MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THESIS

TRAWLER DESIGN

By

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Course XIII

Cambridge, Massachusetts

June, 1946
June, 1946

Professor G. W. Swett
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

In partial fulfillment of the requirements for the Degree of Bachelor of Science, I here-with submit the following thesis on "Trawler Design".

Respectfully,

Viggo E. Maack
ACKNOWLEDGEMENTS

I am deeply grateful for Professor Daniell's help and suggestions in writing this thesis. I also wish to acknowledge the assistance given by Professor Burtiner and Professor Chapman in preparation of this thesis.
TABLE OF CONTENTS

PARENT SHIPS

Dimensions 1
Weight Statements 2

THE NEW DESIGN

Changing Speed 3
Change in Cruising Radius 6
Change in Crew and Paying Deadweight 7

POWERING OF THE SHIP

Plot of vs. 9
Dimension and Weight Statement of New Ship 11
EHP Calculations 13

RUDDER CALCULATIONS 16

FUEL OIL CONSUMPTION AND PROPELLER DIMENSIONS 17

SIZE OF CARGO HOLD 23

Fish Hold and Heat Transfer Calculations 25

STABILITY CALCULATIONS

Light Calculation 29
Ready For Sea 31
Load Calculations 33
Cross Curves 35
Curve of Statical Stability 36
TABLE OF CONTENTS (CONT)

Stability Curves Integration 37
Stations for Stability Calculations 38
DISPLACEMENT SHEET 39
DISPLACEMENT AND OTHER CURVES 40
PROFILE PLAN 41
GENERAL ARRANGEMENT PLAN 42
HULL LINES OF THE NEW DESIGN 43
TRAWLER DESIGN

PARENT SHIPS:
JEANNE D'ARC AND VILLANOVA

LWL 123.05'
B 24.00'
H 9.58'
Displacement 406.2 tn.
A 175.8
Wetted Surface 3771 ft²
\sqrt{2WL} 11
B/H 2.64
\frac{A}{(\frac{B}{H})^3} 218
1 .6572

LOA 136'--4\frac{1}{2}" 
LBP 122'
LDWL 124'--8\frac{1}{2}"
Beam 24'

Designed Mean Draft. 10'--8\frac{3}{4}"
Designed Mean Draft to Bottom of Keel 11'--2\frac{3}{4}"
\bar{A} = 515.7 tn.

Designed Drag of Keel 2'--6\frac{1}{2}" 
V = 11kt
WEIGHT STATEMENT OF PARENT SHIP:

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of hull, and hull eng. and hull fitt., outfit, crew</td>
<td>273.6</td>
<td></td>
</tr>
<tr>
<td>Propelling machinery</td>
<td>71.3</td>
<td></td>
</tr>
<tr>
<td>Weight of fuel</td>
<td>31.49</td>
<td></td>
</tr>
<tr>
<td>Weight of water and stores</td>
<td>9.67</td>
<td></td>
</tr>
<tr>
<td>Paying deadweight, permanent ballast</td>
<td>187.82</td>
<td></td>
</tr>
<tr>
<td>Hull and hull fittings</td>
<td>270.1</td>
<td>47.2%</td>
</tr>
<tr>
<td>Propelling mach.</td>
<td>71.3</td>
<td>12.6%</td>
</tr>
<tr>
<td>Fuel and water</td>
<td>40.5</td>
<td>7.0%</td>
</tr>
<tr>
<td>Complements and effects</td>
<td>1.00</td>
<td>0.2%</td>
</tr>
<tr>
<td>Paying deadweight</td>
<td>173.00</td>
<td>30.3%</td>
</tr>
<tr>
<td>Ballast</td>
<td>14.0</td>
<td>2.5%</td>
</tr>
<tr>
<td>Margin</td>
<td>3.0</td>
<td>0.5%</td>
</tr>
<tr>
<td>Total</td>
<td>571.9</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
THE NEW DESIGN:

TRAWLER TO FISH IN THE SEA AROUND ICELAND

CREW: 34 men

CARGO (FISH AND ICE): 270 tons (or there about)

CRUISING RADIUS: 1500 miles

SPEED: about 12kt (cruising)

The parent ship is made for 11kt but the new design should make 12kt, what would save about 10 hours for the distance between Reykjavik and Grimsby (1100 nautical miles).

