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Analyze Performance of Double Acting Tanker While Running Astern in Ice Condition

Efi Afrizal,[a] and Jaswar Koto,[a,b,*]

[a)]*Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia*
[b)]*Ocean and Aerospace Research Institute, Indonesia*

*Corresponding author: jaswar.koto@gmail.com & jaswar@utm.my

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ABSTRACT

The increasing of shipping activities through the Northern Sea Route (NSR) and growth of oil and gas activities in Arctic and Sub-Artic regions require suitable design of ice-going ships and planning operations in ice. In 2002, Sumitomo Heavy Industries has built advanced ice-ship called “Double Acting Tanker”. This paper discussed application of new method to determine ice resistance of Double Acting Tanker running ahead in ice condition. The simulation was carried out at 1 m ice thickness in unfrozen and frozen channels and 0.5 m ice thickness in level ice condition. The simulation results were compared with experimental results.

KEY WORDS: *Running Ahead; Ice Thickness; Double Acting Tanke.*

NOMENCLATURE

AAT	Aker Artic Technology
DAT	Double Acting Tanker
DWT	Deadweight
MW	Mega Watt
NSR	Northern Sea Route

1.0 INTRODUCTION

Ice–going ships have been developed called as Double Acting Tanker (DAT) which can be travel more efficient in astern than ahead at ice conditions as shown in Figure 1 (Juurmaa et al. 2002). A lot of researches have been developed to find the optimum hull design of double acting tanker while operating in sea ice as astern mode. Recent development is by optimization diesel-electric power plan concept combine with an azipod on the propulsion system of DAT. Sasaki et al. (2004) reported experimental result at the full-scale Double Acting Tanker "Mastera" and "Tempera" with 106000 DWT of weight and 16 MW of powering. The experiment had been done at Sagami Bay, Japan for Mastera and at route between Porvoo to Primorsk, Rusia for Tempera. Improvement on performance was obvious when ship could be sailing at the astern mode in the frozen seas where it does not need escort anymore by icebreaker ship.

Figure 1: Double Acting Tanker in ice condition (Juurmaa et al, 2002)

Based on previous findings, the special design was required for ships to be operated in open water and ice conditions. The phenomenon of interaction between ice and ship has been carried out by researchers through empirical mathematical simulation such as Chen and Lee (2003), Lee (2006), Islam, Veitch and Liu (2007) and Tan et al. (2013, 2014). In the phenomenon, there are two forces acting at the same time that compressed by the hull and sucked by the propeller. Jaswar (2005) has developed an empirical mathematical model to predict resistance of Double Acting Tanker (DAT) without taking into account the impact of suction force caused by the propeller as the ship walked toward the rear. This paper discusses mathematical model to predict the strength of the suction force caused by the propeller of DAT during sailing astern.

The uniqueness concept of double acting ship is that could be operated ahead mode if ship was sailing in the open water or to be operated astern mode when the ocean was covered by ice. The performance could be achieved because the DAT ship is using a podded propulsion system which has ability to rotate 360° freely on its axis. The podded propulsion system so that can always be in a state of pulling even when the ship is sailing at ahead or astern modes. "Mastera and Tempera" are examples of ships which were developed with this concept. They had been operating since 2002 and 2003 (Sasaki et al. 2004). Below of this, it would be discussed fundamental concept of Double Acting Tanker and application of proposed method called "Efi-Koto Method" on Double Acting Tanker.

2.0 ICE RESISTANCE WORKING ON SHIP SAILING IN ICE CONDITION

As reported by Jones (2004) in the book His review, below some of those involved in this study will be rewritten again to make clear the double acting ship concept. Significant contribution begin by Jansson (1956[a] and 1956[b]). He discussed in detail the history of icebreaking ship from what he considered the earliest true icebreaker, Eisbrecher 1. The ice–breaker was operated between Hamburg and Cuxhafen, it was built in 1871 and in 1956 it was began to use bow propeller while penetrated on ice. Jansson also discussed the science of icebreaking. He quoted, values for the physical properties of freshwater ice, at -3 °C, as shown in Table 2.1:

Table 2.1 Properties of Freshwater Ice (Jones, 2004)

Elastic Modulus	70,000 kg/cm^2 (6,900 MPa)
Tensile and bending strength	15 kg/cm^2 (1.5 MPa)
Compressive strength	30 kg/cm^2 (2.9 MPa)
Shear strength	7 kg/cm^2 (0.7 MPa)

There was not mentioned of details experiments including that value, some addition information were only for coefficient of friction between ice and metal as 0.10 to 0.15 for fresh or Baltic ice and 0.20 for salt water or polar ice. He gave a simple formula for the total ice resistance as described in Equation (2.1):

$$R_{ice} = (C_1 . h + C_2 . h . v^2) . B \qquad (2.1)$$

Where; C_1 and C_2 are experimental constants, h is ice thickness, v is vessel speed and B is breadth of vessel at waterline.

