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The Nature of Bottom-Trawl Drag

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Historical

The hydrodynamic drag, D_H, of a body immersed in a fluid flow is traditionally described by the equation

$$D_H = C_D \cdot S \cdot q \qquad (1)$$

where C_D = drag coefficient, a function of flow

S = characteristic area of the body

$$q = \rho V^2/2 = \text{hydrodynamic pressure} \qquad (2)$$

ρ = mass density of fluid

V = flow velocity

Many authors (2), (3), (4), (5) discussing the drag of bottom trawls use this relation but unwisely substitute into Equation (1) the expression for "q" given by Equation (2). As a result, the mathematical presentation is cluttered by two additional characters, $\rho/2$, which appear only in association with V^2, and, more important, the substituted equation encourages the incorrect assumption that trawl drag increases as the square of the speed.

In Equation (1), the drag coefficient, C_D, is a function of the pattern of fluid flow through and around the trawl, and this flow pattern is a function of trawl speed. Further, the trawl is a flexible structure whose shape changes with changes in the forces in and on it so that the characteristic area, S, in Equation (1) is also a function of trawl speed. Considering that all three independent variables in Equation (1) are affected by speed, there is no justification to assume that trawl drag varies as the square of the speed. In fact, this assumption was disproven the first time warp tensions and towing speeds were both measured with any degree of accuracy.

Crewe (2) reported trawl drag, D, to increase approximately with the first power of speed, V, i.e.,

$$D = k \cdot V \tag{3}$$

where "k" is an empirical constant, and rationalized this in terms of reduced headline height and frontal area at higher speeds. However, as additional experimental data became available, this direct dependence of drag on speed was shown not to be very accurate (1).

Unfortunately, there is now a tendency for experimental data to be fitted empirically to an equation of the form

$$D = m \cdot V^n \tag{4}$$

where m, n = empirical constants

With two parameters, Equation (4) provides a closer fit than does Equation (3) and is adequate for purposes of interpolation and limited extrapolation. However, the parameters, m and n, cannot be interpreted in terms of the mechanics of trawl drag and an equation of this form cannot lead to a priori prediction of trawl drag.

The purpose of this presentation is to show that speed per se is not a prime cause of trawl drag but that it exerts its influence through other mechanisms, primarily hydrodynamic pressure. Consideration of these prime mechanisms rather than speed provides a more meaningful interpretation of experimental results and can lead to a rational procedure for a priori prediction of trawl drag.

Trawl-net drag

The prime forces acting on a trawl net are shown in Figure 1. These include:

1. Hydrodynamic trawl drag, D_{HT}, of the form given by Equation (1), viz.

$$D_{HT} = S_{DT} \cdot q \tag{5}$$

where $S_{DT} = C_D \cdot S$, the hydrodynamic drag area of the trawl-net, including netting, lines, floats and bobbin gear aft of the wing tips, is a function of trawl shape and fluid flow.

2. Ground-friction drag, D_{GT}, against the sea bed, traditionally of the form

$$D_{GT} = K_F \cdot F_V \qquad (6)$$

where K_F, the ground-friction coefficient, depends primarily on the type of sea bed and type of bobbin gear, but as a first approximation may be considered independent of speed, and where

$$F_V = W_T + \Delta T_V - L_K \qquad (7)$$

is the vertical force or ground-reaction between the trawl and the sea bed.

3. Weight in sea water, W_T, of the trawl net and all attachments aft of the wing tips, including buoyancy of the floats.

4. Wing-bridle tensions which may be resolved into orthogonal components. The components parallel to the direction of tow, T_T, may be added together for the total towing force, which equals the total drag of the trawl-net, i.e.,

$$\Sigma T_T = D_T \qquad (8)$$

The outward components on the port and starboard sides are equal and opposite, and hence complementary, if the trawl follows a straight course. The algebraic sum of the vertical components, ΔT_V, contributes to the reaction between the trawl and sea-bed as given in Equation (7).

5. If there is a kite on the headline, the hydrodynamic force generated by it may be resolved into a lift

$$L_K = S_{LK} \cdot q \qquad (9)$$

and a drag

$$D_K = S_{DK} \cdot q \qquad (10)$$

of the form given by Equation (1).

where $S_{LK} = C_L \cdot S_K$ and $S_{DK} = C_D \cdot S_K$ are respectively the hydrodynamic lift and drag areas of the kite and are functions of kite shape, angle of incidence, etc., but are near enough constant for present purposes.