The first thing I do it to find the effect by changing the speed to 12kt.

\[
\begin{align*}
\omega_a &= 273.6 \\
\omega_b &= 71.3 \\
\omega_c &= 31.97 \\
\omega_d &= 9.67 \\
\omega_e &= 187.82 \\
\Delta &= 574.5 \\
w &= kx^a y^b z^c A^n \\
w &= wAr
\end{align*}
\]

\[
A = \left(\frac{k_r}{k_c}\right)\left(\frac{x'}{x}\right)^{a_y} \left(\frac{z'}{z}\right)^{c_y} = \frac{\omega (\frac{12}{n})^3}{\omega_a (\frac{12}{n})^3} = 1.298
\]

<table>
<thead>
<tr>
<th>(\omega)</th>
<th>273.6</th>
<th>1.00</th>
<th>(r)</th>
<th>273.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>71.3</td>
<td>1.298</td>
<td>(r^{1/3})</td>
<td>92.55</td>
<td></td>
</tr>
<tr>
<td>w</td>
<td>A</td>
<td>r</td>
<td>w</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
<td>----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>31.97</td>
<td>1.00</td>
<td>(r^{1/3})</td>
<td>91.97</td>
<td></td>
</tr>
<tr>
<td>9.67</td>
<td>1.00</td>
<td>1</td>
<td>9.67</td>
<td></td>
</tr>
<tr>
<td>187.82</td>
<td>1.00</td>
<td>1</td>
<td>187.82</td>
<td></td>
</tr>
</tbody>
</table>

\[\Delta' = r\Delta = 273.6r + 124.52r^{1/3} + 197.49\]

\[r = 4141 \cdot 74 - 658 = 0\]

\[r = 1.078\]

\[w_a' = 1.074 \times 273.6 = 292.5\]

\[w_c' = 1.049 \times 71.3 = 74.5\]

\[w_c' = 1.049 \times 31.97 = 33.42\]

\[w_a' = 1.00 \times 9.67 = 9.07\]

\[w_c' = 1.00 \times 187.82 = 187.82\]

\[\Delta' = 597.91\]

That means that I must add 23.4 tons to my displacement.

If this speed change were the only change, I would be satisfied by this and start my design, but as more paying deadweight (fish) and more men are needed, I must make other changes but many changes make the value of the weight equation doubtful.
CHANGE CRUISING SPEED TO 12kt

\[ w_a' = 273.6 \times 1.00 \quad r = 273.6 \quad r^{1/3} \]
\[ w_b' = 71.3 \times 1.00 \quad r^{1/3} = 71.3 \quad r^{1/3} \]
\[ w_c' = 31.97 \times 1.190 \quad r^{1/3} = 38.1 \quad r^{1/3} \]
\[ w_d' = 9.67 \times 1.000 \quad 1 = 9.67 \]
\[ w_e' = 187.82 \times 1.000 \quad 1 = 187.82 \]
\[ r = 1.033 \quad r^{2/3} = 1.0219 \]

\[ w_a' = 273.6 \times 1.033 = 283.0 \]
\[ w_b' = 71.3 \times 1.0219 = 72.9 \]
\[ w_c' = 38.10 \times 1.0219 = 38.9 \]
\[ w_d' = 9.67 \times 1.00 = 9.67 \]
\[ w_e' = 187.82 \times 1.00 = \frac{187.82}{592.27} = \frac{592.27}{574.5} \]

\[ \frac{A'}{A} = 1.032 \text{ (checks)} \]

By just changing the cruising speed, I must add 18 tons to my displacement. If I would take the new weight statement and increase the cruising radius by 25%. (The weight equation is only applicable when there is a change in one weight group.)
CRUSING RADIUS INCREASED BY 25%

\[
A = r A' = 283 r + 72.9 r^{1/2} + 38.9 r^{1/4} + 9.67 + 187.82
\]

\[
r = 1.035 \quad r = 1.023
\]

\[
w_a' = 1.035 \times 283 = 293
\]

\[
w_c' = 1.023 \times 72.9 = 74.6
\]

\[
w_c'' = 1.023 \times 46.8 = 49.8
\]

\[
w_d'' = 1.00 \times 9.67 = 9.67
\]

\[
w_d'' = 1.00 \times 187.82 = 187.82
\]

\[
A'' = 614.89
\]

\[
A'' = \frac{614.89}{592.27} = 1.035 \quad \text{(checks)}
\]

I will still go further and see how doubling the number of crew and increasing the fish and ice weights to 270 tons.
CREW 34 AND PAYING WEIGHT INCREASED TO 270 TONS

\[ w_a'' = 293 \times 1 \times r \] \[ w_d'' = 74.6 \times 1 \times r \] \[ w_c'' = 49.8 \times 1 \times r \] \[ w_a'' = 9.67 \times 2 \times 1 \] \[ w_a'' = 187.82 \times 1.443 \times 1 \]

\[ 293 + 124.4r^{\frac{3}{2}} + 289.34 \]

\[ 0 = 0.387r^{\frac{3}{2}} + 0.898 \]

Solution:

<table>
<thead>
<tr>
<th>Assumed ( r_A )</th>
<th>((0.387r^{\frac{3}{2}} + 0.898) = T)</th>
<th>( r_A - T )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.30</td>
<td>1.355</td>
<td>-0.055</td>
</tr>
<tr>
<td>1.40</td>
<td>1.378</td>
<td>0.022</td>
</tr>
<tr>
<td>1.50</td>
<td>1.401</td>
<td>0.099</td>
</tr>
<tr>
<td>1.60</td>
<td>1.419</td>
<td>0.181</td>
</tr>
</tbody>
</table>

