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LIGTHSHIP COMPONENT MASSES IN PRELIMANARY DESIGN EXAMPLIFIED FOR FISHING VESSEL.

STEPHEN CHIDOZIE DURU
Senior Lecturer and Departmental co-ordinator at the Mechanical/Marine EngineeringDepartment,
Niger Delta University, Amassoma, Bayelsa State, Nigeria.
drscduru@gmail.com

Abstract—:Components of lightship masses is important at early ship design stages in other to estimate cost of building the ship as well as aid later stages of the projected new ship design processes. A rational method is derived here giving new matrices equations for the estimation of lightship and deadweight of a projected ship design. The method is validated by calculation of component masses of a projected new fishing vessel. A comparison of the result of this new method with that of empirical methods of three well known authors ,D.G.M Watson, M.F.C Santarelli, and W. B. Wilson show an increase in value of lightship weights respectively above the rational method presented in this work.

Index Terms—Components, masses, lightship, weight, rational method

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1 Introduction

COMPONENT masses of ships are all the masses that make up the lightship displacement weight of the ship and is presented at preliminary ship design stages by most references [1],[2],[3],[4],[5],[6].It can be expressed as:

$$M_L = M_A + M_O + M_M + M_R \qquad (1)$$

M_A = Mass of all materials of the shell, bottoms, stiffeners, machinery and equipment foundation structures, appendages on the hull and superstructure.
M_O = Mass of all equipment and outfit items, heating, ventilations, air conditioning equipments utilities., sanitary and home equipments, wall panels, hatches, cargo gears, fire and safety wares, electrical, and pneumatic equipment outside the engine room, mooring and anchor equipments.
M_M = Mass of the engine room installed items namely, main propulsion engine, gearbox, shafting, propeller, electrical units and gears, pumps, piping, compressors, all machineries and accessories in the engine room
M_R = This accounts for tolerances in design of the above items as well as item not accounted for in the above list.
Computation of these masses are necessary to satisfy the concept, preliminary and contract design stages relating to establishment of construction, and shipbuilding costs amongst other factors. It also necessary for the initial parameters leading to the final detailed design and drawings of the vessel.

Various methods and empirical formulas has been proposed for the ship masses calculation for conventional ships but mainly for transport vessels namely tankers, bulk carriers, container ships and others but there are few written on fishing vessels component masses computation especially in recent times .

The method posited here includes another more mathematical rational approach involving a Partial differential equation method. This rational method combine the recommendation of most classification societies, the cubic number method, the rate per meter method, and other known (above referenced methods), all combined in a new rational equation methods. A numerical example of this new method is carried out for a projected fishing vessel design also presented. The result is compared with the empirical formulas method by Santarelli [1], D.G.M Watson [3], and W. Brett Wilson[2].

2 Methods

This method presented below in section 2.1 will be based on preliminary dimension of the projected new vessel(see Table 1) which have been predicted by existing empirical methods [1], [2],[3],[7], [8] or others, then, we can employ data from exiting pattern vessel (see Table 2) of length not greater than or less than 15 percent of the projected new vessel.

In 2.2 we will calculate component masses for the same new vessels using the known empirical methods of three referenced authors and compare the results of the calculation in order to validate the proposed new method.

Table 1 Projected vessel data

Projected design vessel data
L_{AO} = L = 25.93m
B = 8.30 D = 4.45m
T = 3.13 CB = 0.489m
∇ = 327.76m³ Δ = 338.00t
V = 10Kn P = 725hp
DWT = ? RPM 1800
$M_L = M_A + M_E + M_M + M_R$ = ?

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Table 2 Pattern(existing) vessel data

Pattern vessel data	
L_{OA} = 25.80m	L_O = 23.00m
B_O = 7.20m	D_O = 3.49m
T_O = 2.85m	C_{BO} = 0.431m
∇_O = 220.74m 3	Δ_O = 226.26t
V_O = 11Kn	Po = 570hp
DWT_O= 45t	M_{AO} = 73.9t
M_{EO} = 39.0t	M_{MO} = 45.5t
M_{SO} = 16.6t	M_{RO} = 6.26t
M_{LO} = 73.9+39.0+45.5+6.26 = = 181.26t	

Where:

L, L_O = length between perpendiculars for the projected new vessel and pattern vessels respectively.