Thus, the total drag of the trawl is seen to originate from two distinct and different sources, viz., hydrodynamic pressure and ground friction. From Equations (5), (10), (6) and (7) and Figure 1, the total trawl drag aft of the wing tips is seen to be

$$D_T = D_{HT} + D_K + D_{GT} \tag{11}$$

$$= (S_{DT} + S_{DK}) \cdot q + K_F \cdot (W_T + \Delta T_V - L_K)$$

Now the tensions in the wing bridles originate primarily in the drag of the trawl-net, which has just been shown to contain a hydrodynamic component which varies directly as the hydrodynamic pressure, q, and a ground-friction component which is essentially independent of hydrodynamic pressure and speed. Thus, the algebraic sum of the vertical components of the wing-bridle tensions, ΔT_V, can be expected to assume the form

$$\Delta T_V = a \cdot q + b \tag{12}$$

where a, b = empirical constants.

Figure 2 and Table 1, based on measurements from a Yankee 41-5 trawl, show Equation (12) to be correct within very acceptable limits of accuracy.

Substituting into Equation (11) for ΔT_V and L_K from Equations (12) and (9) respectively, and using Equation (8)

$$D_T = (S_{DT} + S_{DK} + K_F \cdot (a - S_{LK})) \cdot q + K_F \cdot (W_T + b)$$

$$= \Sigma T_T = c \cdot q + d \tag{13}$$

$$\text{where } c = S_{DT} + S_{DK} + K_F \cdot (a - S_{LK}) \tag{14}$$

$$\text{and } d = K_F \cdot (W_T + b) \tag{15}$$

are empirical constants. Again, Figure 3 and Table 1, based on measurements from a Yankee 41-5 trawl, show Equation (13) to be correct within very acceptable limits of accuracy. The slight curvature which often appears in the points on plots such as Figure 3 probably is a consequence of hydrodynamic drag area of the trawl, S_{DT}, decreasing as the height of the headline decreases with increasing speed and hydrodynamic pressure. However, contrary to the observation of Crewe (2), this is obviously a second-order effect and can be neglected for present purposes.

The drag area, S_{DK}, and the lift area, S_{LK}, of the kite may be estimated from hydrofoil theory. In the absence of a kite $S_{DK} = S_{LK} = 0$.

The ground-friction coefficient may be calculated from experimental results by Equation (15), i.e.,

$$K_F = d/(W_T + b) \tag{16}$$

Then, the hydrodynamic drag area of the trawl-net may be calculated from Equation (14), i.e.

$$S_{DT} = c - S_{DK} - K_F \cdot (a - S_{LK}) \tag{17}$$

These empirical constants and characteristic parameters with their 95% confidence limits from six tows with a Yankee 41-5 trawl are summarized in Table 1, demonstrating the validity of this analysis.

It remains only to express the hydrodynamic drag area of the trawl, S_{DT}, in terms of the construction and shape of the trawl and to express the ground-friction coefficient, K_F, in terms of type of sea-bed and type of bobbin gear to obtain a rational procedure for the a priori prediction of trawl drag.

Trawl-door forces

As pointed out by Crewe (2) the action of the trawl doors is quite complex, involving changes in heel angle and "bite" into the sea-bed with changes in towing speed and hydrodynamic pressure. However, as with the trawl net, the forces generated by the trawl doors originate in two basic mechanisms, viz., hydrodynamic pressure and ground friction.

Figure 4 and Table 1 show a very good empirical linear regression on hydrodynamic pressure of both drag and sheer (spreading force) generated by standard, 4.5 x 10.0 ft (1.37 x 3.05 m), 1600 lb (725 kg) rectangular doors in results obtained from the Yankee 41-5 trawl tested for trawl-net drag. It is interesting to note that both sheer and drag include ground "friction" components, even though friction is normally considered to act only in the direction opposite to the direction of motion.

Total trawl drag

The drag of the whole trawl, as measured at the vessel, includes the drag of the net, the doors, and the lines. The geometry of the system changes considerably with changes in speed. Nevertheless, as with trawl components, total trawl drag originates from two basic mechanisms, viz., hydrodynamic pressure and ground friction. Thus, it is not surprising to see in Figure 5 and Table 1 a good, empirical, linear regression of total trawl drag on hydrodynamic pressure, exhibiting components of both ground friction and hydrodynamic origin.

