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Trials on the Drag of a Streamlined Body and its Towing Cable

(Feltham 3.11.61)

BY

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Introduction

Various acoustic devices used at sea are required to be towed beneath the ship while it is underway. In order to reduce fatigue in the towing cable and drag on both cable and transducer, it is necessary to streamline them with fairings. The present study is to determine the drag forces and stability of a fibreglass streamlined body containing an echo-sounder transducer (or equivalent weight) and of various configurations of moulded rubber fairing clipped onto the towing cable.

The trials were prompted by the observation of the towed transducer of the precision echo-sounder on H.M.S. "Owen" which was found to ride much nearer the surface than was predicted. The overall drag forces were several times those calculated assuming reasonable drag coefficients. The addition of extra weight to the fish did not appreciably alter its depth and it appeared that much of the drag was due to the cable.

The trials

A fibre glass fish, towing cables and fairings were towed at the Ship Hydrodynamics Laboratory, Feltham, on November 3rd 1961. Runs were made in the ¼ mile tank at speeds between 10 and 25 ft/sec (6 and 15 kts). The depth of the tank was 25 ft.

The streamlined fish

The fish consists of an aluminium framework on which are mounted a 16 kc/s MS transducer and lead weights. The fairing and fins are of fibre glass constructed by SARO. The dimensions and shape of the fish are shown in Fig. 1. The position of towing point and centre of gravity are shown in Fig. 2.

Weight of fish in air = 532 lb.
Weight of fish in water = 406 lb.

The fish was balanced in air to be approximately horizontal. It was then balanced to be horizontal ± 1° by suspending in water in the river Wey at Godalming.

The fish was instrumented for the trials for the following measurements:-

(a) Depth d (Bourdon tube with 2kΩ potentiometer).
(b) Angle ($\alpha°$) of towing spar from vertical. (Pendulum on circular 500Ω potentiometer).
(c) Angle ($\beta°$) of body from horizontal. (Pendulum on circular 500Ω potentiometer).

These were continuously monitored by the circuit shown in Fig. 3.

The towing cable and fairing

The fish was towed on 15 ft of STC armoured four-core cable (E6/30) covered with HD Polythene and with OD = 0.270".

A synthetic rubber fairing (cf. Fig. 4) was attached to the cable by ½" wide clips every 4" and was free to rotate.

Weight of fairing and wire in air = 15 lb.
Weight of fairing and wire in water ≈ 12 lb.

Subsidiary towing trials

Simultaneous with the towing trials of the fish, streamlined leads (weight = 52 lb) were towed.

(a) One lead on very short wire just below surface.
(b) One lead on varying lengths of BP single core armoured cable

(OD = 0·312") faired with

(i) fairing as on fish, clipped every 4";
(ii) fairing as on fish, clipped every 12".

Calibration of gauges and other experimental measurements

The depth gauge was calibrated in terms of depth to the towing point while lowering the fish into the tank.

The potentiometer giving the angle of spar ($\alpha°$) was calibrated at the N.I.O. before trials, at Feltham after the trials and at N.I.O. after trials and the curve is shown in Fig. 5. The earlier calibrations showed doubts about the range 0 - 10° and were inconsistent with trials, due presumably to friction in the pendulum. The latest calibration has been used for the determinations of α.

The potentiometer giving the angle of body ($\beta°$) was calibrated twice and the curve is shown in Fig. 6.

The angles of entry ($\gamma°$) of the wires into the water were measured directly.

The tension (T lb) of the fish towing cable was measured by a spring balance at the top of the tow.

Experimental results

The experimental results are tabulated in Table I. A preliminary run at 20 and then 25 ft/sec produced too much spray and only rough measurements could be made. Thereafter nine runs were made at approximately 10, 15, 18 and 20 ft/sec.

Runs (1) - (3).	Chiefly for fish tow and for zero length measurements of angle of tow of streamlined lead.
Run (4).	Comparison of fairings with 4" and 12" clip spacings with 11 ft tow.
Runs (5) - (7).	Comparison of above fairings with 5 ft tow at higher speeds.
Runs (8) - (9).	Comparison of fairing with 4" clips and no fairing.

It was noticed that the fish showed a continual tendency to ride to starboard increasing to about 2 to 3 ft displacement at 20 ft/sec.

The streamlined leads showed a very strong tendency to ride to port sometimes as much as 10 ft. At higher speeds the fairing on entering the water at higher angles planed over the surface.

Reduction of results

Drag of the fish

Mean values of the towing angles and tensions of the fish tow are given in Table II and Fig. 7.

Let W = weight of fish in water in lb.
D = horizontal drag in lb.

then $\tan \alpha = \frac{D}{W}$. (1)

If C_D = drag coefficient of fish
A = area of cross section = 2·0 sq. ft.
ρ = density of water = 62·3 lb per cu. ft.
v = velocity of tow in ft/sec.

then $D = \frac{\frac{1}{2} C_D \rho A v^2}{g}$ lbs. (2)

hence $C_D = \frac{2Wg \tan\alpha}{\rho A v^2}$ (3)

Values D and C_D are listed in Table II, and illustrated in Fig. 8.

The drag to weight ratio of the fish at 20 ft/sec

$$= \frac{D}{W} = \frac{76}{406} = 0{\cdot}18.$$

Drag on cable and fairing

Assume that the drag forces on the cable and fairing can be represented by forces on an equal length of straight cable at an angle ϕ to the vertical where $\phi = \frac{\alpha + \gamma}{2}$ (cf. Fig. 9).

Approximate cable profiles are shown in Fig. 10.
Let d_t = transverse drag on cable and fairing in lb.

d_ℓ = longitudinal drag on cable and fairing in lb.

w = weight in water of cable and fairing in lb.

T_o = tension at top of cable in lb.

T_ℓ = tension at bottom of cable = W cos α in lb.

Resolving along cable

$$d_\ell = (T_o - T_\ell) \cos\left(\frac{\gamma - \alpha}{2}\right) - w \cos\left(\frac{\alpha + \gamma}{2}\right)$$

Resolving perpendicular to the cable

$$d_t = (T_o + T_\ell) \sin\left(\frac{\gamma - \alpha}{2}\right) + w \sin\left(\frac{\alpha + \gamma}{2}\right).$$

The main contribution to longitudinal drag is indicated by the difference between tensions at the top and bottom.

The main contribution transverse drag is indicated by the difference between wire angles at the top and bottom.

Let C_d = drag coefficient of cable and fairing.

r = radius of cable = 0·135" = 0·011 ft.

and ℓ = length of cable = 14 ft.

then $d_t = \frac{1}{2} \cdot \frac{C_d \rho}{g} \cdot 2r\ell\, v^2 \cos^2\phi.$

Therefore $C_d = \frac{g d_t}{\rho r \ell\, v^2 \cos^2\left(\frac{\alpha + \gamma}{2}\right)}$

Values of d_ℓ, d_t and C_d are listed in Table III and illustrated in Fig. 11.

The transverse drag to weight ratio of the cable and fairing at 20 ft/sec $= \frac{d_t}{w} = \frac{166}{12} = 13{\cdot}8.$

giving an asymptotic angle of 86° from the vertical.

Drag of cable and fairing on streamlined leads

In Fig. 12 the angles of entry of the top of the tow into the water are plotted against different velocities for various lengths of tow.

In Fig. 13 the same angles are plotted against length of tow for different velocities.

Since the shape of the wire for a given speed is determined only by what is below it, then it is possible to construct curves of the wire shapes from the above graphs by reading the angle of tow for a given immersed length. The angles have been read at 5 ft intervals from the smoothed curves in Figs 12 & 13 and the 5 ft sections plotted end to end in Fig. 14 The wire angle at the bottom is controlled entirely by the drag and weight of the streamlined body and if the curves were continued to an infinite cable length, then an angle is reached at the top asymptotically which is controlled entirely by the drag and weight per unit length of the cable. The length of the transition zone is dependent on the relative drag/weight of the fish compared with that of the cable.

For comparison with the cable and fairing in the towed fish, the drag and drag coefficient was calculated for that part of the tow where the angle was not too great. For this, the lower ten feet of the tow at 10 ft/sec was used where $\alpha = 8°$, $\gamma = 27°$.

No measurements were made of cable tension. Hence the top tension was calculated from $T_o = T_\ell + w + d_\ell$ where the value of d_ℓ was obtained from the fish towing cable (Fig. 12).

For 10 ft of cable and fairing, at 10 ft/sec

$d_\ell = 18$ lb.

$d_t = 24$ lb.

and $C_d = 1{\cdot}0$.

Comparison of fairing with 4" and 12" spaced clips

Four runs were made for direct comparisons between the two fairings, one with 11 ft of cable at 10 ft/sec and three with 5 ft of cable at 10, 15, 18 ft/sec. Table I shows that at the low angle of entry, there was no significant difference, but that at higher angles on longer tows, the 12" spaced fairing was significantly worse, the transverse drag being about 20% higher.

Comparison of fairing with 4" spaced clips and no fairing

With 5 ft tow, the drag on the unfaired cable was significantly less than on the faired. With 20 ft there was no significant difference.

Conclusions

The drag coefficient of the streamlined fish (0·1) was approximately equal to that predicted and therefore was satisfactory. The fish showed no signs of instability at speeds up to 25 ft/sec (15 kts) although it showed a tendency to go to one side.

The drag coefficient of the cable and fairing on both tows (1·5 - 2·5 and 1·0) is considerably higher than expected. Since the drag coefficient of an unfaired cylinder is 1·1, this means that the effective area presented to the flow is greater than that of the cable itself, due possibly to the fairing not streaming straight astern of the cable. The observations of both towed bodies riding out to one side or the other confirms an asymmetry that might arise from the same cause. Looking down the fairing to the fish, one could see it ballooning out not only astern but also to one side showing that the sideways forces originated in the fairing and not in the body towed.

