

where S is a representative area, ρ the density of the fluid (water) and C_D the drag coefficient, then at model scale

$$D_m = \tfrac{1}{2}\rho \, V_m{}^2 S_m \, C_D = \tfrac{1}{2}\rho \, \frac{V^2}{8} . \frac{S}{64} . C_D = \frac{D}{512} \tag{3}$$

This means that angles are preserved under Froude number scaling i.e. wire angles and frame attitudes measured at model scale may be taken to directly apply to the full-scale situation under the assumptions of the scaling (viscous forces ignored).

3. DESCRIPTION OF TOWING TRIALS

3.1 ORIGINAL CONFIGURATION

The model was attached to the towing carriage of the wave tank facility so that it was suspended some 10 to 20 cm above the bottom of the tank. The original configuration was tested first. This has a weight of 570 gm in water with no additional self righting aids. The model was towed at a variety of speeds 0 - 35 cm/s and when the model was judged to be steady, the towing wire angle to the vertical was measured at the carriage. Knowing the weight of the model in water and the wire angle, the drag of the nets and frame can be calculated, ignoring any lift forces, from the relation

$$D_m = W_m \tan\theta \qquad (4)$$

where θ is the wire angle measured from the vertical. As has been suggested, this ignores any lift force that may be generated by the bottom runners or the structure, all of which will more efficiently produce drag rather than lift. The drag of the wire rope holding the model has similarly been ignored but both of these approximations can be expected to be reasonable at the slow speeds of most interest (about 26 cm/s).

In the full scale deployment operation from the ship the cable is payed out at 0.5 m/s so the sledge is in effect being towed at a slower speed than the ship speed as well as dropping through the water. On recovery the reverse is true but roll stability during recovery is much less important, the primary object being to get the frame on the bottom the right way up. Due to the limited depth of water in the towing tank, paying out and hauling in trials were not feasible. However from the zero winch speed trials conducted, the behaviour of the frame on a moving cable can be deduced, this is discussed later.

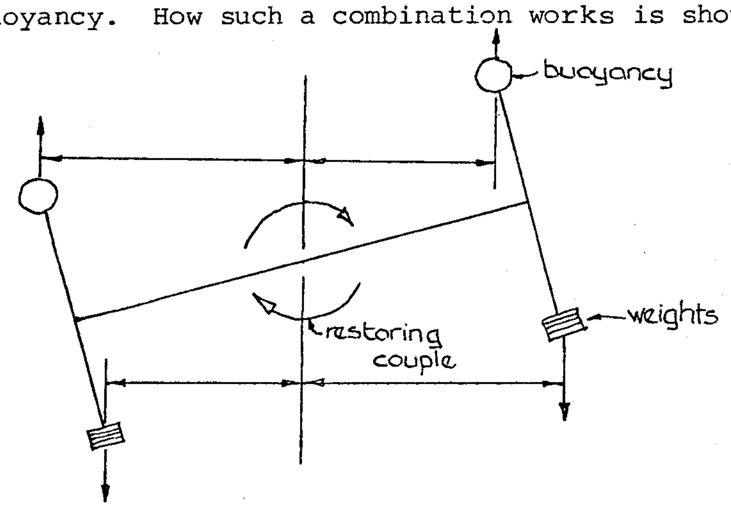
The results of the trial of this first configuration are summarized in fig. 3. The most striking and disturbing feature is that on increasing the towing speed from 25 to 30 cm/s, the model rolled into an inverted position and did not recover. The rolling was apparently caused by the drag on the odometer wheel, since it rolled over wheel side up, but this was probably aided by the unsymmetrical loading of the sledge, the camera and net monitor being heavier than the wheel. During further tests on this configuration, the model was perturbed while being towed at various speeds and its subsequent motion observed. It was found that the frame was almost neutrally stable and would remain for long periods in most positions. There seemed to be only one strongly preferred attitude which was inverted, in which position it presented the most drag.

These first findings were encouraging in that the observed behaviour of the Mark 1 sledge was being reproduced by the model in some measure. The frame had neutral roll stability in the upright position and more positive roll stability when inverted, and tended to tow wheel side up.

3.2 THE SEARCH FOR A SUITABLE SELF-RIGHTING DEVICE

In the introductory section some possible devices were mentioned. The first to be tried was a small wing mounted on one side on the top corner of the frame above the camera. Because of the different attitudes of the frame when upright and inverted, it was thought that a small wing might just balance the wheel drag when the frame was upright if at small incidence, but when inverted might provide sufficient lift, due to its new higher incidence, to right the frame. A small variable incidence wing of 7.5 cm span and 4 cm chord was mounted on the model and several self-righting trials at various speeds (0 - 52.5 cm/s) and wing incidences were carried out. The results indicated the unsuitability of this type of device without some form of active control. To make the wing effective, the speed had to be increased to an equivalent ship speed of 3 kts or more and then under some circumstances the frame would cork-screw through the water. But most damning of this method was the fact that at low speeds and near design towing speed, the wing did nothing to improve the roll stability of the frame. So the hydrodynamic control surface solution was discarded.

The most promising theoretical solution that would improve roll stability and possibly even give a full self-righting ability was a combination of added weight and buoyancy. How such a combination works is shown diagrammatically below.



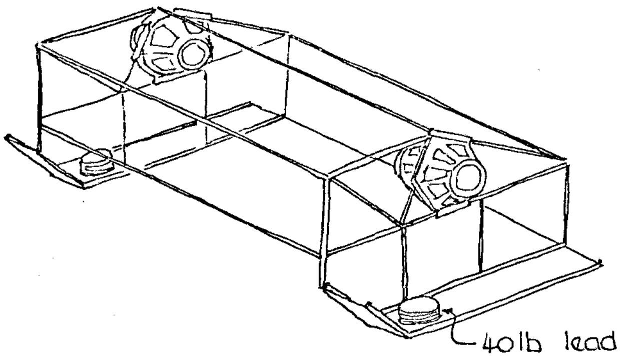
Notice that it is only the vertical separation from the roll axis that brings about the righting moment correcting any displacement in roll. Unfortunately, because of the nets, it is not feasible to put buoyancy and weights directly above and below the roll axis, as would be desirable, and a small penalty is paid in lost righting moment for having to displace these additions to the corners of the frame.

Several combinations of weight and buoyancy were tested but the most effective was the use of four ping-pong balls mounted in two pairs on the top rear cross bar (see photographs fig. 4). Another important modification was to trim the sledge for roll in air so that it was balanced about its longitudinal axis. To accomplish this, the extra lead weights attached to the bottom runners were removed and 16 gm added on the wheel side runner. That is 16 gm added weight in water which is equivalent to 18 lb full-scale in water. The ping-pong balls are 1.5 in diameter giving 29 gm buoyancy force each. Four ping-pong balls are thus equivalent to 128 lb full-scale nett buoyant force. This configuration in water weighs 440 gm, equivalent to 496 lb full scale.

A series of drag tests, stability tests and self-righting experiments were carried out and photographs were taken through the glass windows of the towing tank recording the attitude of the frame and bridle towing angles. The series of photographs and recorded data is shown in figs. 4A to 4G. Figs. 4A to 4E show towing tests at increasing speeds. At the highest speed, fig. 4E, the top of the sledge is about 7 cm below the free surface of the water. The sledge was deliberately inverted for fig. 4F and had to be held on edge for fig. 4G, the bamboo cane for doing this having been removed immediately before the taking of this picture, this being an unstable attitude for this configuration. Fig. 5 relates the measured incidence of the sledge to the towing speed, translated into equivalent ship speed. The stability tests indicated that the buoyancy gave the sledge a positive righting moment. If the sledge was pulled over onto its side then it would self-right, but if the sledge was rolled onto its back, some assistance was needed to right it because of the stronger natural stability of the frame in this attitude. However, it was found the the frame could be made to right itself if the towing speed was increased to 52.5 cm/s or 3 kts. full scale speed. At this speed the angle of incidence of the frame was much reduced and any small perturbation would tend to initiate a corrective rolling motion, eventually bringing the frame into the upright position where it was most stable. The drag of the wheel was evidently sufficient for this purpose, for the sledge was always observed to roll upright wheel side up.

3.3 FINAL CONFIGURATION

Unfortunately the placing of the buoyancy on the top cross-bar was not a good engineering solution and buoyancy of a similar scaled up size was not readily available. The favoured solution was to mount two 17 in diameter glass spheres, each giving 56 lb nett upthrust in water, in the frame as shown in the diagram below.

