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A New Approach to Establish Empirical Formula for Estimating Fishing Boat Resistance

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Abstract – *Resistance estimation is the basis for solving many important problems in ship design, such as selecting the suitable propulsion system, optimizing the hull form, etc. Three methods commonly used to estimate ship resistance are an empirical method, CFD analysis, and model testing. Compared with the last two ones, the empirical method in the form of approximate curves or formulas allow estimating resistance very fast without effort, cost, or ship lines, etc. However, it is extremely difficult and costly to establish such curves or formulas, and they also rarely give the expected accuracy when computational ships differ from test ships. In this paper, we present a simple approach to obtain an empirical formula for accurately estimating the resistance of fishing boats based on the existing model test data of the Food and Agriculture Organization (FAO) of the United Nations. The application of the research results to the Vietnamese fishing fleet has validated the reliability of this approach when the deviations of the resistance values calculated from the established empirical formula and the corresponding model and actual test data are within ±4%.*

Keywords — *empirical formula, FAO, fishing boat, resistance, Vietnamese.*

I. INTRODUCTION

Resistance estimation is one of the first problems that need to be solved in the ship design process and is the main basis for solving many other important problems such as selecting the right propulsion system, optimizing the hull form, etc. Therefore, there have been many studies trying to find out how to determine the ship resistance quickly and accurately. Until now, the three methods commonly used to estimate ship resistance are computational fluid dynamics method or also know as CFD analysis, model testing, and empirical method. CFD analysis is a modern method that has been widely used recently, which involves creating a complete 3D hull model and performing a numerical simulation of fluid flow around it to compute the hydrodynamic forces acting on the hull [1]. However, CFD analysis takes a lot of time, effort and does not always provide highly accurate resistance results [2]. Also, it can be costly and requires the ship's lines drawing.

Model testing is the most accurate and reliable method for estimating resistance based on building a scaled-down model of the real ship, testing to determine the model resistance in a towing tank, and transfer the model resistance to a real ship [3]. However, model tests are quite cost-prohibited, so it is often performed in necessary cases or to validate the other methods. The empirical method is presented in the form of the approximate curves or formulas/ equations, which are established based on systematizing model test data set of a series of ships with similarities in geometrical characteristics and hull form [3]. Due to such an approach, there are many empirical curves or formulas that are applied to different types of ships, and the result of the empirical curves or formulas are also different. Some well-known empirical resistance formulas can be listed, such as Holtrop-Mennen's formula for conventional ships [4], the formula for the planing hull of Savisky [5], Blount [6], or Doust's regression equation for fishing boats [7], etc. Compared with the above two methods, the empirical method allows estimating the resistance very quickly with limited initial data without effort, cost, or availability of ship lines. But the establishment of empirical formulas is extremely difficult and expensive, and their accuracy is often uncertain due to the differences between calculated ships and those which were used in the model test to establish the formulas.

Starting in 1950 and for a long time, a model test dataset of 576 fishing boats was performed or sponsored by the Food and Agriculture Organization of the United Nations (FAO). Then, FAO scientists Hayes (1964) and Doust (1969) had made a regression analysis of this dataset to establish the empirical formula for estimating the resistance of trawlers [8]. It is worth mentioning that FAO model test data was collected for a very large number of fishing boats in many countries, with the hull form parameters varying in a fairly wide range. So the empirical formula established based on this data may not ensure the desired accuracy when applied to specified fishing boat fleets whose hull parameters vary within small ranges, or outside the defined range of valid hull parameters. In this paper, we present a simple approach to establishing an empirical formula to accurately estimate the resistance of a specific type of fishing boat based on FAO model test data.

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II. MATERIAL AND RESEARCH METHOD

In term of the method, the empirical resistance formula will be established based on fishing boat model test data, which was published in two FAO publications: Computer-aided studies of fishing boat hull resistance (Hayes and Engvall, 1969) [9] and Fishing Boat Tank Test (Jan-Olof Traung, 1965) [10]. The first document presents the model test data tables of 576 fishing boats collected from all FAO member states, while the second one presents the hull lines and resistance curves of 250 fishing boats that have been tested in the European tanks. Base on these two documents, an empirical formula for estimating the resistance of a specific type of fishing boats, called research fishing boats, can be established according to the following steps:

(1) Analysis of the hull lines of research fishing boats to determine variation ranges of the hull form parameters which have a great effect on the resistance of common ships in general, fishing boats in particular.

(2) Analysis of the hull lines in document [9] to select the fishing boat models with hull lines and hull form parameters similar to the research fishing boats.

(3) Establish a model test data set to formulate the empirical formula for estimating the resistance of the research fishing boats as follows:

(i) Analysis of the model test data tables in document [10] to select the model test data set corresponding to the variation range of the hull form parameters of the research fishing boats determined in step (1).

(ii) Digitize the resistance curves of the fishing boats selected in step (2) to determine the resistance test data and add them to the resistance test data set already in step (i) to obtain a new resistance test data set suitable for research fishing boats.

(4) Perform a regression for test data set already in step (ii) to establish the empirical resistance formula for the research fishing boats.

(5) Compare the resistance values calculated from the established formula and from the model and actual test of some research fishing boats to evaluate the accuracy and reliability of this approach in general and the empirical formula in particular.

III. RESULTS AND DISCUSSIONS

The following section presents the results and discussions of applying this approach to establish the empirical formula for estimating the resistance of the Vietnamese fishing fleet.

A. Analysis of the Hull Lines of Vietnamese Fishing Boats

The total number of fishing boats in Vietnam today is more than 120,000, but most are wooden and composite hull boats. Steel fishing vessels account for a low proportion, below 2%. One of our research projects carried out in 2014 with funding from the Vietnamese Government has identified the basic features of the Vietnamese fishing fleet as follows [11].

a) Features of hull form parameters:

Our studies have shown that the variation range of the hull form parameters of Vietnamese fishing fleets depends on many factors such as fishing ground, type of fishing gear, etc. Table 1 shows the variation range of hull form parameters of Vietnamese fishing boats of FAO model test dataset, and the study range was selected based on these two ranges [11].