At 20 ft/sec, the lateral displacement of the fish was about 3 ft in 14 ft length, i.e. lateral deflection of about 12°. If the cable tension is 530 lb, the lateral force must be approximately 110 lb. This drag is comparable to the fore and aft drag of the fish which results in an observable angle of deflection of the towing spar. No such lateral deflection was observed on the spar and therefore this must originate mostly in the cable and fairing. The lateral curvature of the cable confirms this.

A possible explanation of this lateral drag is that the fore and aft curvature of the fairing imposed by the curvature of the wire resulted in an instability of the fairing which made it go to one side. However when this deflecting force is calculated using measured elastic constants of the fairing, it is insufficient to make any measurable effect when the radius of curvature is of the order of 40 ft.

The most plausible explanation is that an asymmetry has been produced in the fairing partly in the moulded cross section, partly by distortion of the clips while rivetting and partly by the asymmetry of the rivets. This asymmetry has produced an increased fore and aft drag and also a lateral drag.

The ratio of the drag to weight of the cable and fairing is 77 times that of the fish. Ideally the two values should be equal. By suitable redesign of the fairing it may be possible to reduce the drag coefficient from 1·5 to 0·1, i.e. by a factor of 15. A further reduction in the drag to weight ratio of the cable may be achieved by increasing the weight in water by about a factor of 5, i.e. to 60 lb. for 14 ft.

These changes in the fairing would mean that the asymptotic angle for the towing cable would be approximately that of the fish spar and hence unlimited increase of depth could be achieved by increase of cable length.

APPENDIX 1

TRIALS ON 0·580" DIAMETER CABLE AND FAIRING

(N.P.L. 27.11. 1)

Following the conclusions reached in the body of this paper and because cable failure in the field of the 0·312" diameter cable, further trials were made in a tank at the National Physical Laboratory on the drag of new and larger cable with and without a rubber fairing.

A lead streamlined body (identical to that used in the subsidiary trials at Feltham) was towed on 8 feet of cable at speeds between 13·5 and 20·3 ft/sec (8 and 12 kts). Measurements were made of:-

(a) angle of entry of cable into the water ($\gamma°$)
(b) tension of cable at the top (lb)

Cable

The cable was a four-core armoured cable specially designed by Standard Telephones and Cables for towing the echo-sounder fish. (Spec. E6/32).

OD = 0·580"
Breaking strain = $4\frac{1}{2}$ tons
Surface of slightly rippled P.V.C.
Weight in air = 0·34 lb/ft

Fairing

The fairing was nearly triangular in section tapering from 0·45" near the cable to zero at 2·25". It was of medium soft rubber and was internally reinforced with a nylon cord down the leading edge. It was clipped close to the cable every 4" with $\frac{1}{2}$" wide preformed clips, rivetted from alternate sides in order to avoid asymmetry. The corners on the leading edge of the fairing were bevelled in order to reduce possible turbulence.

Results

(1) Streamlined lead, 8 ft of cable and fairing (7·5 ft in water).

v ft/sec	v^2 (ft/sec)^2	γ deg.	T(corr^{td}) lb.
0	0	0	55
13·5	182	35	63
13·5	182	34	62
15·2	232	39	65
16·9	286	44	69
16·9	286	42	67
18·6	346	47	69
20·3	413	50	78
20·3	413	49	75

(2) Streamlined lead and 8 ft of cable (7·5 ft in water) with no fairing.

v ft/sec	v^2 (ft/sec)^2	γ deg.	T(corr^{td}) lb.
13·5	182	46	57
16·9	286	50	59
20·3	411	53	63

(N.B. The cable vibrated continually during the runs without fairing.)

(ii)

Fig. 15 shows the angles of entry γ plotted against v^2 for the 0•580" cable with and without fairing, and for the 0•312" cable with synthetic rubber fairing reduced to 7•5 ft immersed length using the data of Figs 12 and 13. The angle $\alpha°$ for zero length is plotted, the data being from Fig. 12.

Fig. 16 shows the tension T plotted against v^2.

From page 3 the transverse drag on the cable and fairing for small angles is given by

$$d_t = (T_o + T_\ell)\sin\left(\frac{\gamma - \alpha}{2}\right) + w\sin\left(\frac{\alpha + \gamma}{2}\right)$$

and the drag coefficient c_d by

$$c_d = \frac{gd_t}{\rho r \ell v^2 \cos^2\left(\frac{\alpha + \gamma}{2}\right)}$$

The drag and drag coefficients were calculated for the cable and fairing and the cable alone for a speed of 10 ft/sec for which the angle γ is not too great.

Assuming $w = 3$ lb.

$T_o = 50$ lb.

$\ell = 7•5$ ft.

$r = \frac{0•580}{2 \times 12} = •024$ ft.,

then at $v = 10$ ft/sec:-

Faired cable $d_t = 15$ lb, $\frac{d_t}{\ell} = 2•0$ lb/ft, $c_d = 0•35$.

Unfaired cable $d_t = 27•6$ lb, $\frac{d_t}{\ell} = 4•0$ lb/ft, $c_d = 0•70$.

The assumption that γ is small is hardly justified for the unfaired cable at 10 ft/sec ($\gamma = 37°$). Therefore in order to verify the drag coefficient for an unfaired cable at near normal incidence a point was taken from the graph at $v^2 = 20$ where the curve is almost linear and the drag coefficient was calculated. However since there are no experimental points in this region the check is only rough. At $v = 4•5$ ft/sec, for unfaired cable, $c_d = 1•0$. This compares favourably with theoretical value (1•1).

The convergence of γ for faired and unfaired cables at higher velocities results from the rapid increase of longitudinal drag of the faired cable as the angle γ increases compared with that of the unfaired cable.

The towing characteristics of the echo-sounder fish on 40 ft of the faired 0•580" cable can be calculated from the above data. Fig. 17 shows the forces acting on the two tows at speeds of $v^2 = 200$ and 400 (ft/sec)^2. On the short tow with the streamlined lead at $v^2 = 200$ (ft/sec)^2 we have

$$d_v = 63 \cos 36 - 47 - 3 = -4 \text{ lb.}$$

$$d_h = 63 \sin 36 - 11 = 27 \text{ lb.}$$

Assuming that the mean shape of the long tow with the fish at $v^2 = 400$ (ft/sec)^2 is approximately the same as the short tow, then

$$D_v \approx \left(\frac{L}{\ell}\right).\left(\frac{V}{v}\right)^2 d_v = -40 \text{ lb.}$$

$$D_h = \left(\frac{L}{\ell}\right).\left(\frac{V}{v}\right)^2 d_h = 290 \text{ lb.}$$

Hence T_2 = 520 lb and $\gamma = 44°$: the value of γ justifies the assumption of similarity of mean shape. It therefore appears that the faired 0·580" cable is suitable for use with the echo-sounder fish at 20 ft/sec (= 12 kts).

Appendix 2

Towing characteristics of Fibre glass P.E.S. fish with E6/32 cable

(Measurements on R.R.S. "Discovery II" January - March 1962)

Weight of fish in air with Edo transducer = 578 lb) mean = 545 lb.
" " " " " " NIO transducer = 511 lb)
Height of towing point above sea level = 7 ft.
Length of E6/32 cable (pudding ring to pudding ring) = 40 ft.
Extra distance to top swivel and to transducer = 1 ft.
(Cable length during latter part of cruise = 38 ft).

Cable and fairing as described in Appendix 1

Measurements made at different speeds:-

(1) Mean horizontal distance between towing point and point of entry of cable into water s_1.

(2) Mean horizontal distance between towing point and body of fish obtained by viewing from vertically above (fish in clear water) s_2.

(3) Depth of fish below sea level d obtained directly from difference between depth of water below fish (in shallow water) and depth below sea level determined by difference of 1st and 2nd multiple echoes. These were done with a cable length of 38 ft (10.3.62).

(4) Angle of towing spar α on top of fish was obtained from tank trial data. (Fig. 7)

Observed data

Speed kts.	Speed ft/sec.	s_1 ft.	s_2 ft.	α	d ft.
7.5	12.7	4.5	15.5	4.5°	-
9	15.2	7	22	6.5°	-
10.25	17.3	7	23.5	8.0°	-
0	0	0	-	0°	32
4	6.8	1.0	-	1.5°	30
6	10.2	2.7	-	3.0°	29
8	13.5	4.5	-	5.2°	28
10	16.9	6.7	-	7.5°	25

Smoothed values (ℓ = 39 ft)

Speed Kts.	s_1 ft.	s_2 ft.	α	d ft.
0	0	0	0	32
2	0.3	2.0	0.5°	32
4	1.0	6.0	1.5°	31
6	2.7	12.0	3.0°	30
8	4.8	17.5	5.2°	28
10	7.1	23.5	7.5°	25

Depth of fish correction

Speed kts.	DOF fms.
0	+5
2	+5
4	+5
6	+5
8	+5
10	+4

The cable profiles were drawn using the data s_1, s_2, and α and the towing length of 39 feet overall. The depth of fish was measured from these profiles. The differences between these values and those observed from multiple echoes are within the experimental error.