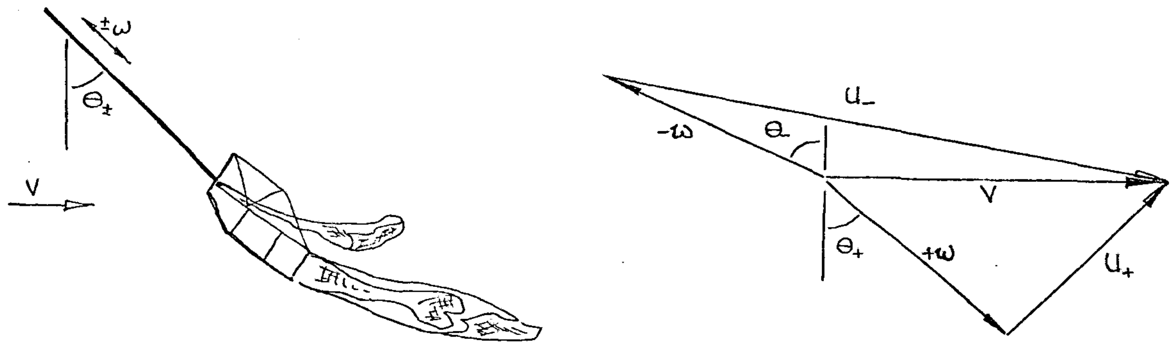


Since this arrangement would mean reducing the separation of the buoyancy from the roll axis, it was suggested that extra weights be added at a forward position on the runners as shown to increase the righting moment. Two 35 gm lead weights corresponding to two 40 lb full scale weights were stuck on with plasticine. The model floats were modelled by turning some expanded P.V.C. material used as net floats into the correct shape to give the approximate buoyancy of the Benthos glass spheres. A final series of tests was then carried out to check that this solution would behave as the previously successful configuration. The final configuration weighed 425 gm in water, equivalent to 480 lb full-scale.

The results of the drag test and self-righting test are shown in figs. 6 and 7. Fig. 6 shows the drag curve for this final configuration for the frame upright and inverted. The frame was found to be self-righting if the towing speed were increased to 2.8 kts full scale. This is a similar figure to that found for the previous configuration. The stability characteristics were found to be as before. The addition of the weights, although found to be unnecessary for the righting of the sledge, did reduce the wire angle to the vertical by 3° and were thus thought to serve a useful purpose. Fig. 7 relates the drag coefficient, calculated from (2) using the planform area of the sledge as the representative area S, to both the towing speed and wire angle. It can be seen that the drag coefficient varies quite a lot with the changing angle of the frame but at around the design speed $C_D \simeq 1$.

4. EFFECTS OF PAYING OUT AND HAULING IN THE CABLE

In deploying and recovering the sledge, the effect of the moving wire is to change the relative flow direction and velocity as seen by the sledge. Let the wire speed be w where w is positive for paying out and negative for hauling



in. The relative flow vector U_+ for deployment and U_- for recovery are shown in the sketch above. The unknown quantity is θ the wire angle during these operations which because of the changed flow vector will be different in each case. Consider the drag force acting on the sledge. D may be calculated from either (4) or (2). If an average drag coefficient $C_D \simeq 1.0$ is assumed for the expected range of values of θ, then equating (4) and (2) gives

$$W \tan\theta = \tfrac{1}{2}\rho\, S\, C_D\, (V - w\sin\theta)^2 \qquad (5)$$

where $(V - w \sin\theta)$ is the horizontal component of the resultant velocity U. Given W = 480 lb, S = 5.9 m², V = 1.5 kt and w = ± 0.5 m/s equation (5) can be reduced to

$$\tan\theta_\pm = 1.42\left(0.56 + \frac{\sin\theta_\pm}{4}(\sin\theta_\pm \mp 3)\right) \qquad (6)$$

where θ_+ is the solution for the minus sign before the 3 and θ_- the solution with the positive sign (θ_+ paying out angle, θ_- hauling in). This equation can be solved by an iterative procedure if a starting value for $\theta_\pm$ on the R.H.S. of (6) can be obtained. The value used was $\theta_+ = \theta_- = 36^\circ$ which is the wire angle given by fig. 6 for zero wire speed. On substituting this value into the R.H.S. of (6) a 2nd approximation for θ_+ and θ_- can be obtained by solving for the L.H.S. value and so on. After five iterations θ_- had converged to within 0.1° and after ten iterations θ_+ had similarly stabalized the final values being

$$\theta_+ \text{ (deployment)} = 23.5^\circ\ ;\ \theta_- \text{ (recovery)} = 63.7^\circ$$

These are to be compared with $\theta_o = 36^\circ$ for zero wire speed.

For these values of cable angle, the horizontal and vertical velocity components as seen by the sledge are

		Drag force
Deployment	horizontal velocity = 0.55 m/s ≃ 1 kt vertical velocity = 0.46 m/s	210 lb
Recovery	horizontal velocity = 1.2 m/s ≃ 2.3 kts vertical velocity = -0.22 m/s	970 lb

Notice from these figures the large differences in the drag force for deployment and recovery indicating that in recovery the cable tension will be approximately 5 times that for deployment. The vertical velocities give some indication of the time that the sledge will require to reach bottom. In 4000 m of water the minimum time to reach bottom will be 2.4 hrs. This is a minimum because cable drag effects, which will slow the descent by increasing the cable angle as more cable goes out, have been ignored. Cable forces will be very considerable when fishing at great depth so this time may be in considerable error.

5. CONCLUDING REMARKS

It is believed that the ability to model the complex benthic sledge structure and nets has been demonstrated by the qualitatively similar stability characteristics of the Mark 1 full scale sledge compared with the first model configuration investigated. However this confidence will only be bourne out by trials of the final configuration, suggested in this report, at full scale. A successful self-righting method has been proved at model scale where by increasing towing speed to 3 kts and stopping paying out the cable, the sledge will turn upright if it has become inverted in the deployment process. The addition of the two 17" diameter glass spheres reduces the sledge weight in water by 112 lb. This loss is partially offset by the addition of two 40 lb lead weights but more weight may need to be attached if operation of the sledge proves problematical. It has also been indicated that the sledge should be statically balanced in roll. This is perhaps an obvious thing to say but seems to have been overlooked on previous occasions. Since this operation is impractical as sea, a static balance on land will probably suffice. The suggested additions of buoyancy and weight in the correct places not only gives the sledge a self-righting capability but it also greatly improves its natural stability in the upright position. This is probably the most important feature and it is hoped that this will mean that the self-righting procedure will never need be put into action.