Table 1. The variation range of hull form parameters

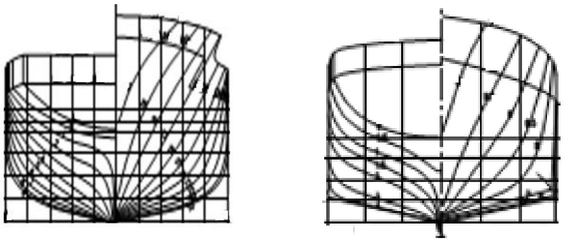
Parameters	FAO data	Vietnamese fishing boats	Study range
$V_S/\sqrt{gL}$	0.35	0.20 ÷ 0.40	0.20 ÷ 0.40
L/B	3.10 ÷ 5.60	3.20 ÷ 5.00	3.20 ÷ 5.00
B/T	2.00 ÷ 4.50	2.20 ÷ 4.20	2.20 ÷ 4.20
$L/\Delta^{1/3}$	3.75 ÷ 5.00	3.50 ÷ 5.50	3.75 ÷ 5.00
C_B		0.55 ÷ 0.72	0.55 ÷ 0.72
C_P	0.55 ÷ 0.70	0.65 ÷ 0.73	0.65 ÷ 0.70
C_M	0.53 ÷ 0.93	0.85 ÷ 0.92	0.85 ÷ 0.92
LCB = X_c/L (%)	- 4.0 ÷ 2.0	-3.7 ÷ 0.0	-3.7 ÷ 0.0
1/2 α_E (dgree)	15 ÷ 35	20 ÷ 42	20 ÷ 35
1/2 α_R (dgree)	30 ÷ 80	-	30 ÷ 60
TRIM	-0.04 ÷ 0.08	-	-0.04 ÷ 0.08
A/A_{max}	0.00 ÷ 0.02		0.00 ÷ 0.02

Nomenclature in Table 1.

$V_S/\sqrt{gL}$ - the ratio of the shipping speed to the length.
$L/\Delta^{1/3}$ - the ratio of the length to the displacement.
C_B, C_P, C_M - block, prismatic, and mid-ship coefficients.
1/2 α_E, 1/2α_R - half-angle of entrance and exit, respectively.
LCB - longitudinal centre of buoyancy.
L/B, B/T - ratio of the length to the breadth, and ratio of the breadth to the draft, respectively.
A/A_{max} - ratio of the keel cross-sectional area to the maximum transverse section area.
TRIM - the difference between the drafts forwards and aft.

b) Features of hull lines:

The hull lines of Vietnamese fishing boats are quite similar to some of the fishing boats which were used in model testing by FAO, with two basic types: round bottom hull as shown in Fig. 1a, and chine hull as shown in Fig.1b.



(a) round-bottom (b) chine hull

Fig. 1. Hull lines of Vietnamese steel fishing boats

B. Establish the resistance test data suitable for Vietnamese fishing boats.

a) Determining resistance test data from FAO data:

The FAO model testing data in document [9] are presented in tabular form depending on the known hull form parameters. On these tables, the model test data corresponding to the variation range of hull form parameters of Vietnamese fishing boats will be marked (shaded rectangles) as shown in Table 2. Many such tables are processed to select all matching data.

Table 2. Marking selected areas on FAO data tables

L/B=3.7		B/T=2.8		C_P					$V_S/\sqrt{L}$ = 1.1	
$L/\Delta^{1/3}$	½α_E	C_M at C_P=0.55		0.575	0.600	0.625	0.650	0.675	C_M at C_P=0.70	
3.75	15.0	1.32								1.04
	17.5									
	20.0									
	25.0									
	30.0									
	35.0									
4.00	15.0	1.09			20.48	18.77	17.66	16.80	15.95	0.86
	17.5				20.90	19.34	18.37	17.65	16.94	
	20.0				21.57	20.15	19.32	18.74	18.18	
	25.0				23.05	21.91	21.37	21.08	21.81	
	30.0				23.96	23.11	22.85	22.84	22.86	
	35.0				23.60	23.04	23.07	23.35	23.64	
4.25	15.0	0.91	17.31	16.02	15.61	15.67	15.87	15.99	15.87	0.71
	17.5		17.45	16.30	16.03	16.23	16.58	16.85	16.86	
	20.0		17.82	16.82	16.70	17.04	17.53	17.94	18.10	
	25.0		18.73	18.02	18.18	18.81	19.58	20.28	20.72	
	30.0		19.07	18.64	19.08	20.00	21.06	22.04	22.77	
	35.0		18.14	18.00	18.73	19.93	21.28	22.55	23.56	
4.50	15.0	0.77	15.91	15.61	15.88	16.38	16.86	17.12	17.04	0.60
	17.5		16.05	15.89	16.30	16.94	17.56	17.97	18.03	
	20.0		16.43	16.42	16.97	17.75	18.51	19.06	19.27	
	25.0		17.34	17.61	18.45	19.52	20.57	21.40	21.90	
	30.0		17.67	18.23	19.35	20.71	22.05	23.17	23.95	
	35.0		16.74	17.59	19.00	20.64	22.26	23.67	24.74	
4.75	15.0	0.65	16.85	16.70	16.99	17.44	17.81	17.93	17.68	0.51
	17.5		16.99	16.98	17.42	18.01	18.52	18.78	18.68	
	20.0		17.37	17.50	18.08	18.81	19.47	19.88	19.92	
	25.0		18.28	18.70	19.56	20.58	21.52	22.22	22.54	
	30.0		18.61	19.32	20.47	21.77	23.00	23.98	24.59	
	35.0		17.68	18.68	20.11	21.71	23.22	24.48	25.38	
5.00	15.0	0.56	17.79	17.48	17.59	17.83	17.99	17.90	17.45	0.44
	17.5		17.93	17.76	18.01	18.40	18.70	18.75	18.44	
	20.0		18.30	18.28	18.68	19.20	19.65	19.85	19.68	
	25.0	1.32	19.21	19.48	20.16	20.97	21.70	22.19	22.31	
	30.0		19.55	20.10	21.06	22.16	23.18	23.95	24.35	
	35.0		18.62	19.46	20.71	22.10	23.40	24.45	25.14	

Selection of resistance correction coefficients ΔC_R due to the effect of other hull form parameters is shown in the following tables, from Table 3 to Table 5.