A.S.L.
22.3.1962

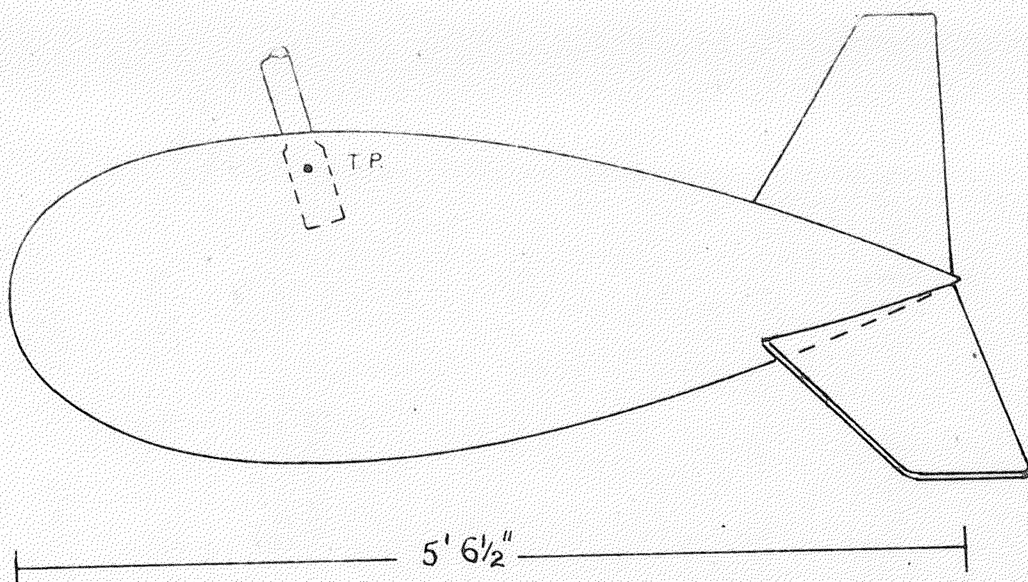
Fish						Streamlined lead (1)		Streamlined lead (2)	
						Fairing (i)		Fairing (ii)	
Run	Speed ft/sec	α μA	β μA	γ deg.	T lb.	γ deg.	δ ft	γ deg.	δ ft
Prelim	25	20	22	-	620	-	-	-	-
	0	8	18	0	418	0	23·5	0	0
1	10·2	11	20	15	440	40		10	
	0	8	17	0	418	0	23·5	0	0
2	15·1	14	21	25	476	~75		13	
	0	8 5	18	0	418	0	10·7	0	0
3	20·1	17	20·5	30	530	70		19	
	0	8	18	0	418	0	11·3	0	11·3
4	10·1	11	19	12·5	-	26		41	
	0	8	18·5	0	420	0	5	0	5
5	10·1	10·5	19	13	438	23		21	
	0	8	17	0	418	0	5	0	5
6	15·0	14·5	20·5	24	478	35		43	
	0	8	18	0	420	0	5	0	5
7	17·7	15·5	21·5	28	504	43		48	
								<u>No fairing</u>	
	0	8	18	0	420	0	5	0	5
8	15·0	14	20·5	23	475	38		30	
	0	8	17	0	420	0	19	0	20
9	10·1	11	21	13	440	44		48	

Table I - Experimental data

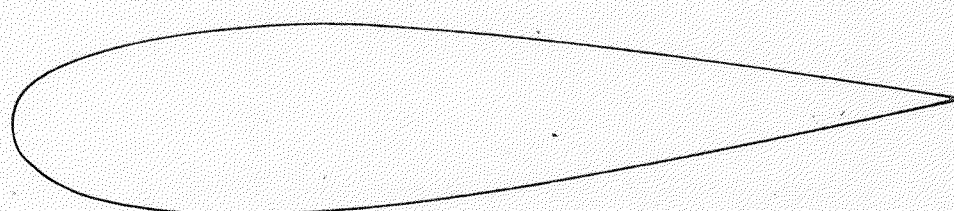
v ft/sec	v^2 $(ft/sec)^2$	α deg	β deg	γ deg	T lb	D lb	C_D
10	100	3·0	1·0	13	440	21	0·11
15	225	6·5	1·5	24	478	46	0·10
17·7	314	8·0	2·0	28	502	57	
20	400	10·0	2·5	30	530	72	0·09
25	625	13·5	3·0	–	620	98	0·08

Table II – Drag characteristics of streamlined fish

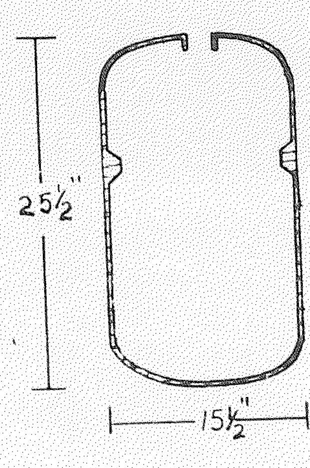
v ft/sec	v^2 $(ft/sec)^2$	d_v lb	d_t lb	C_d
10	100	22	76	2·5
15	225	58	136	2·1
17·7	314	82	162	1·8
20	400	114	166	1·5



