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Measured Towing Characteristics of Canadian East Coast Otter Trawls

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The purpose of the major fishing gear engineering research program at the Fisheries Research Board of Canada Biological Station in St. Andrews, N.B. is to establish verified engineering principles for the rational design of groundfish otter trawls such as are used by the Canadian fisheries in the North-West Atlantic. The first phase of the program was the development of suitable, specialized instrumentation, as described by Carrothers (1), for measuring pertinent variables in full-scale trawls while under tow. The second phase of the program was to take measurements with typical commercial trawls under experimental conditions at sea. The data so acquired have been subjected to primary reduction and have been reported in detail by Carrothers, Foulkes, Connors, and Walker (2). The third phase of the program, now under way, is the analysis of these data, including the extension of information available from them through recognized engineering principles.

The purpose of this paper is to present a summary of the most salient features of Canadian otter trawl behaviour as revealed by these experimental data. The attached charts give curves for the total drag force at the towing block (in pounds divided by 100), the average of the two warp tensions (in pounds divided by 100), the distance between the two wing tips (in feet), and the height of the centre of the headline above the sea floor (in feet multiplied by 10), all plotted against the speed of the trawl through the water in knots. The trawl speed was calculated from the hydrodynamic or stagnation pressure as measured by a recording pitotmeter suspended in the mouth of the trawl from near the centre of the headline.

The range of the data points about these curves is, on the average: headline height ± 0.5 ft., wing spread ± 2.0 ft., total drag force ± 500 lb., average warp tension ± 300 lb. The data points were not scattered randomly about the given curves, but tended to be concentrated in discrete curves for different tows, indicating that some factor in addition to speed through water was affecting the variable being measured. This was particularly true of headline height.

In general, as a result of ocean currents, the speed of the trawl through the water was different from the speed of the vessel through the water and from the speed of tow relative to the sea floor. The plots against trawl speed through the water gave the most consistent results and, hence, are presented here. The other speeds plus the ocean currents near the surface and near the sea floor were measured and will be included in the detailed analysis.

Most of the measurements were taken on Sable Island Bank, Western Bank, Emerald Bank, and in Northumberland Strait between Prince Edward Island and Cape Breton Island, under relatively good conditions. Sites were selected to have relatively smooth and level sea floor for a radius of about 5 miles, and experiments were conducted in relatively good weather to avoid excessive data fluctuations from vessel motion. Generally, the cod-end was left open to avoid variations resulting from accumulating catch and to improve the reproducibility of the data.

In all but one case, the height of the headline above the sea floor is seen to decrease with increasing trawl speed. This correlation was also observed by Crewe (3) in British trawls and is a result of the changing balance of forces on the headline. Generally, the hydrodynamic forces, including drag of the headline, floats, etc., increase approximately as the square of the towing speed through the water. On the other hand, the hydrostatic lift (buoyancy) of the floats remains essentially constant, independent of the towing speed. Thus, because the headline is towed by its ends from points near the sea floor, as speed is increased in the absence of increase in lift force, the increasing drag force, acting sternward on the headline, forces the centre of the headline aft and down. Obviously, the desired towing speed must be taken into account when selecting the number of floats, higher speeds requiring more floats for the same headline height. This trend applies only to the range of conditions encountered while the measurements were being taken; the effect of added flotation decreases as the amount of flotation present and the towing speed are increased.

Generally, the transverse distance between the two wing tips (wing spread) is seen to remain essentially constant with changing towing speed. By contrast with the constant hydrostatic lift force from the floats, the spreading force from the doors is predominantly hydrodynamic in nature, increasing approximately as the square of the towing speed through the water. Thus, as the drag force increases with increasing speed, the ratio between the spreading force and the drag force, and hence also the wing spread, remain essentially constant.

The total drag of British trawls was reported by Crewe (3) to increase essentially linearly with increase in speed. However, our data from Canadian trawls consistently show a curvilinear relationship. The drag of a trawl may be described by the expression

$$D = C_D \cdot A \cdot (0.5\, \rho\, V^2)$$

where D = total drag of the trawl in pounds

A = effective hydrodynamic area of the trawl in square feet

ρ = mass density of sea water ≈ 1.99 lb-sec^2/ft^4 ($SG \approx 1.026$; $\gamma \approx 64$ lb-f/ft^3 ; $g = 32.17$ ft/sec^2)

V = towing speed in relation to the water in feet per second (1 knot = 1.688 ft/sec)

$0.5\ \rho\ V^2 = q$ = hydrodynamic or stagnation pressure in pounds per square foot

C_D = dimensionless drag coefficient, characteristic of a particular trawl but generally dependent on the towing speed and on the particular shape assumed by the trawl in the water.

Crewe (3) used the frontal area of his trawl as the effective hydrodynamic area (A) and considered the drag coefficient (C_D) to be essentially constant within his range of experimental conditions. The linear relationship between the trawl drag (D) and the towing speed (V) then implies that the frontal area of the trawl varies inversely as the towing speed. The Canadian data agree with this concept in a very general way, e.g., at constant wing spread, the headline height vs speed curve is concave upward and slopes down to the right (rectangular hyperbola). However, contrary to Crewe, the Canadian drag vs speed data are persistently curvilinear, and generally the curves extrapolate to the V = 0 axis at some finite drag, i.e., they are not of the form $D = kV^2$, where k is a constant. This implies that the drag coefficient (C_D) is not constant but assumes higher values at lower towing speeds - a trend in common with most submerged objects at relatively low Reynold's numbers.

The selection of the frontal area of the trawl as the "characteristic" hydrodynamic area (A) should also be considered further, even though changes in frontal area help to explain apparent anomalies in the drag vs speed relationship. The hydrodynamic drag of a trawl is caused primarily by inertial pressure forces exerted by the water on the various solid parts of the trawl; but the frontal area of a trawl is by no means solid. At constant frontal area, trawl drag at a given towing speed is changed by changes in the ratio of twine thickness to mesh size or by changes in the taper rates, causing corresponding changes in the value of the drag coefficient (C_D) when the frontal area is taken as the hydrodynamic area. Also, the frontal area of a given trawl varies during the course of a tow and would have to be monitored continuously in order to be useful. Modern hydrodynamic theory for screens uses the plane area of the screen as the hydrodynamic area, but if this were done for trawl netting, the drag coefficient (C_D) would become very much a function of the angle of attack of the water onto the netting. The solid area of the knots and mesh bars projected onto the plane of the netting and the frontal area of floats, etc. are constant and measurable for any given trawl, but if these areas are totalled for the effective hydrodynamic area (A), then known hydrodynamic interference between various trawl components would cause the drag coefficient (C_D) to be very much a function of the particular shape assumed by the trawl under various towing conditions. The selection of the most useful hydrodynamic area (A) will have to await a deeper understanding of the fluid mechanics of netting.

The average of the tensions in the two warps is greater than half the total drag of the trawl because two other force components, in addition to trawl drag, contribute to the tensions in the warps. These other components originate in the spreading forces exerted transversely by the doors and in the downward force exerted by the weight of the warps in the water and by part of the weight of the doors as the warps try to lift them off the sea floor. The total drag is the only force from the trawl which must be overcome by the propulsion of the vessel. The warp tension, which is the vector sum of the drag force, the spreading force, and the weight force, is the stress which determines the required strength of the warps, towing block, gallows, etc.

The Yankee 35 trawl (52-ft headline, 76-ft footrope) and the Yankee 36 trawl (60-ft headline, 80-ft footrope) of Figs 1 and 2 are essentially the same except that the Yankee 36 has longer wings and, in this case, is fitted with heavier footrope and doors and with longer ground warps. The higher headline of the Yankee 36 trawl probably results from the longer wings. The wing spread of the Yankee 36 trawl was the wider of the two, in spite of the longer ground warps, both because of the longer wings and because of the larger doors. The greater drag of the Yankee 36 can be expected from the larger doors and heavier footrope and, to some extent, from the longer wings.

The data in Figs 3, 4, and 5 are for three Yankee 41-5 trawls (79-ft headline, 100-ft footrope) in which the most pronounced difference was the weight of the footrope. The wing spread of the three trawls is remarkably consistent. The progressively higher headline with successively heavier footrope is probably caused by the bosom of the footrope being pushed aft with respect to the wing tips by the increased drag, providing slack in the netting and allowing the headline to rise. The trawl for Fig. 5 also had somewhat more flotation in the bosom, lifting the headline even further. Warp tensions and total drag are expectedly higher with heavier footrope. Changing the depth and correspondingly changing the warp length for the trawl in Fig. 4 made no noticeable difference to its towing characteristics.

The data in Figs 5 and 6 are for the same trawl except that the ground warps were shorter for Fig. 6. The shorter ground warps expectedly extended the spread of the wings, but the higher headline is a little harder to explain. It is possible that the wider wing spread shifted the division of load on the wing bridles toward the upper bridles or that the greater tension in the shorter ground warps reduced sag, thereby raising the forward ends of the wing bridles and elevating the whole headline, or it is possible that the wider spread permitted a greater hydrodynamic lift on the netting and/or headline. The warp tensions and total drag are, if anything, decreased by using the shorter ground warps, despite the associated increase in frontal area of the trawl.

The data in Fig. 7 are for the same trawl as those in Figs 5 and 6 except that the 30-ft bridles have been replaced by short bridles, Danleno butterflies, and bobbins. The total distance from the wing tips to the doors is essentially the same in the trawl for Fig. 7 as in the trawl for Fig. 6. Unfortunately, the wing-spread meter was not functioning with the Danleno gear. The headline was noticeably lower with the Danleno gear than with either of the trawls with wing bridles, showing the advantage of bridles, even as short as 30 feet, when towing on smooth sea floor. The Danleno gear also increased the total drag and the tensions in the warps; at the same engine speed the trawl with the Danleno gear towed more slowly than the trawls with wing bridle gear.