Table 3. Correction ΔC_{R1} due to effect of $1/2\alpha_R$ and C_P

½α_R	C_P						
(degree)	**0.550**	**0.575**	**0.600**	**0.625**	**0.650**	**0.675**	**0.700**
20	-0.53	-0.41	-0.29	-0.18	-0.06	0.06	0.17
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.44	0.32	0.21	0.09	-0.03	-0.14	-0.26
35	0.80	0.56	0.33	0.09	-0.14	-0.37	-0.61
40	1.06	0.71	0.36	0.01	-0.37	-0.69	-1.04

Table 4. Correction ΔC_{R2} due to effect of $1/2\alpha_R$ and LCB

LCB	½α_E (degree)					
(%)	**15**	**17.5**	**20**	**25**	**30**	**35**
2.0	1.43	0.62	0.00	-0.69	-0.65	0.13
0.0	0.66	0.28	0.00	-0.29	-0.21	0.24
-2.0	0.00	0.00	0.00	0.00	0.00	0.00
-4.0	-0.54	-0.22	0.00	0.17	-0.02	-0.58

Table 5. Correction ΔC_{R3} due to effect of TRIM

TRIM	-0.04	-0.01	0.02	0.05	0.08	0.11
ΔC_{R3}	-0.49	-0.33	-0.16	0.00	0.16	0.33

Table. 6. Correction ΔC_{R4} due to effect of A/A_{max}

A/A_{max}	0	0.01	0.02	0.03	0.04	0.05
ΔC_{R4}	0	2.25	4.34	6.43	8.52	10.61

To conform to the regression analysis, the selected data are rearranged in a new table as the resistance coefficient C_{R16} (resistance coefficient of the 16-ft model is used to calculate FAO model test data) as a function of hull form parameters. The first part of this new resistance data table is shown in Table 7, and of course, a table with such data is very large.

Table 7. The resistance data for regression analysis in the form $C_{R16} = f(L/B, B/T, C_M, C_P, ½\alpha_E)$

Resistance	Hull form parameters				
coefficient C_{R16}	**L/B**	**B/T**	**C_M**	**C_P**	**½ α_E**
16.73	3.1	2.6	0.861	0.550	20
16.88	3.1	2.6	0.861	0.550	25
16.47	3.1	2.6	0.861	0.550	30
14.61	3.1	2.6	0.861	0.550	35
19.98	3.1	2.8	0.928	0.550	20
19.07	3.1	2.8	0.888	0.575	20
18.85	3.1	2.8	0.851	0.600	20
19.94	3.1	2.8	0.928	0.550	25
19.31	3.1	2.8	0.888	0.575	25
19.38	3.1	2.8	0.851	0.600	25
19.46	3.1	2.8	0.928	0.550	30
19.13	3.1	2.8	0.888	0.575	30
19.48	3.1	2.8	0.851	0.600	30
17.65	3.1	2.8	0.928	0.550	35
17.60	3.1	2.8	0.888	0.575	35
18.24	3.1	2.8	0.851	0.600	35
21.72	3.1	3.0	0.911	0.600	20
21.09	3.1	3.0	0.875	0.625	20
22.11	3.1	3.0	0.911	0.600	25
21.77	3.1	3.0	0.875	0.625	25
22.19	3.1	3.0	0.911	0.600	30
22.14	3.1	3.0	0.875	0.625	30
21.04	3.1	3.0	0.911	0.600	35
21.27	3.1	3.0	0.875	0.625	35
22.86	3.1	3.2	0.897	0.650	20
21.33	3.1	3.2	0.864	0.675	20
23.74	3.1	3.2	0.897	0.650	25
22.50	3.1	3.2	0.864	0.675	25
24.41	3.1	3.2	0.897	0.650	30
23.46	3.1	3.2	0.864	0.675	30
23.98	3.1	3.2	0.897	0.650	35

In addition, it should be noted that these resistance data were calculated based on resistance coefficient (C_{R16}) in the American measurement system, so it is necessary to perform a conversion to the total ship resistance (R) in the metric system by the following formula:

$$R = C_R \frac{\Delta V_s^2}{L} \quad (1)$$

where Δ is displacement (T-Longton), V_S is ship speed (knot), L is ship length (feet), C_R is total resistance coefficient calculated by the following formula:

$$C_R = C_{R16} + \Delta C_{R1} + \Delta C_{R2} + \Delta C_{R3} + \Delta C_{R4} \quad (2)$$

with resistance coefficient C_{R16} is calculated from Table 7, ΔC_{R1}, ΔC_{R2}, ΔC_{R3}, ΔC_{R4} are respectively corrections due to effect of hull form parameters such as $1/2\alpha_R$ and C_P (Table 3), $1/2\alpha_R$ and C_P (Table 4), TRIM (Table 5), A/A_{max} (Table 6). The full data tables above can be found in the reference [12].

b) Determine resistance test data from specific boats:

Model test data in the form of effective power curves of a large number of fishing boats are presented in the document [10]. A comparative study was performed to select the FAO-tested fishing boats with features of the hull lines and variation range of hull form parameters similar to Vietnamese fishing boats. As a result, sixteen fishing boats were selected with their hull form parameters, and model test cases are shown in Table 8.