After that, Jones (2004) in his report said credited to Kashteljan et al. (1968) whom the first detailed attempt to analyse level ice resistance by breaking it down into components. Where on the paper, it was appeared like an Equation (2.2) to determine the total of ice resistance, R_{TOT}:

$$R_{TOT} = k_1 \mu_o B \sigma h + k_2 \mu_o B \rho_i h^2 + k_3 \frac{1}{\eta_2} B^{k_4} v^{k_5} \qquad (2.2)$$

Where; σ is ice strength, B is ship beam, h is ice thickness, v is ship speed, and ρ_i is the density of ice. μ_o and η_2 are related to Shimansky's ice cutting parameters, and k_1, k_2, k_3, k_4, k_5 are coefficients experimentally determined (0.004, 3.6, 0.25, 1.65, and 1.0 respectively).

In the Equation (2.2), that compose of several parts like, first component $R_1 = \mu_o B \sigma h$ is resistance due to breaking the ice, second component represented of $R_2 = k_2 \mu_o B \rho_i h^2$, is resistance due to forces connected with weight (such as submersion of broken ice, turning of broken ice, change of position of icebreaker, and dry friction resistance) and third is component of $R_3 = k_3 \frac{1}{\eta_2} B^{k_4} v^{k_5}$ for determined of resistance due to passage through broken ice

Lewis and Edwards (1970) gave a good review of previous work and derived the Equation (2.3);

$$R_{im} = C_o \sigma h^2 + C_1 \rho_i g B h^2 + C_2 \rho_i B h v^2 \qquad (2.3)$$

Where;

R_{im}	=	mean resistance excluding water
g	=	acceleration due to gravity
C_0, C_1, C_2	=	non-dimensional coefficients to be determined experimentally

The first term represents ice breaking and friction, the second accounts for all resistance forces attributable to ice buoyancy, and the third accounts for all resistance forces attributable to momentum interchange between the ship and the broken ice. They conducted non-dimensional analysis by dividing by σh^2 to obtain the Equation (2.4):

$$R' = C_0 + C_1 B' N_\Delta + C_2 B' N_I \qquad (2.4)$$

Where;

$R' = R_{im}/($, non-dimensional mean ice resistance

$B' = B/h$, non-dimensional beam

$N_\triangle = \rho_i g h/$, volume metric number

$N_I = \rho_i \sigma /$, inertial number

Crago et al. (1971) describe a set of model test in "wax-type" ice on 11 icebreakers. By considering a simple bow geometry and the vertical force acting on the ice sheet, they derived Equation (2.5) for the ice thickness, h ;

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$$\frac{h\sqrt{\tau}}{\sqrt{T_t}} = \frac{1.53}{\sqrt{\tan(i+\beta)}} \quad (2.5)$$

Where;

τ = ice tensile strength
T_t = Thrust
i = stem angle
$\beta = \tan^{-1} f$; f is the coefficient of friction

Enkvist (1972) made a major addition to the literature of ship performance in level ice. On the article narrated of experimental on model tests for three ships; Moskva-class, Finncarrier, and Jelppari, and was able to compare his results with limited full-scale data from all three. From a combination of analytical work, dimensional analysis, and a few assumptions, they derived a semi–empirical Equation 2.6 where defined ice resistance based on three terms:

$$R_{TOT} = C_1 Bh\sigma + C_2 BhT\rho_{\Delta} g + C_3 Bh\rho_i v^2 \quad (2.6)$$

Where;

T = draft of ship
ρ_w = density of water
ρ_i = Density of ice
$\rho_{\Delta} = \rho_w - \rho_i$

Milano (1973) made a significant advance in the purely theoretical prediction of ship performance on ice. He considered the energy needed for a ship to move through level ice, which varied somewhat with ice thickness. For example, for very thick ice the ship moves through the ice-filled channel (E_1) , impacts the various bow and cusp wedges causing local crushing (E_2), climbs onto the ice (E_3) until sufficient force is generated to cause fracture, at which time the ship falls (E_4) , and moves forward, forcing the ice downward (E_5). The total energy loss due to ship motion can be calculated using Equation (2.7);

$$E_T = E_1 + E_2 + E_3 + E_4 + E_5 \quad (2.7)$$

Vance (1975) obtained an "optimum regression equation" from five sets of model and full-scale data, of the Mackinaw same data as used by Edwards et al. (1972), Moskza, Finncarrier, Staten Island, and Ermak. Equation (2.8) was resulted by regression to define ice resistance:

$$R_{(ice)} = C_S \rho_{\Delta} g B h^2 + C_B \sigma B h + C_V \rho_i V^2 L h^{0.65} B^{0.35} \quad (2.8)$$

Where; $R_{(ice)}$ is the resistance due to ice, L is length of vessel, and C_S , C_B , C_V are empirically determined values. The first term is a submergence term, the second a breaking term, and the third term is a velocity dependent resistance.

An example of a fit to his equation is shown in Figure 4.1 in which the Mackinaw full-scale data (label FS) are shown fitted to his equation above (label FSR) and a model-scale regression to his equation (MSR) is also shown. Good agreement is found between the model and full-scale results.