Elevation



Plan



Section

Fig 1 and 2

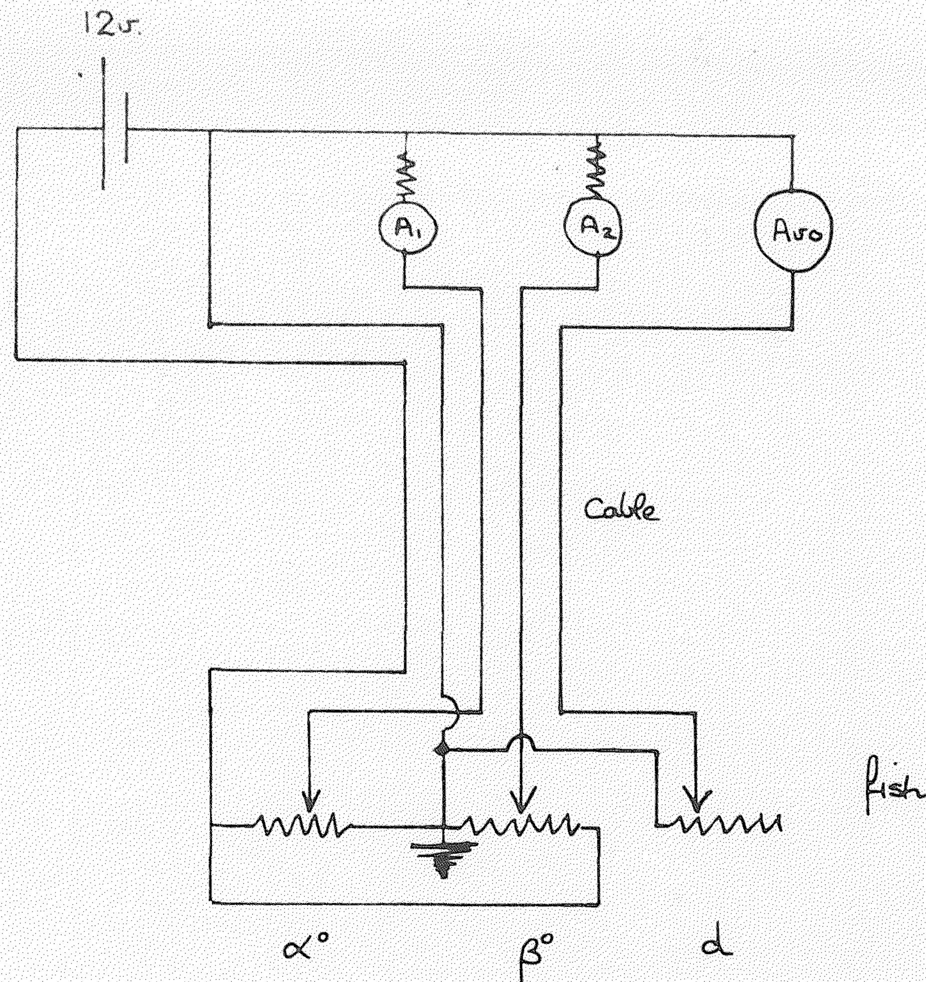


Fig. 3. Circuit for fish parameters

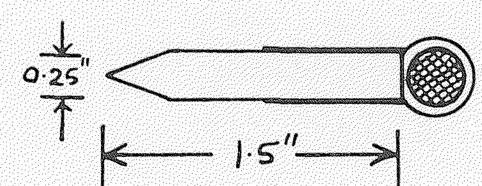


Fig. 4. Synthetic rubber fairing

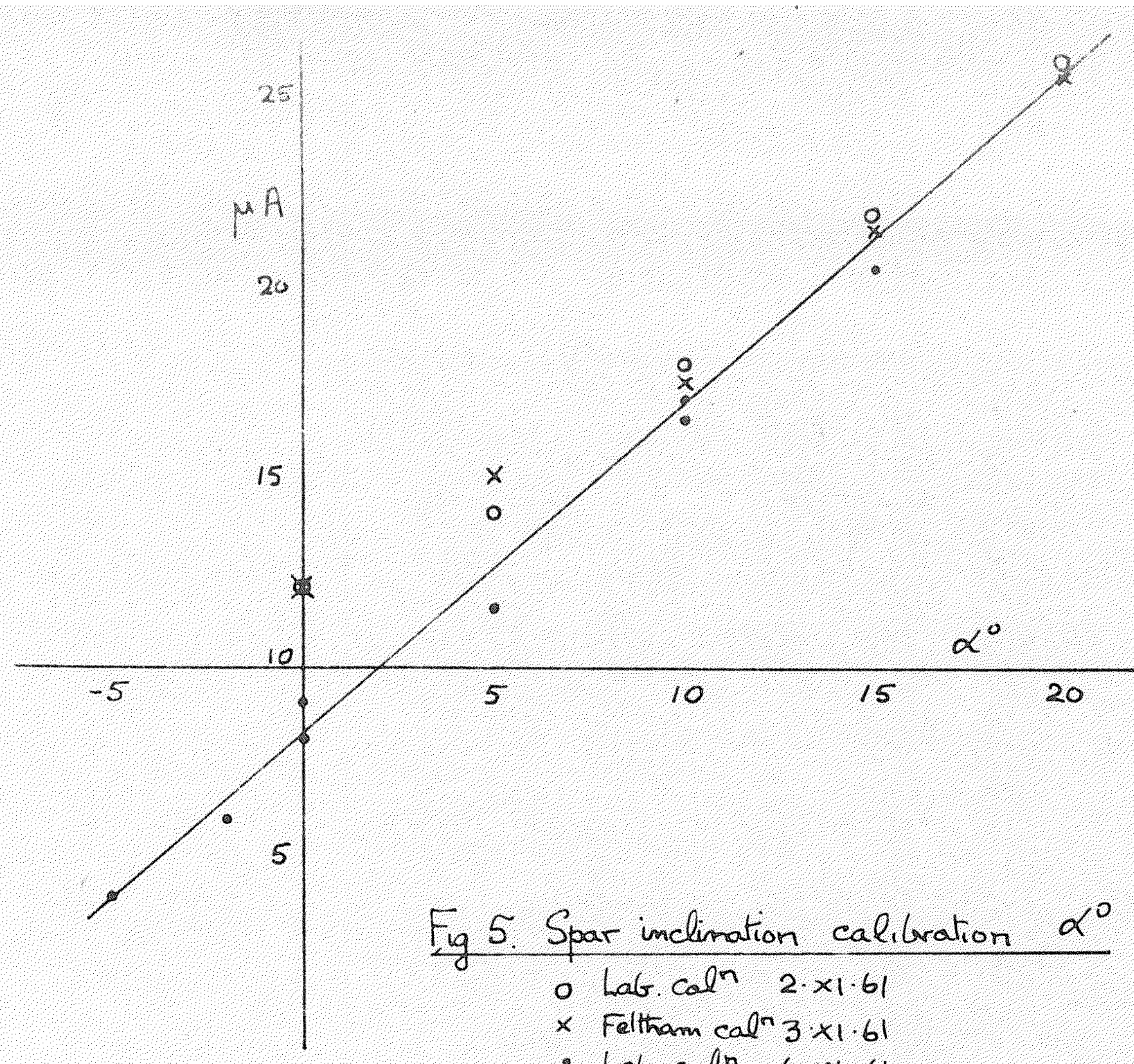


Fig 5. Spar inclination calibration α°

o Lab. cal^n 2.x1.61
x Feltham cal^n 3.x1.61
• Lab. cal^n 6.x1.61

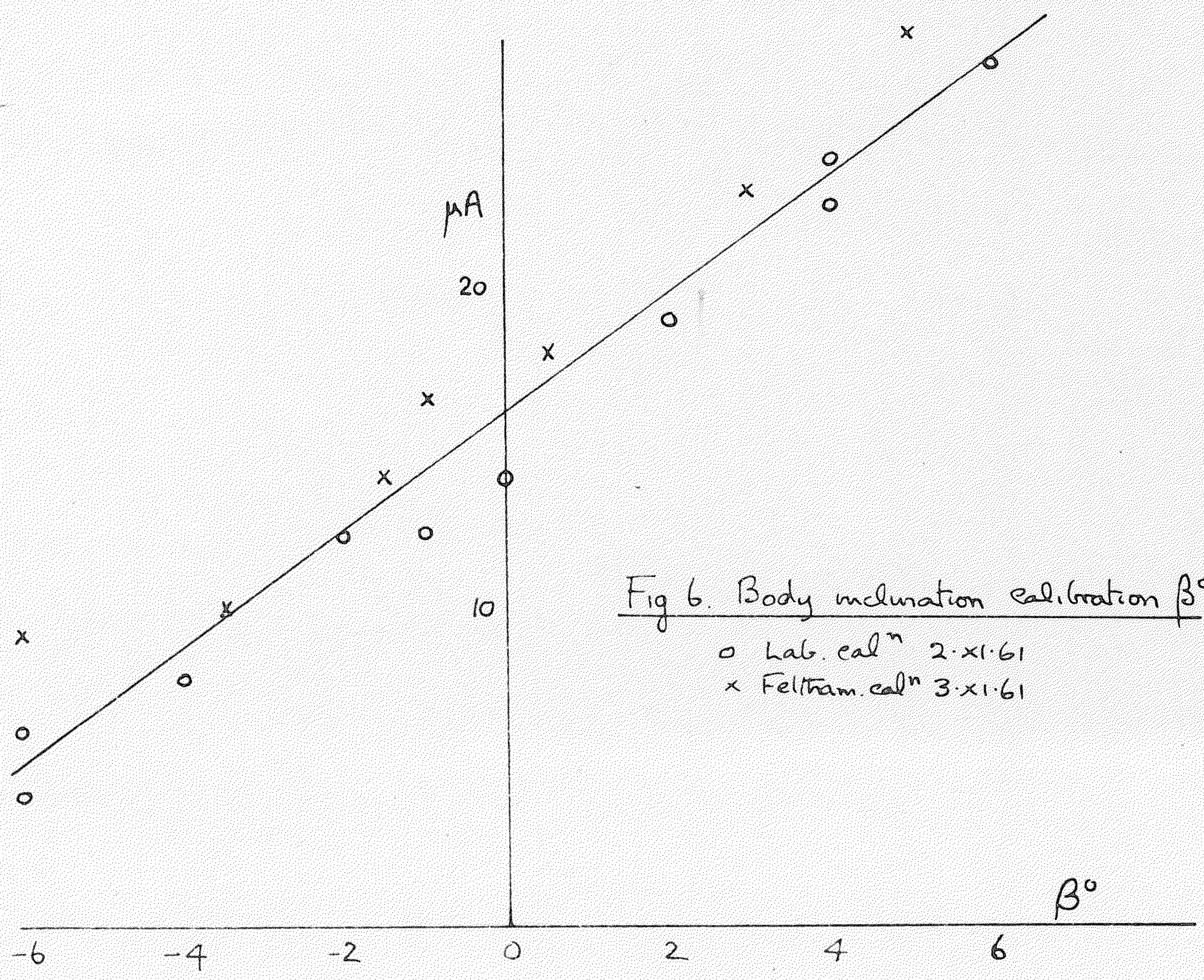