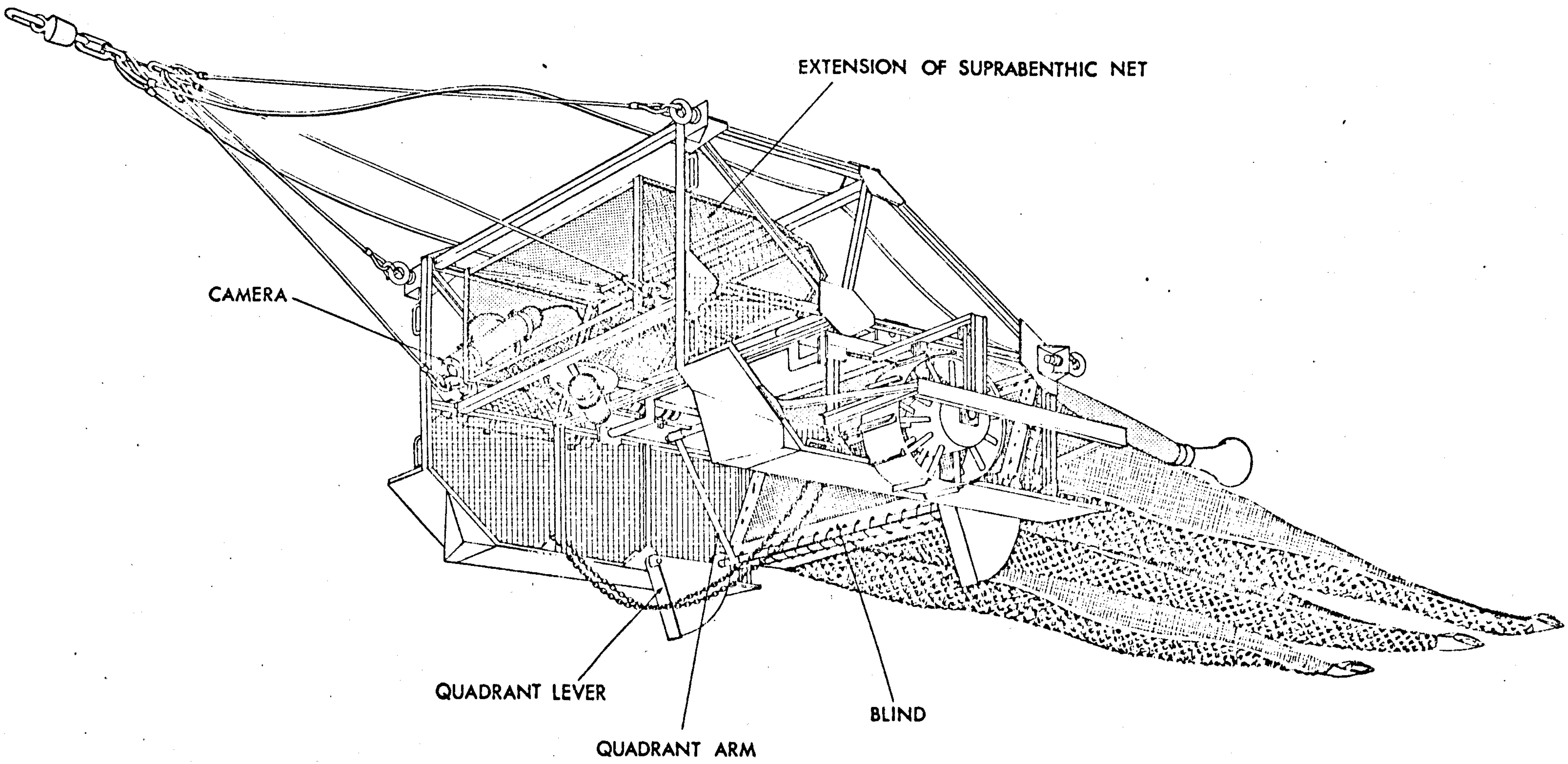
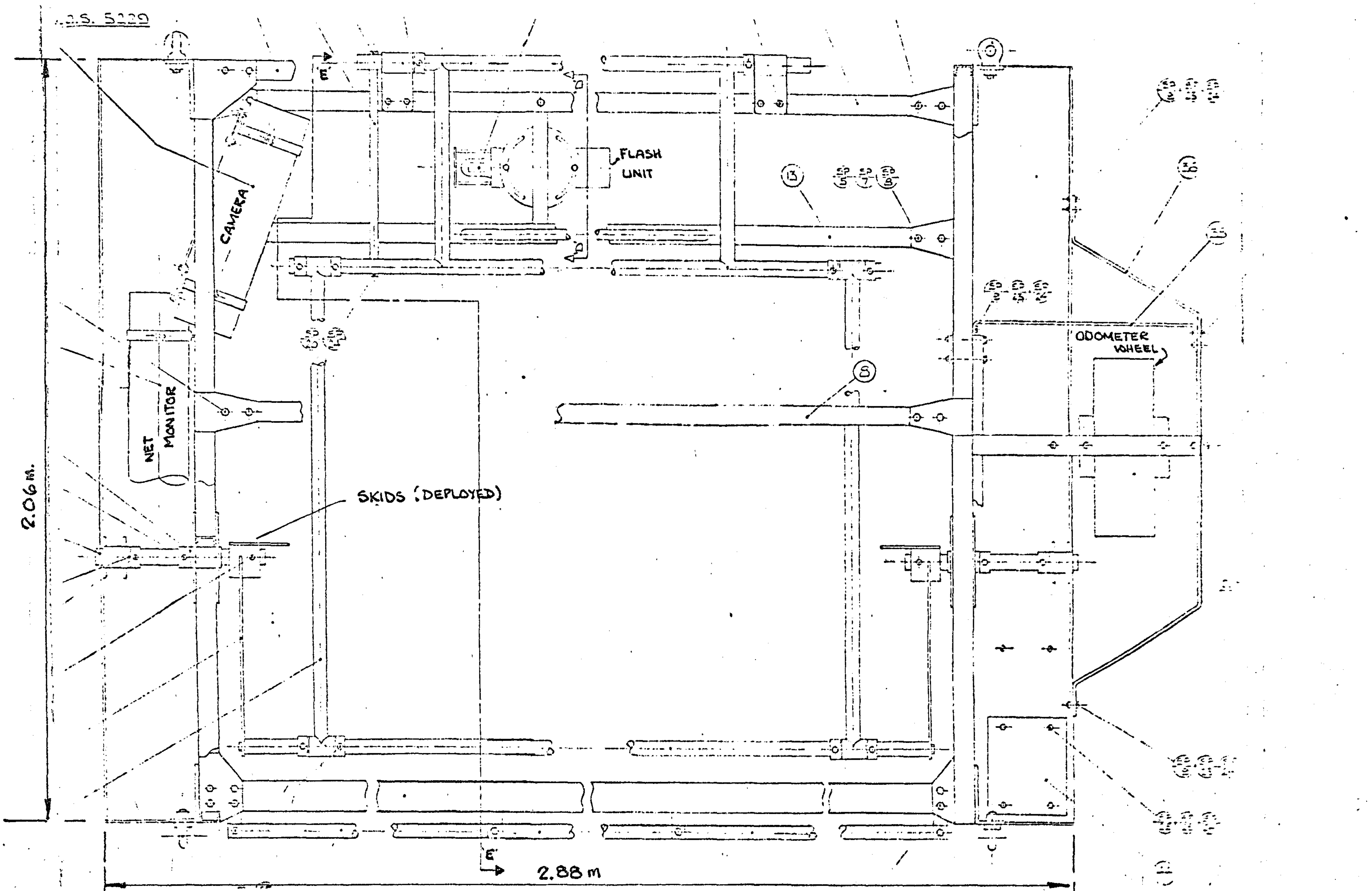

EXTENSION OF SUPRABENTHIC NET
CAMERA
QUADRANT LEVER
QUADRANT ARM
BLIND

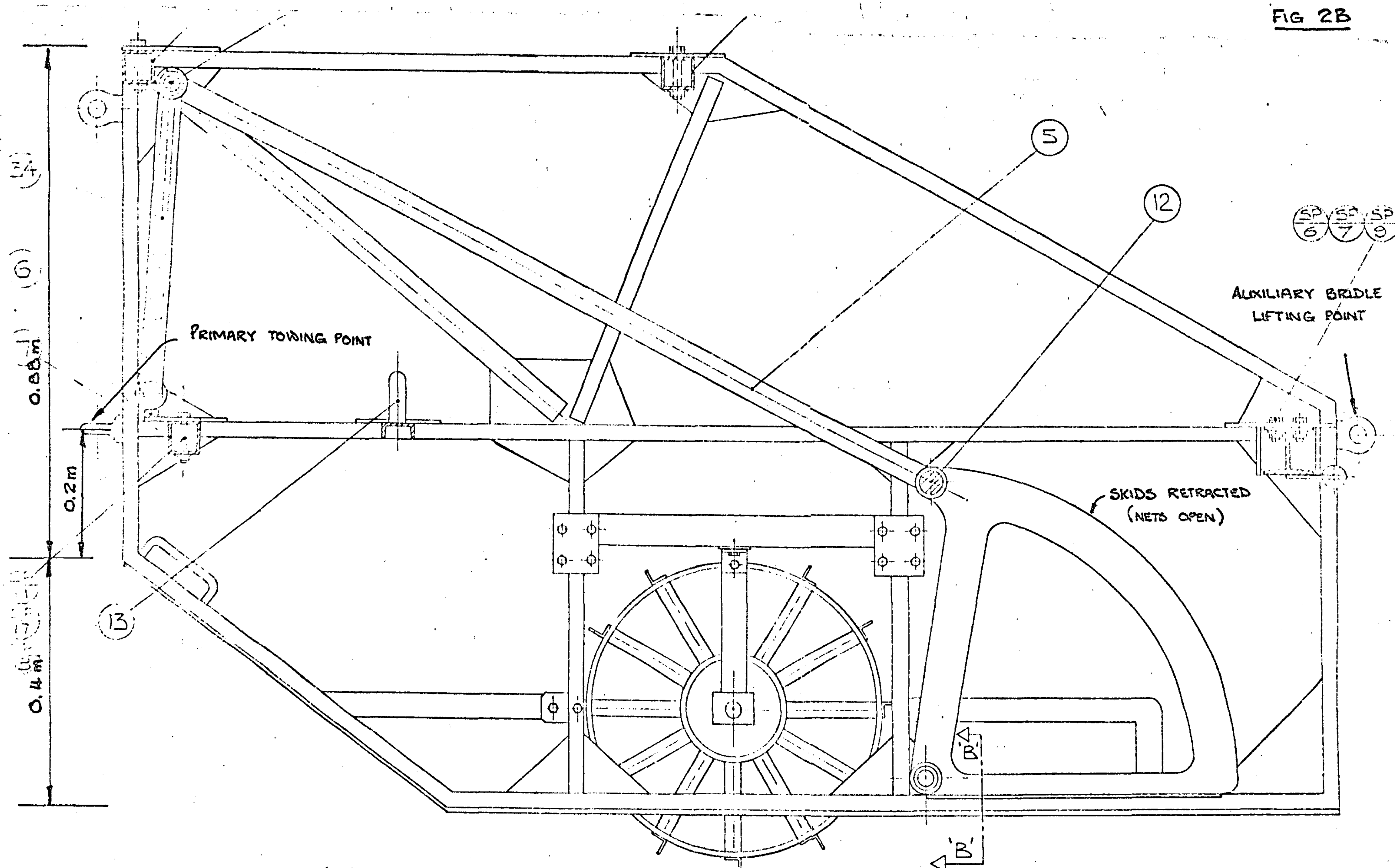
FIG. 1.