Diagram showing the relationship between Assumed \( r_A \) and \((0.387r^{\frac{3}{2}} + 0.898) = T\) with a line drawing a path for the values of \( r_A \) from 1.30 to 1.60, with the calculated values marked on the graph.


\[ r = 1.372 \quad r^{\frac{3}{2}} = 1.234 \]

\[ w_a'' = 293 \times 1.372 \quad 402.0 \]

\[ w_5'' = 64.6 \times 1.234 \quad 92.1 \]

\[ w_c'' = 49.8 \times 1.234 \quad 61.5 \]

\[ w_d'' = 19.24 \times 1 \quad 19.2 \]

\[ w_e'' = 270 \times 1 \quad \frac{A''}{A} = \frac{867.2}{614.9} = 1.380 \]

PARENT SHIP:

\[ \frac{B}{H} = 2.64 \quad \frac{A}{(\frac{L}{2})^2} = 218 \quad H_{90} = 175.8 \text{ ft} \]

\[ m = .761 \quad b = .605 \quad \ell = .661 \]

\[
\begin{array}{cccccc}
\frac{V}{\sqrt{A}} & .90 & .95 & 1.00 & 1.05 & 1.10 \\
\hline
\{ R_i \} & \{ R_i \} & \{ R_i \} & \{ R_i \} & \{ R_i \} & \{ R_i \} \\
5.5 & 8.5 & 14 & 18.5 & 22 & \\
4.6 & 8.3 & 15.5 & 20.8 & 24.0 & \\
4.8 & 8.3 & 15.1 & 20.2 & 23.5 & \\
4.6 & 5.1 & 5.6 & 6.2 & 6.7 & \\
5.45 & 6.04 & 6.64 & 7.35 & 7.94 & \\
10.25 & 14.34 & 21.74 & 27.55 & 31.44 & \\
\end{array}
\]
Plot of total resistance factor of displacement vs. speed-length ratio

Taken from Taylor

\[ \frac{1}{h_{1/2}} = 0.64 + 2.18 \]

\[ L = 0.661 \]

\[ \frac{1}{h_{1/4}} = 2.64 \]
At 11 kt
\[ \frac{V}{V_L} = \frac{11}{V_L} = 1.01 \]
\[ \frac{R_t}{A} = 23 \text{ **} \]
\[ R_t = 23 \times 406 = 9230 \text{ **} \]

EHP = \(.003071 \times 9230 \times 11 = 312 \)

According to this calculation (which is far from being exact), I get my new
\[ \frac{A'}{A} = \frac{867.2}{406} = 2.134 = \frac{L_3}{L_1} \text{ (length ratio)} \]
\[ L = 1286 \quad L_2 = 1.656 \]

New Dimensions:
\[ LWL = 123 \times 1.286 = 156' \]
\[ B = 24 \times 1.286 = 30.8' \]
\[ H = 9.58 \times 1.286 = 12.3' \]

For \( \frac{V}{V_L} = 1.01 \)
\[ V = V_0 \sqrt{\frac{L_3}{L_1}} = 11 \sqrt{\frac{1.656}{2.3}} = 12.4 \text{ kt} \]

Then I would have EHP:
\[ R_t = 23 \times 867.2 = 19920 \text{ **} \]

EHP = \(.003071 \times 19920 \times 12.4 = 760 \)

But by keeping the speed down to 12, I get:
\[ \frac{V}{V_L} = \frac{12}{12.5} = .96 \]
\[ \frac{R_t}{A} = 16 \text{ **} \]
\[ R_t = 16 \times 867.2 = 13875 \text{ **} \]

EHP = 572
Summary:

As my ship is going to be operated under quite a different condition than the parent ship and I have no Icelandic parent ship because I think there is no convenient parent ship as all the Icelandic trawlers have been bought second-hand and not for Icelandic conditions, I take my ship nearest to the final calculations on page 8.

\[
\begin{align*}
    w_a &= 402 \text{ (hull, hull eng., hull fitt., crew)} \\
    w_c &= 92.1 \text{ (weight of propelling mach.)} \\
    w_s &= 61.5 \text{ (weight of fuel)} \\
    w_w &= 19.2 \text{ (weight of water and stores)} \\
    w_e &= 270.0 \text{ (paying deadweight, ballast, margin)} \\
    \lambda &= 867.2 \\
    \text{LWL} &= 156.' \\
    B &= 30.8' \\
    H &= 12.3' \\
    V &= 12\text{kt} \\
    A_{xx} &= 291 \text{ ft}^2
\end{align*}
\]
Now I would like to group the weights into the following groups:

<table>
<thead>
<tr>
<th>Group</th>
<th>Weight in tons</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w_1$ = hull and hull fittings</td>
<td>39.1</td>
<td>45</td>
</tr>
<tr>
<td>$w_2$ = propelling mach.</td>
<td>92.1</td>
<td>10.6</td>
</tr>
<tr>
<td>$w_3$ = fuel and water</td>
<td>80.7</td>
<td>9.1</td>
</tr>
<tr>
<td>$w_4$ = complements and effects</td>
<td>1.8</td>
<td>0.2</td>
</tr>
<tr>
<td>$w_5$ = paying deadweight</td>
<td>287</td>
<td>0.33</td>
</tr>
<tr>
<td>$w_6$ = ballast</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>$w_7$ = margin</td>
<td>1</td>
<td>0.00</td>
</tr>
<tr>
<td>$\frac{w skype}{EHF} = \frac{92.1}{512} = 0.1799$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta a )</td>
<td>875</td>
<td>900</td>
</tr>
<tr>
<td>( \frac{\Delta a}{a} )</td>
<td>1.005</td>
<td>1.033</td>
</tr>
<tr>
<td>( \sqrt[3]{\frac{\Delta a}{a}} )</td>
<td>1.001</td>
<td>1.012</td>
</tr>
<tr>
<td>( \sqrt[3]{\frac{\Delta a}{a}} )</td>
<td>1.003</td>
<td>1.022</td>
</tr>
<tr>
<td>( L_a = \sqrt[3]{\frac{\Delta a}{a}} )</td>
<td>158.1</td>
<td>159.2</td>
</tr>
<tr>
<td>( \sqrt{L_a} )</td>
<td>12.5</td>
<td>12.63</td>
</tr>
<tr>
<td>( \sqrt{\frac{1}{2}} )</td>
<td>.960</td>
<td>.950</td>
</tr>
<tr>
<td>( R/t/4a )</td>
<td>15.9</td>
<td>14.5</td>
</tr>
<tr>
<td>( R_{F_a} )</td>
<td>13920</td>
<td>13040</td>
</tr>
<tr>
<td>( -0.03071x+3 )</td>
<td>.03687</td>
<td></td>
</tr>
<tr>
<td>EHP</td>
<td>514</td>
<td>482</td>
</tr>
<tr>
<td>( w_{1a} )</td>
<td>92.6</td>
<td>86.8</td>
</tr>
<tr>
<td>( w_{1a} )</td>
<td>393.5</td>
<td>405.0</td>
</tr>
<tr>
<td>( w_{2a} \sqrt{\frac{1}{1-a}} )</td>
<td>80.9</td>
<td>82.5</td>
</tr>
<tr>
<td>( w_{4a} )</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>( w_{5a} )</td>
<td>287</td>
<td>287</td>
</tr>
<tr>
<td>( w_{6a} )</td>
<td>18</td>
<td>18.2</td>
</tr>
<tr>
<td>( w_{7a} )</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>( \Delta a' )</td>
<td>874.8</td>
<td>882.3</td>
</tr>
<tr>
<td>( \Delta a'-\Delta a )</td>
<td>-0.2</td>
<td>-17.7</td>
</tr>
</tbody>
</table>
Principal Dimensions:

\[
\frac{A'}{A} = \frac{374.5}{370.6} = 1.005 = \alpha^2
\]

\[
\alpha = 1.001
\]

\[
\alpha' = 1.003
\]

\[LWL = 156.1\]'

\[B = 30.8\]'

\[H = 12.3\]'

\[V = 12\text{kt}\]

\[A_{\delta \delta} = 300\]

\[w_1 = 392.2\]

\[w_2 = 92.2\]

\[w_3 = 80.8\]

\[w_4 = 1.8\]

\[w_5 = 288.2\]

\[w_6 = 17.1\]

\[\frac{w_7}{A} = \frac{2.2}{374.5} \text{ tons}\]

When I have done this, I take the Vincent Curves of sectional areas and plot my curve for sectional areas vs. length B.P. Having my curve plotted, I get 882 tons which is about 1.1% off. I consider that satisfactory.

I also took my moment readings and found that by this curve my C.B. is at my section.
RUDDER CALCULATIONS

I use balanced rudder—streamlined.

\[ L \times H = 156 \times 12.3 = 1918.8 \]

My parent ship has a rudder area of 50 square feet and \( L \times H \) is \( 123 \times 12 = 1476 \)

My rudder area should be:

\[ 50 \times \frac{1918}{1976} = 65 \text{ sq. ft.}; \frac{A}{LH} = 0.0340 \]

In PNA

\[ P/LH \text{ for a single screw seagoing tugboat} = 0.254 \]

\[ HL = 2190 \, \gamma \, \text{ft}^3 \]

By this I would have 55.4 sq. ft.

I would use 64 ft².

For using an almost rectangular rudder, I find that the center of pressure is 39% from the leading edge.
FUEL OIL CONSUMPTION:

M. E. Vol. 1, page 3 gives a fuel consumption for Geared Diesel as \( \frac{0.9}{21000} \text{ SHP/HR} \) all purposes at 1000 SHP.

In this ship I have two 250 H.P. Auxiliary Diesels to drive the generators for windlass, lighting, radio, grinder (bones and heads grinder) and main engine.