Table 8. Hull form parameters of selected fishing boats

Ship	Case	Hull Form Parameters								
		L	B	LCB	C_P	C_B	L/B	B/T	$1/2a_E$	$L/\Delta^{1/3}$
FA076	I	39.50	9.76	-1.1	0.596	0.524	4.04	2.56	19.5	4.26
	II	39.80	9.76	-2.5	0.597	0.525	4.08	2.56	19.0	4.29
	III	40.10	9.76	-6.7	0.656	0.577	4.11	2.286	18.0	4.01
FA075	I	44.20	10.36	-1.1	0.581	0.524	4.26	2.266	18.5	4.18
	II	44.45	10.36	-1.6	0.586	0.53	4.28	2.266	16.7	4.29
	III	44.55	10.36	-3.0	0.597	0.542	4.3	2.192	17.0	4.22
FA074	I	44.20	10.36	-1.1	0.584	0.527	4.26	2.266	18.5	4.26
	II	44.45	10.36	-1.9	0.590	0.534	4.28	2.266	16.7	4.28
	III	44.55	10.36	-3.2	0.606	0.55	4.30	2.192	17.0	4.20
FAO73	I	44.20	10.36	-0.9	0.583	0.526	4.26	2.266	13.0	4.28
	II	44.45	10.36	-1.5	0.591	0.535	4.28	2.266	11.0	4.28
	III	44.55	10.36	-3.0	0.607	0.551	4.3	2.192	9.0	4.20
FAO72	I	44.20	10.36	-0.7	0.58	0.523	4.26	2.266	13.0	4.28
	II	44.45	10.36	-1.3	0.586	0.53	4.28	2.266	11.0	4.29
	III	44.55	10.36	-2.5	0.598	0.543	4.30	2.192	9.0	4.26
FAO71		39.60	6.712	-0.9	0.66	0.504	5.81	2.28	23.0	5.33
FAO70		39.00	7.884	-0.9	0.66	0.504	4.95	2.28	25.0	4.79
FAO69		39.80	7.3	-0.9	0.66	0.504	5.34	2.28	23.5	5.04
FAO68		39.30	7.0	-1.3	0.666	0.522	5.62	1.94	22.5	4.91
FAO64		42.00	7.6	-0.6	0.673	0.526	5.53	2.305	23.5	5.10
FAO63		38.80	7.3	-0.4	0.652	0.487	5.33	2.415	21.0	5.16
FAO61	I	38.00	7.0	-0.7	0.648	0.496	5.43	2.29	25.0	5.13
	II	38.00	7.0	-6.0	0.658	0.458	5.43	2.665	17.5	5.54
FAO18		39.65	8.7	0.1	0.570	0.460	4.56	2.38	16.0	4.53
FAO15		47.30	10.6	-0.8	0.667	0.556	4.47	2.71	20.5	4.66
FAO13		42.70	10.0	-0.6	0.615	0.538	4.25	2.442	24.5	4.34
FAO12		41.20	10.3	-0.8	0.607	0.459	3.99	2.733	26.5	4.56

Next, the effective power curves of the selected fishing boats are digitized to determine the second resistance test data which is also arranged in a similar table as shown in Table 7. A portion of the data table is shown in Table 9, and similar to the above tables, this full data table is also very large.

Table 9. The effective power test data

L(m)	B(m)	LCB(m)	C_P	C_B	L/B	B/T	$1/2a_E$	$L/V^{1/3}$	Fn	EHP(HP)
44.20	10.36	-0.70	0.58	0.523	4.26	2.266	13	4.18	0.325	687.85
44.45	10.36	-1.30	0.586	0.53	4.28	2.266	11	4.29	0.325	703.51
44.55	10.36	-2.50	0.598	0.543	4.30	2.192	9	4.22	0.325	734.77
44.20	10.36	-0.90	0.583	0.526	4.26	2.266	13	4.26	0.325	750.38
44.45	10.36	-1.50	0.591	0.535	4.28	2.266	11	4.28	0.325	781.65
44.55	10.36	-3.00	0.607	0.551	4.30	2.192	9	4.20	0.325	844.18
44.20	10.36	-1.10	0.584	0.527	4.26	2.266	18.5	4.28	0.325	859.81
44.45	10.36	-1.95	0.59	0.534	4.28	2.266	16.7	4.28	0.325	862.94
44.55	10.36	-3.20	0.606	0.55	4.30	2.192	17	4.20	0.325	969.24
44.20	10.36	-1.10	0.581	0.524	4.26	2.266	18.5	4.28	0.325	687.85
44.45	10.36	-1.60	0.586	0.53	4.28	2.266	16.7	4.29	0.325	719.12
44.55	10.36	-3.00	0.597	0.542	4.30	2.192	17	4.26	0.325	750.38
44.20	10.36	-0.70	0.58	0.523	4.26	2.266	13	4.18	0.35	1000.51
44.45	10.36	-1.30	0.586	0.53	4.28	2.266	11	4.29	0.35	1031.78
44.55	10.36	-2.50	0.598	0.543	4.30	2.192	9	4.22	0.35	1094.31
44.20	10.36	-0.90	0.583	0.526	4.26	2.266	13	4.26	0.35	1100.56
44.45	10.36	-1.50	0.591	0.535	4.28	2.266	11	4.28	0.35	1106.56
44.55	10.36	-3.00	0.607	0.551	4.30	2.192	9	4.20	0.35	1188.11
44.20	10.36	-1.10	0.584	0.527	4.26	2.266	18.5	4.28	0.35	1188.11
44.45	10.36	-1.95	0.59	0.534	4.28	2.266	16.7	4.28	0.35	1203.74

Convert effective power into resistance and combine two defined data sets into a set to establish the empirical formula for estimating the resistance of Vietnamese fishing boats.

C. Establish Resistance Regression Formular

The process of establishing a regression formula based on identified resistance test data was performed using SPSS [13], a common statistical analysis software today, in two steps:

- Perform a correlation analysis to determine and include regression equation for the hull form parameters that have a great effect on resistance.
- Perform a regression analysis to find a resistance formula as a function of the selected hull form parameters.

a) Correlation analysis of hull form parameters:

Table 9 presents the results of correlation analysis of hull form parameters to resistance values based on the resistance data set, which was determined in section B.

Table 9. Correlation analysis of hull form parameters with resistance R

		L	B	LCB	C_M	C_B	C_P	$½\alpha_E$	Δ	R
L	Pearson Correlation	1	.824	.058	-.433	.653	.755	-.521	.889	.373
	Sig(2-tailed)		.000	.385	.000	.000	.000	.000	.000	.000
B	Pearson Correlation	.824	1	-.041	-.691	.533	.833	-.496	.934	.344
	Sig(2-tailed)	.000		.540	.000	.000	.000	.000	.000	.000
LCB	Pearson Correlation	.058	-.041	1	-.165	-.279	-.089	-.271	-.111	-.070
	Sig(2-tailed)	.385	.540		.013	.000	.183	.000	.097	.295
C_P	Pearson Correlation	-.433	-.691	-.165	1	-.049	-.706	.562	-.664	-.325
	Sig(2-tailed)	.000	.000	.013		.466	.000	.000	.000	.146
C_B	Pearson Correlation	.653	.533	.279	-.049	1	.741	-.386	.699	.254
	Sig(2-tailed)	.000	.000	.000	.466		.000	.000	.000	.132
C_M	Pearson Correlation	.755	.833	-.089	-.706	.741	1	-.659	.939	.403
	Sig(2-tailed)	.000	.000	.183	.000	.000		.000	.000	.000
$½\alpha_E$	Pearson Correlation	-.521	-.496	.271	.562	-.386	-.659	1	-.653	.348
	Sig(2-tailed)	.000	.000	.000	.000	.000	.000		.000	.000
Δ	Pearson	.889	.934	-.111	-.664	.699	.939	-.653	1	.415