The data in Fig. 8 are for a Yankee 41-5 trawl made of bitumen-treated nylon netting which is slightly heavy in sea water (weight in sea water ≈ 9.3 lb./100 lb. weight in air) compared with the polyethylene netting, which is slightly buoyant (residual buoyant force in sea water ≈ 6.8 lb./100 lb. weight of netting in air), used in all the trawls so far reported. For Fig. 8 : the doors were the same size as for Figs 5 and 6, larger than for Fig. 4, and heavier than for all three; the footrope was about the same as for Fig. 4 and lighter than for Figs 5 and 6; and the ground warps were shorter than for all three. Unfortunately, the headline height meter was inoperative on the nylon trawl. The wing spread was about the same as in Figs 4 and 5; the tendency for shorter ground warps and larger doors to increase wing spread was off-set by the greater drag of the trawl-net itself. The greater total drag of the nylon trawl is in part due to the heavier doors and in part to the netting.

Figs 9 and 10 vis-à-vis Figs 11 and 12 compare a Yankee 41 trawl (79-ft headline, 100-ft footrope) made from bitumen-treated, iso-tactic polypropylene, multifilament (Ulstron) netting with a similar trawl made from the usual, high-density polyethylene netting. The treated-Ulstron netting was slightly less buoyant (residual buoyant force in sea water ≈ 5.7 lb./100 lb. weight of netting in air) than the polyethylene netting. Both trawls were measured while being towed in two different rigs. In both rigs, the treated-Ulstron trawl had about 15% more flotation on the headline than did the polyethylene trawl. With rectangular doors, the total drags of the two trawls are very similar, but for some reason the treated-Ulstron trawl displays a narrower wing spread. The higher headline of the treated-Ulstron trawl results from this narrower wing spread and the greater flotation. With slotted, oval doors, the wing spreads of the two trawls are very similar, but the treated-Ulstron trawl has lower total drag. Apparently the lower total drag is a reflection of lower netting drag which, combined with the greater flotation, results in the higher headline. The higher headline of the treated-Ulstron trawl at the same wing spread as the polythene trawl gives a larger frontal area in association with lower drag, once more contradicting the functional dependence of drag on frontal area claimed by Crewe (3). The treated-Ulstron trawl behaves much more like a polyethylene trawl than does the treated nylon trawl (Fig. 8), even though the nylon netting and the Ulstron netting are very similar in general appearance.

Figs 9 and 11 vis-à-vis Figs 10 and 12 compare the behaviour of the usual rectangular trawl doors with single-slot oval doors on the same Yankee 41 trawls. The oval doors were smaller (30 sq ft vs 43 sq ft) and lighter (1430 lb vs 1600 lb) than the rectangular doors. With this size disadvantage, the oval doors produced a narrower wing spread, although this wing spread was similar to that reported in Figs 3 to 6 for Yankee 41-5 trawls with rectangular doors. The wing spreads reported for the rectangular doors in Figs 9 and 11, particularly with the polyethylene trawl, are exceptionally wide. Associated with the narrower wing spread when using the oval doors is the expected higher headline. Of particular interest is the shape of curves for wing spread and headline height when using the oval doors. The correlation between wing spread and headline height is sustained through the serpentine shape of both sets of curves, with the increased drag at higher speeds superimposing a downward trend on the headline height curves. This serpentine shape probably results from the lift (spreading force)/drag characteristics of the oval doors, which apparently pass through a minimum at about 3.8 knots and result in an unusual increase in wing spread with increase in speed above this point. This change in lift/drag ratio with towing speed may be a function of the heel angle of the doors, in which case the speed for minimum lift/drag ratio will be a function of the scope ratio (warp length/trawl depth) of the towing warps.

Fig. 13 gives data for a Skagen (vinge) trawl (82-ft headline, 116-ft footrope) which is sometimes used, lightly rigged, on sandy sea floor. There is considerably more netting in the Skagen trawl than in the Yankee 41 trawl, which probably accounts for the similar drag characteristics despite the lighter footrope. The headline of the Skagen trawl is only slightly longer than that of the Yankee 41 and the wing spread is very similar. The Skagen footrope, then, must fish in a deeper "catenary" than does the Yankee 41 footrope. The effect of the longer headline and longer and lighter footrope of the Skagen trawl to increase wing spread is probably being offset by the longer wing bridles. Despite these longer wing bridles and longer wing lines, the headline of the Skagen trawl was not appreciably higher than that of the Yankee 41 trawls. The meshes of the Skagen trawl must have been more closed than those in the Yankee 41 trawls, contributing somewhat to the drag.

Fig. 14 gives data for a Granton trawl (79-ft headline, 120-ft footrope) such as is being used by some of the larger Canadian vessels. This trawl contains quite a bit more netting than the Yankee 41 trawls so naturally produces more drag. However, the wing spreads and the headline heights are very similar in both types of trawl; the Granton trawl has more drag than the Yankee 41 trawls despite a similar frontal area. The similar wing spread despite the longer footrope of the Granton trawl probably results from its greater drag. The headline height of the Granton trawl is probably more restricted by the shorter wing lines (4 ft) than is the headline height of the Yankee 41 trawls (6-10 ft wing lines). Some of the commercial vessels are using longer wing bridels (up to 90 ft) than were used for Fig. 14. However, the gain in headline height normally realized with longer wing bridles is lost in this trawl because of the short wing lines. The reason for the increase in headline height with increase in towing speed is not apparent. This trend is opposite to that for all other trawls studied and opposite to the findings of Crewe (3) for the Granton trawl, however, it is consistent with the decrease in wing spread with increasing towing speed.

Fig. 15 gives data for the Atlantic Western III trawl (79-ft headline, 115-ft footrope) specifically designed by Mr. W.W. Johnson for the Canadian East Coast fisheries. This is a 4-side-seam net, and the advantage of the side panels and long wing lines is obvious in the notably higher headline. This is a big trawl, fitted with a heavy footrope, and has a drag similar to that of the Granton trawl but greater than that of the Yankee 41. This greater drag probably accounts for the narrower wing spread; the Atlantic Western III trawl should be fitted with larger doors than were used for Fig. 15. Even with this abnormally narrow wing spread, the Atlantic Western III trawl had a larger frontal area than either the Granton trawl or the Yankee 41 trawl. This large frontal area of the Atlantic Western III trawl results in a drag coefficient smaller than that for the Granton trawl and similar to that found with the Yankee 41 trawls.

Undoubtedly these general observations, based on an examination of the attached summary of data from an extensive engineering study of Canadian Northwest Atlantic groundfish otter trawls, leave many questions unanswered. It is hoped that a more detailed analysis of the basic data will reveal more extensive and more specific conclusions at some future date, but it is believed that this more general presentation is of some value at the present time.

Sincere appreciation is expressed for the very considerable financial assistance rendered by the Industrial Development Branch of the Canadian Department of Fisheries and Forestry during the instrumentation and experimental phases of this project.

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Bulletin 163, Fisheries Research Board of Canada,(1968).

2. Carrothers, P.J.G., Foulkes, T.J., Connors, M.P., and Walker, A.G.
Data on the Engineering Performance of Canadian East Coast Groundfish Otter Trawls.
Technical Report No. 125, Fisheries Research Board of Canada,(1969).

3. Crewe, P.R.
Some of the General Engineering Principles of Trawl Gear Design.
Modern Fishing Gear of the World: 2, pp. 165-180, (1964).

Trawl Type	Yankee 35
Material	Laid Polythene
Footrope	4 in. Discs
Bridles	30 ft
Ground Warps	90 ft
Doors	3.5 x 6.5 ft, 450 lb
Towing Warps	450 ft
Depth	144 ft
Test Date	Sept. 1965

Fisheries Research Board of Canada

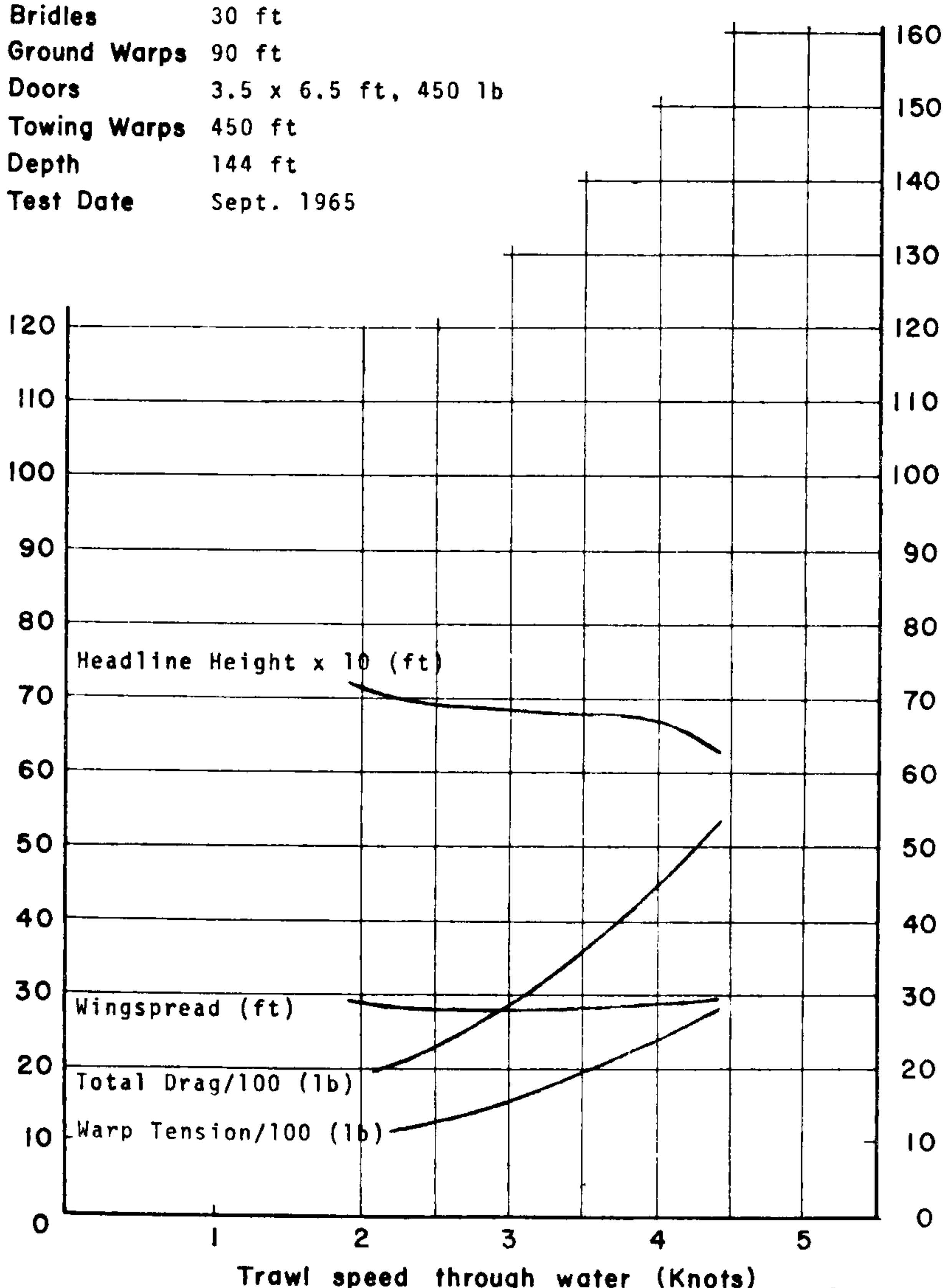

FIG. 1

Trawl Type	Yankee 36
Material	Laid Polythene
Footrope	16 in. Rollers
Bridles	30 ft
Ground Warps	120 ft
Doors	4.1 x 7.5 ft, 700 lb
Towing Warps	450 ft
Depth	145 ft
Test Date	Sept. 1965

