

THE INTERFACE BETWEEN THE MARITIME EDUCATION, TRAINING AND THE TECHNOLOGICAL INNOVATIONS IN THE NEW SHIP DESIGN

Prof. Dr. Adel Ebada, Dean of Maritime Scientific Researches

Arab Academy for Science and Technology & Maritime Transport –

Alexandria - Egypt

e-mail: adel.marine@gmail.com

Abstract Maritime education, training (MET) and research must support the marine students to understand the Technological Innovations in the New Ship Design and Dynamic Stability in the Operational Areas. The ship's master and other officers need to predict in advance the motions of the ship. Ship motion prediction will increase the safety level of navigation in different operational areas such as inland water and different open sea areas.

The studies of human mind shows that the cognitive attitude of ship master/human fall short to cope with multi-variable problems and it always tends to simplify complicated problems in order to find a solution such as predicting the ship motions in different conditions. This fact can be traced when the master handles a ship in variable bad weather.

New Ship designs changed dramatically and in generally trend to have more deck cargo, which leads to higher centre of gravity (*C.G.*) and to higher stability demands. This problem is very obvious in containers vessel as well in *RO-RO*, *RoPax*-Ferries and Cruise liners. The other trend is for higher speeds and better fuel economy, which has led to completely different hull forms. They may face dangerous phenomena, e.g. large angle of rolling, parametric resonance. Ship stability may also be reduced dramatically when there is water on deck or the deck is in the water, on the wave crest and when broaching-to. Consequently, the cargo on board will be subjected to external and internal forces, which may cause shifting cargo, cargo damage, loss cargo and ship's damage or loss.

Therefore, the recent theoretical knowledge and empirical applications in ship hydrodynamics are essential to be applied into the practical world and maritime studies in order to increase safety in ship operations. This research will focus on both areas of the interface between the Maritime Education, Training and the Technological Innovations in the New Ship Design and Dynamic Stability in the Operational Areas.

Key words: MET, New Ship Design, Dynamic Stability, Operational areas.

1 Introduction

The main purpose of this research is to provide the necessary knowledge to ship officers, masters, and persons responsible in the nautical field to achieve a safe voyage with regard to ship stability and its motion. Therefore, there are potential needs to develop the training and education in terms of MET and its assessments .

Ship designs changed dramatically to optimize calm water resistance to increase the speed and to achieve better fuel economy which leads to completely different hull forms. The other trend is to have more deck cargo, which leads to higher stability demands. This problem is very obvious in the modern ships. The behaviour of the modern ships e.g. large container ships may face dangerous phenomena and high probability of synchronisation and parametric resonance.

The hull geometry is to be addressed the hydrodynamics interaction of the hull, propeller and rudder. Special attention should be given to the control of ship motion.

The nautical learners in the maritime institutes study the IMO regulation and the intact stability requirements that cover a specific acceptable level of safety. The current regulations are based only on empirical criteria related to the calm water lever arm curve.

The innovation in the new ships design requires new syllabus for the nautical learners related to the design stability, regulatory stability and operational stability. When applying the science of ship hydrodynamics, it is a must to take into considerations the problems of (dynamic) intact stability.

Therefore, the theoretical knowledge in ship hydrodynamics is essential to apply into the practical world of shipping in order to improve safe ship operation. This study will focus on the potential needs of the interface between the maritime education, training and the technological innovations in the new ship design. Therefore, this paper will offers a case study of how to apply the science of ship hydrodynamics into the real world of shipping for safer operation.

2 Definition of the problem

The new ship designs such as transom aft, barge-type-aft bodies are commonly built and bow flare is often increased to allow for more cargo capacity. The result is a higher centre of gravity than before and the characteristics of the righting lever curves will have changes. Usually they have higher heeling angles. Changes in designs, speeds and size tend to be more

in the future. Consequently, shipmaster and crew on board have difficulties to judge the consequences of these developments and it becomes difficult for them to correctly identify dangerous combinations of wave angle, encounter wave period and ship speed in rough or severe seas. Therefore, they may face dangerous phenomena which may cause shifting cargo and ship's damage or loss.

The majority of the maritime community believes that reducing the speeds in rough conditions is a safer action for sailing but this is not a correct action in many cases especially with some modern vessels. Recently, some of the large container ships suffered from parametric excitation, loosing and /or damaging a lot of cargo and being in the danger of capsize and the appropriate guidance on how to avoid these situations is in general not foreseen.

The master knows that in severe weather conditions, a very efficient way to reduce the risk imposed on the ship, crew and cargo is to avoid sailing in such conditions. Therefore, the master needs reasons to justify his decisions and that reasons cannot be well clarified without demonstrating the ship dynamic stability in all stages of the voyage

The IMO intact stability criteria (resolution A.749 (18), 1995) wrote some years ago based on the static lever arm curve for still water condition and this cannot represent real world.

Even the polar diagram in (MSC/circ. 707 (IMO), 1995 and MSC.1/Circ.1228, 2007) provide a general unified boundary of safe and unsafe combination of the operational parameters for all types of conventional ships. Resolution (MSC.267(85), 2008) as adoption of the international code on intact stability put the responsibilities of ship safety on the administration. The organization mentioned that the performance and the criteria for the identified phenomena related to sailing waves and dynamic stability need to be developed.