	Correlation Sig(2-tailed)	.000	.000	.097	.000	.000	.000	.000		.000
R	Pearson Correlation	.373	.344	-.070	-.325	.254	.403	-.348	.415	1
	Sig(2-tailed)	.000	.000	.295	.146	.132	.000	.000	.000	

The meaning and determination of the Pearson correlation coefficient (r) and the significant value of the Pearson test (Sig.) in Table 9 can be found in the statistical literature [14]. The results in this table show the parameters L, B, C_P, $1/2\alpha_E$, Δ are strongly correlated with resistance because the value of Sig (2-tailed) is less than .05 and the Pearson coefficient is high. The similar correlations of remaining parameters LCB, C_M, C_B with resistance are not or very weak because the value of Sig (2-tailed) is greater than .05 and the Pearson coefficient is small, so they can be ignored in the resistance regression equation. This is also consistent with the fact because the effects of the ignored parameters on resistance are taken into through their relationships with the parameters in the regression equation. Different from FAO's previous resistance empirical formulas, a speed parameter is included in the regression equation so that resistance values can be calculated at different boat speeds. Based on these analyses, resistance regression equation can be established as a function as follows:

$$R = f(L, B, C_P, 1/2\alpha_E, \Delta, V_S) \tag{3}$$

b) Regression analysis of resistance data:

Table 10 shows the results of regression analysis for the defined resistance test data set using SPSS.

Table 10. The results of regression analysis for the defined resistance test data set

Types of regression functions	Regression parameters							
	R	R^2	R_a^2	Std. Error	R	R^2	R_a^2	Std. Error
	L - R				C_M - R			
LINEAR	.627	.393	.391	456.610	.633	.401	.398	453.846
LOGARITHMIC	.615	.379	.376	462.065	.407	.166	.162	535.351
INVERSE	.591	.350	.347	472.774	.583	.340	.337	476.081
QUADRATIC	.676	.457	.452	432.903	.692	.479	.475	423.943
CUBIC	.675	.455	.450	433.657	.695	.483	.478	422.463
COMPOUND	.977	.954	.954	1.140	.978	.957	.957	1.097
POWER	.974	.948	.948	1.208	.819	.670	.669	3.051
S CURVES	.964	.929	.929	1.414	.960	.921	.920	1.495
GROWTH	.977	.954	.954	1.140	.978	.957	.957	1.097
EXPONENTIAL	.977	.954	.954	1.140	.978	.957	.957	1.097
LOGISTICS	.977	.954	.954	1.140	.978	.957	.957	1.097
	B - R				D - R			
LINEAR	.642	.412	.409	449.649	.680	.462	.460	429.779
LOGARITHMIC	.627	.393	.390	456.641	.627	.393	.390	456.637
INVERSE	.560	.314	.311	485.553	.435	.189	.185	527.913
QUADRATIC	.671	.451	.446	435.449	.701	.492	.487	418.794
CUBIC	.673	.453	.448	434.456	.708	.501	.494	416.092
COMPOUND	.977	.954	.954	1.139	.965	.931	.930	1.400
POWER	.977	.954	.953	1.144	.977	.955	.954	1.132
S CURVES	.944	.891	.891	1.752	.837	.701	.700	2.906
GROWTH	.977	.954	.954	1.139	.965	.931	.930	1.400
EXPONENTIAL	.977	.954	.954	1.139	.965	.931	.930	1.400
LOGISTICS	.977	.954	.954	1.139	.965	.931	.930	1.400
	$1/2a_E$ - R				V - R			
LINEAR	.513	.263	.259	503.333	.763	.582	.580	379.077
LOGARITHMIC	.578	.334	.331	478.258	.682	.465	.462	428.899
INVERSE	.658	.432	.430	441.656	.435	.189	.186	527.811
QUADRATIC	.663	.440	.435	439.763	.918	.842	.841	233.316
CUBIC	.673	.453	.446	435.403	.938	.880	.878	203.982
COMPOUND	.908	.824	.823	2.228	.993	.986	.986	.635
POWER	.956	.914	.913	1.561	.991	.983	.982	.703
S CURVES	.950	.902	.902	1.660	.876	.767	.766	2.564
GROWTH	.908	.824	.823	2.228	.993	.986	.986	.635
EXPONENTIAL	.908	.824	.823	2.228	.993	.986	.986	.635
LOGISTICS	.908	.824	.823	2.228	.993	.986	.986	.635

The meaning and determination of the quantities included in Table 10, such as multiple regression (R), R square (R^2), adjusted R square (R_a^2), and standard error of the estimate (Std. Error), can be found in the literature on statistics [14]. The result in Table 10 shows among 11 types of regression functions in SPSS, and the power function is the most suitable because the value of the R coefficient is the correlation between the actual and predicted value of all independent variables on the resistance data of this function is the highest. Thus, a power function correlation between resistance and hull form parameters can be assumed for the resistance formula. Also, the R-square values when estimating regression for the power function of all independent variables are high, so it can be assumed the relationship between the dependent variable (resistance) and each independent variable in this function (hull form parameter) is also in the form of power functions. However, the results of the above analysis are not final due to at this time, only the correlation between the dependent variable and each dependent variable has been determined, while the correlation between these variables is complicated due to the interactions between independent variables.

Therefore, the general form of the resistance regression equation can be determined as follows:

$$R = \sum_{i=0}^{k} a_i L^{n_{i1}} B^{n_{i2}} \left(\frac{1}{2}\alpha_E\right)^{n_{i3}} C_P^{n_{i4}} \Delta^{n_{i5}} V_S^{n_{i6}} \tag{4}$$

where a_i is the coefficient of the regression equation.