FIG. 2A



PLAN VIEW OF BENTHIC-BIO-SLEDGE NET FRAME
DIMENSIONS APPROXIMATE

FIG 2B



SECTION 'EE' of FIG 2A
BUT SHOWING SKIDS RETRACTED OPENNING UPPER AND LOWER NETS.

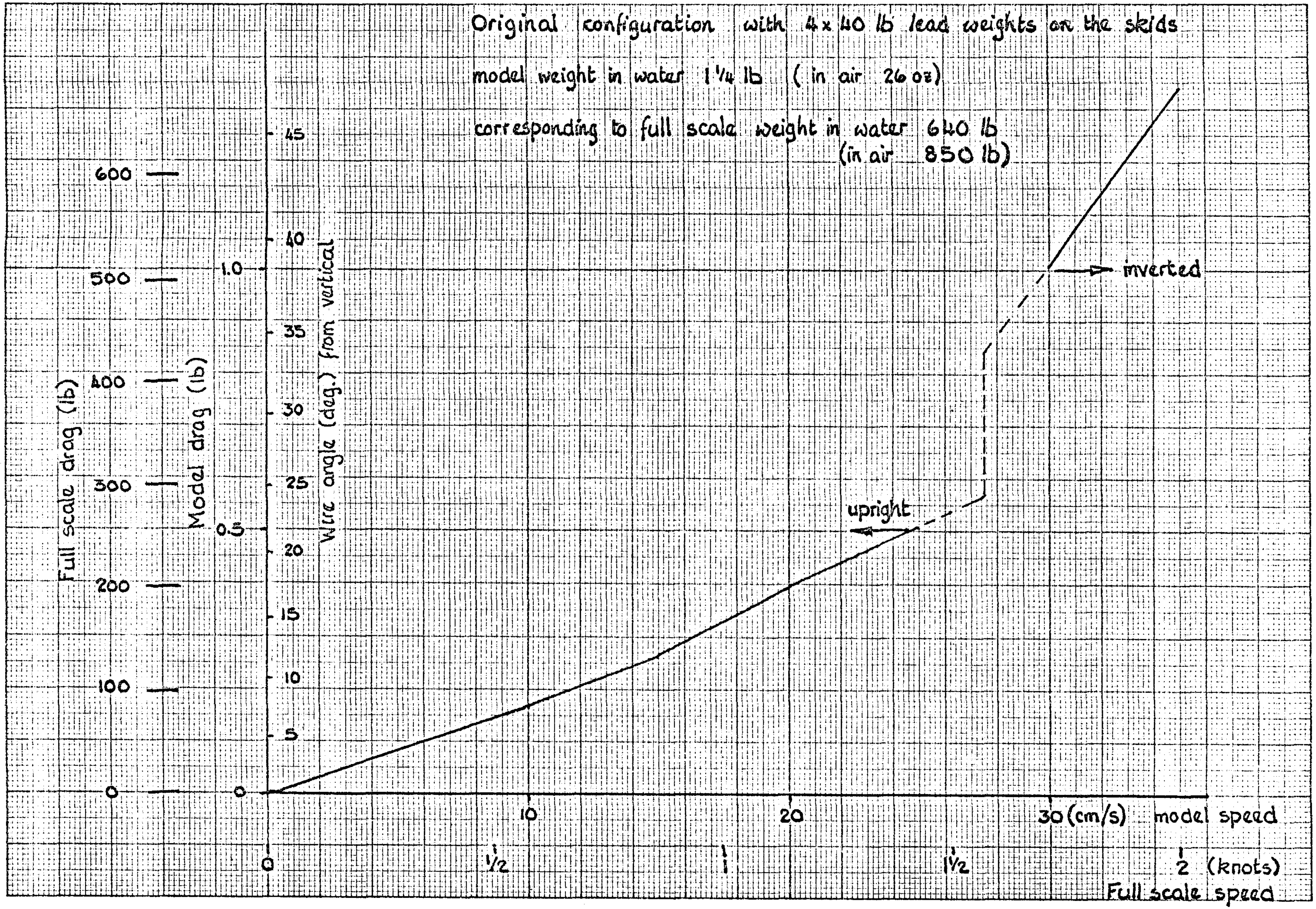

Original configuration with 4 x 40 lb lead weights on the skids
model weight in water 1 1/4 lb (in air 26 oz)
corresponding to full scale weight in water 640 lb
(in air 850 lb)
Full scale drag (lb)
0
100
200
300
400
500
600
Model drag (lb)
0
0.5
1.0
Wire angle (deg.) from vertical
5
10
15
20
25
30
35
40
45
upright
inverted
10
20
30 (cm/s) model speed
0
1/2
1
1 1/2
2 (knots)
Full scale speed

FIG. 4A

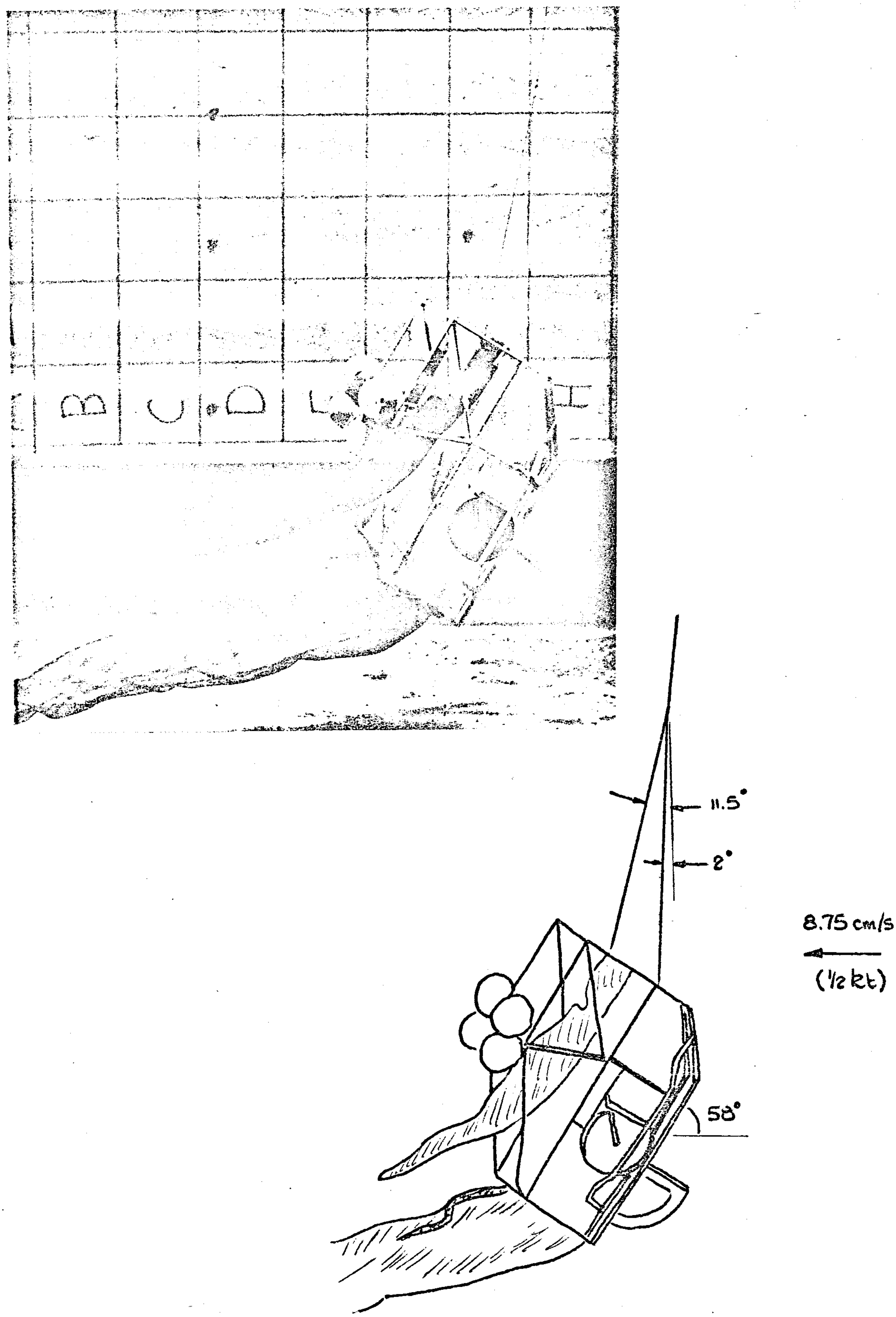
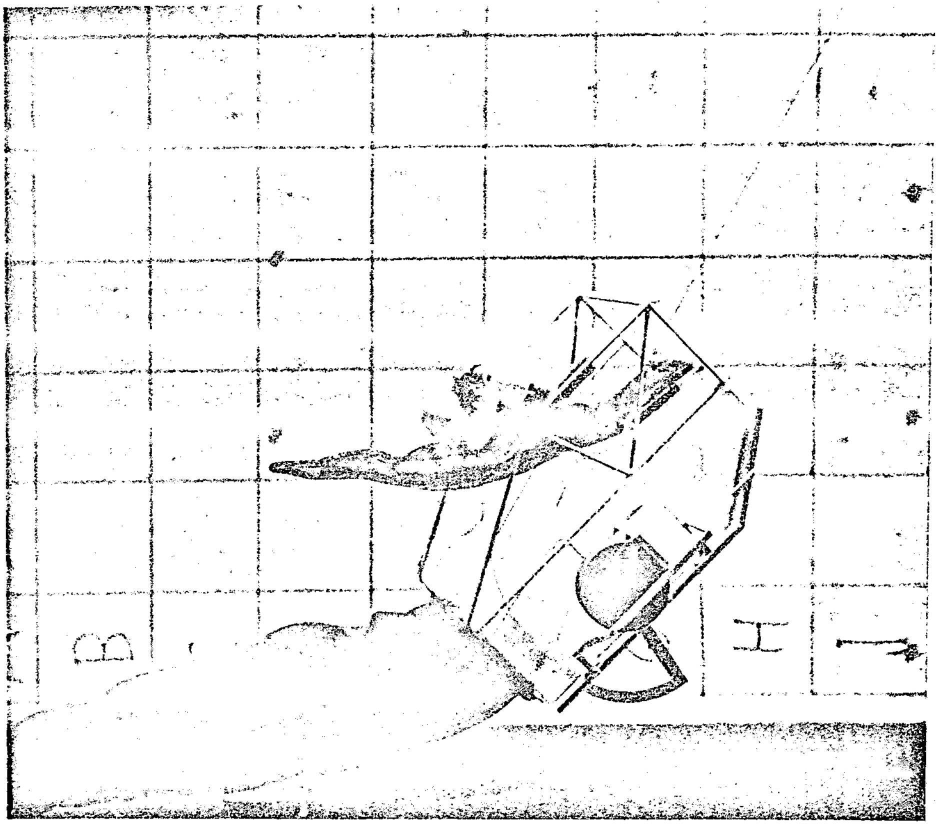