Fig 6. Body inclination calibration β°

o Lab. cal^n 2.x1.61
x Feltham. cal^n 3.x1.61

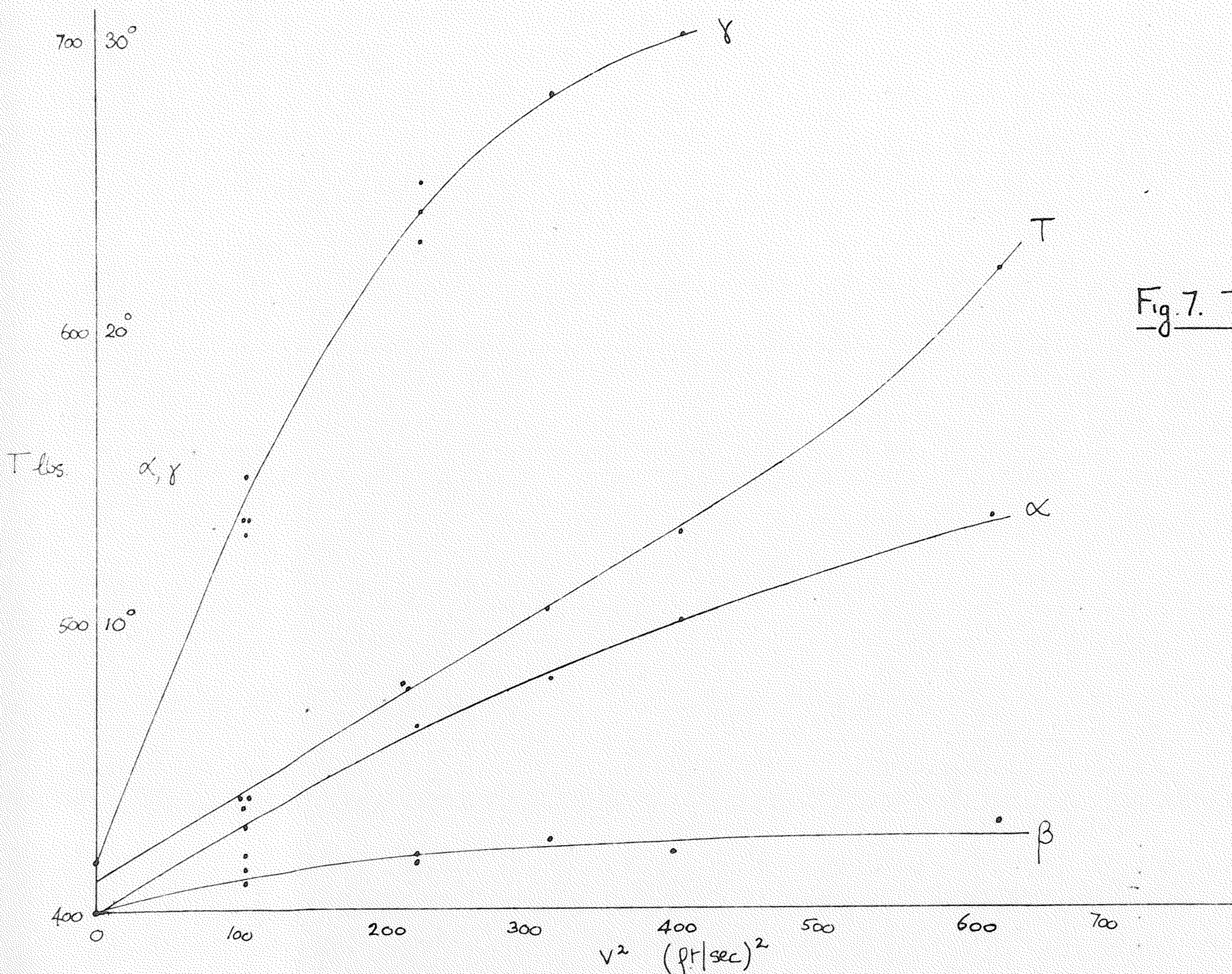


Fig. 7. Towing angles and tension

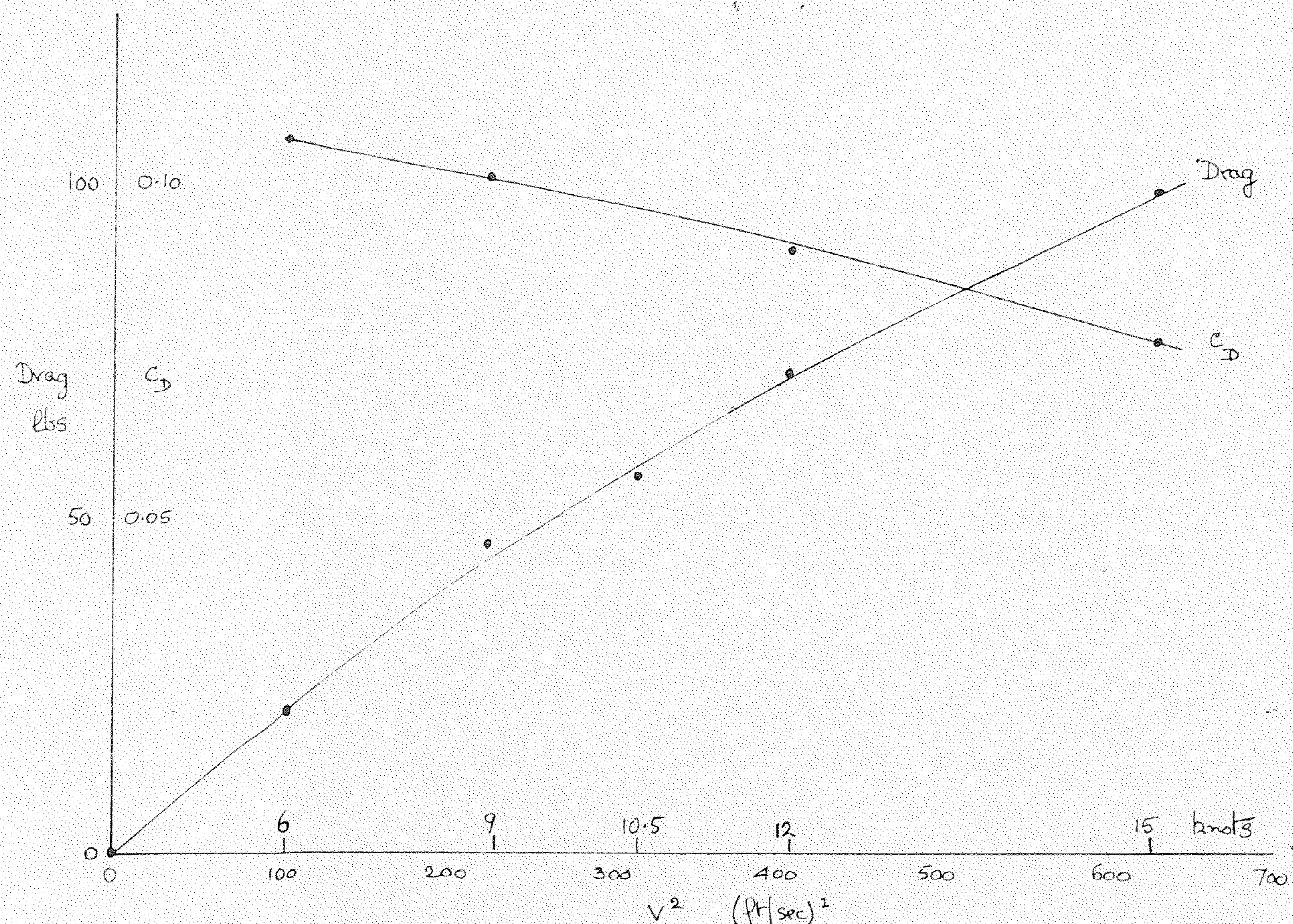


Fig. 8. Drag and drag coefficient of streamlined fish

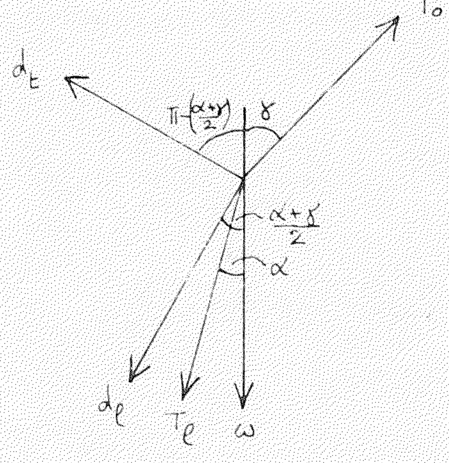


Fig. 9 Forces on towing cable

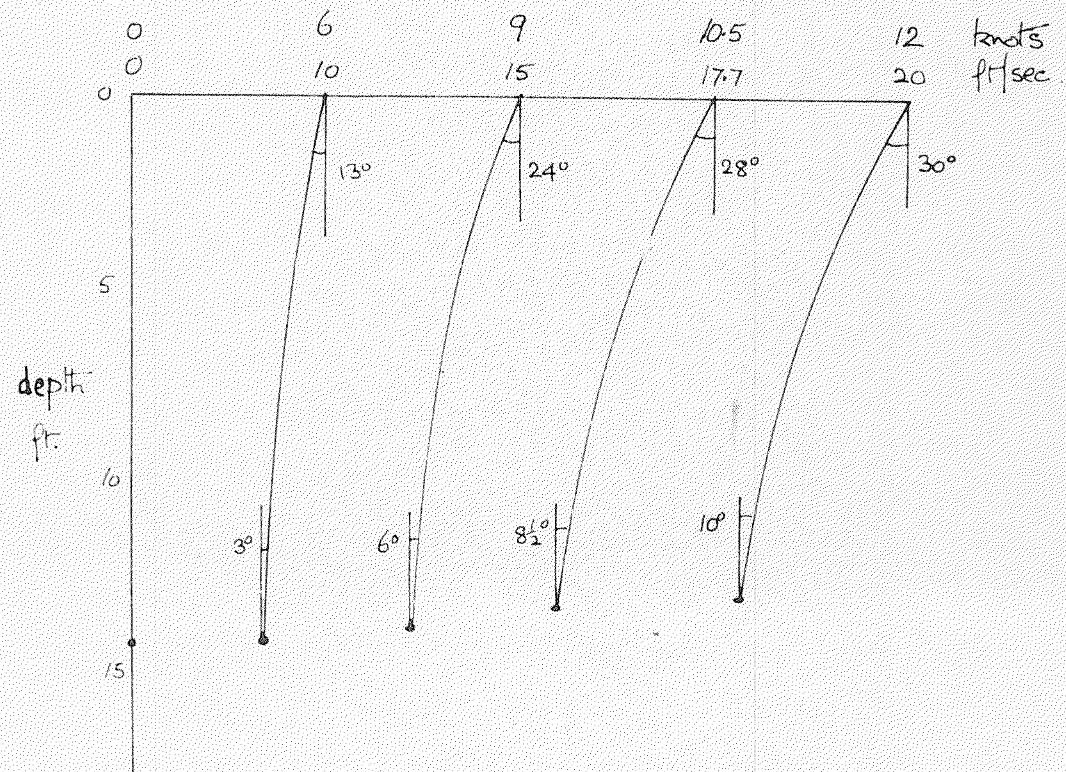