After many regression calculations, it can be seen that with k = 3, the resistance values calculated from the regression equation is very close to actual values, therefore, can be expressed the resistance regression equation as follows:

$$R_T = a_1 L^{a_2}.B^{a_3}.0.5\alpha_E^{a_4}.C_P^{a_5}.\Delta^{a_6} V_S^{a_7} + a_8 L^{a_9} B^{a_{10}} 0.5\alpha_E^{a_{11}} C_P^{a_{12}}.\Delta^{a_{13}} V^{a_{14}} + a_{15} L^{a_{16}}.B^{a_{17}}.0.5\alpha_E^{a_{18}}.C_P^{a_{19}}.\Delta^{a_{20}} V_S^{a_{21}} \tag{5}$$

where the values of the coefficients (a_i) are determined using SPSS and shown in Table 11.

Table 11. The coefficients (a_i) of the regression equation

Coefficients	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
a_1	4.22612E-12	2.6949E-11	-4.89081E-11	5.73603E-11
a_2	1.695053715	1.455895235	-1.17547798	4.56558541
a_3	-8.364176195	2.19208219	-12.68621891	-4.042133475
a_4	0.632238254	0.382341928	-0.121610372	1.386086879
a_5	-14.83655878	5.305919959	-25.29803365	-4.375083917
a_6	4.124515702	1.622580352	0.925337481	7.323693922
a_7	4.429483057	0.404931712	3.631095037	5.227871077
a_8	1.09309E-15	1.45796E-12	-2.87351E-12	2.87569E-12
a_9	-65.08529955	28.57271831	-121.4210107	-8.749588364
a_{10}	108.4864185	574.2726774	-1023.784559	1240.757396
a_{11}	0.000318457	0.142673202	-0.280984715	0.28162163
a_{12}	111.1408698	39.2923986	33.66958426	188.6121554
a_{13}	-1.962374239	1.55261026	-5.023595165	1.098846686
a_{14}	21.72051439	3.178536419	15.45351845	27.98751033

a_{15}	40491.08902	322373.0298	-595119.2057	676101.3837
a_{16}	-19.72536623	4.880552085	-29.3481599	-10.10257257
a_{17}	28.38449642	7.088653736	14.40807509	42.36091775
a_{18}	0.04766876	0.06970403	-0.089763949	0.185101469
a_{19}	31.21465383	6.770105818	17.86630098	44.56300669
a_{20}	-0.140557962	0.513933176	-1.153859906	0.872743981
a_{21}	3.242442101	0.153314285	2.940158322	3.544725879

The meaning and determination of the quantities in Table 10 can be found in the literature on SPSS [13] or statistics [14].

D. *Validate established resistance formula*

The accuracy and reliability of the established empirical formula are evaluated and validated by comparing resistance calculated from the empirical formula (empirical resistance) and the model test data (test resistance) of some Vietnam fishing boats, including steel and wooden hull.

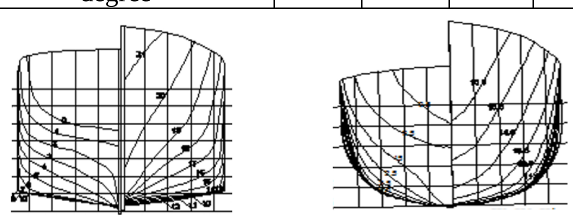
a) For the wooden fishing fleet:

Vietnamese wooden fishing boats are built according to long-time traditional patterns with their overall length of fewer than 25 meters, straight bow, transom stern, a large keel on the bottom extending from stern to bow to create the hull strength. The hull form depends on the fishing ground, fishing gear, local model, etc. but not much different with the cross-sections having U-shaped and gradual changing to V-shape in the bow region to develop the exploitation deck in the forebody [11]. Until now, four typical Vietnamese wooden fishing boats, denoted M1317A, M1319, M250-2, MH076, have been tested in towing tanks to determine resistance data [15], [16], [17].

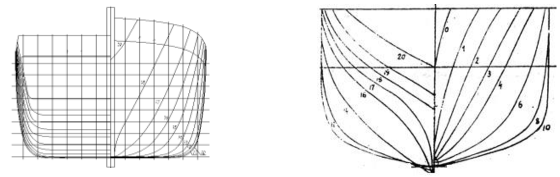
The hull form parameters and the hull lines of these models are shown in Table 12 and Fig. 2.

Table 12. Hull form parameters of tested models

Parameters	Tested Models			
	M1317	M1319	M076	M250
Length overall L_{OA}, m	21.9	17.4	20.5	29.3
Length of waterline L_{WL}, m	19.0	14.8	17.8	27.48
Maximum Breadth B_{max}, m	4.48	3.88	6.10	6.54
The breadth of waterline B, m	4.48	3.14	6.10	6.54
Draft d, m	1.23	1.80	1.85	2.89
Displacement Δ, ton	64.7	19.9	124.4	321.8
Midship coefficient C_M	0.87	0.84	0.84	0.85
Block coefficient C_B	0.59	0.55	0.59	0.59
Prismatics coefficient C_P	0.68	0.64	0.70	0.67
The angle of the entrance α_E, degree	54	52	47	45



(a) M1317 (b) M1319



(c) MH076 (d) M 250

Fig. 2. Hull lines of the tested models

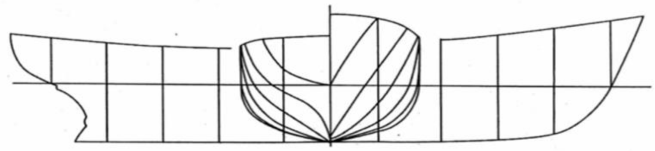
A comparative study found that the deviations (δ) between the resistance values obtained from the established empirical formula (R_e) and the corresponding model test data for these boats were less than 5%, as shown in Table 13.