FIG. A8



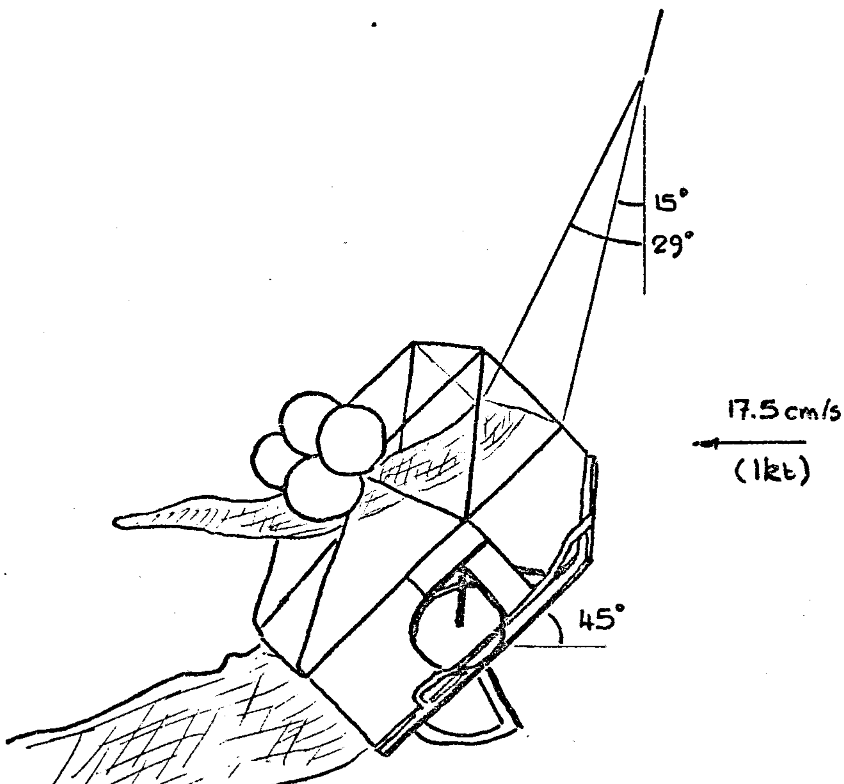
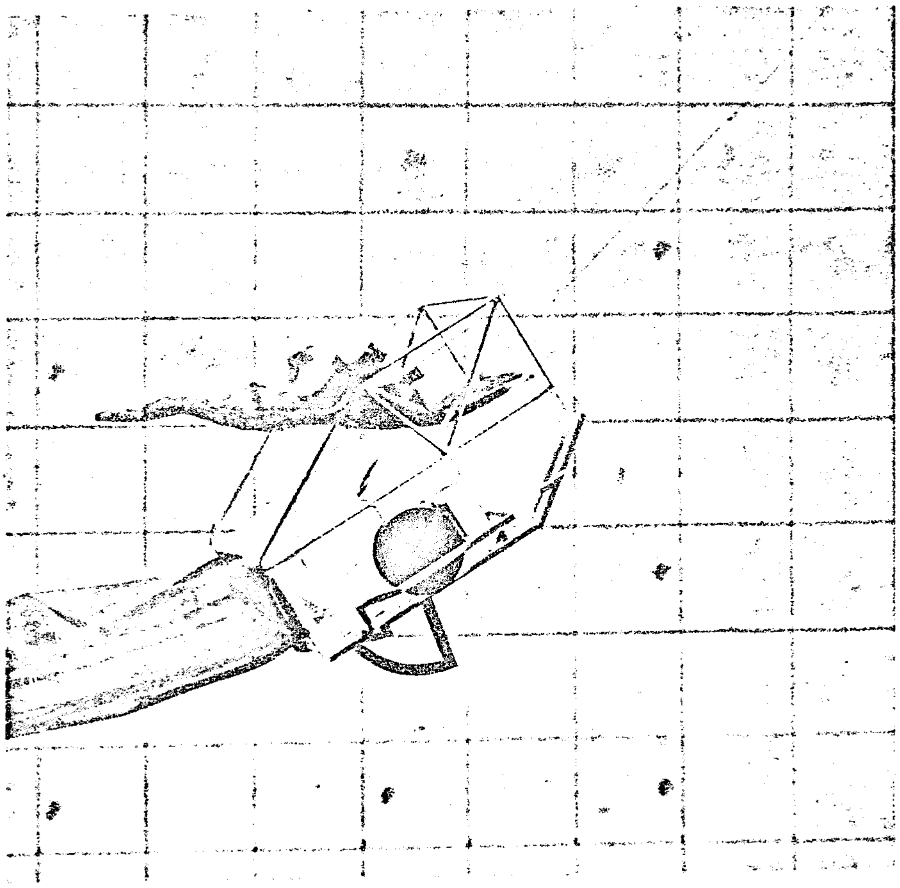