Fisheries Research Board of Canada

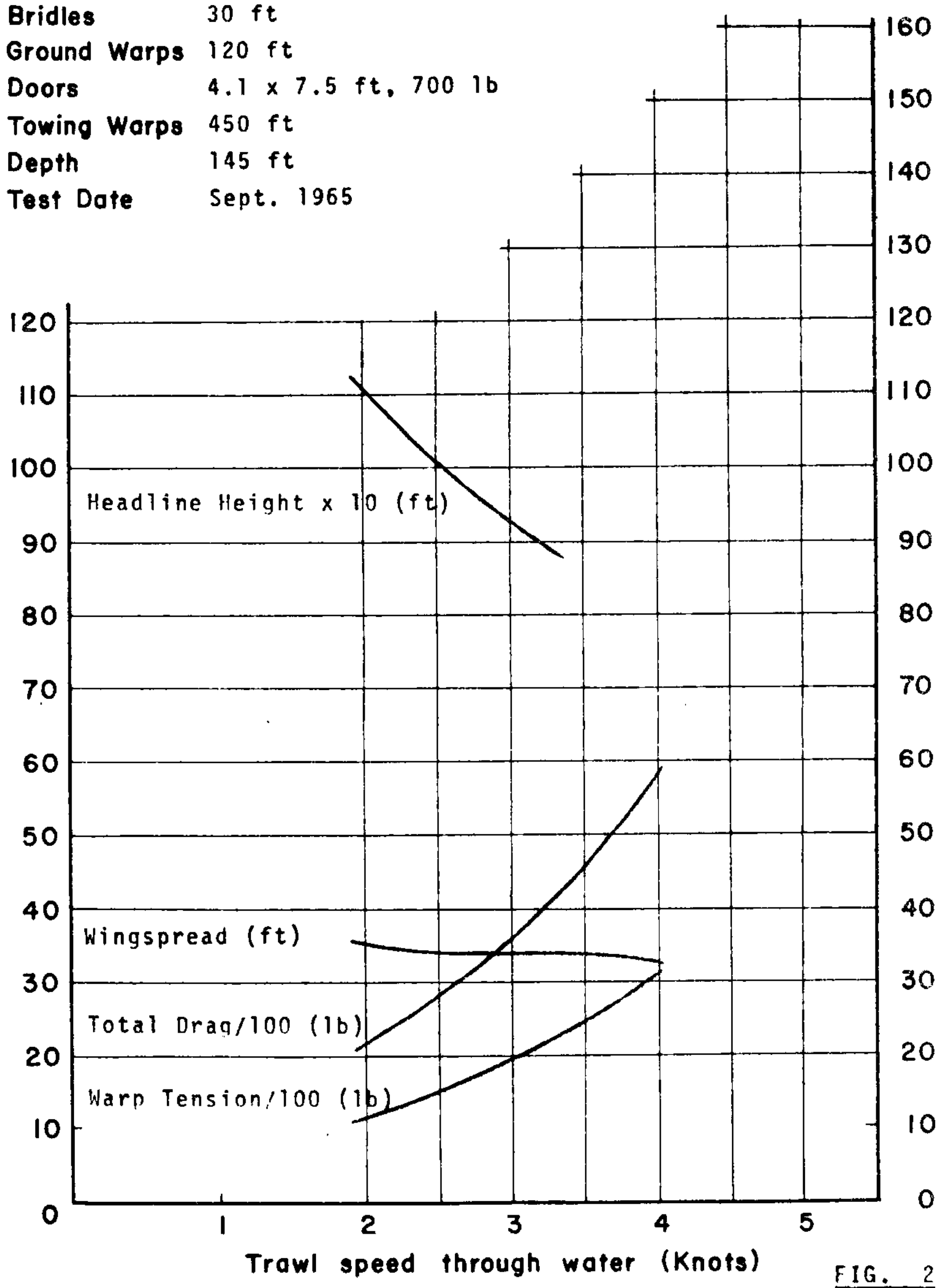

FIG. 2

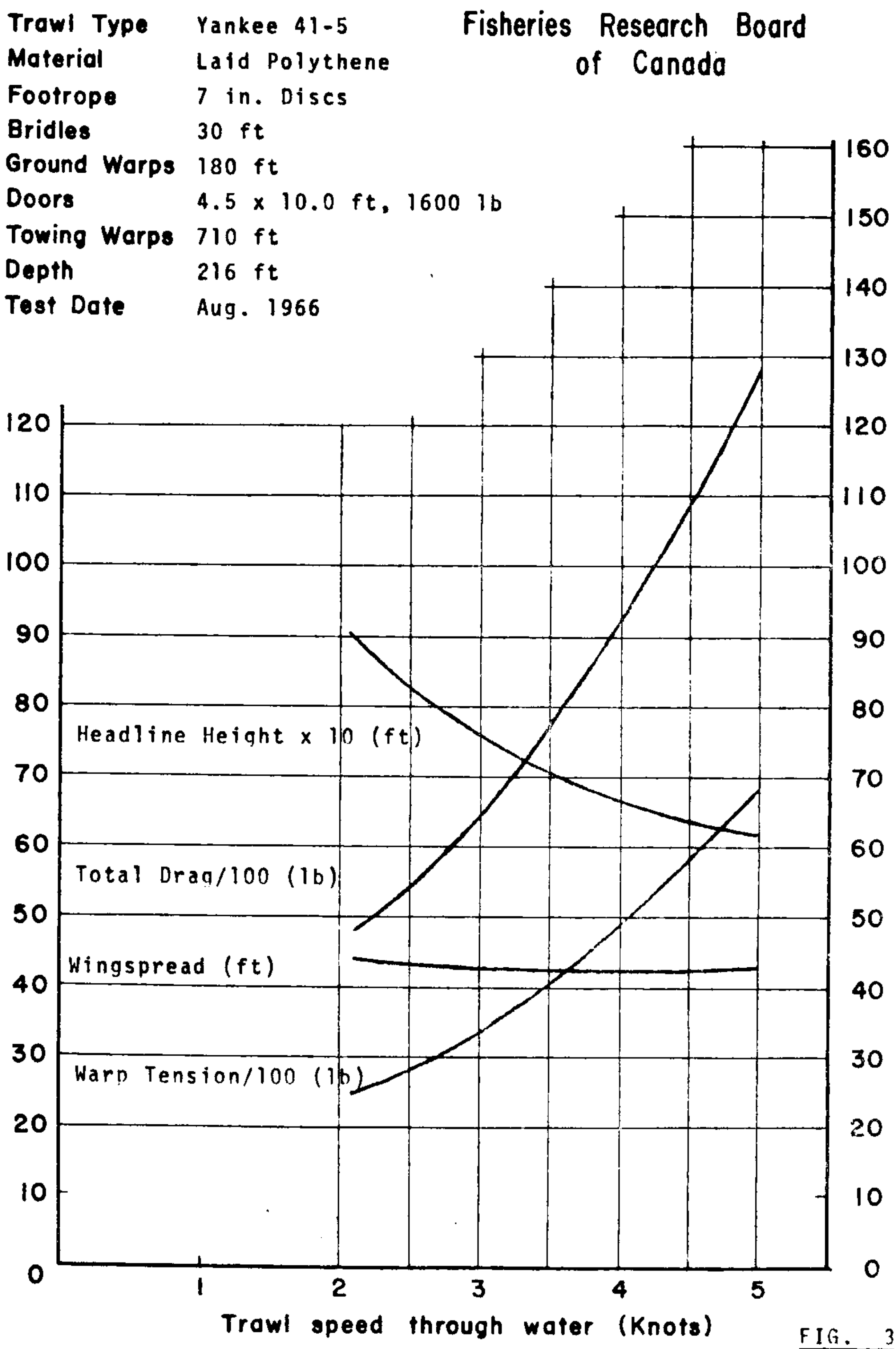
Trawl Type Yankee 41-5
Material Laid Polythene
Footrope 7 in. Discs
Bridles 30 ft
Ground Warps 180 ft
Doors 4.5 x 10.0 ft, 1600 lb
Towing Warps 710 ft
Depth 216 ft
Test Date Aug. 1966
Fisheries Research Board of Canada
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Headline Height x 10 (ft)
Total Drag/100 (lb)
Wingspread (ft)
Warp Tension/100 (lb)
1
2
3
4
5
Trawl speed through water (Knots)

FIG. 3

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Trawl Type	Yankee 41-5
Material	Laid Polythene
Footrope	18 in. Rollers
Bridles	30 ft
Ground Warps	180 ft
Doors	4.5 x 10.0 ft, 1600 lb
Towing Warps	710 ft, 998 ft
Depth	215 ft, 284 ft
Test Date	Aug. 1966