L_{OA} = length overall of the vessel.

B,D,T = breadth, depth, and draft respectively projected. new vessel.

B_O,D_O,T_O = breadth, depth, and draft respectively for the pattern existing vessel.

∇,Δ,DWT = displacement by volume and by weight and deadweight respectively of projected vessel.

∇_O,Δ_O,DWT_O = displacement by volume and by weight Anddeadweight respectively of pattern vessel.

V, V_O= speed of projected and pattern vessels respectively in calm water.

P, P_O = Main propulsion power for projected new vessels and pattern existing vessel respectively.

C_B, C_{BO} = Block coefficient of the projected and pat tern vessel respectively

2.1 PARTIAL DIFFERENTIATION METHOD FOR SECOND STAGE DESIGN

This method require the use of all the values of Table 2 to calculate the values marked ?in Table 1 using the rational method presented below. In this method ,

$$M_L = M_a + M_E + M_M + M_s + M_R \quad (2)$$

M_a are hull and superstructure material mass including solid ballasts only.

M_a=M_A

M_O= M_E + M_S, were

M_E are outfit and inventory masses of vessel outside accommodation and,

M_s are accommodation outfit masses.

M_M are engine room machinery, electrical equipment and spare parts masses.

The displacement of the loaded shipΔ in tonnes can be expressed as:

Take, $\Delta = M_L + DWT = \sum M_i$ (3)

DWT is the deadweight of the vessel.

M_i = component masses of vessel

if, $M_L = \sum_{i=1}^{i=n} . M_{\Delta i}$ (4)

(as the vessels lightweight components),

and $DWT = \sum_{i=1}^{i=n} .M_{ci}$ (5)

(as deadweight component) ,

then, $\Delta = \sum_{i=1}^{i=n} .M_i = \sum_{i=1}^{i=n} . M_{\Delta i} + \sum_{i=1}^{i=n} .M_{ci}$(6)

Therefore, $\Delta - \Delta_o = d\Delta = \sum_{i=1}^{i=n} .dM_{\Delta i} + \sum_{i=1}^{i=n} .dM_{ci}$ (7)

but, from it is known by hull form definition that

$\Delta = L*B*T*C_B*\rho$ (8)

Therefore,

$$d\Delta = (\partial\Delta_o/\partial L_O)dL + (\partial\Delta_o/\partial B_O)dB + (\partial\Delta_o/\partial T_O)dT + (\partial\Delta_o/\partial C_{BO})dC_B \quad (9)$$

or, $d\Delta = \sum_{i=1}^{i=4} . (\Delta_o/x_{jo})dx_j$ (10)

wherex$_{oj}$= L_O, B_O, T_O, C_{Bo} for j = 1,2,3,4 for the pattern vessel andxj= L, B, T, C_B for j = 1,2,3,4 for the projected design ship.

Since, $M_{\Delta i}$= f(L, B, T, CB, D, v)

therefore, $\sum_{j=1}^{j=6} .dM_{\Delta i} = \sum_{j=1}^{j=6} .(\partial M_{i0}/\partial X_{j0})dX_j$ (11)

$=\sum_{j=1}^{j=4} .(\partial M_{i0}/\partial X_{i0})dX_j + \sum_{j=5}^{j=6} .(\partial M_{i0}/\partial X_{i0})dX_j$(12)

Putting (10) and (12) in (7) we get

$dDWT=\sum_{j=1}^{j=n'} .dM_{ci}=\sum_{i=1}^{i=4} .(\Delta_o/x_{jo})dx_j-$

$(\sum_{j=1}^{j=4} . \sum_{i=1}^{i=n''} .(\partial M_{i0}/\partial X_{i0})dX_j$

$+\sum_{j=5}^{j=6} . \sum_{i=1}^{j=n''} .(\partial M_{i0}/\partial X_{i0})dX_j)$ (13) when,

j =1, x_{1o} = L_O for pattern vessel dimension and x_1= L, for the projected vessel dimension.