Table 13. Comparison of resistance values obtained from the empirical formula (R_e) and the model test (R_t)

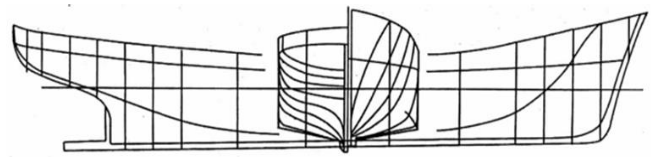
Speed (knot)		3.66	5.30	7.21	7.66	8.40	8.74	9.04
M 1317	R_e (N)	77.9	239.9	318.2	551.3	819.6	959.4	1084.3
	R_t (N)	75.7	232.8	313.5	543.5	805.9	939.7	1054.8
	δ (%)	2.86	3.04	1.50	1.43	1.70	2.10	2.80
Speed (knots)		3.24	4.66	7.05	7.52	8.00	8.51	8.58
M 1319	R_e (N)	28.0	77.4	245.2	287.9	347.5	401.9	423.3
	R_t (N)	26.9	75.3	240.1	282.7	342.2	392.6	414.5
	δ (%)	3.95	2.74	2.12	1.84	1.54	2.36	2.12
Speed (knots)		6.00	7.00	8.00	9.00	10.00	11.00	12.00
MH 076	R_e (N)	531.3	691.6	1096.2	1708.0	2653.3	4128.3	6901.7
	R_t (N)	515.1	672.3	1069.0	1656.3	2560.6	4013.1	6703.3
	δ (%)	3.15	2.87	2.54	3.12	3.62	2.87	2.96
Speed (knots)		6.50	7.50	8.50	9.50	10.50	11.20	11.50
M 250	R_e (N)	1021.6	1389.0	2292.6	4132.4	7540.8	10238.2	11463.2
	R_t (N)	984.6	1354.7	2221.3	4060.9	7330.4	9939.0	11141.2
	δ (%)	3.76	2.53	3.21	1.76	2.87	3.01	2.89

b) For the steel fishing fleet:

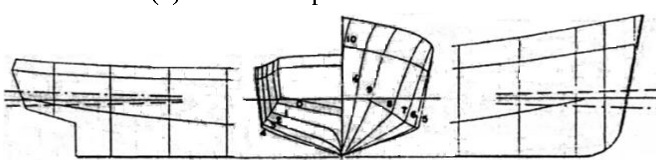
Vietnamese steel fishing boats have only been developed in recent years with the support of the government's policies to modernize the offshore fishing fleet and logistic service fleet. In fact, different from the design of other conventional ships, it is not immediately straightforward to design steel fishing boats that can be effectively operated for a particular fishery. It takes a long time to model tests or field trials to choose the most suitable models for a particular fishing ground and gear. Due to the wooden fishing boat models are well-suited to Vietnamese fisheries so when performing the national project of designing the Vietnamese steel fishing boat models [18], we analyzed 16 models in Table 8 and selected 4 fishing boats (72, 73, 74, 75) with the hull lines and hull form parameters most suitable to the Vietnamese fishing fleet, then adjust these boats as close as possible to the Vietnamese wooden hull form. As a result, four models of steel fishing boats have been designed, built, put into operation in Vietnam's fishing ground and have achieved high quality and efficiency recently [19]. Depending on the fishing gears, these include a round bottom hull (designed denoted M1) for purse seine, lift net (Fig. 3a), V-shaped one hard chine hull (designed denoted M2), and two hard chine hull (designed denoted M3) for gill net, trawler (Fig. 3b, 3c), or U-shaped chine hull (designed denoted M4) for hook and line (Fig. 3d).



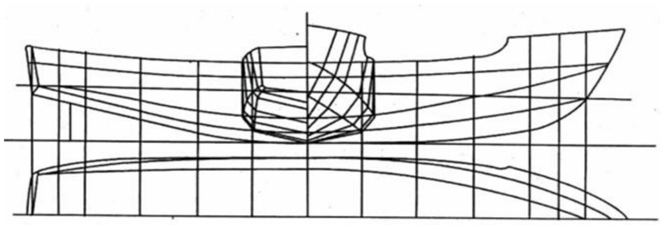
(a) M1 - Round bottom hull



(b) M2 - U-shaped soft chine hull



(c) V-shaped hard one chine hull



(c) V-shaped hard two chine hull

Fig. 3. Four hull lines of Vietnamese steel fishing boat models

The hull form parameters of the four above steel fishing boat models are shown in Table 14.

Table 14. Hull parameters of steel fishing boat models

Parameters	Models			
	M1	M2	M3	M4
Length overall L_{OA}, m	29.0	32.5	27.0	30.8
Length of waterline L_{WL}, m	26.5	30.5	24.8	27.2
The breadth of waterline B, m	6.35	7.32	5.70	6.45
Draft d, m	2.75	3.05	2.20	2.70
Displacement Δ, ton	247.8	393.2	173.1	268.6
Midship coefficient C_m	0.84	0.92	0.85	0.90
Angle of entrance α_E (degree)	40	45	40	45
Horsepower (HP)	900	1200	830	1000
Speed (knots)	10.5	11.5	10.0	10.5

A comparison study between the required horsepower values obtained from the empirical formula (N_e) and the actual test (N_t) [20] for these fishing boats under no-load (case I) and full-load (case II) showed a well-suited with actual operation as shown in Table 15. S

Table 15. Comparison of resistance values obtained from the empirical formula (R_e) and the model test (R_t)