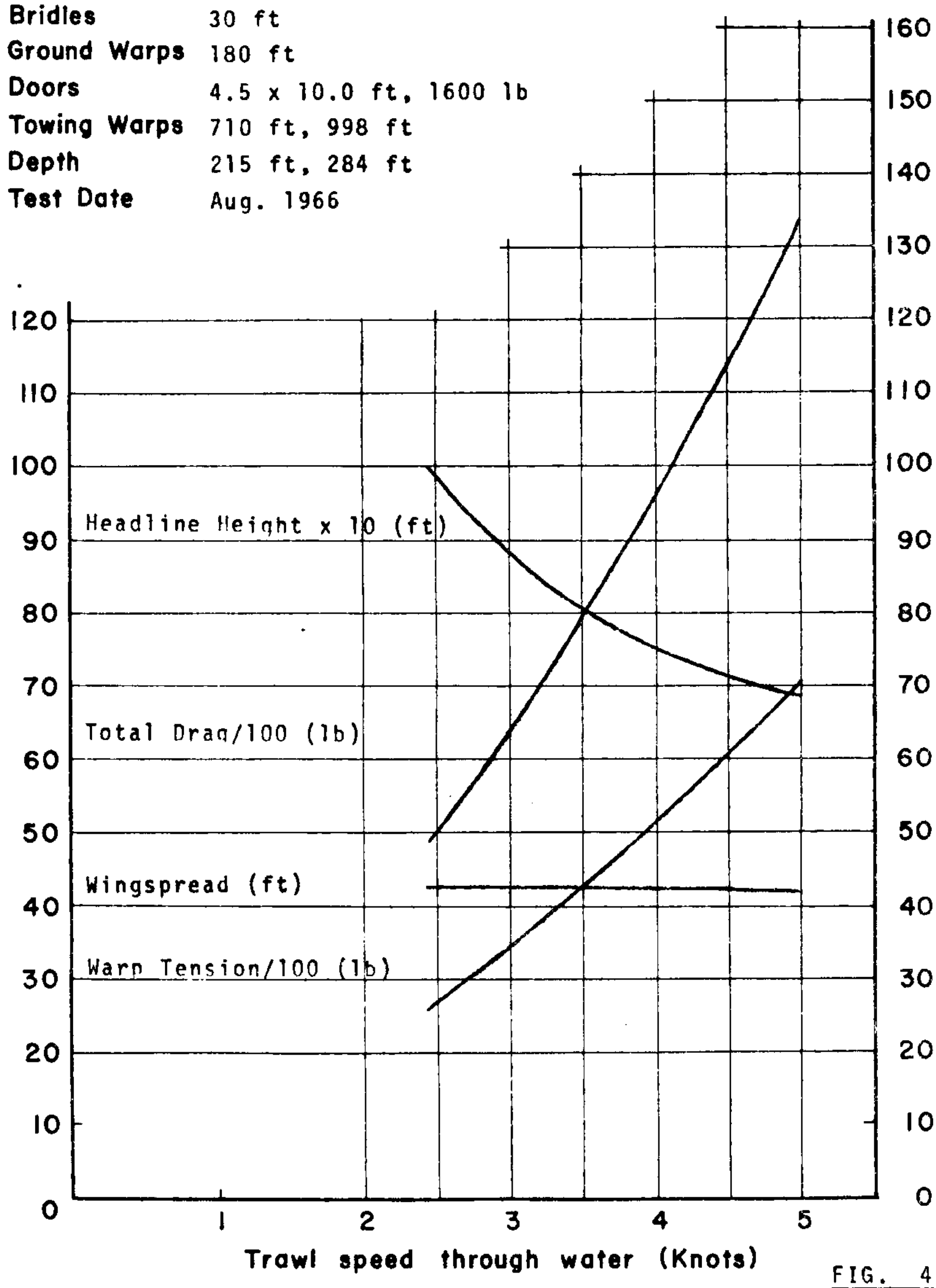

FIG. 4

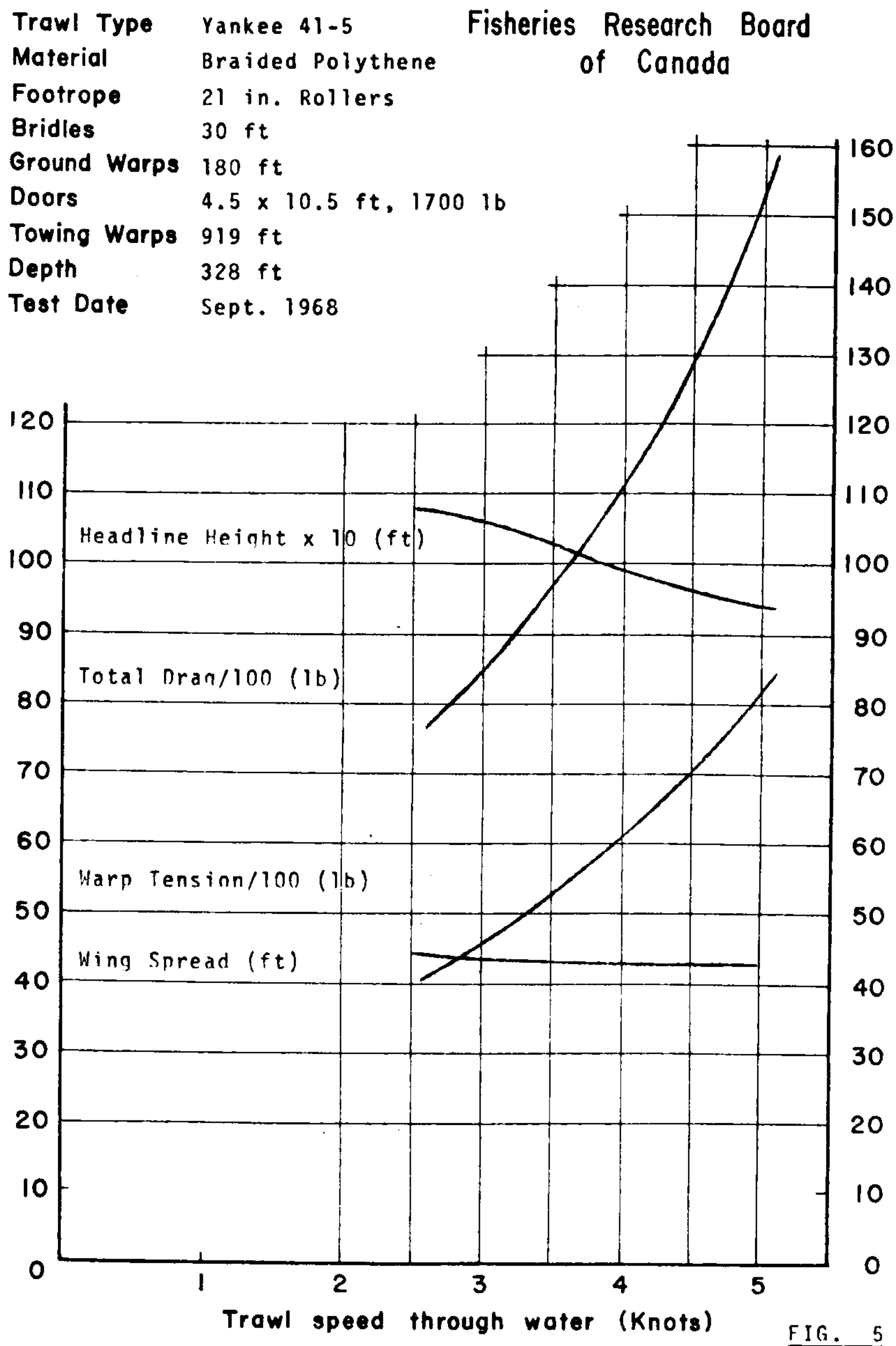
Trawl Type Yankee 41-5
Material Braided Polythene
Footrope 21 in. Rollers
Bridles 30 ft
Ground Warps 180 ft
Doors 4.5 x 10.5 ft, 1700 lb
Towing Warps 919 ft
Depth 328 ft
Test Date Sept. 1968
Fisheries Research Board of Canada
Headline Height x 10 (ft)
Total Drag/100 (lb)
Warp Tension/100 (lb)
Wing Spread (ft)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
1
2
3
4
5
Trawl speed through water (Knots)