Moral

Think pressure, not speed, for a meaningful analysis of trawl drag.

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TABLE 1

Forces and parameters, with 95% confidence limits, from a Yankee 41-5 trawl.

Tow Number	23	24	25	26	27	28
Trawl depth (fm)	36	36	37	36	47	48
Warp length (fm)	118	118	118	119	166	166
Course (deg)	176	32	222	133	251	73
Current (deg)						
Bottom	-	-	-	-	10	24
Surface	274	281	281	284	230	346
Equation (12)						
ΔT_V(lb)	±1.3	±1.6	±2.0	±4.7	±4.3	±2.2
a (sq ft)	0.49±0.02	0.50±0.02	0.70±0.04	0.72±0.10	0.97±0.08	0.80±0.04
b (lb)	19.4±0.44	17.8±0.53	19.9±0.67	18.4±1.57	18.2±1.18	20.9±0.71
Equation (13)						
D (lb)	±440	±280	±506	±450	±449	±244
c (sq ft)	104±9.6	108±6.4	98±10.7	109±10.8	105±10.0	104±5.2
d (lb)	1155±145	1232±93	1587±169	1250±150	1308±124	1258±81
Equation (16)						
K_F(lb)	10.1±1.25	10.9±0.82	13.8±1.45	11.0±1.31	11.6±1.10	10.9±0.69
Equation (17)						
S_{DT}(lb)	99±9.7	103±6.4	88±10.7	101±11.0	94.0±10.1	95.7±5.21
Starboard door						
Drag (lb)	±225	±160	±76	±114	±161	±163
Area (sq ft)	15.7±5.0	15.6±3.7	19.2±1.6	16.9±2.7	29.7±3.6	18.4±3.4
Friction (lb)	859±75	730±53	459±25	631±38	437±45	776±54
Sheer (lb)	±104	±161	±64	±110	±158	±96
Area (sq ft)	33.6±2.3	29.0±3.7	27.1±1.3	27.0±2.6	29.5±3.5	20.8±2.0
Friction (lb)	187±35	387±54	535±21	221±37	282±44	471±32
Port door						
Drag (lb)	±246	±195	±128	±381	±417	±168
Area (sq ft)	17.1±5.4	24.3±4.4	22.5±2.7	28.8±9.2	30.5±9.3	13.2±3.6
Friction (lb)	577±82	363±65	399±43	320±127	-39±116	887±56
Sheer (lb)	±162	±104	±72	±221	±378	±144
Area (sq ft)	22.6±3.6	19.6±2.4	17.7±1.5	19.6±5.3	25.6±8.4	21.1±3.1
Friction (lb)	427±54	498±35	502±24	665±74	501±105	447±48
Total trawl drag (lb)						
Area (sq ft)	148	154	149	165	173	144
Friction (lb)	2600	2488	2480	2225	1914	2988