similarly and respectively, j =2, x_{2o} = B_O and x_2= L, j =3, x_{3o} = T_O, x_3= T

j =4, x_{4o} = C_{BO} and x_4 = C_B, j =5, x_{5o} = D_O and x_5 = D

and finally

j =6, x_6o = v_O and x_4 = v

Also when,

i = 1, 2,3,4,5, the component masses M_1= M_a, M_2= M_E, M_3= M_M, M_4= M_S, and M_5= M_R respectively.

When we substitute the partial differencials as follows: ∂M_{1O}= ∂M_{aO} = a, ∂M_{2o}= ∂M_{Eo}=e , ∂M_{3o}= ∂M_{Mo}=m , ∂M_{4o}= ∂M_{so}=s , and ∂M_{5o}= ∂M_{ro}= r as well as n′ = 4 and n″ = 4 considering available data of the pattern vessel in Table (2), the equation (12) can be presented in the matrices format for easy computation as:

$$D(DWT) = \left[\frac{\Delta}{\mathbf{L}} \quad \frac{\Delta}{\mathbf{B}} \quad \frac{\Delta}{\mathbf{T}} \quad \frac{\Delta}{\mathbf{CB}}\right]_0 \begin{bmatrix} \mathbf{dL} \\ \mathbf{dB} \\ \mathbf{dt} \\ \mathbf{dCB} \end{bmatrix} -$$

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$$\left[\begin{bmatrix} \frac{a}{\partial L} & \frac{a}{\partial B} & \frac{a}{\partial T} & \frac{a}{\partial CB} \\ \frac{e}{\partial L} & \frac{e}{\partial B} & \frac{e}{\partial T} & \frac{e}{\partial CB} \\ \frac{m}{\partial L} & \frac{m}{\partial B} & \frac{m}{\partial T} & \frac{m}{\partial CB} \\ \frac{s}{\partial L} & \frac{s}{\partial B} & \frac{s}{\partial T} & \frac{s}{\partial CB} \\ \frac{r}{\partial L} & \frac{r}{\partial B} & \frac{r}{\partial T} & \frac{r}{\partial CB} \end{bmatrix}_{\mathbf{0}} \begin{bmatrix} \mathbf{dL} \\ \mathbf{dB} \\ \mathbf{dT} \\ \mathbf{dCB} \end{bmatrix}\right]^{\boldsymbol{t}} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} +$$

$$\left[\begin{bmatrix} \frac{a}{\partial D} & \frac{a}{\partial V} \\ \frac{e}{\partial D} & \frac{e}{\partial V} \\ \frac{m}{\partial D} & \frac{m}{\partial V} \\ \frac{s}{\partial D} & \frac{s}{\partial V} \\ \frac{r}{\partial D} & \frac{r}{\partial V} \end{bmatrix}_{\mathbf{0}} \begin{bmatrix} dD \\ dV \end{bmatrix}\right]^{\boldsymbol{t}} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \quad (14)$$

tmeans transpose of the matrix.
0means with respect to pattern ship
NOTE that the author will be happy to be remembered by this matrices (call it DuruSteviematrices for ship hull weights.). It can be used for all types of vessels or ocean going ship.

It is notable that equation (13) (14) consider incremental deadweight in terms of knowncomponent of masses and dimensional parameters of the pattern vessels (see Table 2) and the differences between these values with the predicted dimensions of the projected design vessel (see Table 1). Hence

$DWT = (DWT)_O + d(DWT)$ (14)
and
$M_L = \Delta - DWT$ (15)

The sample computation using this method is as follows:
Basing on the data in Table 2. Taking P_a, P_E, P_M, P_S, P_R, as constants with respect to the hypothetical relationship between the respective masses M_a, M_E, M_M, M_S, M_R and the dimension L, B, T, D, C_B and solving for equation (14) using parameters of the pattern vessels will give:

$M_a = P_a{*}L{*}B{*}T{*}C_B$ (t) (16)

$\partial M_{aO}/\partial L_O = M_{aO}/L_O = a_o/L_O = 73.9/23 = 10.26$ t/m,

similarly
$a_o/B_O = 10.26$ t/m, $a_o/T_O = 25.93$t/m $a_o/C_{BO} = 171.46$ t

$M_a = P_E(L{*}B{*}D)2/3$ (t) (17)

$\partial M_{EO}/\partial L_O = 2M_{EO}/3L_O = 2\, e_o/3L_O = 2{*}39/3{*}23 = 1.13$ t/m,

similarly,
$2\, e_o/3B_O = 3.61$ t/m, $2\, e_o/3D_O = 7.45$t/m

$M_M = P_M = (L{*}B{*}T{*}C_B)^{2/3}{*}V^3$ (t) (18)

$\partial M_{MO}/\partial L_O = 2M_{MO}/3L_O = 2m_o/3L_O = 2{*}45.5/3{*}23 = 1.39$ t/m,
similarly,
$2m_o/3B_O$=4.21t/m, $2m_o/3T_O$=10.64 t/m, $2\, a_o/3C_{BO}$ = 70.38t/m

$3m_o/v_O = 24.12$ tm/s.

$M_S = P_S{*}L{*}B$ (t) (19)
$\partial M_{SO}/\partial L_O = M_{MO}/L_O = s_o/L_O = 0.72$ t/m,
similarly,
$s_o/B_O = 2.31$t/m.

$M_R = P_R{*} L{*}B{*}T{*}C_B{*}\rho$ (20)
$\partial M_{RO}/\partial L_O = M_{RO}/L_O = r_o/L_O = 0.27$ t/m,
$ro/B_O = 0.79$ t/m, $r_o/T_O = 2.20$ t/m, $r_o/C_{BO} = 13.14$ t

$L - L_O$= dL=2.93m, similaly, dB=1.1m, dT = 0.28m, dD=0.96m

$dC_B = 0.058$, dv = -0.5144 m/s $d\nabla = 107.01$ m3 $d\Delta = 111.74$t

$\Delta_o/L_O = 226.26/23 = 9.84$t/m, similaly$\Delta o/BO = 31.43$ t/m, $\Delta_o/T_O = 79.38$ t/m, $\Delta_o/C_{BO} = 524.97$ t

d(DWT) = $[\mathbf{9.84} \quad \mathbf{31.43} \quad \mathbf{79.38} \quad \mathbf{524.97}] \begin{bmatrix} \mathbf{2.93} \\ \mathbf{1.1} \\ \mathbf{0.28} \\ \mathbf{0.058} \end{bmatrix}$-

3.2110.2625.93171.461.133.61001.394.2110.6470.380.72

2.31000.270.792.2013.142.931.10.280.058$\Big]_{\boldsymbol{t}}$*11111*+$\Big[$**00**

7.450024.120000*0.95−0.514*$\Big]_{\boldsymbol{t}}$*11111*= **52.74t**

Therefore $DWT = DWT_O + d(DWT) = 45 + 52.74t = 97.74t$
Therefore $ML = \Delta - DWT = 338 - 97.74 = 240.26t$
This method above is inclusive of the Rate per meter method.

Consider the constant P_a, P_E P_M, P_S P_R, in equations (16), (17), (18), (19) and (20) respectively as constants for the pattern and projected new design vessel we have:

$M_a = M_{ao}{*} ((L{*}B{*}T{*}CB)/(L_O{*} B_O{*} T_O{*} C_{BO})) = 119.67t$
$ME = M_Eo{*} ((L{*}B{*}D)/L_O{*} B_O{*} D_O)) = 54.61t$
similarly,
$M_M = 43.341t$ $M_S = 21.57$ t $M_R = 10.14t$
which when added gives
$M_L = 119.67+54.61+43.34+21.57+54.61 = 249.33t$
This above method is similar to the cubic, quadric and methods