In general, the assessments in the maritime institutes for the marine subjects are separated or isolated test for each subject. In this context, it can be defined as "One Link Assessment". That mean, the assessments are subject by subject as clarified in this context separated or isolated. Therefore, these mode of assessments will not address the real practical world of the sea voyage. They will cover the complete sea voyage as separated links of topics, e.g. ship stability, stowage cargo, sailing navigation and*etc.* In this perspective the roll of the MET became imperative to train the learners and to put the right assessment that corresponding the real practical sea voyage life.

3 Ship's motions and general guidance

To solve the problem that defined in item 2 in this paper, it needs a clarification to tackle the interface among ship's motions and the different marine subjects.

Manoeuvring is addressing ship behaviour in the horizontal plane (surge, sway, yaw motions), this will affect mainly the ship handling, the surface navigation, the collision avoidance and in general the safe of the watch keeping. Stability and sea keeping are addressing ship behaviour in the longitudinal and transverse plane (mainly heave, pitch and roll motions). Mainly, Ship construction, design stability, regulatory stability, operational stability and ships form will be significant subjects in type of motion.

There are some phenomena raise the risk of ship heavily motion or capsizing such as pure loss of stability, especially in wave crest, roll resonance, parametric rolling, cargo shift and broaching to. In other words, the major causes for big amplitude of ship motion or increase the risk of capsize are the phenomena of broaching, loss of transverse stability and low cycle resonance e.g. synchronisation and parametric rolling.

The following is item 4 in this paper is a case study of a real ship in real sea voyage. The study will show the different marine curriculums integrated together to be in one chain implementation to achieve a safe sea voyage. A modern ship with initial hull form and a modification for the same ship to optimise sea keeping safety.

4 Case study " *M/V. Cementina*" and two ships' forms

This study will focus on ship roll motion, synchronous rolling and parametric rolling.

4.1 *M/V: Cementina*

The author assumed three scenarios for the *M/V: Cementina* with its condition of loading and the sailing operation area in beam seas and quartering seas. The ship is a bulk carrier (after a marine survey renewed to carry cement cargo). The recently ship particulars are Lengths over all (*LOA*) 64.10 m, Length between perpendicular(*L*)=58.10 m, Molded breadth (*B*)=10.83 m, Molded depth to upper deck (*D*)=4.57 m, Draft on summer freeboard (*T*)=4.39 m, Dead weight to summer freeboard (*DWT*)=1229.40 T and *CB* at summer free board=0.7. The main ratio will be defined as $B.T=10.82*4.39=47.5$, $B/T=10.82/4.39=2.46$ and $L/D=58.1/4.57=12.71$. The main dimensions decide many of the ship characteristics, e.g. stability, hold capacity, power requirements and economic efficiency (Schneekluth & Bertram, 1998). The sea area of operation is North Atlantic and Baltic Sea. For the first scenario, the equations that govern the roll motion in beam seas as follows:

$$a \ddot{X}_4 + b \dot{X}_4 + c X_4 = d \quad (1)$$

Where: a , b & c are proportionality factors, \ddot{X}_4 is roll acceleration, \dot{X}_4 is roll Velocity, X_4 is roll angle and d is external roll excitation. The proportionality factors “ a ” depends on influence of surrounding water, inertia, displacement, ship’ beam, roll coefficient and radius of gyration. Radius of gyration depends on cargo stowage and mass distribution in the ship. In other words, it is the inertia mass moment of the rolling ship including the hydrodynamic mass moment effect of the surrounding water. The parameter “ b ” in the roll motion equation describes the damping. It is more common to introduce a dimensionless parameter “ D ” as follows:

$$b/a = 2 \delta \quad (2)$$

$$D = \delta / \omega_o \quad (3)$$

Where: δ is a coefficient in the exponent of the exponential decay of the roll motion in time and ω_o is the natural circular roll frequency. The proportionality factor “ c ” as a restoring coefficient can be expressed as follows:

$$C = g \cdot \Delta \cdot GM \quad (4)$$

$$\Delta = displacement = \rho \nabla \quad (5)$$

Where: Δ is the displacement, ρ is the water density and ∇ is the under water volume. The relation between “ c ” and “ a ” as a ratio c/a is equal to the natural circular roll frequency squared:

$$\omega_o^2 = c/a \quad (6)$$

$$\text{Ship natural circular frequency} = \omega_o = 2 \pi / T_o \quad (7)$$

The prediction of the natural circular frequency can be found out as follows:

$$\omega_o = \sqrt{\frac{g \cdot \Delta \cdot GM}{\Delta \cdot i' T^2}} \quad (8)$$

Where: Δ is the displacement and “ $i' T$ ” is the radius of gyration.

$$GM = \lim_{n \rightarrow \infty} \left(\frac{fr \cdot B}{T_o} \right)^2 \quad \therefore \quad T_o = \frac{fr \cdot B}{\sqrt{GM}} \quad (9)$$

The rolling coefficient “ fr ” depend on the loading condition and the cargo plan. “ B ” is the ship’s beam. In addition to apply the above equations to calculate the maximum linear roll for the *M/V. Cementina* in the beam seas, the author assumed the scenarios for the regular wave of maximum occurrence in the North Atlantic, other for one particular extreme but rare wave and the third in roll resonance, (ship damping $D = 0.10$). The maximum occurrence in the North Atlantic was a wave height (H_w) of 1.5 meter and wave time period (T_w) of 6 to 7 sec.