FIG. 4C



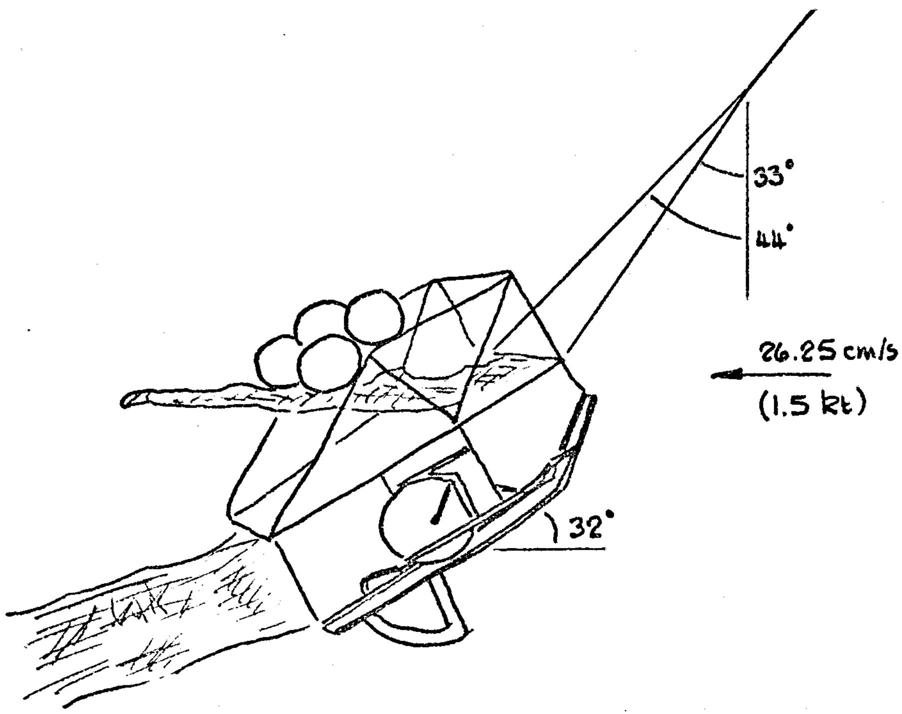
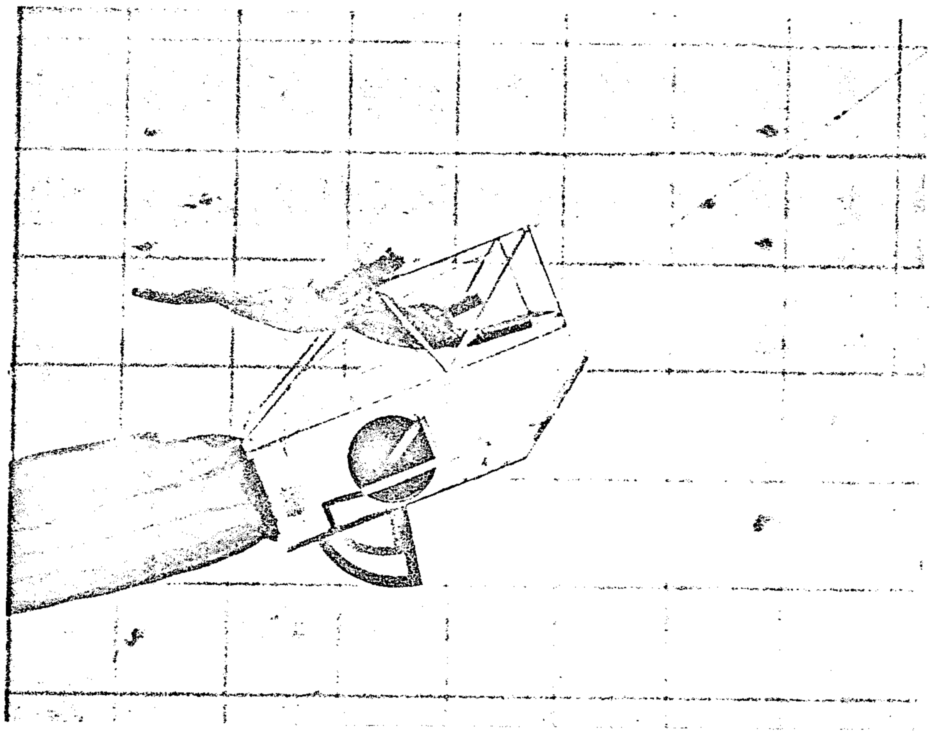
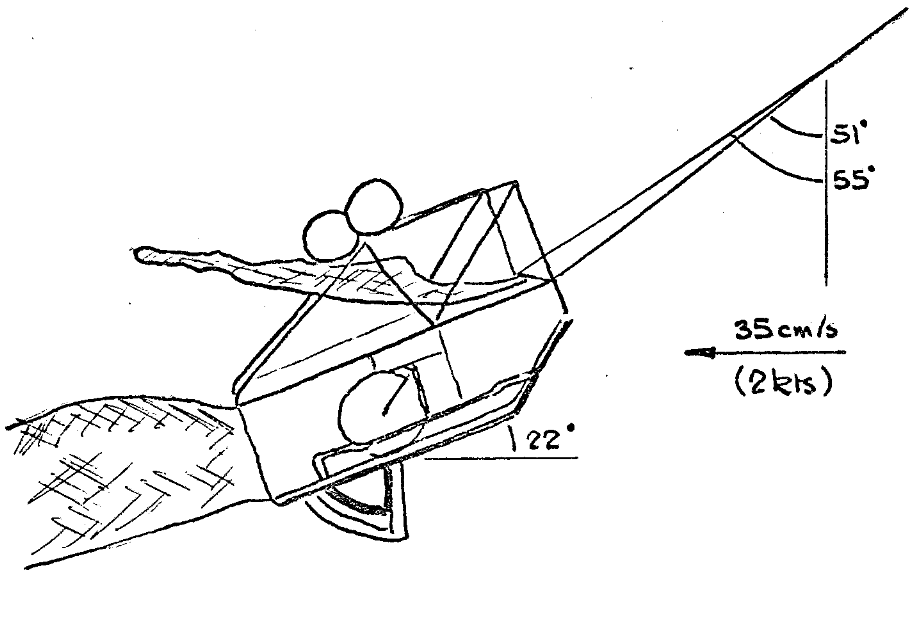
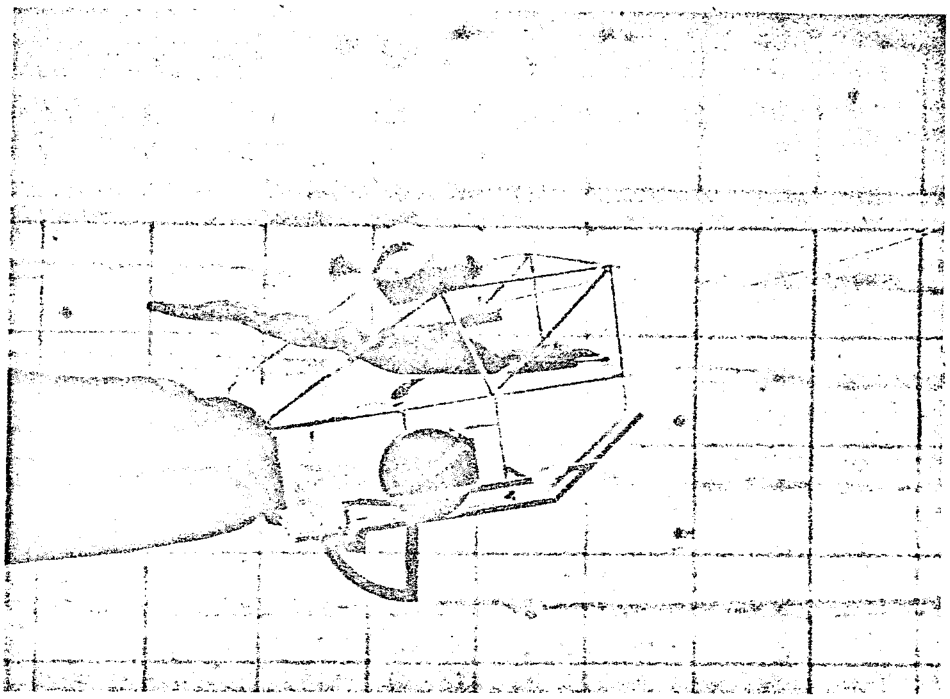


FIG. 4D







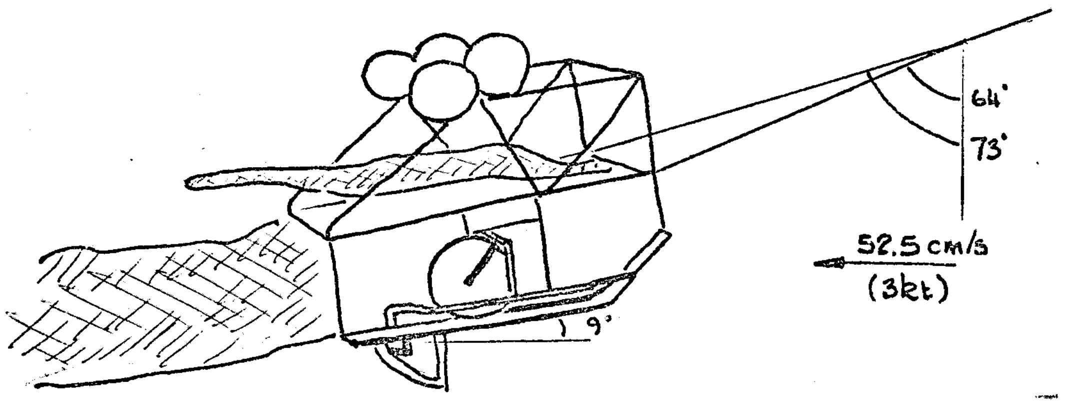
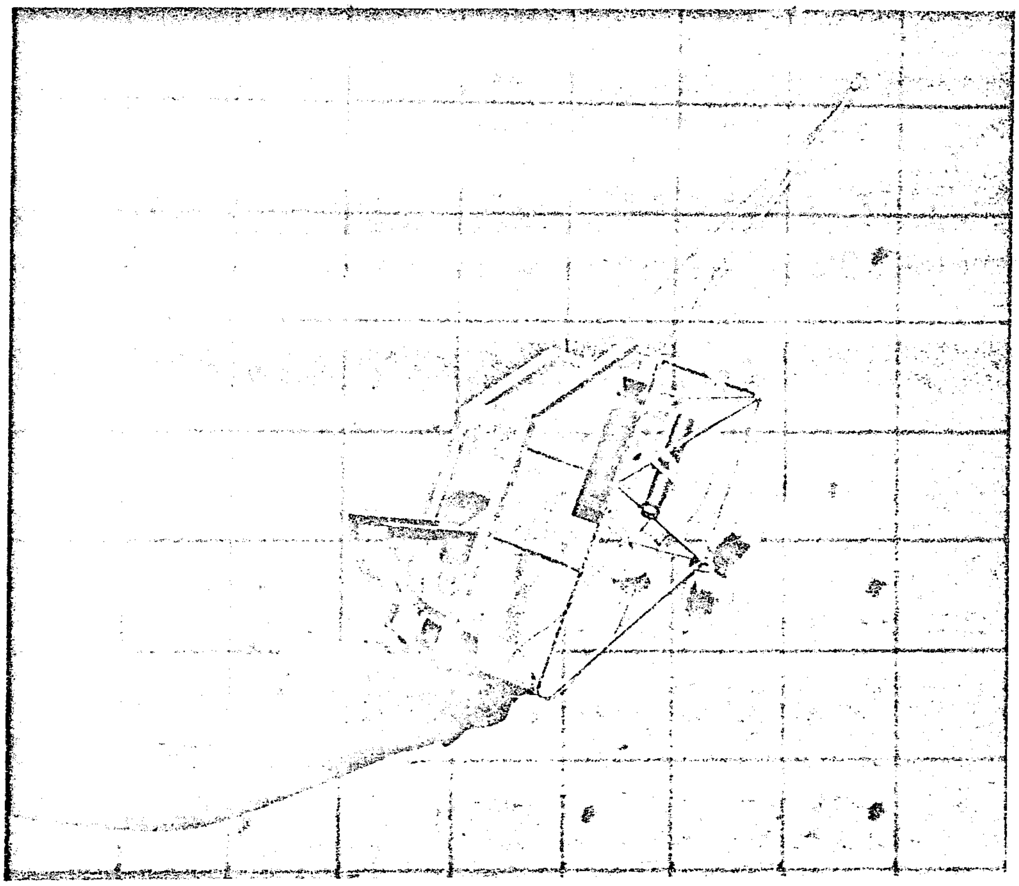