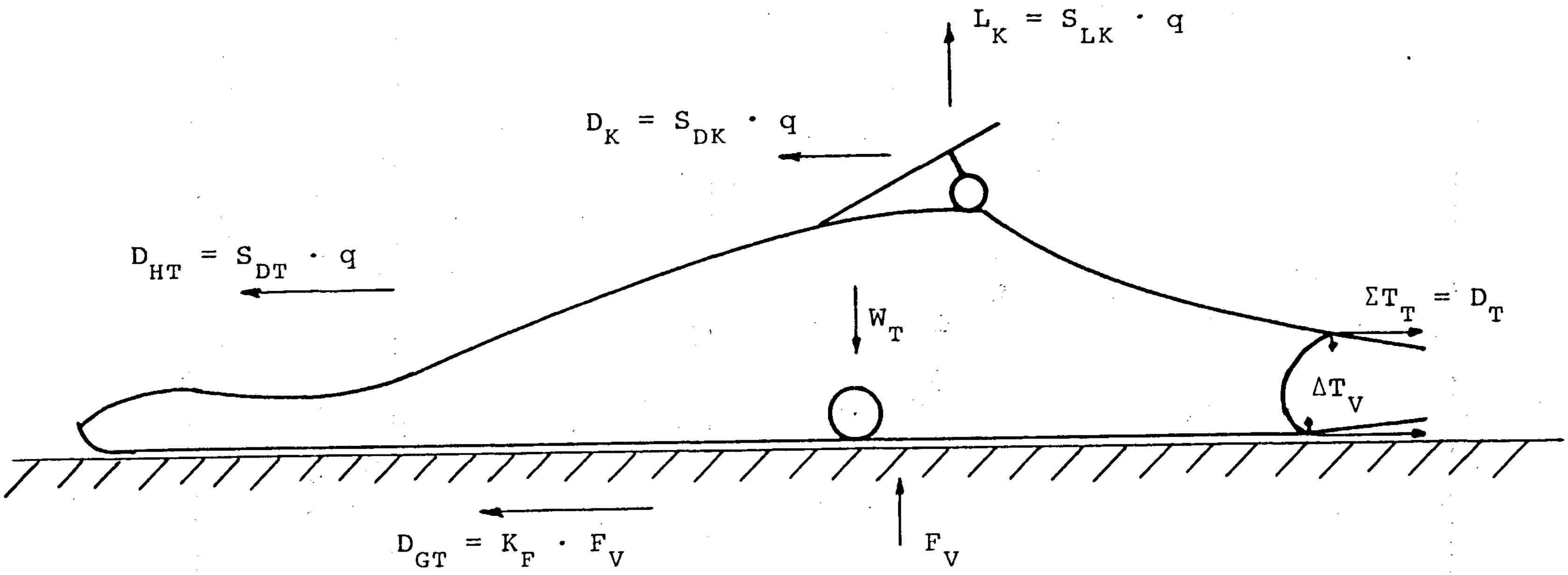

Fig. 1. Principle forces acting on a trawl-net.