FIG. 5

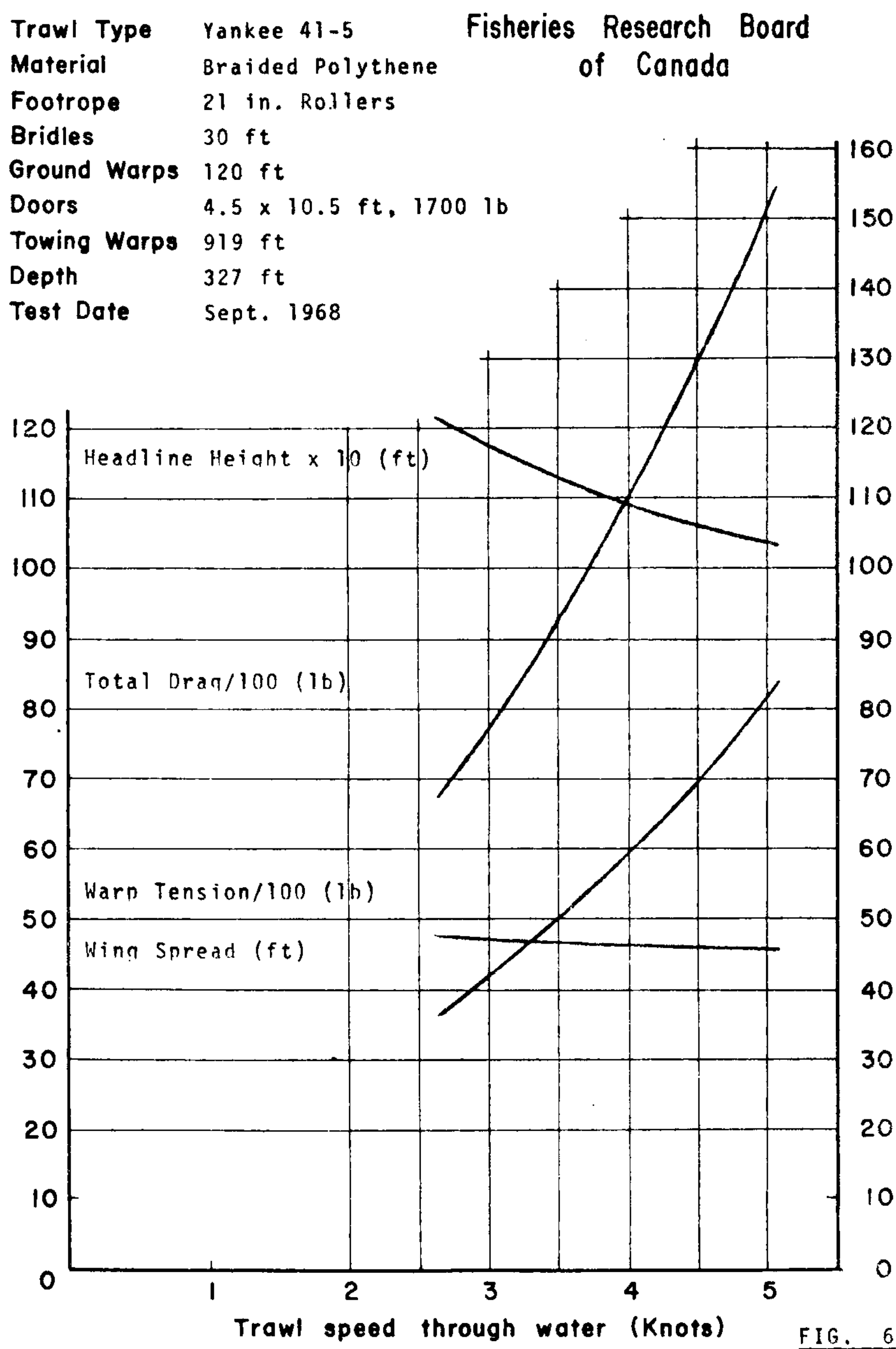
Trawl Type Yankee 41-5
Material Braided Polythene
Footrope 21 in. Rollers
Bridles 30 ft
Ground Warps 120 ft
Doors 4.5 x 10.5 ft, 1700 lb
Towing Warps 919 ft
Depth 327 ft
Test Date Sept. 1968
Fisheries Research Board of Canada
Headline Height x 10 (ft)
Total Drag/100 (lb)
Warp Tension/100 (lb)
Wing Spread (ft)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
1
2
3
4
5
Trawl speed through water (Knots)

FIG. 6

Trawl Type	Yankee 41-5
Material	Braided Polythene
Footrope	21 in. Rollers
Bridles	6 ft + Danleno
Ground Warps	138 ft
Doors	4.5 x 10.5 ft, 1700 lb
Towing Warps	919 ft
Depth	328 ft
Test Date	Sept. 1968

Fisheries Research Board of Canada

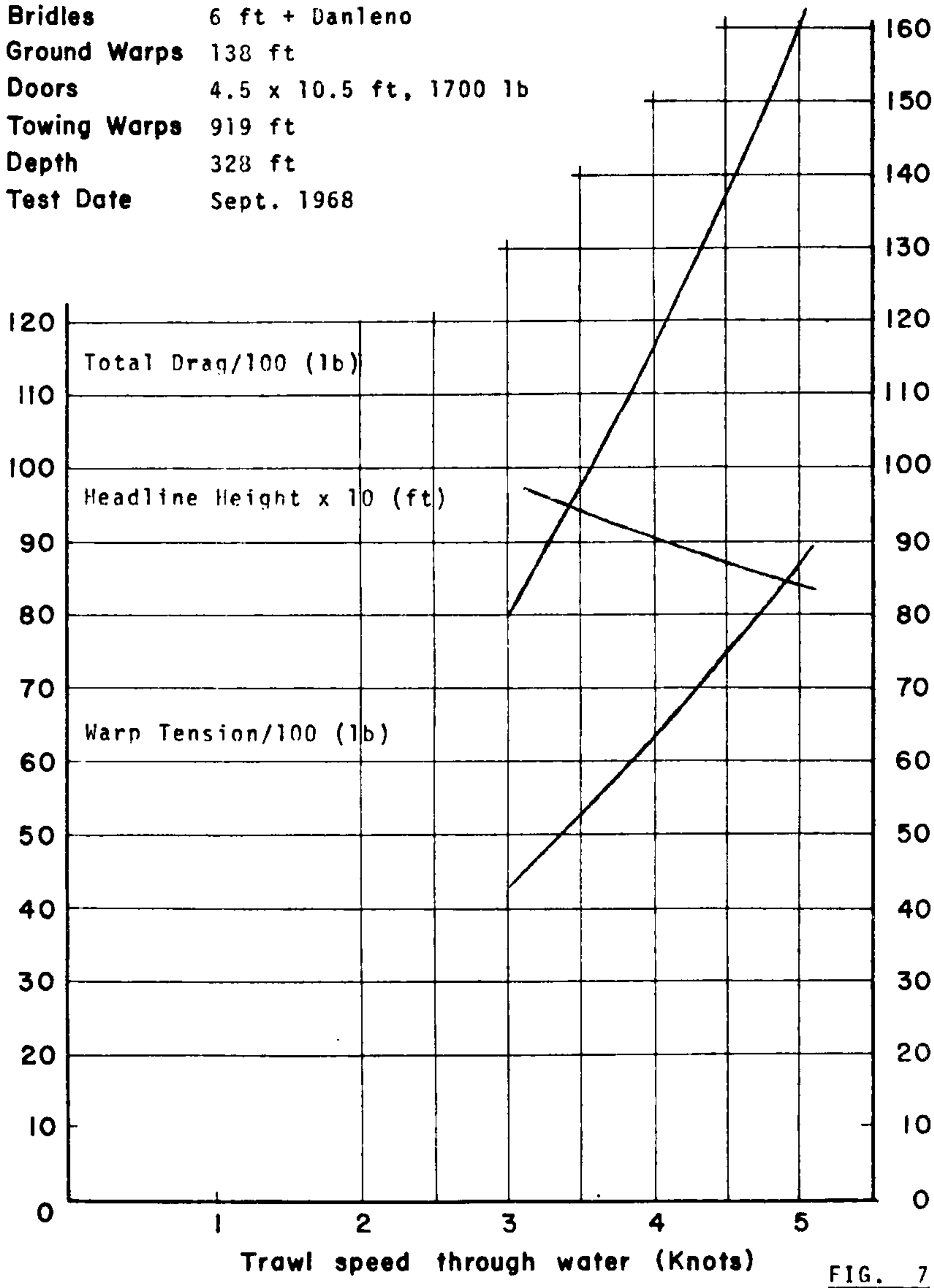

FIG. 7

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Trawl Type	Yankee 41-5
Material	Treated Laid Nylon
Footrope	18 in. Rollers
Bridles	30 ft
Ground Warps	90 ft
Doors	4.5 x 10.5 ft, 1800 lb
Towing Warps	671 ft
Depth	220 ft
Test Date	Oct. 1965

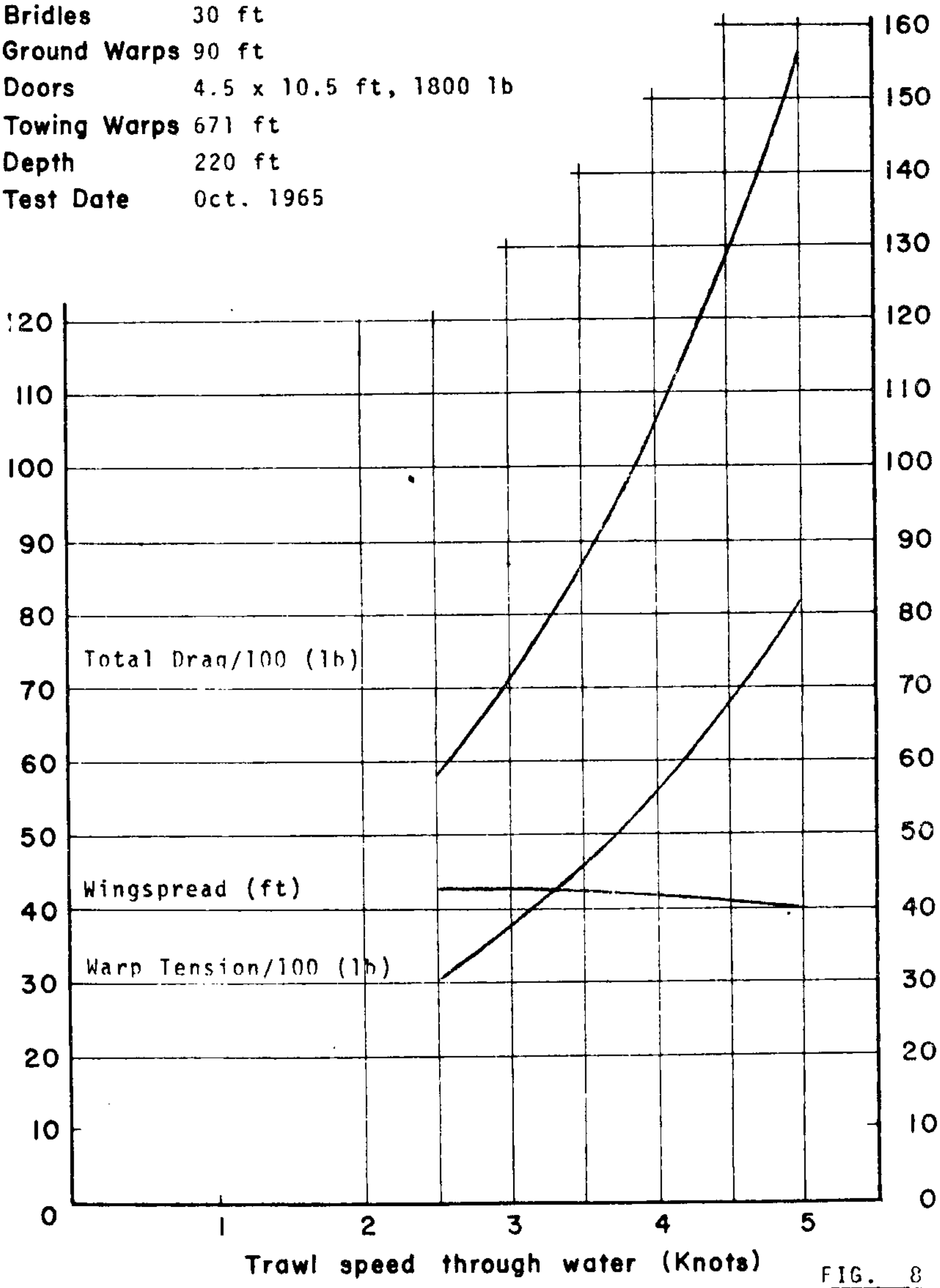

FIG. 8

Trawl Type	Yankee 41
Material	Laid Polythene
Footrope	18 in. Rollers
Bridles	30 ft
Ground Warps	180 ft
Doors	4.5 x 9.5 ft, 1600 lb
Towing Warps	1000 ft
Depth	327
Test Date	July, 1967