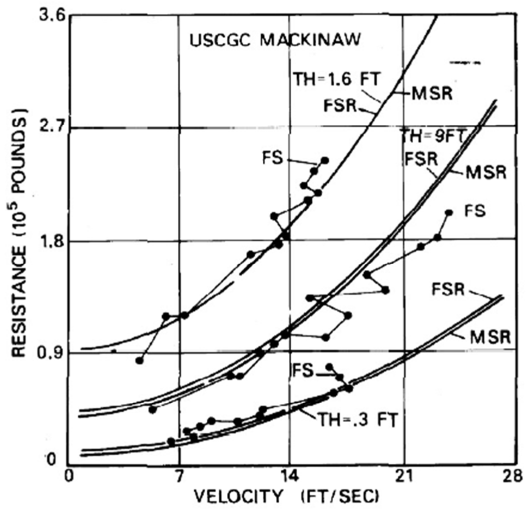

Figure 2.1 Result using optimum Regression (Vance, 1975)

Edwards et al. (1976) presented full-scale data for the Louis S. St. Laurent collected by analysing ramming type tests using Equation (2.9). The equation is in non-dimensional form.

$$\frac{R}{\rho_w g B h^2} = 4.24 + 0.05\frac{\sigma}{\rho_w g h} + 8.9\frac{V}{\sqrt{gh}} \quad (4.9)$$

Kotras et al. (1983) in his paper proposed an equation based on Nagle's thesis (Nagle, unpublished) which describe yet by another semi-empirical approach. In his proposed equation the total ice resistance is given by

$$R_{ice} = R_B + R_{Bf} + R_T + R_{Tf} + R_S + R_{Sf} \quad (2.10)$$

Where ;

R_{ice} = total ship ice resistance
R_B, R_{Bf} = normal and frictional resistance due to breaking of level ice
R_T, R_{Tf} = normal and frictional resistance due to broken ice floes
R_S, R_{Sf} = normal and frictional resistance due to submerging broken ice

Since 1985, development of new icebreaking forms has been having significant value, more scientific approach had been used such as modelling of ships in ice with extensive model testing and, most recently, numerical methods. Canadian Arctic oil exploration and development led to new designs such as the Kigoriak, and Terry Fox, while other activities led to the Oden, double acting tankers (DAT) with Azipods, FPSO's in ice, and research ships such as the Nathaniel B. Palmer, USCGC Healy, and the converted CCGS Franklin now called CCGS Amundsen.

An interesting development in the mid-80's, Zhan et al. (1987) was made a full-scale resistance trial of the Mobile Bay in uniform level ice. Denny (1951) had been reported the same term, in the principle the experiment method is parallels with the open water trials of the Greyhound (Froude, 1874) and Lucy Ashton.

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While such tests are clearly difficult to perform, in theory they provide a direct measurement of full-scale resistance. They also conducted full scale propulsion tests. They found the best fit to their towed resistance results was with the Equation (2.11):

$$\frac{R_{ice}}{\rho_w g B h^2} = C_0 + C_1 \frac{v^2}{gB} \cdot \frac{L^3}{h} \tag{2.11}$$

Where;

$C_0 = 4.25$

$C_1 = 3.96x10^{-5}$

Lindqvist (1989) had included submersion component in the Equation (4.12) to determine ice resistance working. Based on his observation from the full scale experimental, he conclude that ice would be fractured in the one continue cycle including rotating and sliding of broken ice floes.

$$R_i = \delta\rho . g . h_i \left(T \frac{B+T}{B+2T} + \mu \left(0.7\, L - \frac{T}{\tan \emptyset} - \frac{B}{4 \tan \alpha} + T \cos \emptyset . \cos \psi \sqrt{\frac{1}{\sin^2 \emptyset} + \frac{1}{\tan^2 \alpha}} \right) \right) . \left(1 + 9.4 \frac{v}{\sqrt{g . L}} \right) \tag{2.12}$$

Where $\delta\rho$ is the density difference between the water and the ice, g is the acceleration of gravity, h_i is ice thickness, L , B, and T are the length, breadth and draft of the ship, μ is the frictional coefficient, $\emptyset$ is the stem angle, α is the waterline entrance angle, v is the ship speed in ice and ψ is the angle between the normal of the hull surface and the vertical vector and can be define by ;

$$\psi = arctan \frac{\tan \emptyset}{\sin \alpha}$$

Tan et al. (2013) has rearranged formula of Lindqvist and present coefficients that were applied to represent each of step on the ice breaking including crushing, braking and submersible. That is showed in Equation (2.13):

$$F_x^{ice} = c_h h_i^2 + \left(b_h + \frac{1.4 C_h}{\sqrt{g}} v_x \right) h_i^{1.5} + \left(s_h + \left(\frac{1.4 b_h}{\sqrt{g}} + \frac{9.4 s_h}{\sqrt{g L_{wl}}} \right) v_x \right) h_i \tag{2.13}$$

3.0 HULL RESISTANCE IN OPEN WATER

The performance of a ship related to resistance loading at the ship. Total resistance, R_T at the open water is the force required to make the ship traveling in the certain speed. Resistance working at the ship consists of several components. Commonly, general measured are pressure resistance and friction resistance R_F (Frisk and Tegelhall, 2015). Other components often used in analysis performance of ship are viscous resistance, R_V and wave resistance, R_W. If vessel traveling through open water, some resistance can be in form of shear force is known as viscous resistance. In addition, the resistance also could be found in a form of wave resistance due to water wave. Besides, other resistance could be working on the up side of vessel caused by air specified as minor resistance. The total resistance of ship in open water can be expressed as Equation (3.1).

$$R_T = R_F + R_V + R_W \tag{3.1}$$

The total resistance coefficient, C_T is a dimensionless quantity which can be defined as Equation (3.2). This coefficient used to characterize total resistance in the different hulls.

$$C_T = \frac{R_T}{\frac{1}{2}\, \rho\, U^2\, A_w} \tag{3.2}$$

Where; R_T is the total resistance, ρ is density of water, U is hull speed and A_w is the wetted surface area.