Fig. 10. Profiles of fish towing cable

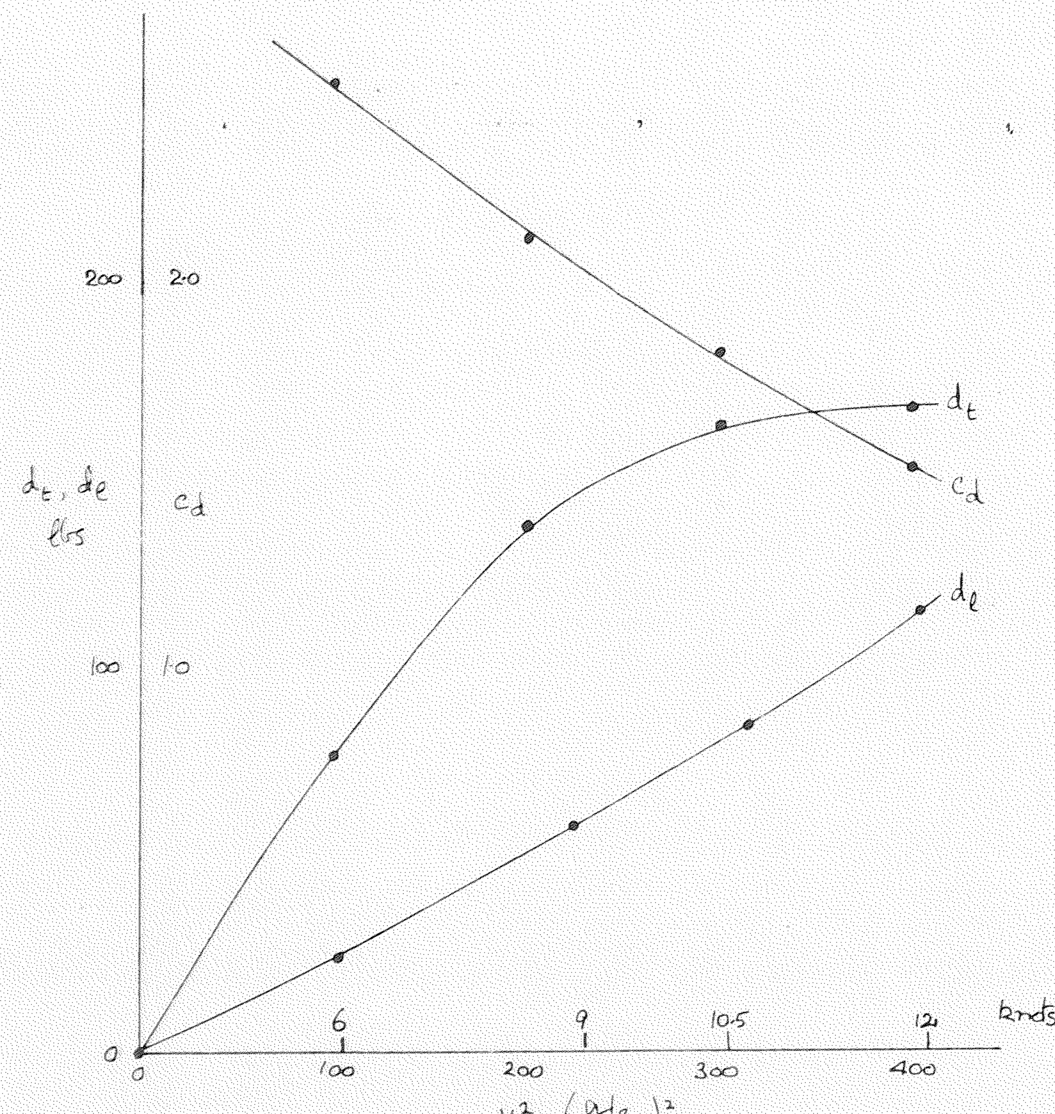


Fig 11. Drag and drag coefficient of faired cable on fish tow.

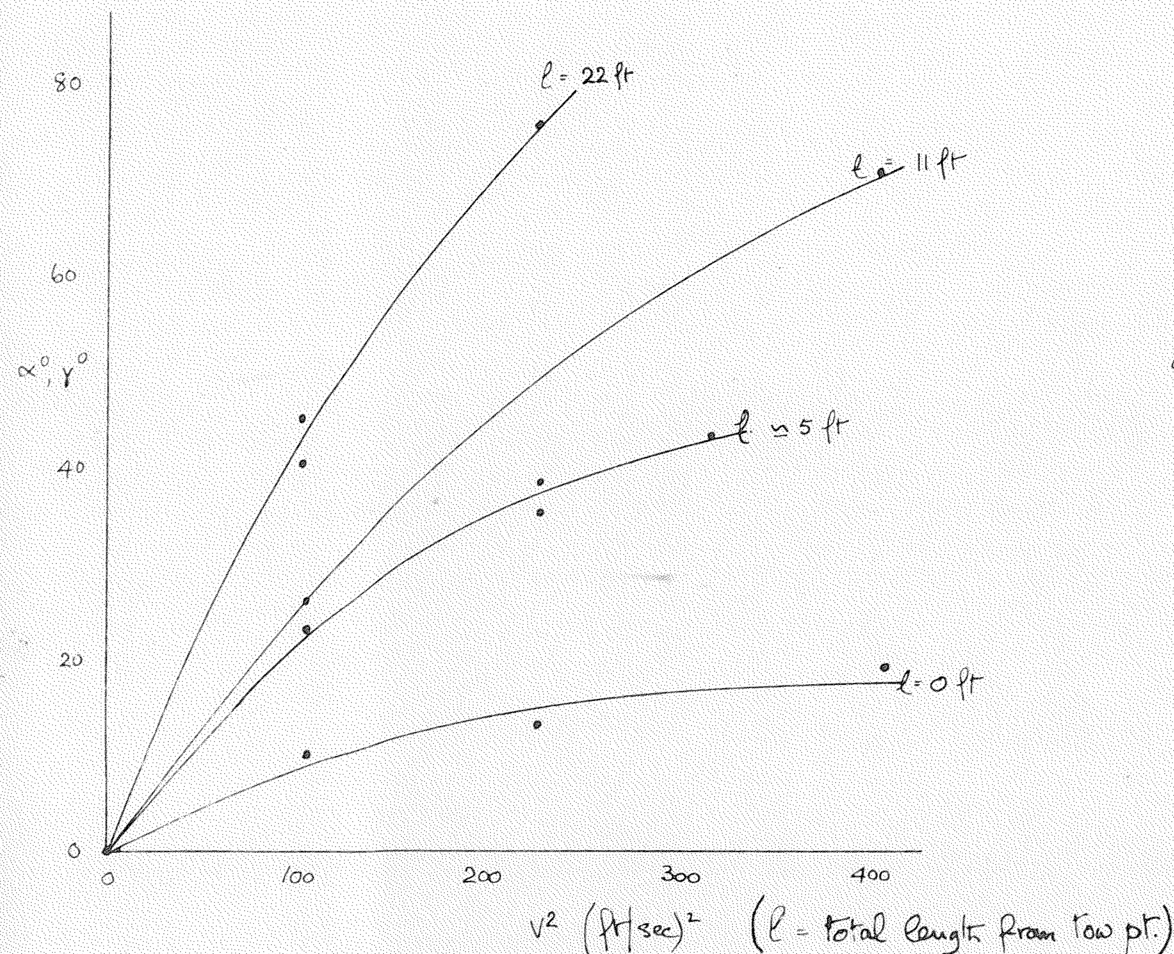


Fig. 12. $\alpha^\circ; \gamma^\circ$ vs. V^2 for cable on lead.

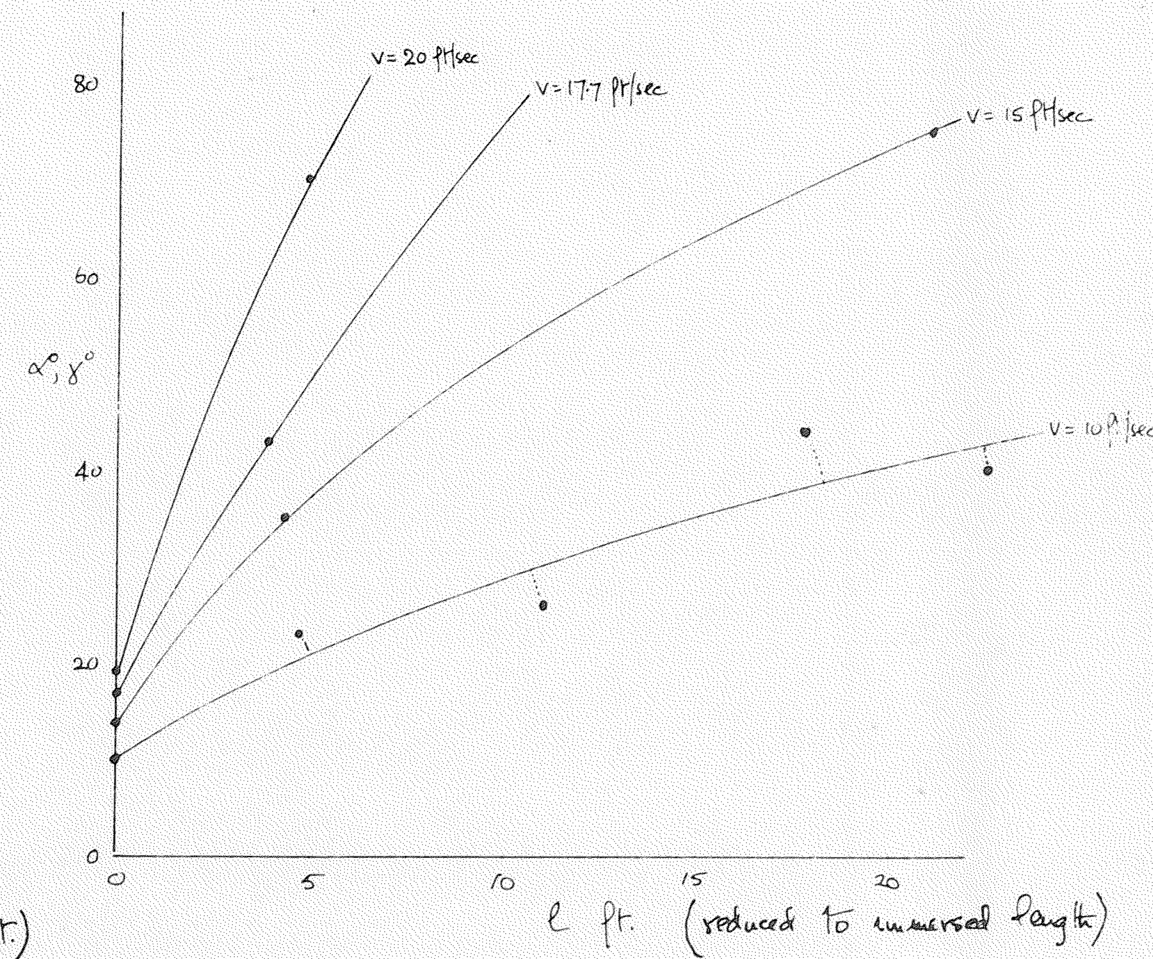


Fig. 13. $\alpha^\circ; \gamma^\circ$ vs. l for cable on lead.