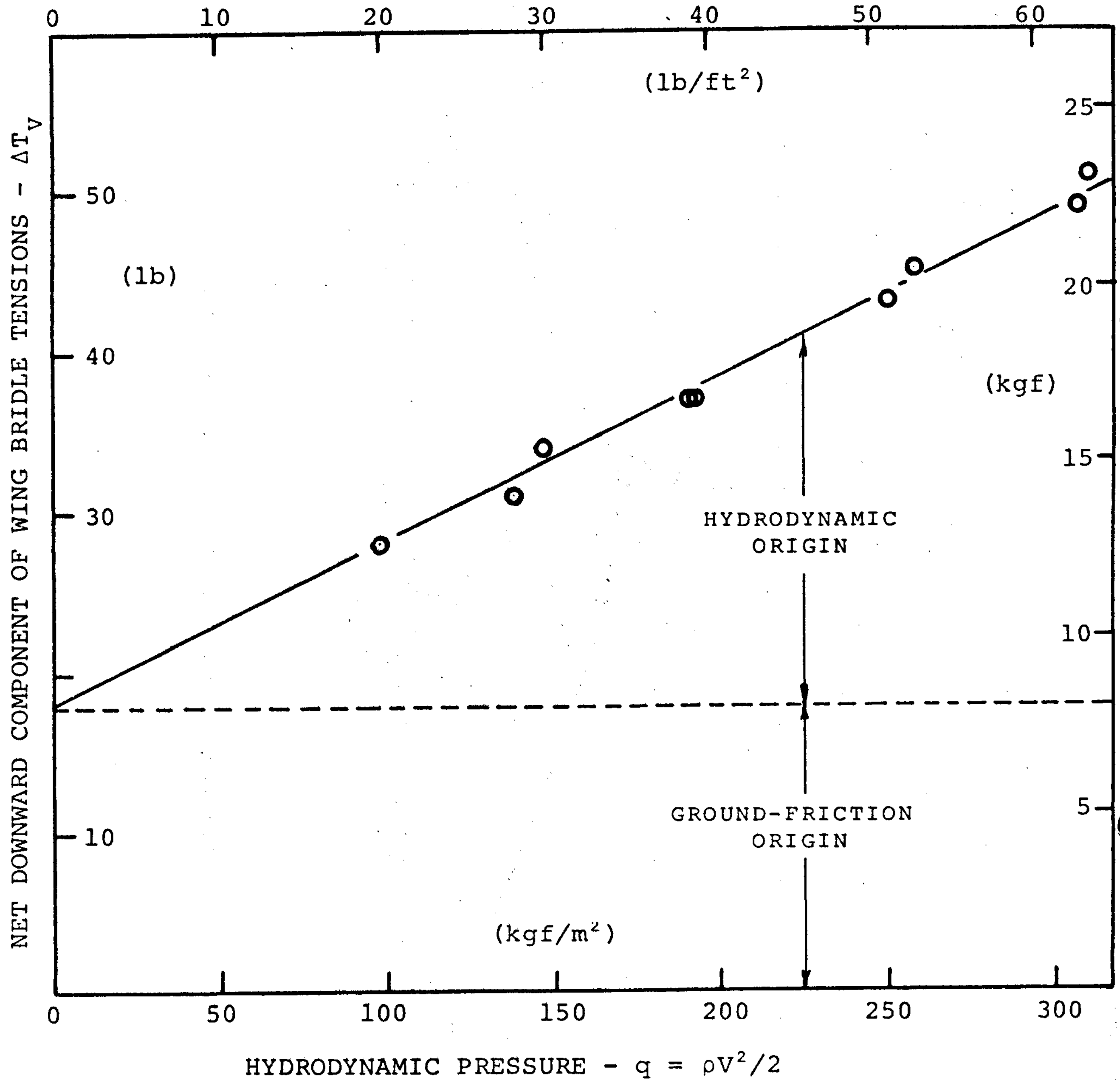

Fig. 2. Net downward component and wing-bridle tensions as a function of hydrodynamic pressure. (Yankee 41-5 Trawl - Tow 24)