4.0 ICE SHIP SAILING IN ICE CONDITION

The first model of ice basin was built in the Soviet Union by AARI, 1955. That was needed to observe either of hull form or propulsion could be effect to ice–breaking ship performance. In ice model test, Froude scaling law is using to associate ice model test and full scale situation. Wilkman (2015) revealed that total resistance is the summation of ice resistance and open water resistance. Ice resistance is an amount of resistance to breaking ice, resistance of some component sink ice under hull and resistance velocity due to dynamic working. Experiment in ice model scale test can be contributed to reducing huge investment before the real ship was manufactured.

Performance ship on ice was measurable in capability of ship to break ice and to manoeuvre in ice condition. That could be confirmed through achieved speed by ship when sailing in uniform or certain ice thickness, ice ridges or in the level ice condition (Wilcox, 1994). The velocity of ship on ice condition can be determined through thrust of propeller available to overcome the ice resistance. Performance of propulsion system can be improved thru modification on hull shape and some change into propulsion design, both of that could minimize an effect of resisting forces and maximize the propulsive forces. The ice resistance is assuming linear to ship speed which composed of three components, like described in Equation (4.1):

$$R_{ice} = R_b + R_s + R_f \tag{4.1}$$

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Each component R_b, R_s and R_f, successively are breaking, submersion and friction components. The breaking component is related to break the ice such as crushing, bending and turning of ice. The submersion component is concerned to push the broken ice down along the ship hull. The friction component is connected to slide the broken ice along the ship hull. In general velocity of the ship depends on working ice resistance associated to friction component. The total resistance working on ice, R_{total} is the sum of ice resistance, R_{ice} and open water resistance, R_{ow}, as expressed in Equation (4.2):

$$R_{total} = R_{ice} + R_{ow} \tag{4.2}$$

Figure 4.1 describe interaction happening between hull and ice including crushing, bending, submersion and friction of ice at bow hull.

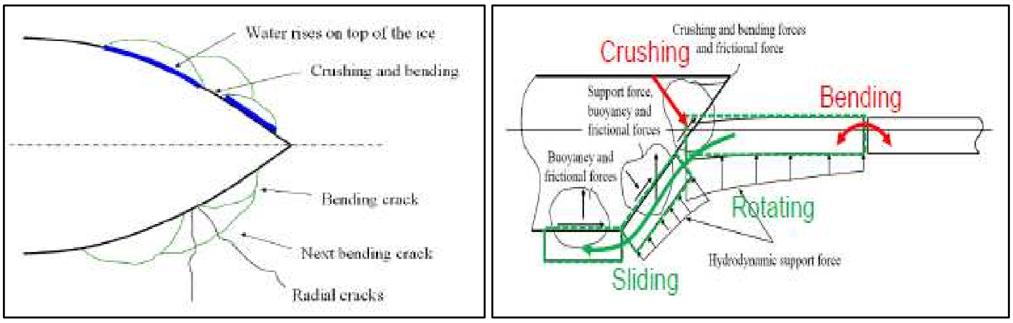

Figure 4.1 Hull and ice interaction (Wilcox, 1994)

4.1 Ice-Ship Sailing Ahead in Ice Condition

4.1.1. Ice-Ship Sailing Ahead in Ice Condition – Unfrozen Channel

In this condition, the ship resistance is defined as the average value of all longitudinal forces caused by ice acting on the structures. stated that total resistance to ship's continuous motion through ice-infested waters is expressed as the summation of resistance developed in failing the ice, the momentum interchange between the ship and the ice, ice buoyancy forces and the open water resistance as in Equation (4.3) (Jaswar 2005):

$$F_{ship-HUC} = F_{water-frict} + F_{sub} + F_{frict} + F_{moment} \tag{4.3}$$

Where; the above equation is summation that consists of all longitudinal forces as stated below.

a. Water Friction Resistance ($F_{water-frict}$)

To determine the frictional resistance coefficient, William Froude's approach yielded that the frictional resistance coefficient was related to the resistance coefficient of plate with the same length and wetted surface area of the ship or model hull, which can express in Equation (4.4) and Equation (4.5):

$$C_f = \frac{R_f}{\frac{1}{2}\rho V^2 S} \tag{4.4}$$

Or:

$$F_{water-frict} = F_{wf}^{H(uF)} = \frac{1}{2} C_{wf}^{H(uF)} \rho V^2 S \tag{4.5}$$

Where:

$F_{wf}^{H(uF)}$	is head unfrozen water friction resistance
$C_{wf}^{H(uF)}$	is head unfrozen water friction resistance coefficient
R_f	is frictional resistance (N)
ρ	is density of water (kg/m^3)
V	is ship or model speed (m/s)
S	is wetted surface of ship or model hull (m^2)

Several friction lines based only on the Reynolds number were developed later, both theoretically using boundary layer theory and experimentally. For laminar flows, the resistance coefficient was formulated from boundary layer theory by Blasius, as shown in Equation (4.6):

$$C_f = 1.328.\sqrt{Rn} \tag{4.6}$$

So-called plate lines were developed for turbulent boundary layer flows from the leading edge. These plate lines were extended to include full scale Reynolds numbers. The formulations, such as the Schoenherr Mean Line or the ITTC-1957 Line (Molland et al. 2011), which are determined, as indicated in Equation (4.7) and Equation (4.8):

$$Schoenherr: \quad \frac{0.242}{\sqrt{C_f}} = log_{10}(Rn.C_f) \tag{4.7}$$

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$$ITTC - 1957: \quad C_f = \frac{0.075}{(Log_{10}(Rn) - 2)^2} \quad (4.8)$$

The latter one is accepted as a standard by the International Towing Tank Conference (ITTC). As a matter of fact, it is not too important that a flat plate with a certain length and wetted surface has a resistance coefficient exactly according to one of the mentioned lines. The Froude hypothesis is crude and correlation factors are required afterward to arrive at correct extrapolations to full-scale values. These correlation factors will depend on the plate line which is used.

b. Submersion Resistance (F_{sub})

The submersion resistance is assumed arise from work required to tip and submerge the broken an ice cusps. The submersion resistance depends on buoyancy of force of the ice cusp due to different density between the ice cusp and seawater, as expressed in Equation (4.9):

$$F_{sub} = F_{sub}^{H(uF)} = C_s^{H(uF)}.(\rho_{water} - \rho_{ice}).g.D.B.h \quad (4.9)$$

Where:

$F_{sub}^{H(uF)}$ is head (unfrozen) submersible resistance
$C_s^{H(uF)}$ is head unfrozen submersion coefficient
ρ_{water} is water density 1.025 ton/m3
ρ_{ice} is ice density 0.918 ton/m^3
g is acceleration of gravity 9.81 m/s^2
D is depth of ice cusp
B is width of the ice cusp

c. Friction Resistance (F_{frict})

The frictional resistance is found when buoyancy force of the broken ice is against the hull and underside of the broken ice field as well as the effect of hull form such as friction between ice and hull and broken ice piece and under surface of the broken ice cover. The frictional resistance can be expressed as Equation (4.10):

$$F_{frict} = F_f^{H(uF)} = C_f^{H(uF)}.\rho_{ice}.g.r.h.B.V/\sqrt{L.g}.f(a,b,C_w) \quad (4.10)$$

Where:

$F_f^{H(uF)}$ is head unfrozen friction resistance
$C_f^{H(uF)}$ is head unfrozen friction coefficient
L is ship length
C_w is water plane area coefficient of entrance part
V is speed of ship

c. Momentum Resistance (F_{moment})

Loss momentum resistance is developed when resistive force attributable to extract momentum from the ship and imparting it to broken ice pieces. The time rate of change momentum of the ship is equal to resultant force on ship, which can be expressed as Equation (4.11):

$$F_{moment} = F_m^{H(uF)} = C_m^{H(uF)}.\rho_{ice}.B.h.V^2.f(a,b) \quad (4.11)$$

Where:

$F_m^{H(uF)}$ is head unfrozen momentum resistance
$C_m^{H(uF)}$ is head unfrozen momentum coefficient
ρ_{ice} is density of ice
B is breadth of ship
h is thickness of ice
V is velocity of the ship
a, b are component angle fore or aft parts

Figure 4.2 showed ice resistance working on Double Acting Tanker in graph and related with velocity of the ship, while sailing ahead in unfrozen condition at 1 m ice thickness.

It can be seen from that graph, through full scale experiment testing at 1m ice thickness, Double Acting Tankers had been sailing using two variations value velocity of the ship 1.2m/s and 2.5m/s while ice resistance working measured 790 kN and 980kN respectively. These results showed an increasing value of ice resistance through the length of increasing velocity of ship.

Ice resistance of simulation results generated adjacent with experimental full scale data and approximate not slightly different. Velocity of ship 1.2m/s and 2.5 m/s related at ice resistance 810 kN and 977 kN. On the other side, total ice resistance from simulation indicated not much different. Both of lines curve simulation result (ice resistance and total resistance) almost coincided. It is indicated there are no resistance wave arising due to motion influence of water. It might be said that resistance total at unfrozen condition almost entirely is ice resistance.