64°
73°
52.5 cm/s
(3kt)
9°

FIG. 4F



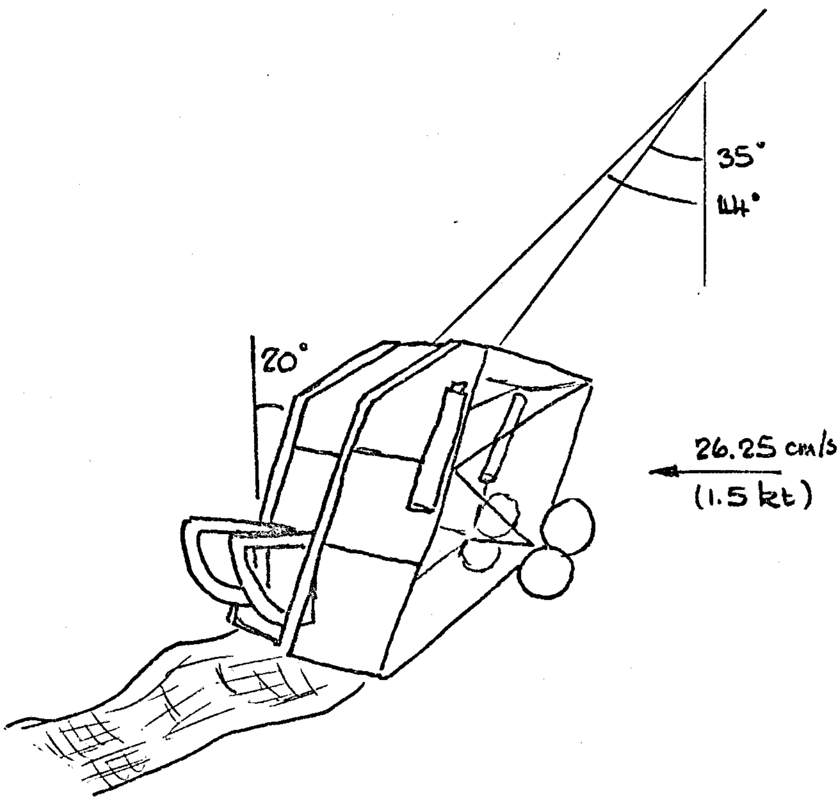
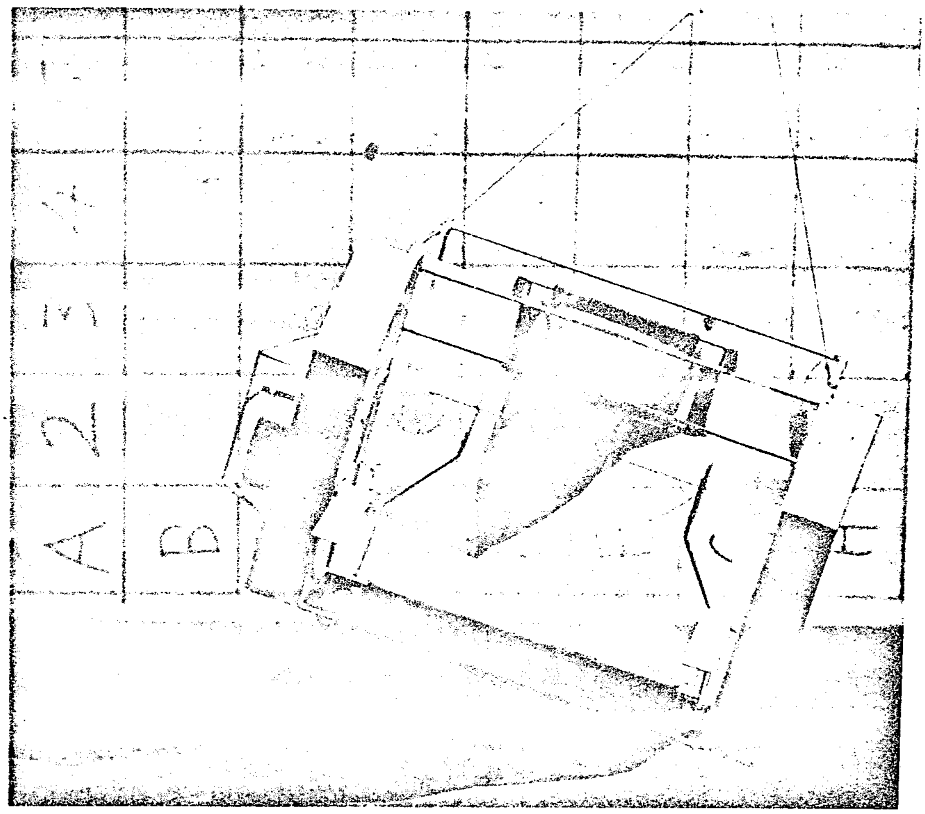


FIG. 4G.