EHP Calculations:

From my displacement curve I have \( A = 850 \) tons at \( H = 12.3 \)

\[
\begin{align*}
B/H &= 2.49 \\
V &= 12 \text{ knots} \\
V/\sqrt{L} &= 0.961 \\
\frac{A}{(\frac{L}{2})^2} &= 2.22 \\
\frac{b}{m} &= 0.506 \\
= 0.506 \times 0.789 &= 0.641 \\
R_i &= R_T - 1.8 \\
R_T &= \sqrt{S \times 7.82^5} = 5.190 \times 5690 \times 73 = 4790 \text{ ft} \\
S &= 15.65 \sqrt{1.82 \times 3850} = 5.690 \text{ ft}^2
\end{align*}
\]
From interpolation between beam length ratio and from the curve, I get \( \frac{R}{L} = 9.62 \# \text{/ton} \)
PROPELLER AND FUEL CONSUMPTION

\[ R_t = 4790 \ 9.62 \times 850 - 12970 \# \]

\[ EHP = 0.003071 \times 12970 \times 12 = 478 \]

\[ PHP = \frac{EHP}{e_p \times e_r \times e_h} \quad e_h = \frac{1-t}{1-w} \]

\[ w = 0.23 \quad \text{(PNA VII p. 149)} \]

\[ t = kw = 0.70 \times 0.23 = 0.16 \]

\[ e_h = \frac{0.84}{0.77} = 1.08 \quad e_r = 1 \]

I find \( e \) from Schoernherr's curves.

\[ d = 7.5' \quad 4 \text{ blades} \]

\[ \text{RPM} = 240 \quad \text{MWR} = 0.25 \]

\[ V = 12 \ k\text{t} \quad \text{BL. Th. Fr.} = 0.05 \]

\[ EHP = 478 \quad n = 3.33 \ r/\text{sec.} \]

\[ K_t = \frac{326 \times EHP}{Vn^2d^3(1-t)} = 0.221 \]

\[ J = \frac{1.689 \ V(1-w)}{nd} = 0.62 \]

From the chart I get \( e_p = 63.1\% \quad p/d = 0.96 \]

If I now assume several \( n \) values and make \( d = 7.5 \)

\[ EHP = 478 \quad V = 12k\text{t} \]

and find the maximum efficiency.

\[ K_t = \frac{326 \times 478}{1.99 \times 12 \times 0.84 \times 3150} \frac{1}{n^2} = 2.46 \frac{1}{n^2} \]

\[ J = \frac{1.689 \times 12 \times 0.771}{7.5} \frac{1}{n} = 2.08 \frac{1}{n} \]
RPM = 165
n = 2.75  
kt = 0.325  
T = 0.775  
ep = 0.52  
p/d = 1.33

RPM = 180
n = 3  
kt = 0.273  
T = 0.694  
ep = 0.605  
p/d = 1.17

RPM = 195
n = 3.25  
kt = 0.233  
T = 0.64  
ep = 0.629  
p/d = 1.00

RPM = 210
n = 3.50  
kt = 0.20  
T = 0.594  
ep = 0.636  
p/d = 0.85

RPM = 225
n = 3.75  
kt = 17.5  
T = 0.555  
ep = 0.621  
p/d = 0.78

RPM = 240
n = 4.00  
kt = 0.154  
T = 0.52  
ep = 0.608  
p/d = 0.41
By this calculation I get maximum efficiency for

\[
\text{RPM} = 208 \quad \text{Pitch} = 6.6 \quad \text{p/d} = 0.88
\]

\[
\text{ep max.} = 63.8\%
\]

\[
\text{PHP} = \text{EHP} = 478 \quad \text{EHP} = 694
\]

\[
\text{epxe} \times 1.08 \times 1
\]

\[
\text{BHP} = \frac{\text{PHP}}{\text{et}} = \frac{694}{0.95} = 732 \quad \eta = \text{Eff. of transmission}
\]

\[
\text{JHP} = \frac{\text{BHP}}{\text{em}} = \frac{732}{0.80} = 915 \text{ HP}
\]

I use 1100 for rough weather and hauling.

Total HP of the ship is then:

Main engine \hspace{1cm} 1100

2 Aux. engines \hspace{1cm} \frac{500}{1600} \text{ HP}

My fuel consumption would be:

\[
1600 \times .48 \text{ #/hr.} = 1600 \times .48 \times 24 = \#/	ext{day} = 18400 \#/	ext{day} = \frac{1600 \times .48 \times 24}{.95 \times 62.4} = 310 \frac{\text{#}}{\text{day}}
\]

or 4.72 tons a day

If the cruising radius takes 14 days, I need space for fuel oil of 4350 ft\(^3\).

P. N. A. gives 2½ - 2½ deduction for the framing in double bottom so I need really 4350 \times 1.025 = 4460 \text{ ft}^3 of the displacement volume.