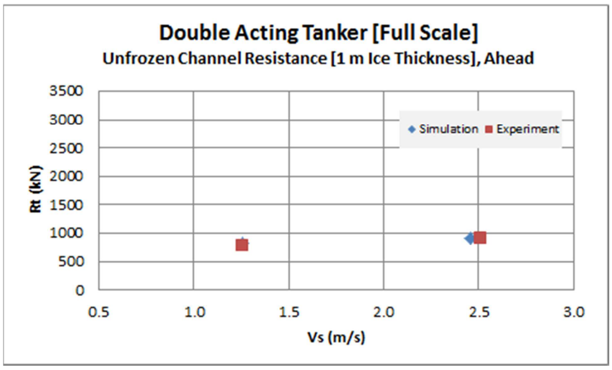

Figure 4.2: Ice resistance of DAT at unfrozen channel Ice [1 m Ice Thickness], Ahead condition

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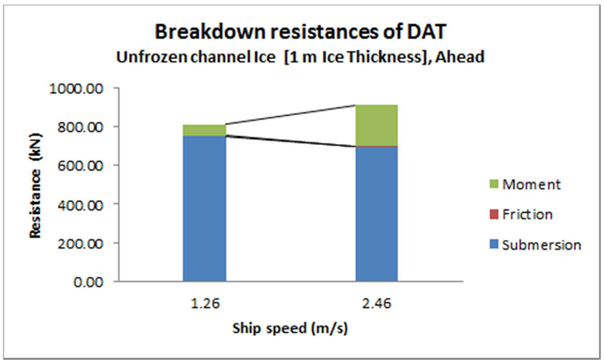

Figure 4.3: Breakdown ice resistance of DAT at unfrozen channel Ice [1 m Ice Thickness], Ahead condition

4.1.2. Ice-Ship Sailing Ahead in Ice Condition – Frozen Channel

In the frozen channel of ice condition, the ice resistance is important parameter as the additional component to determine the total ship resistance that operated in this region. The breaking force is related to the breaking of ice. The total ship resistance can be stated below as the Equation (4.12) (Jaswar 2005):

$$F_{ship-HFC} = F_{water-frict} + F_{sub} + F_{frict} + F_{moment} + F_{ice} \quad (4.12)$$

Where :

$F_{ship-HFC}$	is the head frozen channel resistance
$F_{water-frict}$	is water friction resistance
F_{sub}	is submersion resistance
F_{frict}	is friction resistance
F_{moment}	is the momentum resistance
F_{ice}	is the ice breaking resistance

a. Ice Breaking Resistance (F_{ice})

The ice resistance is acting on the ship which can be defined below as the Equation (4.13):

$$F_{ice} = F_{iB}^{H(F)} = C_{iB}^{H(F)}.\sigma.h^2.\mu.f(a,b) \quad (4.13)$$

Where :

$F_{iB}^{H(F)}$	is head frozen icebreaking resistance
$C_{iB}^{H(F)}$	is head frozen icebreaking coefficient
σ	is ice flexural strength
h	is ice thickness
μ	is coefficient of kinetic friction of ice and hull
a, b	are component angle fore or aft parts

b. Water Friction Resistance ($F_{water-frict}$)

Water friction resistance which is working in the head frozen condition could be calculated as the same way at the head unfrozen channel as had been shown in the Equation (4.20) channel but for the head frozen condition there are being changed in the coefficient of water friction resistance. It was explicitly observed in the Equation (4.14).

$$F_{water-frict} = F_{wf}^{H(F)} = \frac{1}{2} C_{wf}^{H(F)}.\rho.V^2.S \quad (4.14)$$

Where :

$F_{wf}^{H(F)}$	is head frozen water friction resistance
$C_{wf}^{H(F)}$	is head frozen water friction resistance coefficient

c. Submersion Resistance (F_{sub})

To determine submersion resistance in the frozen channel, it would be calculated using the same equation where previously used for submersion resistance in the unfrozen channel but foremost, it must be changed into the coefficient submersion resistance. It could be referred to Equation (4.15).

$$F_{sub} = F_s^{H(F)} = C_s^{H(F)}.(\rho_{water} - \rho_{ice}).g.D.B.h \quad (4.15)$$

Where:

$F_s^{H(F)}$ is submersion head frozen resistance

$C_s^{H(F)}$ is head frozen submersion coefficient

d. Friction Resistance (F_{frict})

When the ship running ahead at the frozen condition, that would be making friction resistance by structure interaction of ship to ice. That can be calculated like friction resistance at the unfrozen situation but in the different of friction resistance coefficient, as to be writing in the Equation (4.16).

$$F_{frict} = F_f^{H(F)} = C_f^{H(F)}.\rho_{ice}.g.r.h.B.V\Big/\sqrt{L.g}.f(a,b,C_w) \quad (4.16)$$

Where:

$F_f^{H(F)}$ is head frozen friction resistance

$C_f^{H(F)}$ is head frozen friction coefficient

e. Momentum Resistance (F_{moment})

Ship while sailing on ice could become loss of some momentum when collision with ice. At the frozen condition, momentum loss

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can be determined using Equation (4.17). It was difference of coefficient momentum resistance with the Equation (4.11).

$$F_{moment} = F_m^{H(F)} = C_m^{H(F)}.\rho.B.h.V^2.f(a,b) \qquad (4.17)$$

Where:

$F_m^{H(F)}$ is head frozen momentum resistance

$C_m^{H(F)}$ is head frozen momentum coefficient

Figure 4.4 showed ice resistance working on double acting tanker in graph and related with velocity of the ship, while running ahead in frozen condition at 1 m ice thickness.