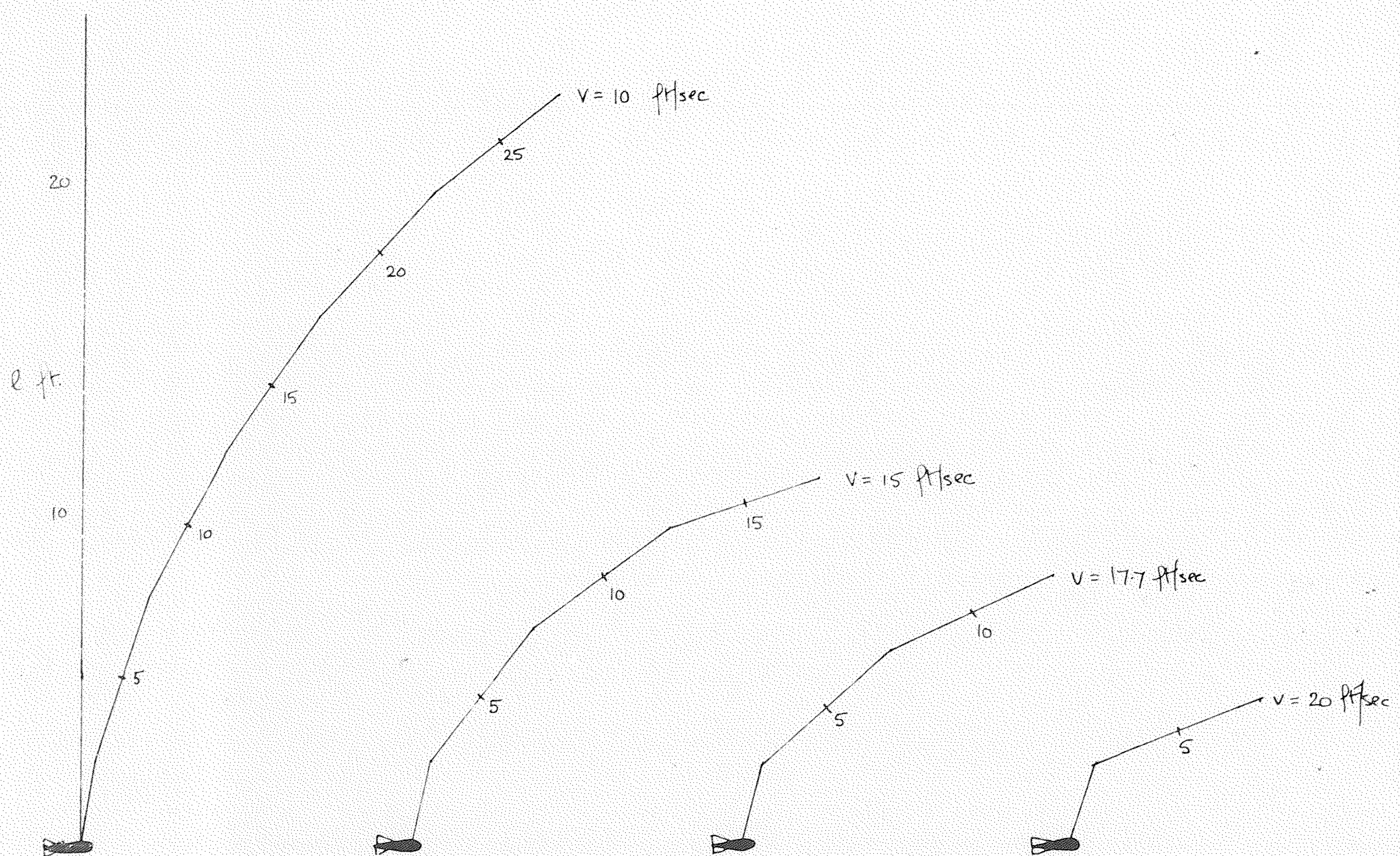


Fig. 14. Profiles of streamlined lead tows.

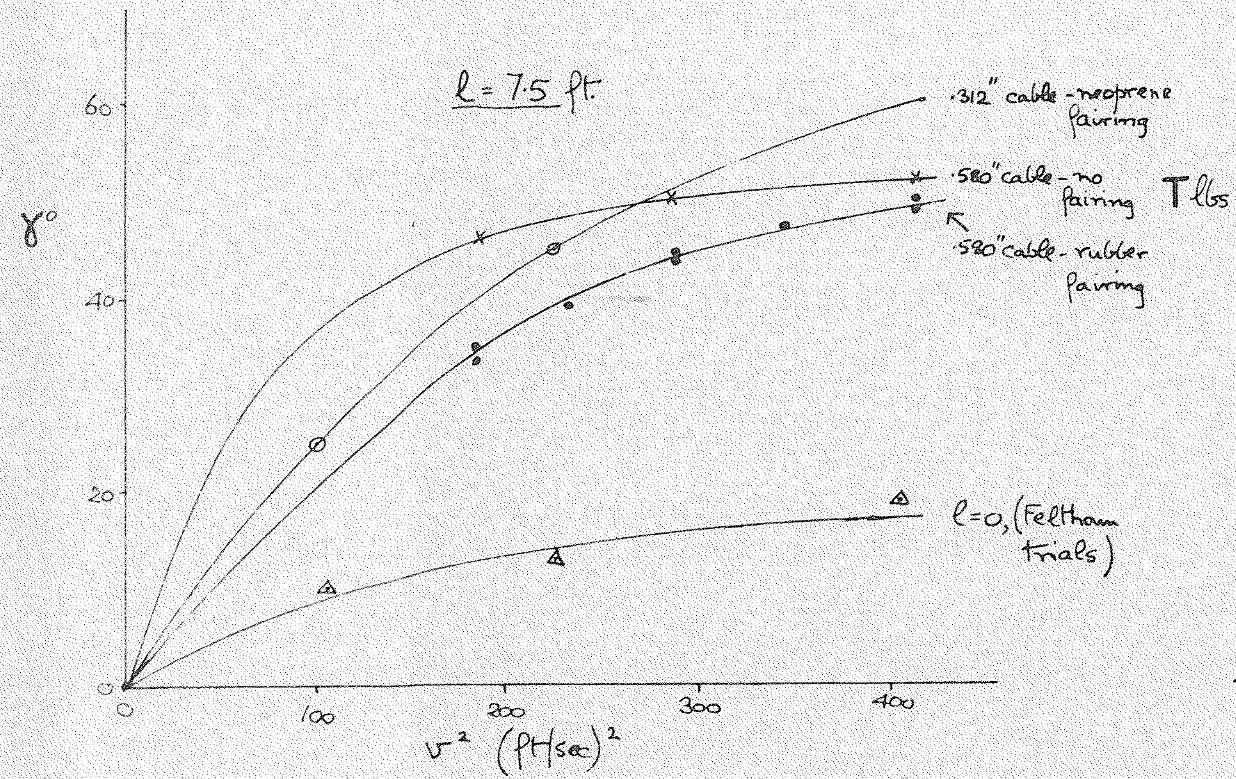


Fig. 15. γ° vs v² for various cables on lead

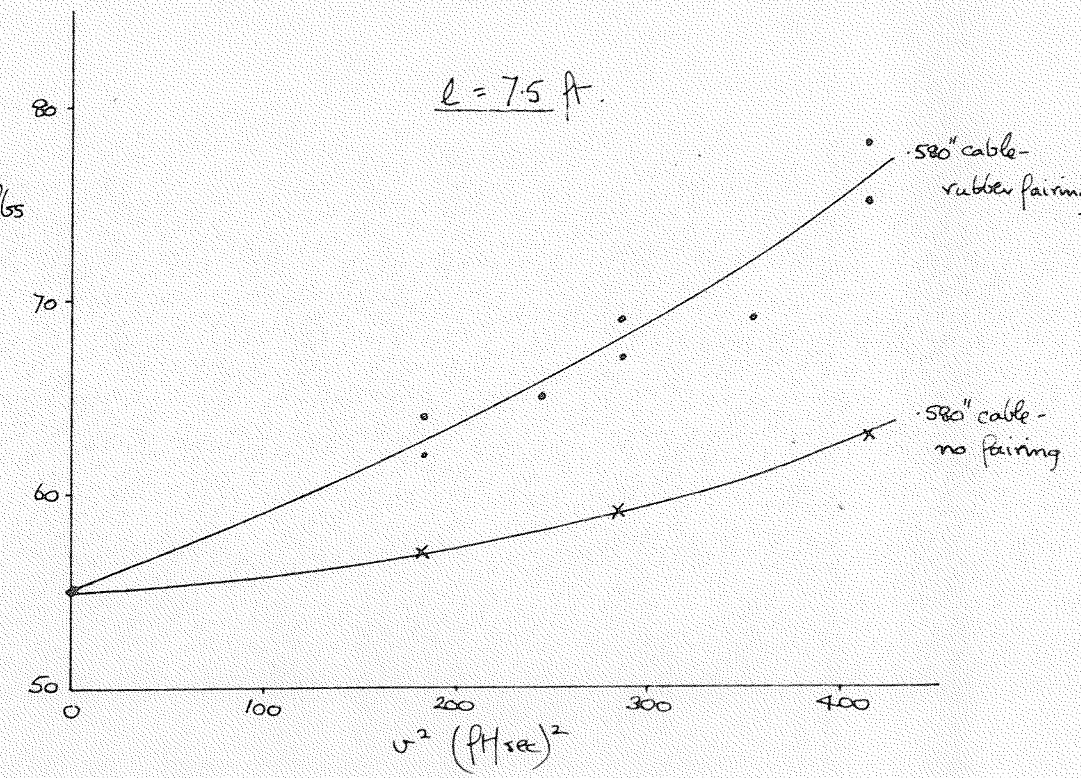
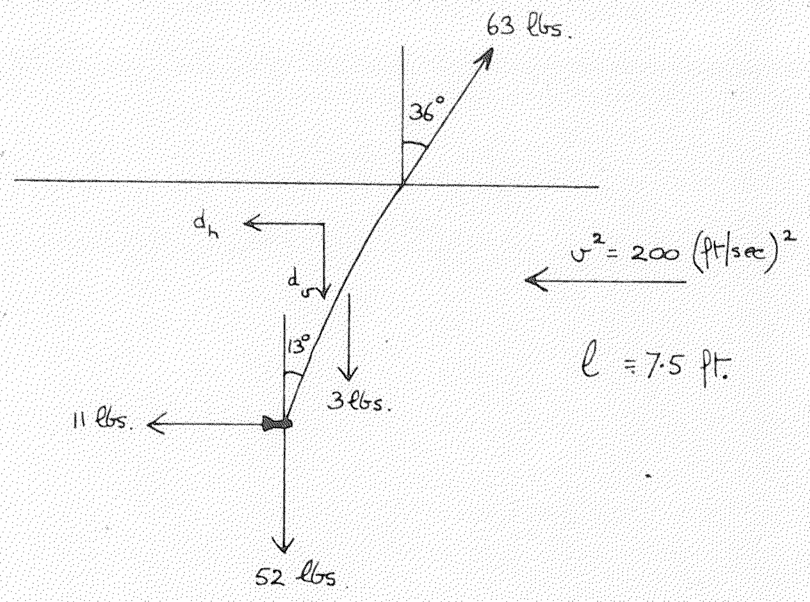