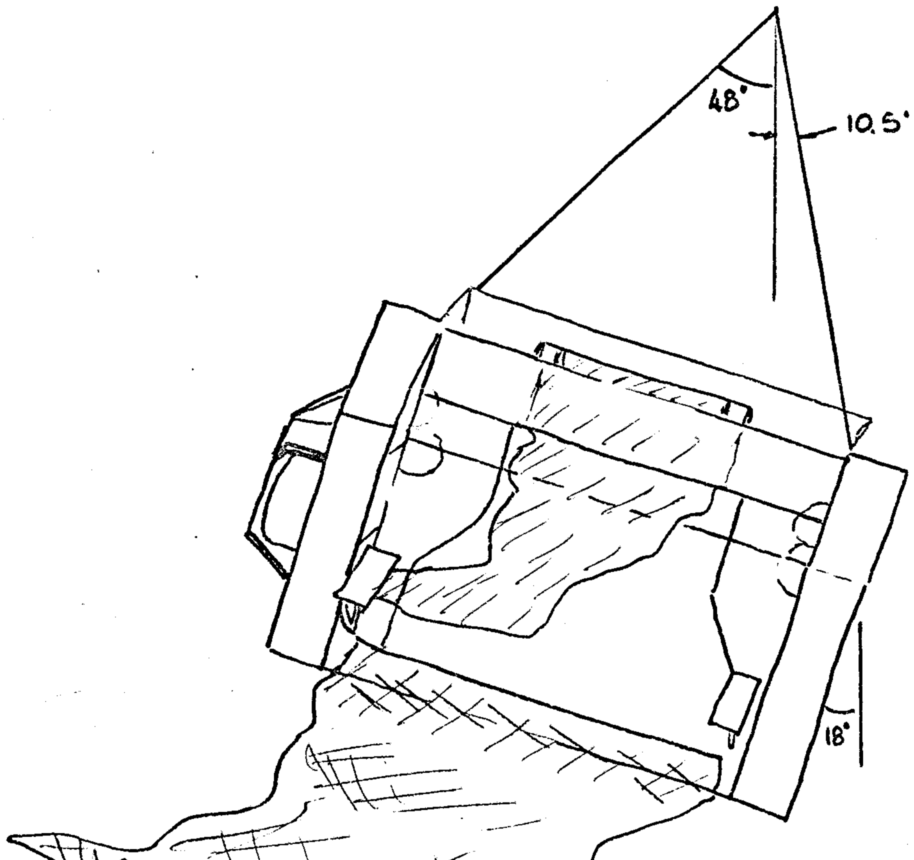
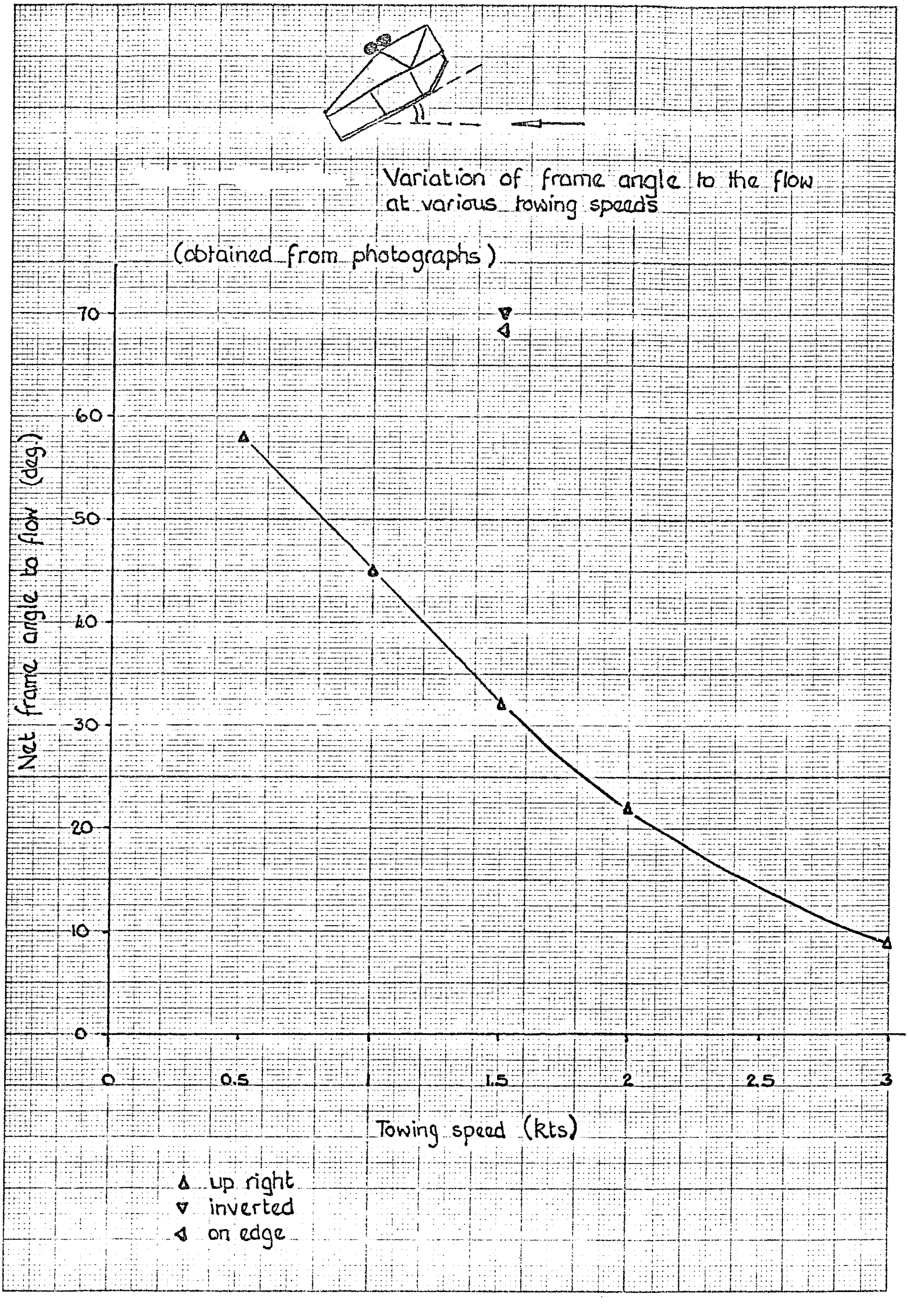
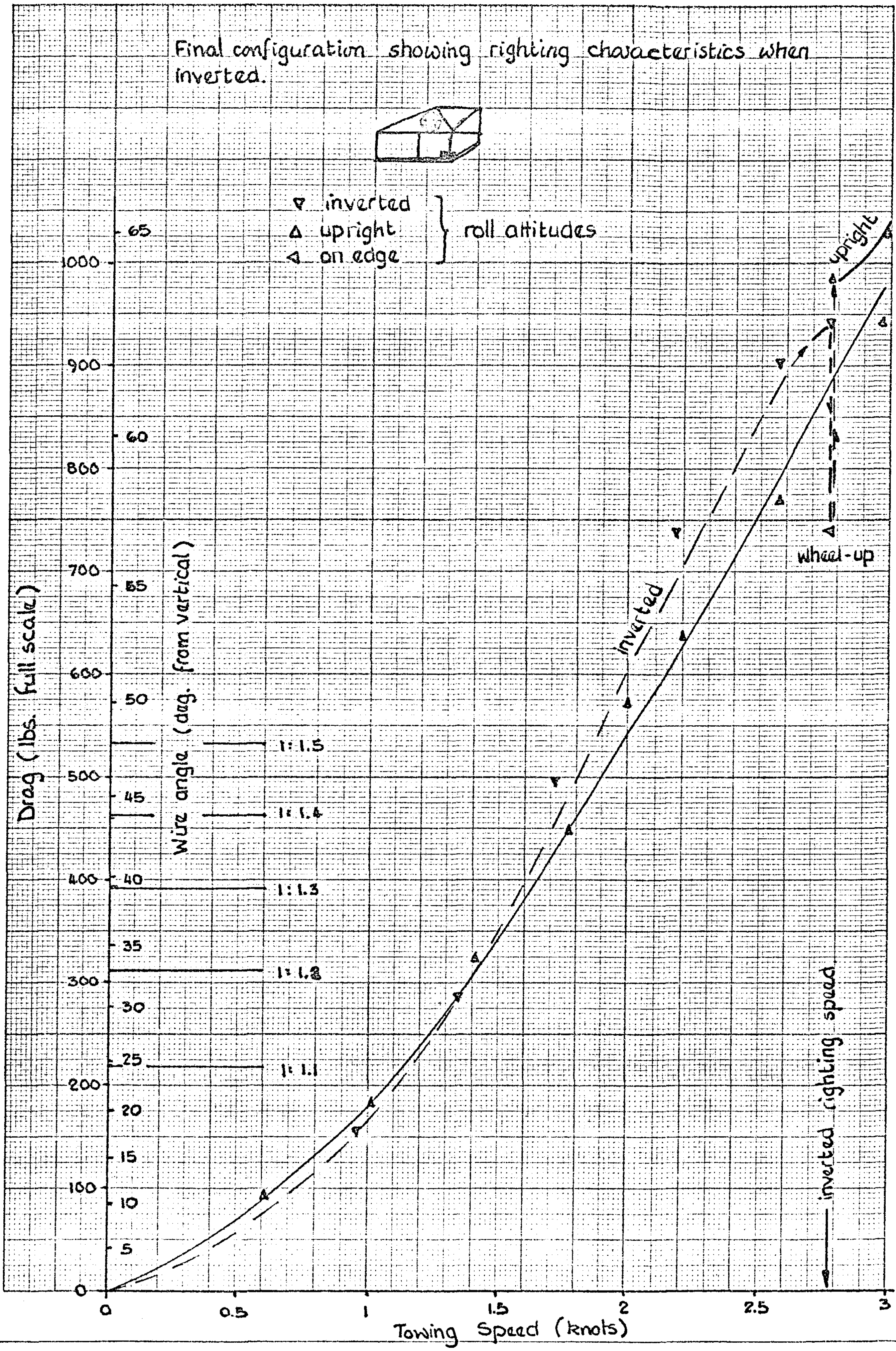


FIG. 5



Variation of frame angle to the flow at various towing speeds
(obtained from photographs)
Net frame angle to flow (deg.)
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
3
Towing speed (kts)
up right
inverted
on edge

FIG. 6


Final configuration showing righting characteristics when inverted.
inverted
upright
on edge
roll attitudes
Drag (lbs. full scale)
Wire angle (deg. from vertical)
Towing Speed (knots)
1:1.5
1:1.4
1:1.3
1:1.2
1:1.1
inverted
upright
wheel-up
inverted righting speed
0
0.5
1
1.5
2
2.5
3
100
200
300
400
500
600
700
800
900
1000
5
10
15
20
25
30
35
40
45
50
55
60
65

Variation of drag coefficient (based on plan area of sledge) with wire angle and velocity.