Speed (knots)			7	8	9	10	11	12
M1	I	N_e (HP)	376.0	494.6	558.0	671.8	911.5	1327.7
		N_t (HP)	389.9	480.0	551.7	660.9	883.2	1281.3
		δ (%)	-3.56	3.03	1.14	1.65	3.21	3.62
	II	N_e (HP)	390.1	506.3	564.0	703.4	939.5	1370.2
		N_t (HP)	403.1	496.3	570.4	683.3	913.1	1324.7
		δ (%)	-3.23	2.01	-1.12	2.94	2.89	3.43
M2	I	N_e (HP)	376.6	477.5	625.8	772.7	979.1	1555.4
		N_t (HP)	391.1	489.2	604.0	749.6	984.6	1616.7
		δ (%)	-3.70	-2.40	3.62	3.09	-0.56	-3.79
	II	N_e (HP)	428.6	544.4	633.3	762.9	1014.0	1699.7
		N_t (HP)	445.0	556.2	629.1	781.8	1033.5	1751.7
		δ (%)	-3.67	-2.12	0.67	-2.42	-1.88	-2.97
M3	I	N_e (HP)	339.8	425.6	548.1	690.5	867.8	1339.8
		N_t (HP)	330.3	420.4	564.3	698.8	896.6	1387.4
		δ (%)	2.88	1.24	-2.87	-1.18	-3.21	-3.43
	II	N_e (HP)	404.9	509.6	653.2	801.5	1033.1	1594.4
		N_t (HP)	395.1	499.0	668.3	826.5	1070.6	1648.0
		δ (%)	2.46	2.12	-2.26	-3.03	-3.50	-3.25
M4	I	N_e (HP)	506.1	606.5	680.7	851.9	1188.3	1891.3
		N_t (HP)	489.4	622.8	693.3	828.2	1153.5	1827.0
		δ (%)	3.40	-2.63	-1.81	2.86	3.01	3.52
	II	N_e (HP)	596.4	741.1	804.6	994.0	1346.7	2118.5
		N_t (HP)	576.2	723.5	786.9	971.3	1301.9	2049.6
		δ (%)	3.50	2.43	2.25	2.34	3.44	3.36

A similar comparison study between the resistance values obtained from the empirical formula (R_e) and the model test (R_t) was also performed for the FAO 72, 73, 74, and 75 boats which were used as a model when designing the above Vietnamese steel fishing boats validated the reliability of the established resistance empirical formula as shown in Table 16.

Table16. Comparison of resistance values obtained from the empirical formula (R_e) and the model test (R_t)

Số Froude (Fn)			0.250	0.275	0.300	0.325	0.350	0.375
FAO 72	I	R_e (N)	4459.0	5490.2	6310.2	7559.0	10101.3	14655.0
		R_t (N)	4504.5	5323.5	6381.4	7623.0	10296.0	14714.7
		δ (%)	-1.01	3.13	-1.12	-0.84	-1.89	-0.41
	II	R_e (N)	4583.6	5354.4	6605.3	7795.2	10773.7	15786.1
		R_t (N)	4639.9	5513.0	6550.9	7774.6	10587.9	15571.6
		δ (%)	-1.21	-2.88	0.83	0.27	1.76	1.38
	III	R_e (N)	4665.4	5707.4	6747.6	8180.3	11303.8	16824.9

		R_t (N)	4823.5	5710.4	6730.2	8111.0	11216.9	16750.6
		δ (%)	-3.28	-0.05	0.26	0.85	0.77	0.44
FAO 73	I	R_e (N)	4473.2	5595.7	6907.7	8573.3	11261.8	18490.9
		R_t (N)	4504.5	5733.0	6666.7	8316.0	11325.6	19219.2
		δ (%)	-0.70	-2.40	3.62	3.09	-0.56	-3.79
	II	R_e (N)	4797.3	5996.4	6782.7	8428.8	11142.1	18885.5
		R_t (N)	4829.6	6125.2	6737.7	8638.1	11355.3	19464.6
		δ (%)	-0.67	-2.10	0.67	-2.42	-1.88	-2.97
	III	R_e (N)	5035.2	6672.4	7405.2	9017.0	11958.0	19352.9
		R_t (N)	5159.8	6526.2	7478.0	9318.7	12178.4	20040.9
		δ (%)	-2.41	2.24	-0.97	-3.24	-1.81	-3.43
FAO 74	I	R_e (N)	4634.3	5804.1	7474.0	9416.4	11834.4	18270.7
		R_t (N)	4504.5	5733.0	7695.2	9528.8	12226.5	18918.9
		δ (%)	2.88	1.24	-2.87	-1.18	-3.21	-3.43
	II	R_e (N)	4545.2	5692.7	7536.5	9247.5	11920.4	18968.1
		R_t (N)	4559.4	5757.4	7711.0	9536.5	12352.5	19015.4
		δ (%)	-0.31	-1.12	-2.26	-3.03	-3.50	-0.25
		R_e (N)	4802.2	6326.6	7964.1	10297.0	14264.0	19940.7
		R_t (N)	4935.5	6526.2	8039.1	10699.2	14101.3	20639.2
		δ (%)	-2.70	-3.06	-0.93	-3.76	1.15	-3.38
FAO 75	I	R_e (N)	4564.0	5717.1	6265.8	7772.9	10499.5	16729.5
		R_t (N)	4504.5	5733.0	6381.4	7623.0	10617.8	16816.8
		δ (%)	1.32	-0.28	-1.81	1.97	-1.11	-0.52
	II	R_e (N)	4550.3	5673.5	6787.4	8052.0	11018.3	17332.8
		R_t (N)	4714.6	5919.4	6438.3	7947.1	10652.0	16769.5
		δ (%)	-1.39	-2.51	2.25	1.32	3.44	3.36
	III	R_e (N)	4791.4	6002.5	6626.7	8266.9	11352.3	17804.1
		R_t (N)	4935.5	6118.3	6730.2	8283.3	11537.4	17947.1
		δ (%)	-2.92	-1.89	-1.54	-0.20	-1.60	-0.80

IV. CONCLUSION

Our research has provided a simple approach to establish the empirical formula for estimating the resistance of specific fishing boats based on FAO's existing model testing data set. The application of this approach to the Vietnamese fishing fleet allows some conclusions to be drawn as follows:

- The resistance empirical formula is established in the form of a power regression function of hull form parameters that have a great influence on resistance, including the ratio of ship length to breadth (L/B), prismatic coefficient (C_P), half-angle of the entrance ($½α_E$), and displacement (Δ).
- Comparative studies between the resistance or required horsepower values obtained from the empirical formula and model or actual tests have validated the accuracy and reliability of this approach as well as the established empirical formula when the deviations (δ) between the comparative resistance values in all cases are within ±4%. In particular, the accuracy of the empirical resistance formula applied to FAO fishing boats is very high because these boats are the subject of the formulation.
- Compared with the rest of the methods, such empirical formula not only allows to estimate the ship resistance in a very simple, fast, and efficient way but also very convenient in solving complex problems based on determine resistance as mentioned above, especially in the absence of ship lines. For example, by alternating the value of hull form parameters in the resistance formula, it is possible to select the optimal parameters corresponding to the minimum resistance to optimize the hull form.

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