It can be read through Figure 6.3 that ice resistance was occurred 920 kN when ship running in 0.8 m/s but if velocity increased to 1.67 m/s, it can produce 1050 kN working ice resistance. If it is looked by way of simulation program approach, both of lines are ice resistance and total resistance still tends to coincide or not seen existence of wave resistance due to influence motion of water. The differences are quite acquired prominent when ship speed is 0.8 m/s its getting 990 kN ice resistance using simulation whereas experimental results obtain 920 kN. But it is not happen at the second point when ship's speed is 1.67 m/s simulation results having ice resistance 1040 kN and that is close to experimental value.

If observed on Figure 4.2 concerning an unfrozen condition ice resistance was quite increasing into frozen as shown on Figure 4.4. It can be evidenced while full-scale experimental result having the same value. It confirmed in the frozen condition had occurred consolidated piece of broken ice so that was needed more thrust power of ship to break ice then had proven with increasing value of ice resistance

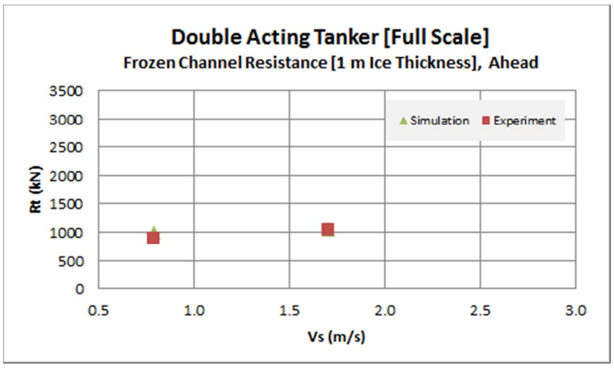

Figure 4.4: Ice resistance of DAT at frozen channel Ice [1 m Ice Thickness], Ahead condition.

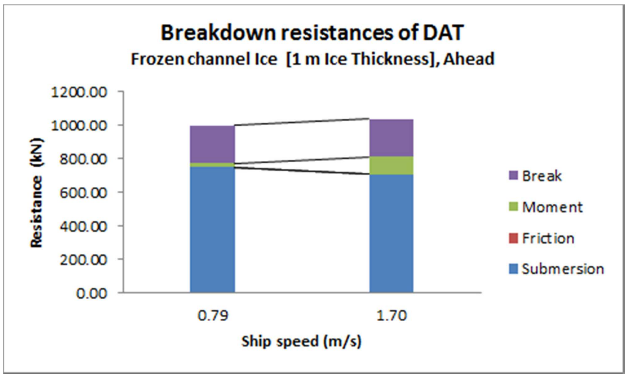

Figure 4.5: Breakdown ice resistance of DAT at frozen channel Ice [1 m Ice Thickness], Ahead condition.

4.1.3. Ice-Ship Sailing Ahead in Ice Condition – Level Ice

Ice resistance which was occurring when ship was sailing on the level ice is the whole sum of some resistance including water friction resistance, submersion resistance, friction resistance, momentum resistance and force to breaking ice resistance, as can be seen in Equation (4.18) (Jaswar 2005):

$$F_{ship-HLI} = F_{water-frict} + F_{sub} + F_{frict} + F_{moment} + F_{ice} \qquad (4.18)$$

It could be confirmed, that is a similar method, was using to determine resistance at the frozen situation as referred to Equation (4.27) previously. Anyway in the next subchapter below of this will be explained as clearly every piece of its.

a. Ice Breaking Resistance (F_{ice})

It can be seen from Equation (4.19) ice resistance was re-emerged like Equation (4.13) where using to calculate at the frozen condition but it was difference in a, $C_{iB}^{H(Li)}$, that is coefficient only for breaking ice in the level ice, when ship was sailing ahead.

$$F_{ice} = F_{iB}^{H(Li)} = C_{iB}^{H(Li)}.\sigma.h^2.\mu.f(a,b) \qquad (4.19)$$

Where :

$F_{iB}^{H(Li)}$ is an icebreaking coefficient

$C_{iB}^{H(Li)}$ is head level ice breaking coefficient

b. Water Friction Resistance ($F_{water-frict}$)

Water friction resistance in the level ice can be determined using Equation (4.20). There is applicable $C_{wf}^{H(Li)}$ as a water friction coefficient when ship was running in the head level ice condition.

$$F_{water-frict} = F_{wf}^{H(Li)} = \frac{1}{2}.C_{wf}^{H(Li)}.\rho.V^2.S \qquad (4.20)$$

Where :

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$F_{wf}^{H(Li)}$ is head level ice water friction resistance
$C_{wf}^{H(Li)}$ is head level ice water friction coefficient

c. Submersion Resistance (F_{sub})

Normally in the level ice condition, there are increasing in the submersion resistance which would be coming from fragments of ice. After ship structure interacted with ice, some fragments could be still floating and shear a shape hull of the ship and other fragments were rubbing the bottom of the hull make. Equation (4.21) could be used to determine the submersion resistance with $C_s^{H(Li)}$ to be useable as submersion coefficient in the head level ice condition.