2.2 EMPIRICAL EQUATION METHOD FOR FISRT STAGE.

Where there is not existing pattern ship data empirical equation methods can be used. This is well known methods. but its application in the case of fishing vessels is not common. this method will be used to estimate the component masses of the same projected new fishing vessel above stated so as to show case application of this method for fishing vessels and to compare results with the methods presented already. Thus, following equation (1) the empirical formulas are summarized below

$M_{A7} = k*E^{1.36}$ (21)

k = 0.0415 by Watson[3], k = 0.037 by Santarelli[1]

$E = L(B+T)+0.85L(D-T)+0.85\sum l_1h_1+0.75\sum l_2h_2$(22)

from similar vessel,

$l_1 = 0.18L$ (m), $h_1 = 0.5D$ (m), $l_2 = 0.26L$ (m), $h_1 = 1.2D$ m, (23)

correction for CB is,

$M_A = M_{A7}$ [1+0.5(CB7-0.70)] (24)

$C_{B7} = C_B + (1- C_B)*(0.8D-T)/3T = 0.512$

$M_O = K_O*L*B$ (25)

were,

$K_O = 4.025L - 0.506$ by Santarelli

Santarelli also [ ] gave a chat shown in Fig 1 below. The author fitted a curve by regression on it to get the formula for net steel weight over the length of the vessels as shown. This gives the Outfit mass as:

$M_O = 57.045$t

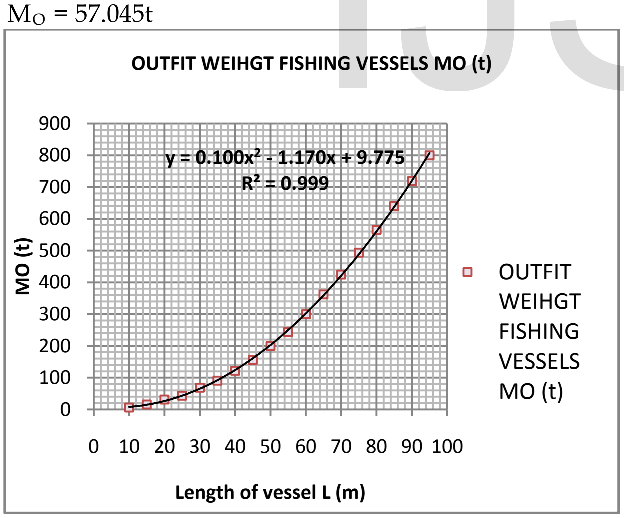

Fig 1.

$M_M = C_m(MCR/RPM)^{0.75}$ by Santarelli (26)

$C_m = 20$ for MCR <= 1000hp

= 30 for MCR > 1000hp

$M_R = 0.07*\Delta = 0.07*327.76 = 22.94$t (27)

By substituting the parameters of the projected new vessel from Table 1 into equations (21 to (27) we get:

E = 25.93(8.3+3.13)+0.85*25.93(4.45-3.13)+
+0.85*4.67*2.23+0.75*6.74*5.34 = 361.319, therefore,

$M_{A7} = 0.0415*361.31 = 124.96$t and $M_A = 113.24$t by Watson

$M_{A7} = 0.037*361.31 = 111.41.96$t and $M_A = 100.96$t by Santarelli

M_O = 8.3* 25.93* 0.2697= 58.045t by Santarelli and Watson

$M_M = 20(725/1800)0.75 = 10.11$ t

$M_R = 0.03*327.76 = 9.83$t

$M_L = 22.94+10.11+58.045 +113.24 = 204.335$t by Watson

$M_L = 22.94+10.11+58.045+100.96 = 192.06$t by Santarelli

W. Brett Wilson[2] gave the following formulas basing on cubic number C_N as:

C_N = L*B*D/2.834 = (25.95*8.30*4.45)/ 2.834 = 338.2012m3

$C_A = 0.236+ C_N/50,000.00 = 0.2428$ for vessels built with mild steel and,

$M_{A-B} = C_A*C_N*1.0163 = 83.441$t

were $M_{A-B} = M_A - M_B$

M_B = Mass of solid ballast.