Fig. 16. Tension vs. v² for ·580" cable on lead.



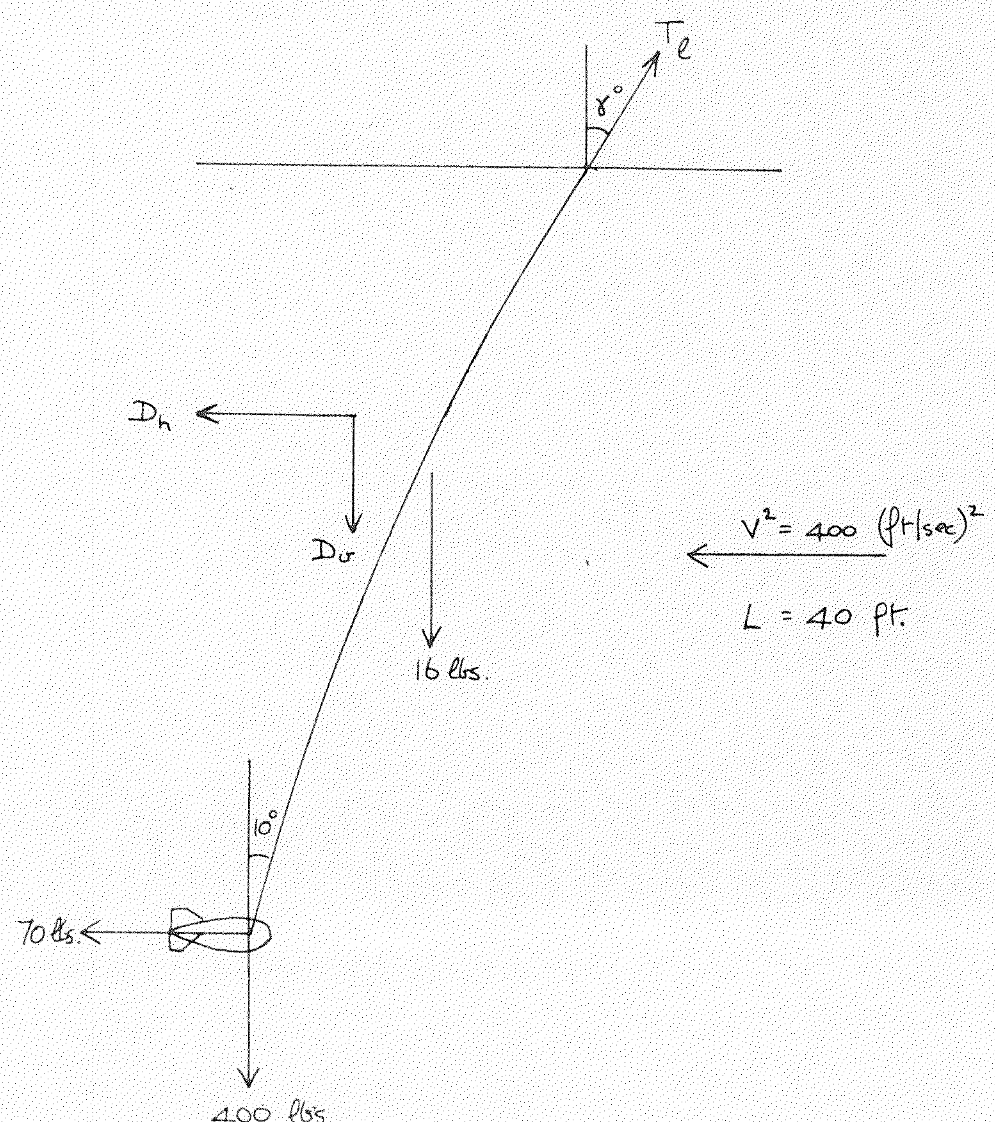


Fig. 17. Comparative forces for wire angle calculation.

PROFILES OF ECHO SOUNDER FISH TOW
(Fibre - Glass Fish + E6/32 Cable)

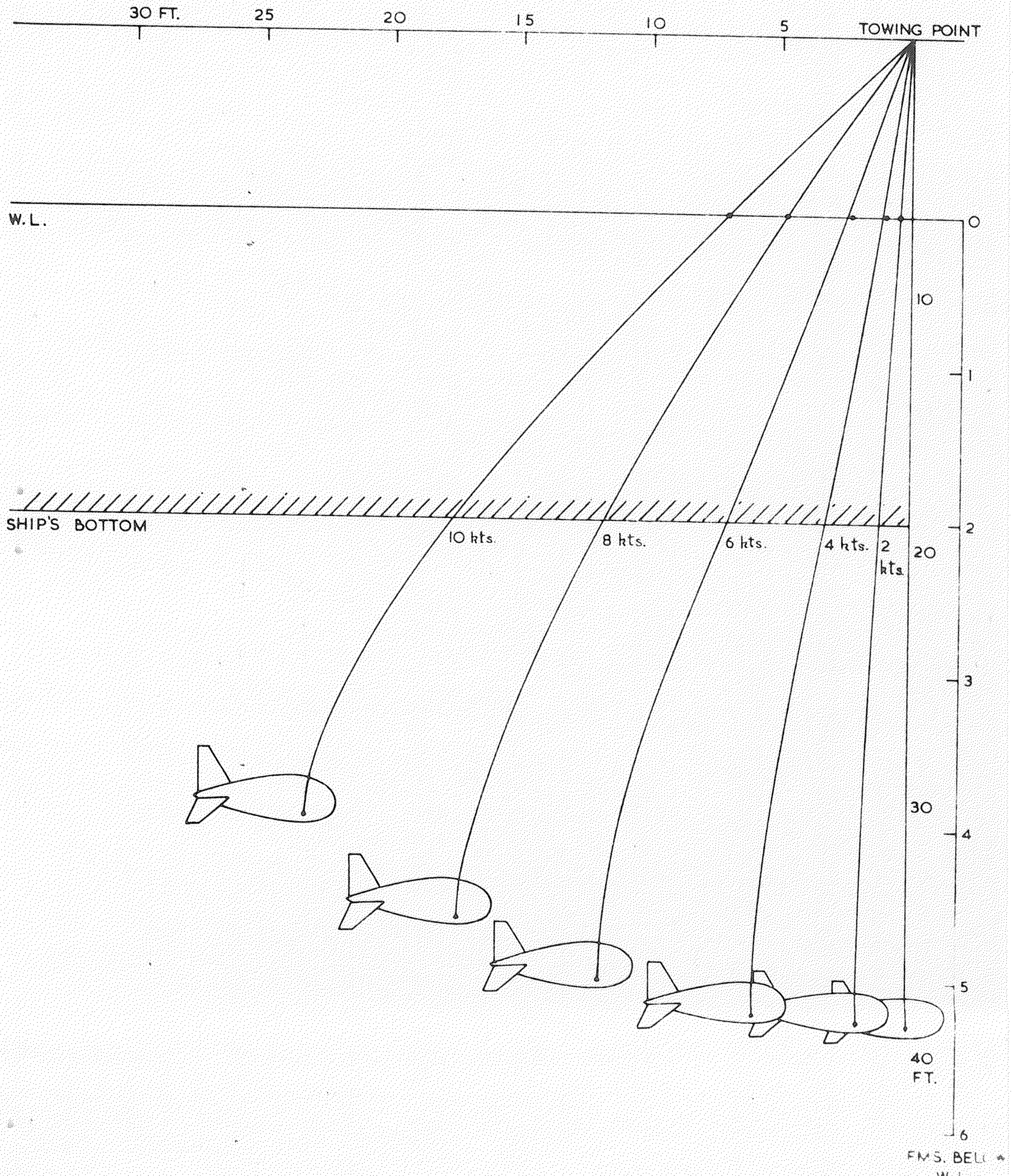


Fig. 18