Fisheries Research Board of Canada

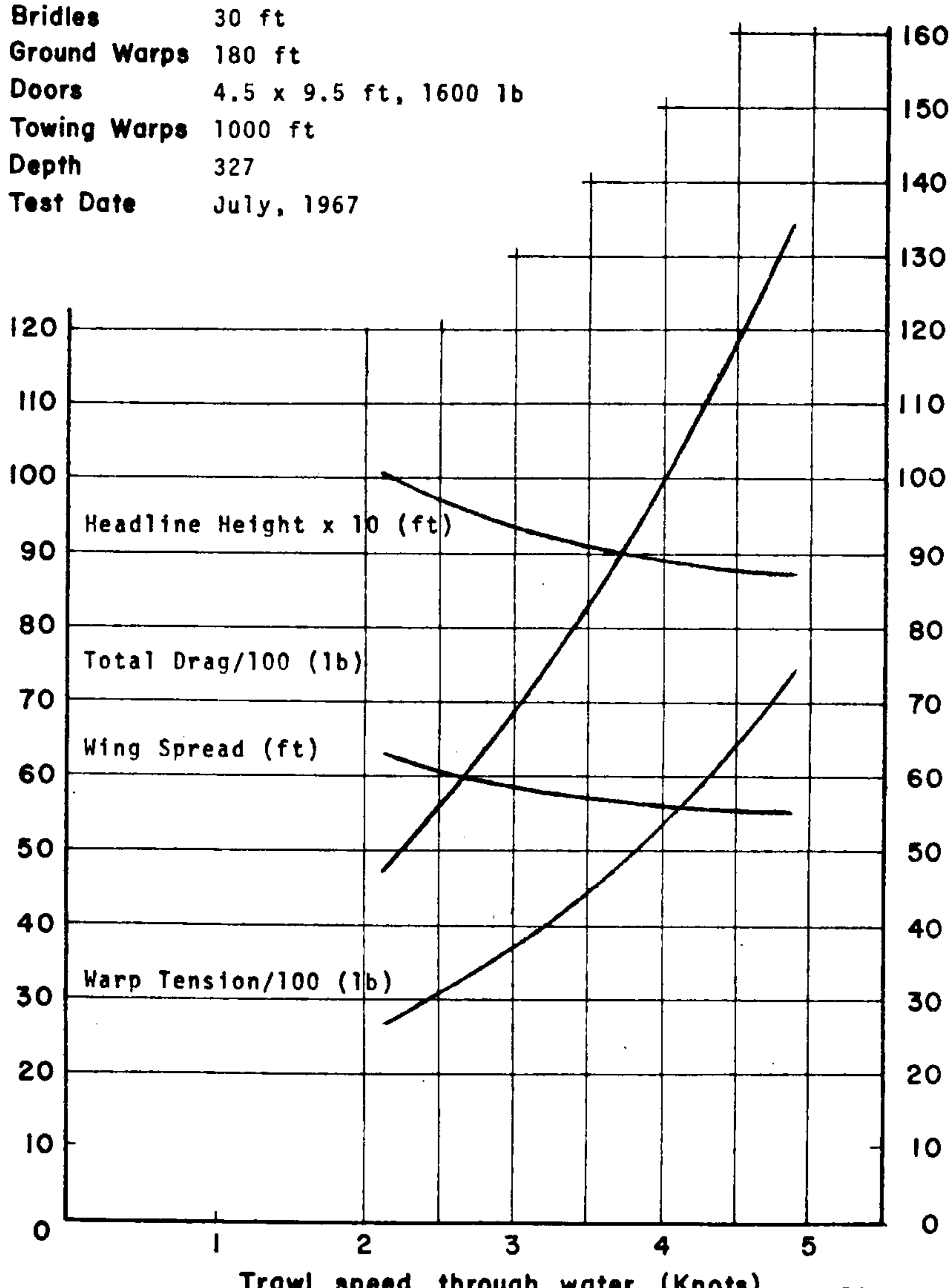

FIG. 9

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Trawl Type	Yankee 41
Material	Laid Polythene
Footrope	18 in. Rollers
Bridles	30 ft
Ground Warps	180 ft
Doors	4.8 x 8.0 ft Oval (BMV),1430 lb
Towing Warps	1000 ft, 1150 ft
Depth	330 ft
Test Date	July, 1967