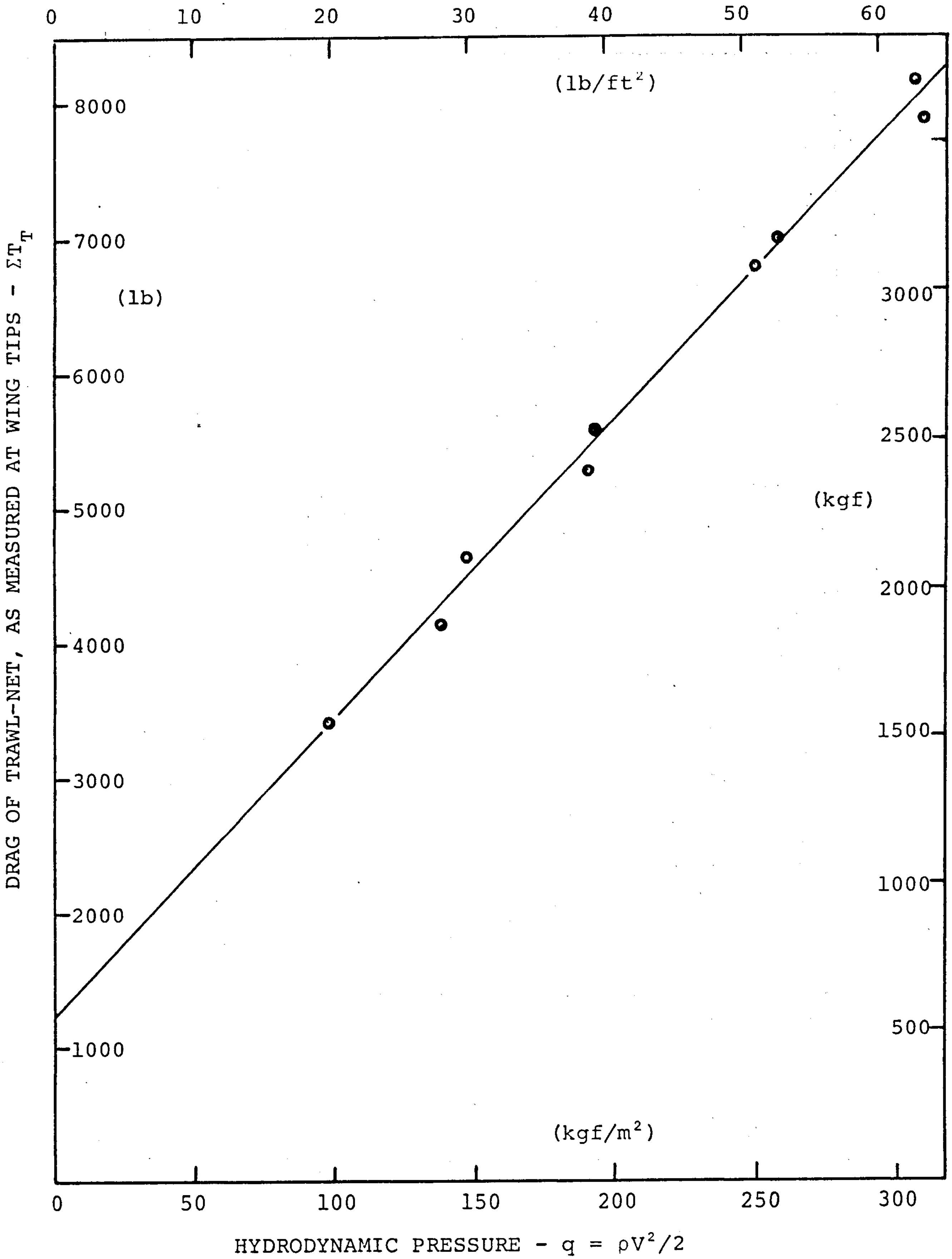

Fig. 3. Trawl-net drag (at wing tips) as a function of hydrodynamic pressure. (Yankee 41-5 Trawl - Tow 24)

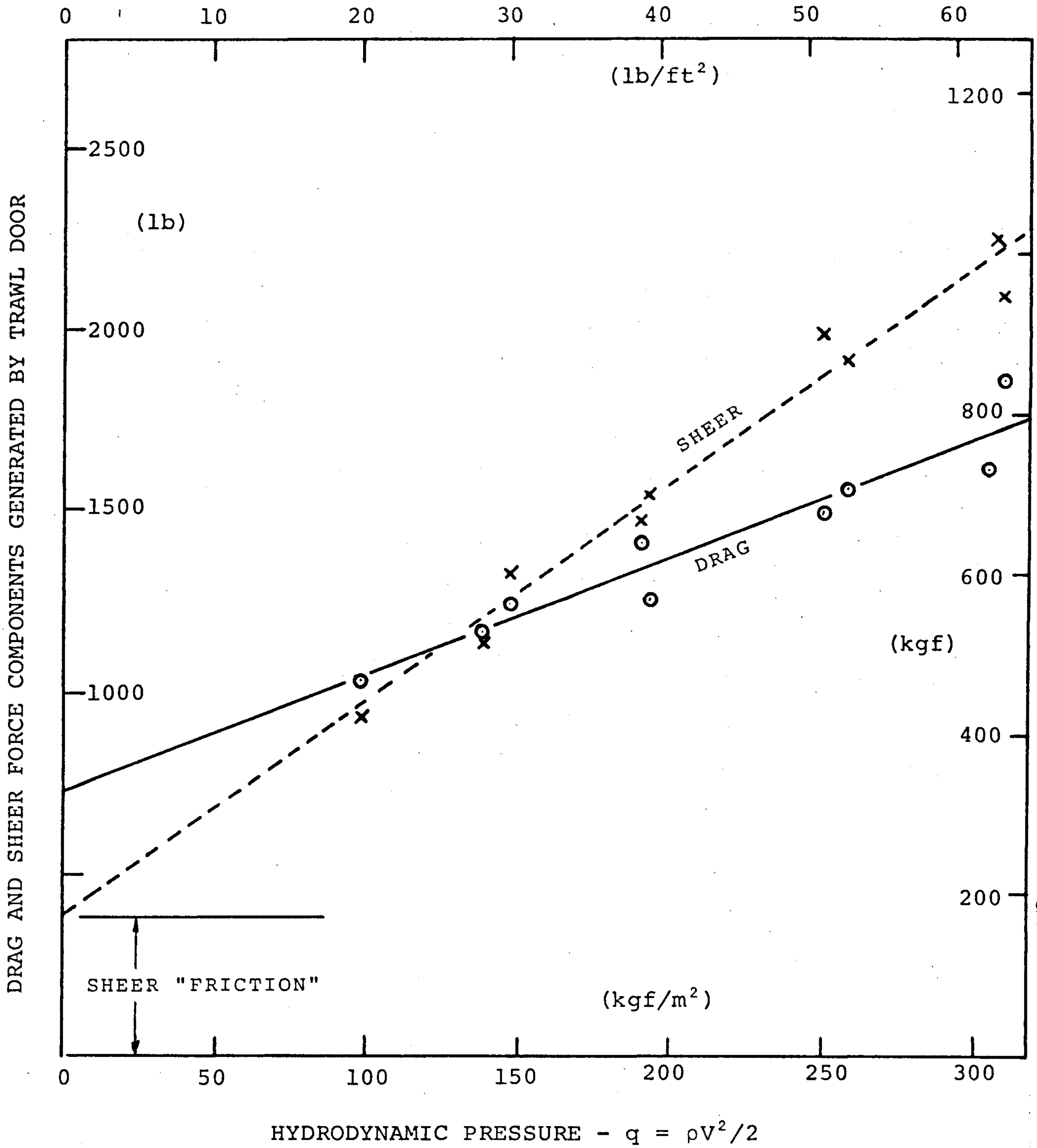

Fig. 4. Drag and sheer (spreading) components of forces generated by a trawl door. (Yankee 41-5 Trawl, starboard door - Tow 24)