I put double bottom at 3' water line and get by this, space of 2800 ft\(^3\). I also put oil in a 3.5' wide space
which I make at aft of the fishholds. (Thermal conductivity of the oil is .109 which is low.) In order to trim the ship I make changes in the 2800 ft. space available in the double bottom and put some of the liver oil tanks aft and the fuel oil more forward. The space I get in this 3.5 ft. oil tank aft of the fish hold is 1870 ft. In order to avoid heat transfer after the oil has been consumed in this tank, I put in cork-plates on the fish hold side of the bulkhead. (thermal conductivity .025)
CARGO HOLD SIZE

Area from top of double bottom to main deck:

<table>
<thead>
<tr>
<th>Station</th>
<th>Area</th>
<th>Ft from St. 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>18.1</td>
<td>0</td>
</tr>
<tr>
<td>½</td>
<td>102.8</td>
<td>7.8</td>
</tr>
<tr>
<td>1</td>
<td>147</td>
<td>15.6</td>
</tr>
<tr>
<td>2</td>
<td>293</td>
<td>31.2</td>
</tr>
<tr>
<td>3</td>
<td>363</td>
<td>46.8</td>
</tr>
<tr>
<td>4</td>
<td>383</td>
<td>62.4</td>
</tr>
<tr>
<td>5</td>
<td>422</td>
<td>78.0</td>
</tr>
<tr>
<td>6</td>
<td>422</td>
<td>93.6</td>
</tr>
</tbody>
</table>

Now I make a plot of the area from station 0 under the main deck. The area under that curve would give me volume up to any point from St. 0.

(plot on next page)
Plot of Transverse Areas Between Tank Top and Main Deck vs. Length from F.P.

1) Volume in ft³ (material for planning water tank of)
vs. Length from F.P.

Limit = 100 ft³

10 20 30 40 50 60 70 80 90 100

Distance in ft from S.W. (F.P.)
P. N. A. M.I. gives for the stowage factor of fish as 50 ft$^3$ to a ton. Using this figure (although I have refrigerating coils in this trawler, which undoubtedly take less space than the ice) and for 290 tons of fish I need $290 \times 50 = 14500$ ft$^3$ or according to the graph, from station 1, 65' aft.

By putting the bulkhead 72.8' aft, I get 17800 ft$^3$ having subtracted for usual framing. As I have insulation and refrigeration, I use this value which leaves me 13800 ft$^3 = 270 - 280$.

FISH-HOLD AND HEAT TRANSFER

In REFRIGERATING ENGINEERING V. 33, 1937, p. 373 is a description of the fish-hold of the trawler, "Storm". There, they use cold air circulating around the hold. By this, they can spare about 2/3 of the ice consumption. Inside the frame flanges is a 3" thick cork-board. Then there is a 3" air passage for the cooling air and nearest to the fish is a waterproof nickel plating.

Down below, I try to calculate or at least to estimate the ratio between the heat transfer coefficient and heat transfer from the aircooing space to the shell out to the sea and to the fish-hold.
The reference I use is McAdams' "Heat Transmission".

According to Am. Bu. Sh., I use 7 x 3.45 x .350 x .500 channel. (I just need the web height) The plate thickness is .32".

Assumed temperature in fish-hold to be 32°F.
" " air-cooling space to be 28°F.
" " of sea to be 60°F.
In order to find the film coefficients and the air cooling space, I assume the shape of the air duct rectangular \( \frac{3}{4}' \times 15' \) as the speed is \( 50 \) of \( \infty \) of the air. This gives me Re's number of 720000, which shows me a turbulent flow.

By using equation 4c, McAdams, p. 168, I get

\[ h_\alpha = 8.42 \]
Heat transfer from cooling air to the sea:

\[ Q_n = U_n A_n (t_r - t_2) \]

\[ Q_n/A_n = U_n (t_r - t_2) = 0.0952 \times (28 - 60) \]

Heat transfer from cooling air to ice in fish-hold:

\[ Q_a = U_a A (t_r - t_3) \]

\[ Q_a/A = U_a (t_r - t_3) = 9.75 \times (28 - 32) \]

Ratio of heat transfer:

\[ \frac{Q_a}{Q_n} = \frac{9.75 \times (-4)}{0.0952 \times (32)} = \left| \frac{12.8}{1} \right| \]

The heat transfer 12.8 times better into the hold than out to the sea.

(Of course, the heat flow is really not from the cold air in the duct out to the sea or into the hold, rather the negative heat (or the cold).)
STABILITY CALCULATION

Light Condition

Lever arms and weights are estimated as close as possible.