$C_A = 0.3+ C_N/2,500$ for vessels built with wood.

$C_o = 0.196+ C_N/17,140 = 0.2157$

$M_o = C_o*C_N*1.0163 = 74.1500$t

$C_M = 0.0537+ C_N/27300 = 0.0.6609$

$M_M = C_o*C_N*1.0163 = 22.716$t

$C_B = 0.0104- C_N/10670 = 0.1357$ for vessels built with mild steel and,

$M_B = C_A*C_N*1.0163 = 46.641$t were,

$C_B = 0.163- C_N/10980$ for vessels built with wood.

$M_R = 0.03*(M_A+ M_o+ M_M + M_B) = 6.808$t

Therefore $M_L = M_A+ M_o+ M_M + M_B+ M_R = 233.76$t by W. Brett Wilson

3 RESULTS

The results of calculations on the component masses of the fishing vessel is summarized in Table 3 below.

Note that $M_A = M_a- M_B$, $M_O= M_E + M_S$ and $M_A = M_{A-B}+M_B$ by the definitions given already for the vessel mass components we have:

s/n	RESULTS					RELATIVE DEVIATION FROM a(%)		
1		a	b	c	d	b	c	d
2	(t)	Partial diff. Method(t)	Watson method (t)	Santarelli method (t)	Wilson method (t)	%	%	%
3	M_A	119.67	113.24	100.96	130.08	5.37	15.6	-8.70
4	M_O	76.18	58.05	58.05	74.15	23.8	23.8	2.66
5	M_M	43.34	10.11	10.11	22.72	76.6	76.7	47.58
6	M_R	10.14	9.83	9.83	6.81	3.04	3.04	32.84
7	M_L	249.33	191.23	178.95	23376	**23.3**	**28.2**	**6.24**

The result show that Wilson's method give result only 6.24% less while Watson and Santarelli methods predicted 23.3%

and 28.22% less respectively than the estimation done by the partial differentiation method presented in this work. This is mainly due to differences in solid Ballast, machinery and reserve masses. It should to be noted that low speed (less than===rpm) engines tend to be heavier than the medium speed(to rpm)engines which in tune is heavier than the high speed (greater than ==rpm) engines for the same power. It is clear that Wilson cubic number method agree more with the method presented here for the fishing vessel.

The empirical method is the first stage while the method presented here is the second and more accurate stage for lightship estimation provided a suitable pattern ship data is available. The difference in main dimension between the pattern ship and the projected new design ship dimensions should not be greater than that of the pattern ship by 15% for good result. They should be of similar structural framing system, and material types, otherwise suitable correction factors should be devised to take care of these differences, some suggestion on these factors exist in literature.

Other methods exist for estimation of lightship components [9] based on later stages of design when the structural detail drawings of the projected vessel are produced.

4 DISCUSSION

The empirical method is the first stage while the method is the second and more accurate stage for lightship estimation provided a suitable pattern ship data is available. the difference in main dimension between the pattern ship and the projected new design ship should not be greater than 15% for good result. They should be of similar structural framing system, and material types, otherwise suitable correction factors should be devised to take care of these differences, some suggestion on these factors exist in literature.
Other methods exist for estimation of lightship components [9] based on later stages of design when the structural detail drawings of the projected vessel are produced.

5 CONCLUSION

The new lightship component matrices derived and presented combined and various existing methods namely, the cubic number method, the rate per meter method, rational equation method, and recommendation of most classification societies. The proposed method can be used for all types of ships provided data of similar ship is available. To validate the method, data obtained for existing pattern fishing vessel and preliminary dimension of a projected new design fishing vessel is used and the result obtained is compared by empirical method of leading authors on the topic namely Watson (UK), Santarelli(Spain), and Wilson(USA). Wilson method agree mostly with the method presented by 6.24% while Watson and Santarelli by 23,3% and 28.22% respectively. the presented method can easily be computerized and integrated as a module in a larger ship design program.

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