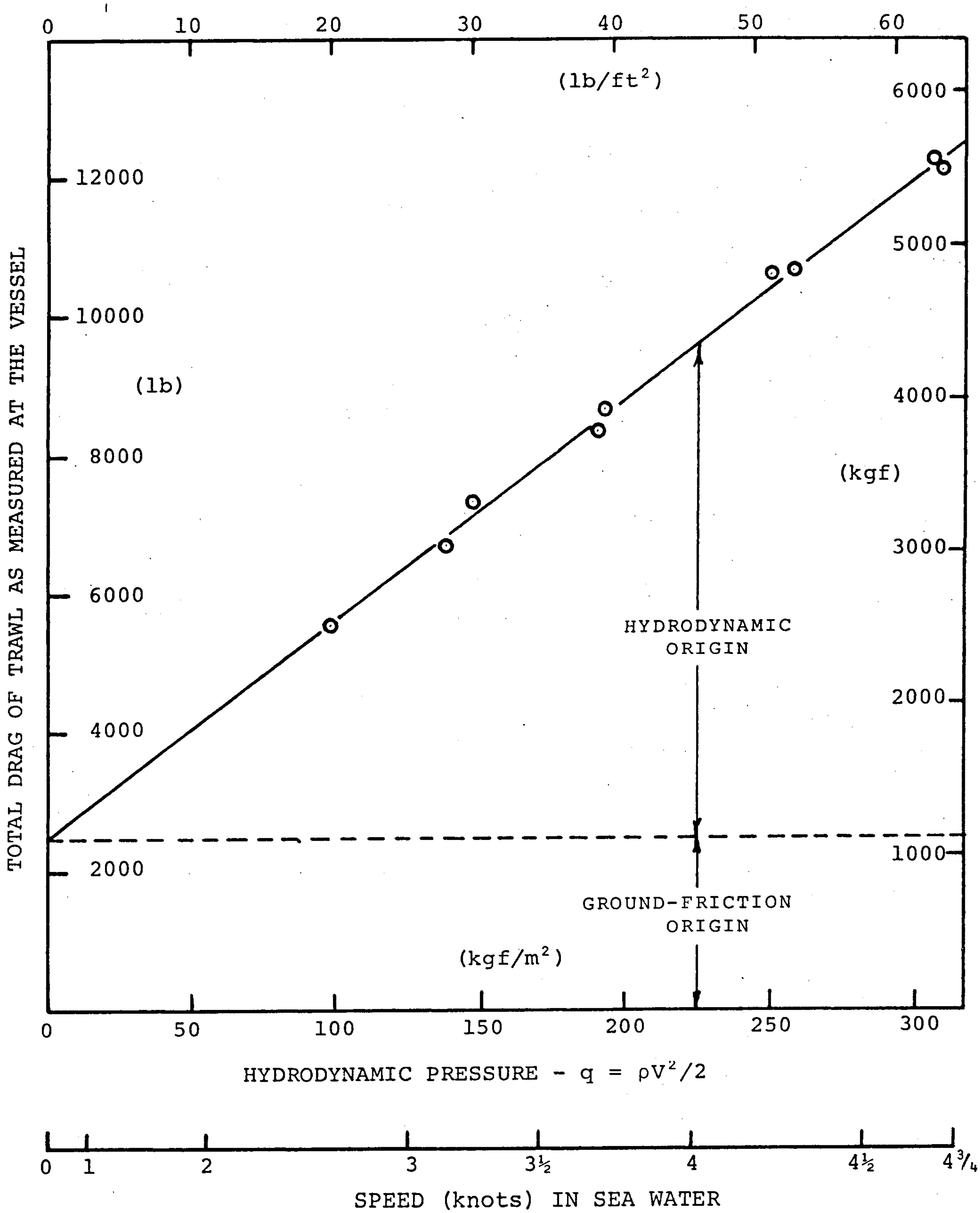

Fig. 5. Total trawl drag (at vessel) as a function of hydrodynamic pressure. (Yankee 41-5 Trawl - Tow 24)