<table>
<thead>
<tr>
<th>Item</th>
<th>Wt.</th>
<th>Vert. C.G. from B.L.</th>
<th>C.G. from</th>
<th>Vert. mom</th>
<th>FWD</th>
<th>FWD mom</th>
<th>Aft.</th>
<th>Aft. mom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Struct. Wt.</td>
<td>351</td>
<td>14.3</td>
<td>5030</td>
<td></td>
<td>5.0</td>
<td></td>
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<tr>
<td>Paint Cement</td>
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<td>15.0</td>
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<td></td>
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<td>Carp. Work</td>
<td>25.6</td>
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<td>35</td>
<td>895</td>
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<td></td>
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<td>Joinerwork</td>
<td>12.0</td>
<td>15.8</td>
<td>190</td>
<td>12</td>
<td>144</td>
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</tr>
<tr>
<td>Hull, Fitt.</td>
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<td>23.0</td>
<td>436</td>
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<td>17.0</td>
<td>519</td>
<td>4</td>
<td>122</td>
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<tr>
<td>Outfit</td>
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<td>Prop. Mach.</td>
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<td>10.0</td>
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<td>31</td>
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<td>Perm. Ballast</td>
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<td>3.0</td>
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</tbody>
</table>

\[
KG = \frac{8260.8}{575.6} = 14.35'
\]

From curves, \( KM \) at 575.6 ton disp. = 17.8'

\[ GM = 17.80 - 14.35 = 3.45' \]

\[ TRIM = -5506 + 383 = 5223 = M_L \]

\[ \frac{5223}{575.6} = 9.09 \text{ C. G. off of } AB \]

\[ d = 9.91 \text{ Distance between C.G. and C.B.} \]
\[ M T \times = 57.5 \text{ ft.-tn} \]

_(From Curves)_

\[ \text{Trim} = \frac{A x 1}{MT} = \frac{575 \times 8.66}{57.5 \times 12} = 8.24' \]

_Trim by Stern_

<table>
<thead>
<tr>
<th>G7 Uncorr.</th>
<th>Sine θ</th>
<th>Kc Calc-K Assumed</th>
<th>Correction</th>
<th>G2c</th>
</tr>
</thead>
<tbody>
<tr>
<td>15°</td>
<td>3.05</td>
<td>.289</td>
<td>1.35°</td>
<td>.75°</td>
</tr>
<tr>
<td>30°</td>
<td>5.00</td>
<td>.500</td>
<td>1.15°</td>
<td>.67</td>
</tr>
<tr>
<td>45°</td>
<td>3.95°</td>
<td>.707</td>
<td>1.35°</td>
<td>.95°</td>
</tr>
<tr>
<td>60°</td>
<td>1.55°</td>
<td>.866</td>
<td>1.35°</td>
<td>1.16</td>
</tr>
</tbody>
</table>

\[ K_{G, \text{Calc}} = 14.55' \]

\[ K_{G, \text{Assumed}} = 13.00 \]

\[ \frac{1.35'}{1.35'} \]
READY FOR SEA

ESTIMATION

<table>
<thead>
<tr>
<th>Item</th>
<th>Wt.</th>
<th>Vert. C.G. from EL Above</th>
<th>Moment</th>
<th>FWD</th>
<th>FWD mom. Aft.</th>
<th>Aft. mom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constr. Wt.</td>
<td>575.6</td>
<td>14.35</td>
<td>8260</td>
<td></td>
<td>9.09</td>
<td>5223</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>127</td>
<td>6.0</td>
<td>764</td>
<td>3.3</td>
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<td>420</td>
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<tr>
<td>Fresh Water</td>
<td>15.3</td>
<td>9.0</td>
<td>138</td>
<td>68</td>
<td>104</td>
<td></td>
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<tr>
<td>Lub. Oil</td>
<td>3.4</td>
<td>8.5</td>
<td>29</td>
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<td>25</td>
<td>85</td>
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<td>Galley Stoves</td>
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<td>50</td>
<td>100</td>
<td></td>
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<tr>
<td>Ice</td>
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<td>10.5</td>
<td>315</td>
<td>54</td>
<td>1620</td>
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<tr>
<td>Oven</td>
<td>3.3</td>
<td>21.</td>
<td>69</td>
<td></td>
<td>42</td>
<td>139</td>
</tr>
<tr>
<td>Free Surface f-o</td>
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</tr>
<tr>
<td>Free Surface W</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>756</strong></td>
<td></td>
<td><strong>9674</strong></td>
<td><strong>1724</strong></td>
<td></td>
<td><strong>5967</strong></td>
</tr>
</tbody>
</table>

\[ KG_{c.m.} = \frac{9674}{756} = 12.8 \]

**KM = 16.2**

**GM = 3.4'**
Trim:

\[-59.07 + 172.4 = 113.3\]

\[\frac{412.43}{556} = 0.741 \text{ CG aft of 50}\]

\[d = 6.06\]

\[MTL = 18.0 \sqrt{1 - d}\]

\[\text{Trim by stream} = \frac{756 \times 6.06}{12 \times 18.0} = 0.49\]

<table>
<thead>
<tr>
<th>(\theta)</th>
<th>G(_{\text{zone}})</th>
<th>Sin(\theta)</th>
<th>K(<em>{\text{zone}}) - K(</em>{\text{stream}})</th>
<th>Correction</th>
<th>G(_{\text{corr}})</th>
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<tr>
<td>15°</td>
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<td>30°</td>
<td>3.85</td>
<td>0.500</td>
<td>-2</td>
<td>1</td>
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</tr>
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<td>45°</td>
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<td>0.707</td>
<td>-2</td>
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<td>2.34</td>
</tr>
<tr>
<td>60°</td>
<td>-2.5</td>
<td>0.866</td>
<td>-2</td>
<td>0.17</td>
<td>0.08</td>
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</tbody>
</table>
## LOAD CONDITION