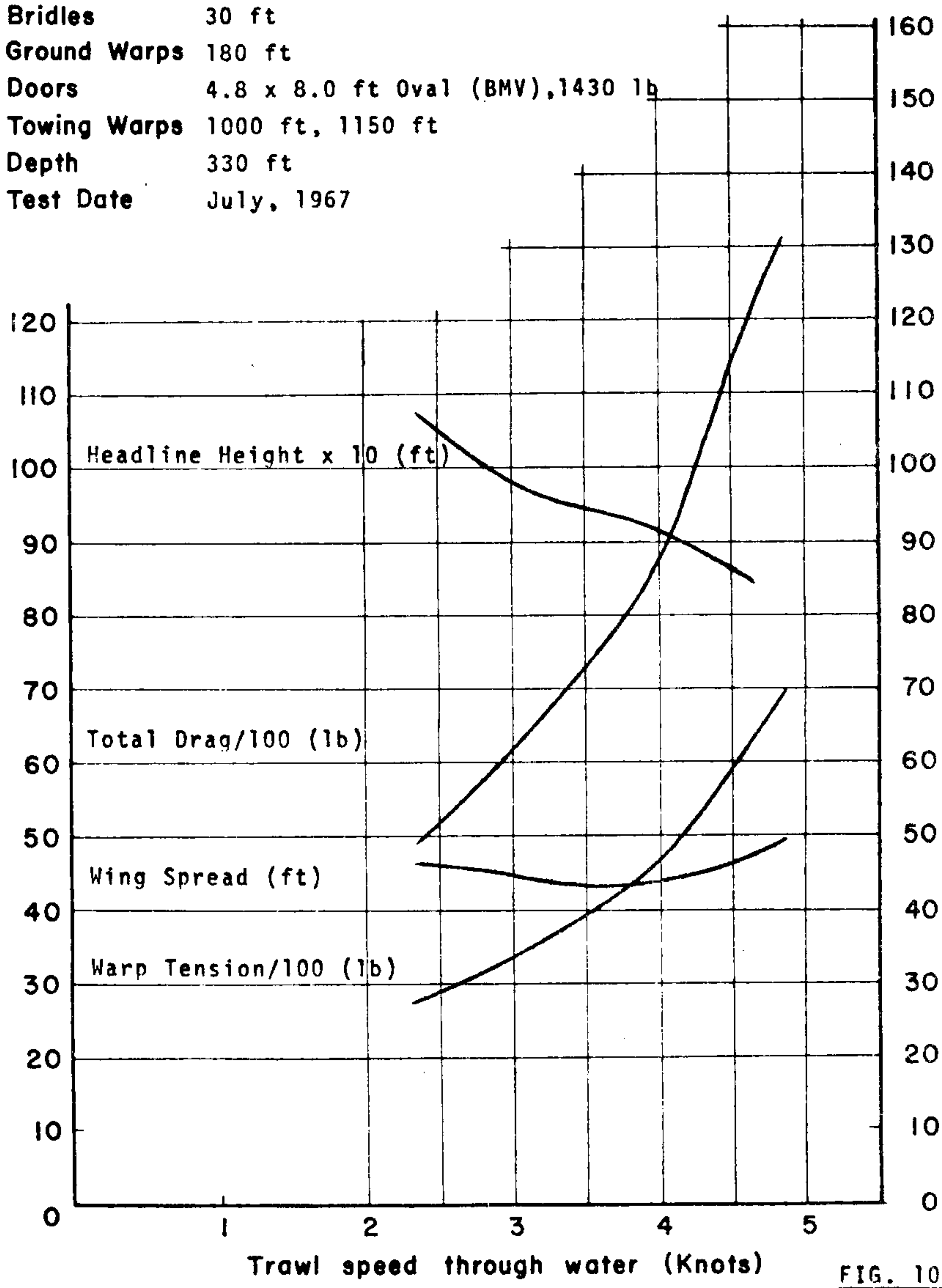

FIG. 10

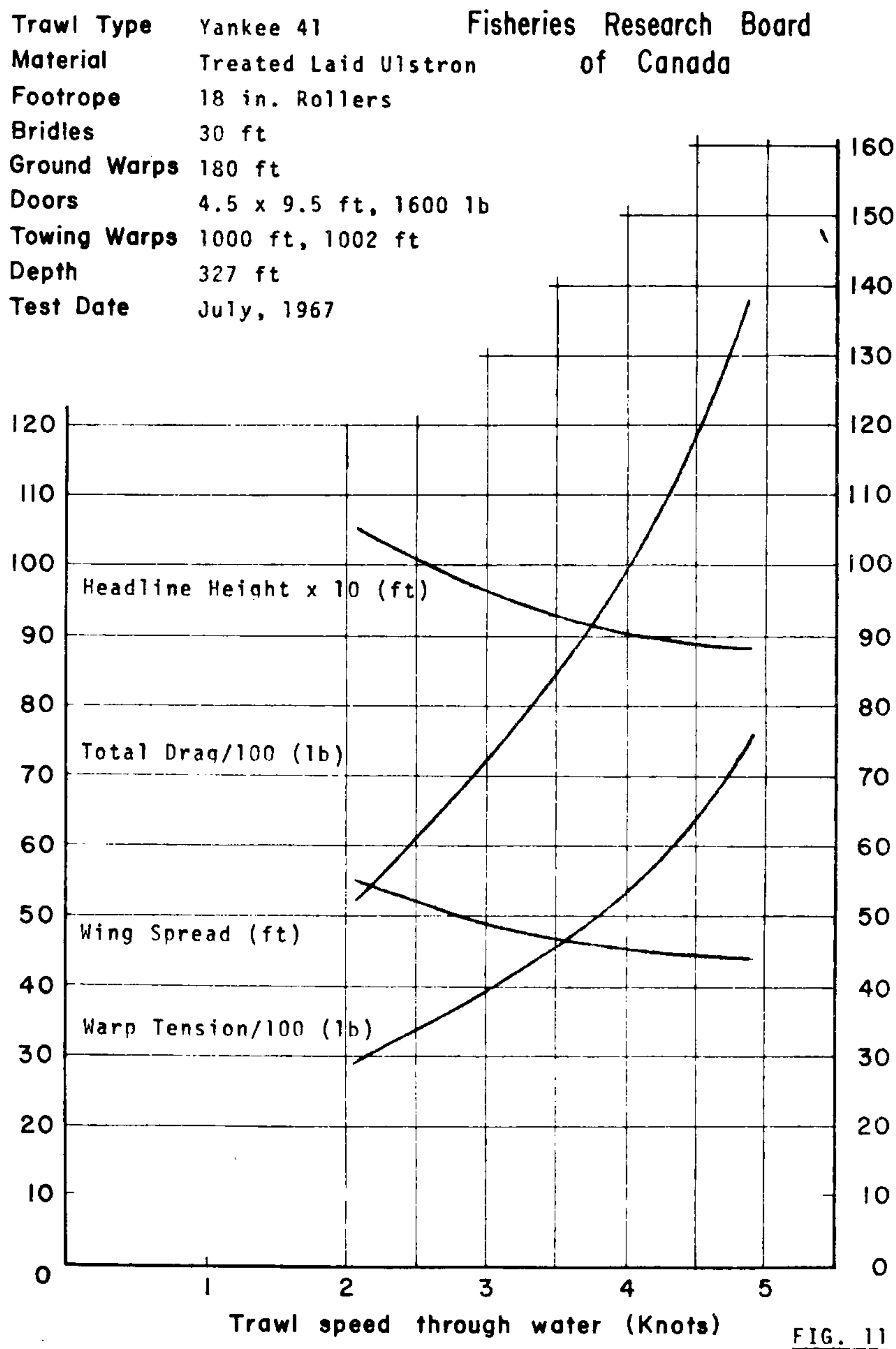
Trawl Type Yankee 41
Material Treated Laid Ulstron
Footrope 18 in. Rollers
Bridles 30 ft
Ground Warps 180 ft
Doors 4.5 x 9.5 ft, 1600 lb
Towing Warps 1000 ft, 1002 ft
Depth 327 ft
Test Date July, 1967
Fisheries Research Board of Canada
Headline Height x 10 (ft)
Total Drag/100 (lb)
Wing Spread (ft)
Warp Tension/100 (lb)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
1
2
3
4
5
Trawl speed through water (Knots)

FIG. 11

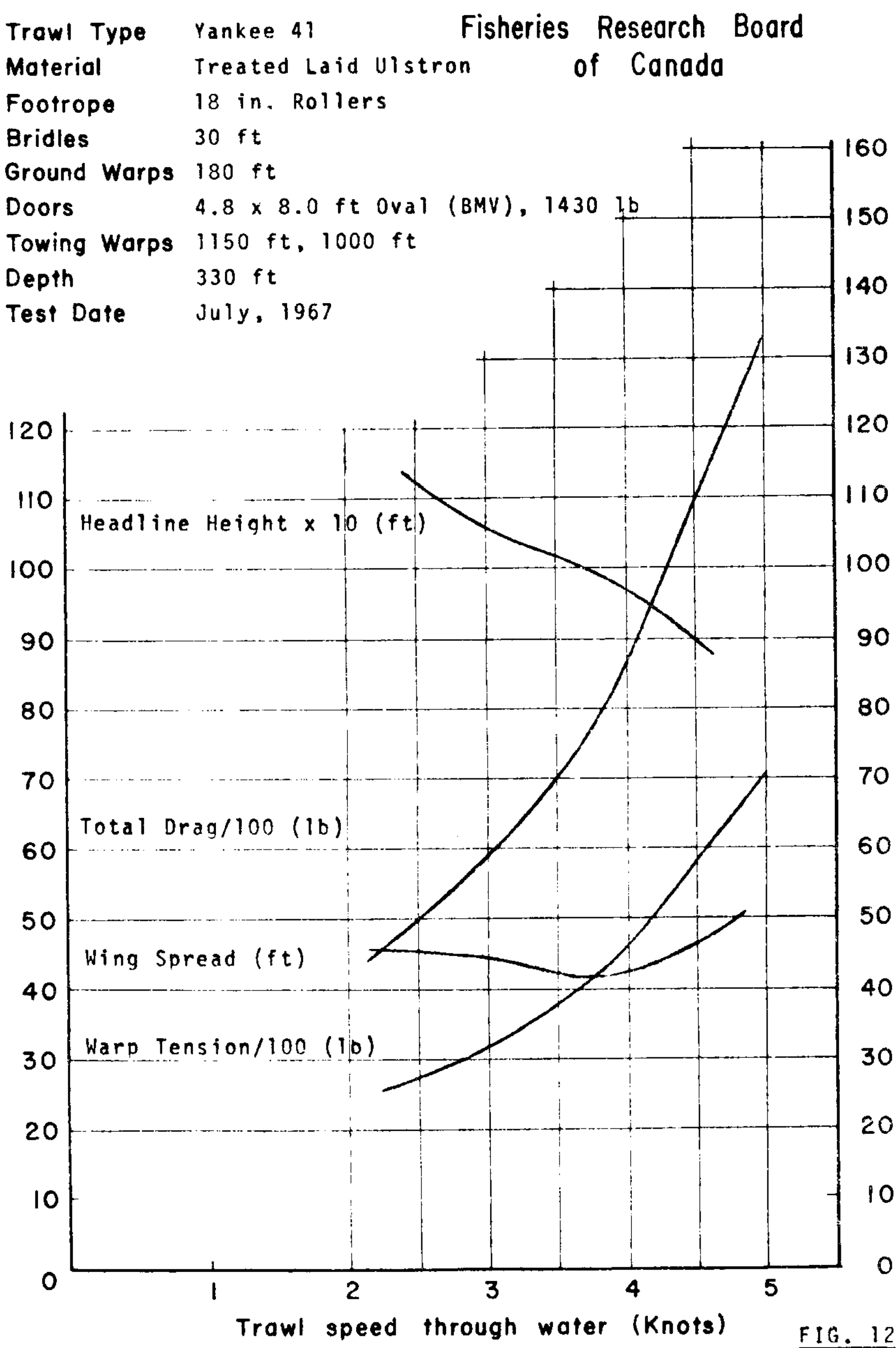
Trawl Type Yankee 41
Material Treated Laid Ulstron
Footrope 18 in. Rollers
Bridles 30 ft
Ground Warps 180 ft
Doors 4.8 x 8.0 ft Oval (BMV), 1430 lb
Towing Warps 1150 ft, 1000 ft
Depth 330 ft
Test Date July, 1967
Fisheries Research Board of Canada
Headline Height x 10 (ft)
Total Drag/100 (lb)
Wing Spread (ft)
Warp Tension/100 (lb)
Trawl speed through water (Knots)

FIG. 12

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Trawl Type	Skagen
Material	Braided Polythene
Footrope	Rounded
Bridles	120 ft
Ground Warps	180 ft
Doors	4.5 x 10.0 ft, 1600 lb
Towing Warps	710 ft
Depth	220 ft
Test Date	Aug. 1966