$$F_{sub} = F_s^{H(Li)} = C_s^{H(Li)}.(\rho_{water} - \rho_{ice}).g.D.B.h \quad (4.21)$$

Where:

$F_s^{H(Li)}$ is head level ice submersion resistance
$C_s^{H(Li)}$ is head level ice submersion coefficient

d. Friction Resistance (F_{frict})

Friction resistance which to be calculated in head level ice condition considers some of parameters consist of waterline angle at the fore, stem angle at the bow, dimension of the ship and density of ice, as can be found in Equation (4.22).

$$F_{frict} = F_f^{H(Li)} = C_f^{H(Li)}.\rho_{ice}.g.r.h.B.V/\sqrt{L.g}.f(a,b,C_w) \quad (4.22)$$

Where:

$F_f^{H(Li)}$ is head level ice friction resistance
$C_f^{H(Li)}$ is head level ice friction coefficient

e. Momentum Resistance (F_{moment})

The last contribution in total resistance which occurs when the ship was sailing in ahead mode is momentum resistance, $F_m^{H(Li)}$. Equation (4.23) can be used to define its. It was similar with the momentum resistance appears in the frozen channel but because of situation in the level ice now, so $C_m^{H(Li)}$ is the head level ice momentum coefficient used to covering it.

$$F_{moment} = F_m^{H(Li)} = C_m^{H(Li)}.\rho.B.h.V^2.f(a,b) \quad (4.23)$$

Where:

$F_m^{H(Li)}$ is head level ice momentum resistance
$C_m^{H(Li)}$ is head level ice momentum coefficient

Figure 4.6 showed ice resistance acting on Double Acting Tanker in the function of velocity of the ship. The ice resistance predicted is for the condition where the ship running ahead in level ice condition at 0.5 m ice thickness.

The Figure 4.6 shows that Range value of ice resistance between each speed of DAT results on the experimental full-scale did not show a significant difference, 2980 kN and 3100 kN, similar with range speed which can reach by ship, at the two state are almost same 0.5 m/s. If looked at the value of ice resistance and a total resistance of simulation results still coincide and that value almost the same as to experimental full-scale 3125 kN. By compare the Figure 4.6 to Figure 4.2 and Figure 4.4, this can clearly found that the increasing in value of ice resistance in level ice condition (Figure 4.6) is almost three times the value of ice resistance in the unfrozen condition (Figure 4.2) and frozen condition (Figure 6.3). Any subject difference is on value speed of vessel which can be reached. Due to higher ice load at the level ice condition, the maximum speed of DAT Tempera achieved with a power of 16 MW is 0.5 m/s, while at the unfrozen condition and frozen condition are 2.5 m/s and 1.7 m/s respectively.

Another thing needs to be examined, if simulation proceeds continuous in other high variable of ship speed, it did not turn out increasing value of ice resistance, and in the predicted results of this simulation was nearly appropriated to average value of ice resistance of experiment full-scale. So in this level ice conditions, distribution strength of ice has been uniform that means there had never been ship running on the route at least since two years ago.

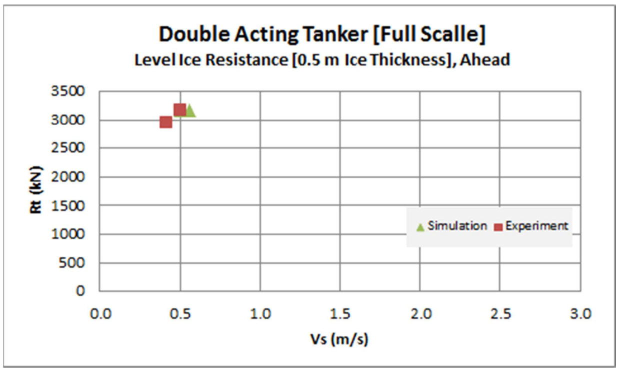

Figure 11: Ice resistance of DAT at level ice [0.5 m Ice Thickness], Ahead condition

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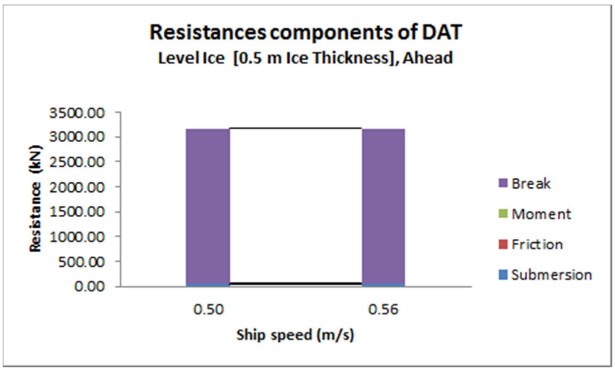

Figure 11: Ice resistance of DAT at level ice [0.5 m Ice Thickness], Ahead condition

5.0 CONCLUSION

In conclusion, this paper has discussed new method to determine performance of Double Acting Tanker operated in ice conditions such as: unfrozen and frozen channels and level ice conditions. The obtained results using the proposed method were compared with the experiment data.

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