### ESTIMATION

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constr. Wt.</td>
<td>576</td>
<td>14.35</td>
<td>8260</td>
<td>9.09</td>
<td>5223</td>
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<tr>
<td>Fuel</td>
<td>65</td>
<td>4.5</td>
<td>392</td>
<td>5.5</td>
<td>357</td>
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<tr>
<td>Water</td>
<td>7.0</td>
<td>6.0</td>
<td>42</td>
<td>52</td>
<td>476</td>
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<tr>
<td>Lub. Oil</td>
<td>2.0</td>
<td>10.0</td>
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<td>25</td>
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<tr>
<td>Galley</td>
<td>1.0</td>
<td>18.0</td>
<td>18</td>
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<td>50</td>
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<tr>
<td>Fish &amp; Ice</td>
<td>270</td>
<td>2970</td>
<td>36</td>
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<td>Crew</td>
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<td>21</td>
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<td>Free Surf. f.o.</td>
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<tr>
<td>Free Surf. f.w.</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>923.9</td>
<td>11830</td>
<td>10226.0</td>
<td>5819.0</td>
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<td></td>
</tr>
</tbody>
</table>

KG calculated = 11830 x 12.8

KM = 15.76

GM = 2.84'
Trim \[ -10.226 + 5.819 \]
= \[ -4.409 \]

\[
\frac{4407}{923.9} = 4.77' \quad \text{G.G. forw. of \textit{XX}}
\]

\[
\frac{.15}{\text{C.B.}} \quad \text{---}
\]

\[
d = 4.62'
\]

MTI = 78.5'

Trim Forward = \[
\frac{923 \times 4.62}{12 \times 78.5} \approx .48'
\]
Curves of Static Stability

Light Condition

GM = 3.45'

Rainy Per Day

GM = 5.40'

Load Condition

GM = 2.84'
<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Area Reading</th>
<th>Check Reading</th>
<th>Multiplier</th>
<th>Final</th>
<th>Initial</th>
<th>Diff.</th>
<th>Multiplier</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final</td>
<td>7661</td>
<td>13887</td>
<td>2.196</td>
<td>4103</td>
<td>10.195</td>
<td>12.196</td>
<td>2.000</td>
<td>16.16</td>
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<tr>
<td>Initial</td>
<td>1526</td>
<td>7661</td>
<td>10.195</td>
<td>12.196</td>
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<tr>
<td>Diff.</td>
<td>6141</td>
<td>6222</td>
<td>0.698</td>
<td>370</td>
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<td>0.808</td>
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<td>14485</td>
<td>15010</td>
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<td>8966</td>
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<td>Initial</td>
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<td>4486</td>
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<td>Diff.</td>
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<td>10623</td>
<td>635</td>
<td>2200</td>
<td>1775</td>
<td>2.795</td>
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<td>Final</td>
<td>10525</td>
<td>16096</td>
<td>1760</td>
<td>4330</td>
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<tr>
<td>Initial</td>
<td>4966</td>
<td>0525</td>
<td>9410</td>
<td>1860</td>
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<tr>
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<td>431</td>
<td>2400</td>
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<td>Final</td>
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<td>6124</td>
<td>6555</td>
<td>7856</td>
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<td>Initial</td>
<td>6050</td>
<td>6115</td>
<td>4768</td>
<td>6355</td>
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<tr>
<td>Diff.</td>
<td>20085</td>
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<td>1197</td>
<td>1242</td>
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### Stability Curves - TiltGator 30°

<table>
<thead>
<tr>
<th>Inclination</th>
<th>Area Reading</th>
<th>Check Reading</th>
<th>Multiplier</th>
<th>∆</th>
<th>Moment Readings</th>
<th>Check Readings</th>
<th>Multiplier</th>
<th>Moment</th>
<th>Cz</th>
</tr>
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<tbody>
<tr>
<td>Final</td>
<td>6.882</td>
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<td>0.0598</td>
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<td>2.770</td>
<td>0.808</td>
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<td>1.090</td>
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<td>Initial</td>
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<td>3.660</td>
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<tr>
<td>Diff.</td>
<td>10.784</td>
<td>10.4284</td>
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### DISPLACEMENT AND METACENTRIC SHEET

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**Principal Dimensions**

- Length over all = 196'
- Beam at LWL = 30.6'
- Depth molded at LWL = 9.6'
- Beam molded = 10.1'

*These Values should check.*

Data for Appendage Column can be obtained by integrator.

| All Symbols Standard |

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For the data inside the table, the values are listed in a structured format, reflecting the dimensions and calculations related to displacement and metacentric characteristics of a vessel. Each row in the table represents a set of calculations or measurements, with columns for specific variables such as half-ordinates, orders, function of areas, and metacentric water lines. The table is designed to facilitate the calculation of pivotal moments and other critical values for naval architecture and engineering purposes.