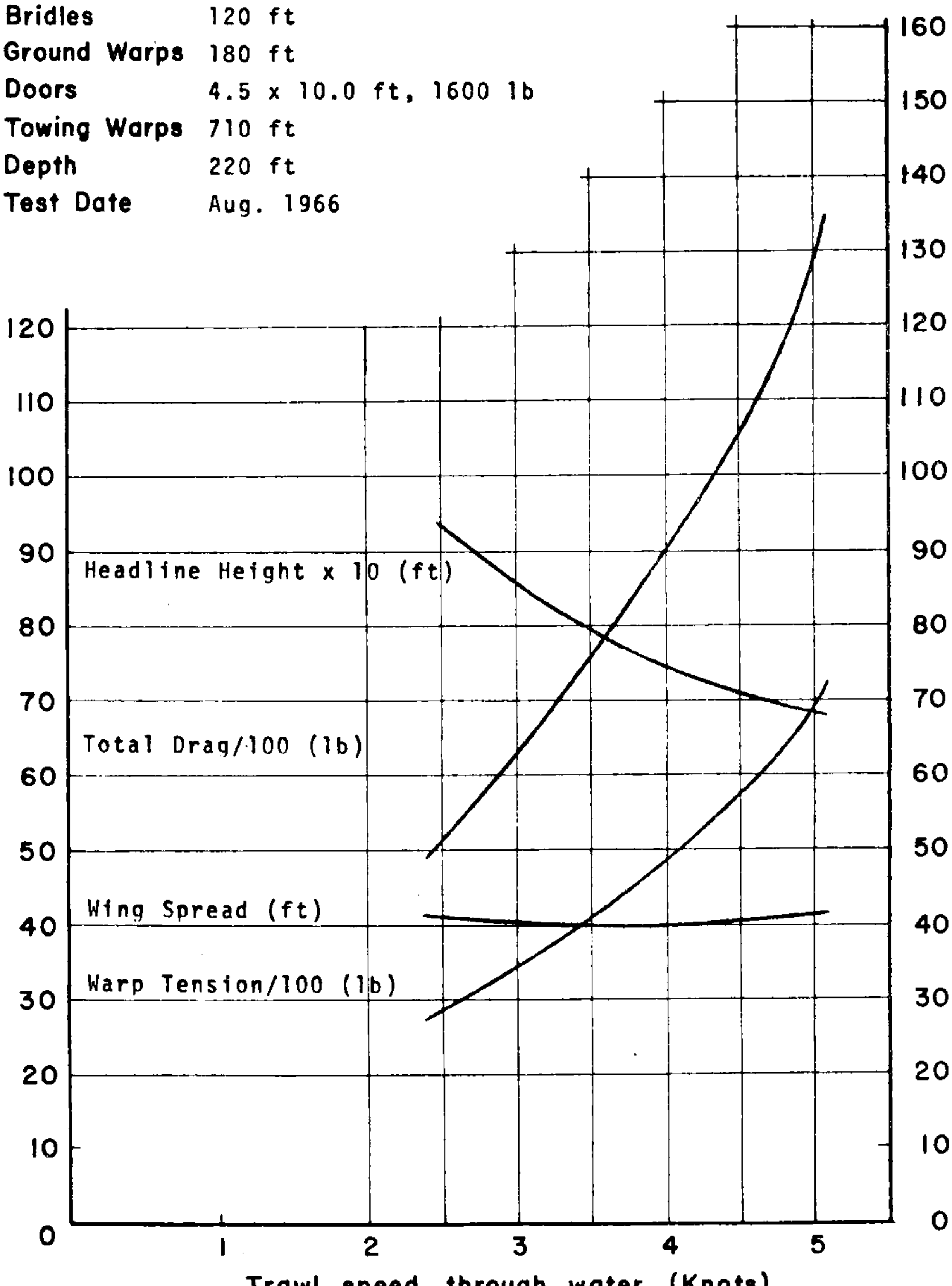

FIG. 13

Trawl Type	Granton
Material	Laid Polythene
Footrope	31 in. Rollers
Bridles	30 ft
Ground Warps	120 ft
Doors	4.5 x 10.5 ft, 1700 lb
Towing Warps	919 ft
Depth	326 ft
Test Date	Sept. 1968

Fisheries Research Board
of Canada

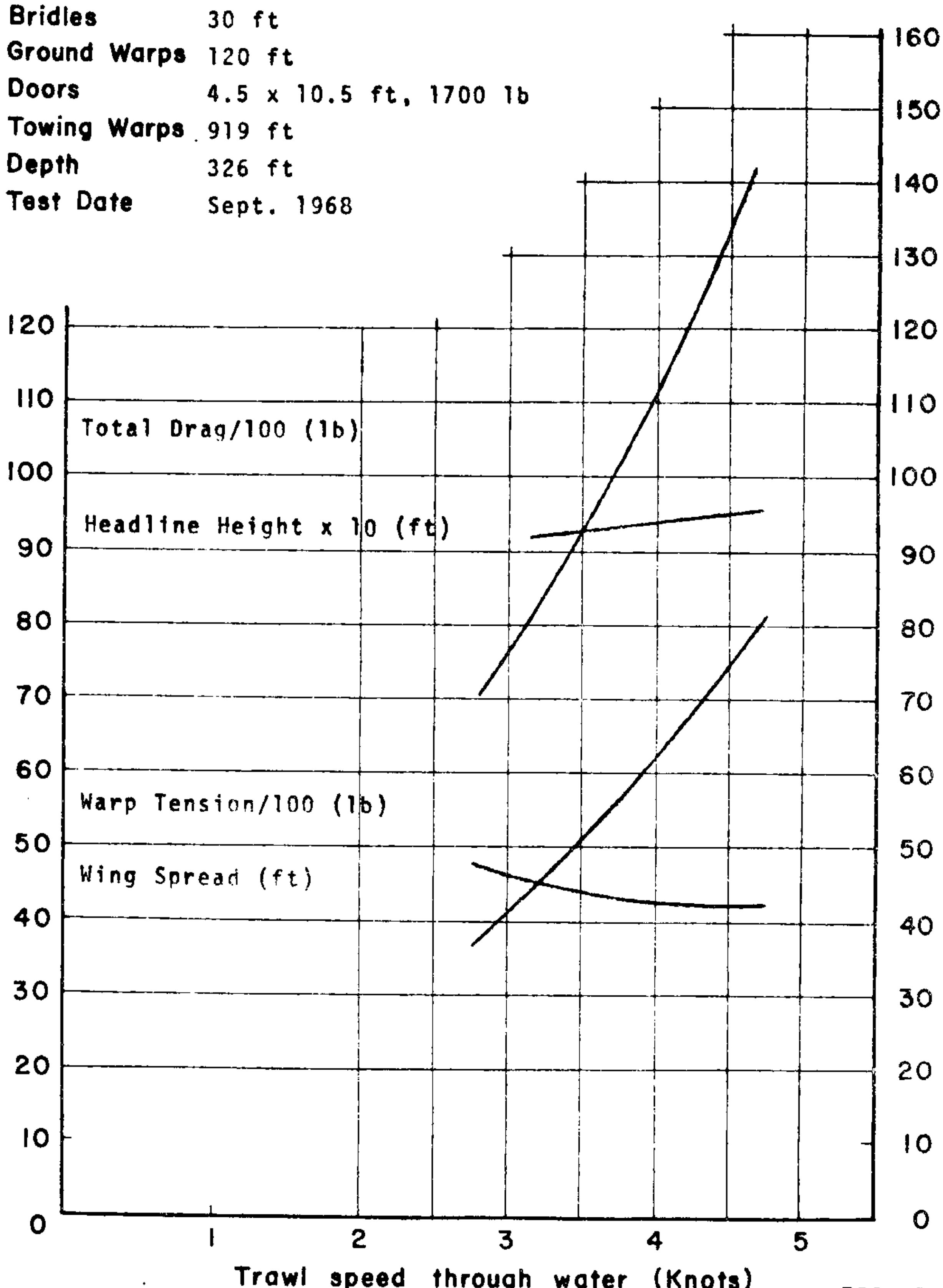

FIG. 14

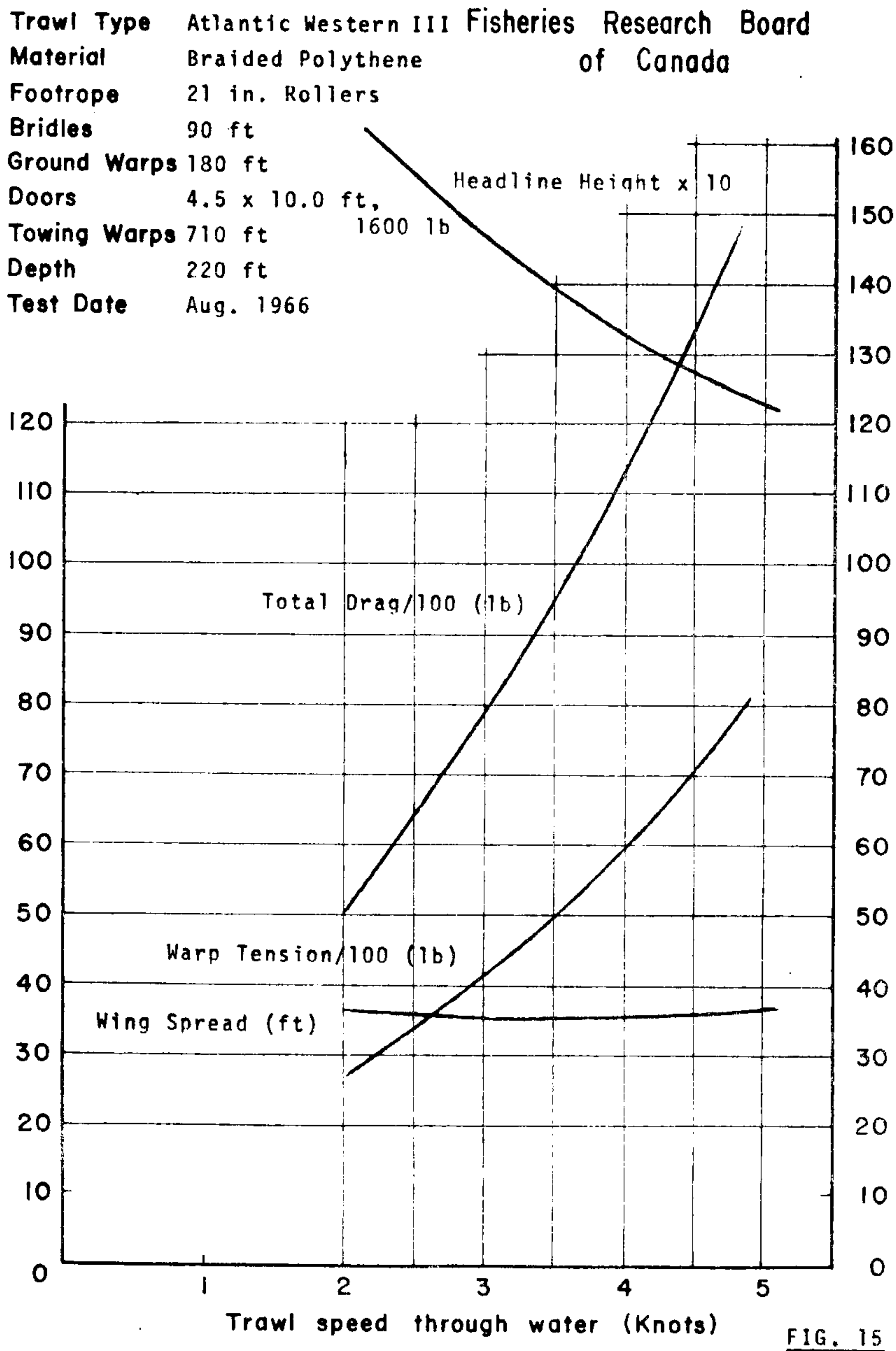
Trawl Type Atlantic Western III
Material Braided Polythene
Footrope 21 in. Rollers
Bridles 90 ft
Ground Warps 180 ft
Doors 4.5 x 10.0 ft, 1600 lb
Towing Warps 710 ft
Depth 220 ft
Test Date Aug. 1966
Fisheries Research Board of Canada
Headline Height x 10
Total Drag/100 (lb)
Warp Tension/100 (lb)
Wing Spread (ft)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
1
2
3
4
5
Trawl speed through water (Knots)

FIG. 15