The one particular extreme but rare wave was a wave height (H_W) of *9.5 meter* and wave time period (T_W) of *6 to 7 sec*. The following set of equations used to find out the maximum roll angle (Kastner, 2001) and (kobyliniski & Kastner, 2003):

$$\text{Wave length } (T_W) = \frac{g}{2\pi} \cdot T_W^2 \quad (10)$$

$$\mathcal{G}_{max.} = \text{maximum wave slope} = \pi \cdot H_W / L_W \quad (11)$$

$$\eta = \omega_w / \omega_o = \text{tuning factor} \quad (12)$$

$$V_3 (\text{amplification factor}) = \frac{1}{\sqrt{(1-\eta)^2 + 4D^2\eta^2}} \quad (13)$$

$$\Phi_{max.} = \mathcal{G}_{max.} \cdot V_3 \quad (14)$$

The result of the maximum roll angle ($\Phi_{max.}$) in the maximum occurrence in the North Atlantic was *4.5 degrees*. For the one particular extreme but rare wave was *29 degrees*. In case of resonance when $T_O = T_W$ which about *8.9 seconds* with the maximum amplification factor was *69.5 degrees*.

The second scenario is a resonance in the stern quartering sea. The excitation frequency is expressed by the encounter spectrum of the pitch P , which is about double the response roll frequency of spectrum R (or the inverse pitch period about one half the roll periods). When the encounter wave period equal double ship natural rolling period, the ship will pitch two times against one time roll. In this case the GM will decrease and the parametric rolling will increase. Mathieu resonance occurs when the wave periods of encounter T_E is nearly one half of the natural roll period T_O or when they both are nearly equal. Condition for Mathieu resonance in following sea and quartering sea to be avoided:

$$T_E = \frac{1}{2} T_O \quad (15)$$

$$T_E = T_O \quad (16)$$

The author assumed other three scenarios for the M/V : *Cementina* with its condition of loading and the operation area of sailing in North Atlantic in *30 and 60 degrees* stern quartering seas.

In the first and second scenarios, the ship achieves all the requirement of the stability conditions (proximal $GM = 0.16$ meter) and assumed to sail in speed *20 knots*. In the first scenario, the wave time was *12 seconds* and stern quartering sea was *30 degrees* as shows in figure 1. In the second scenario, the wave time was *6 seconds* and stern quartering sea was *60 degrees*. Equation 17 is to find out the encounter period (Kastner, 2001) and (kobyliniski & Kastner, 2003). See figure 1.

$$T_E = \frac{T_W^2}{T_W - (2\pi/g) \cdot V \cdot \cos.\chi} \quad (17)$$

Where: (V) is the ship's speed and (χ) is the sea encounter angle.

The result of the first scenario compared with the dangerous resonance zone, Synchronous rolling motion will started to occur when T_E nearly equal $T_O = 22.9 \text{ sec}$. Parametric rolling, which will occur when $T_E = \frac{1}{2} T_O$. That mean $T_E = 11.45 \text{ sec}$.

Figure 1 shows in general, the risk of resonance period for *M/V Cementina* with ship's speed *20 knots*, and waves time between 6 and 12 sec., will be approximately between sea encounter angle 30 and 60 degrees.

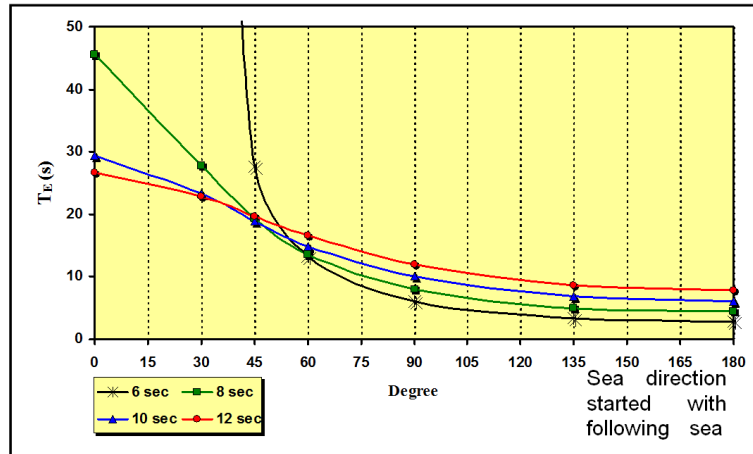


Figure 1: The probability of encounter periods when the ship running in *20 knots*.

The result of the second scenario compared with the dangerous resonance zone, Synchronous rolling motion will start to occur when T_E nearly equal $T_O = 13.3 \text{ sec}$. Parametric rolling, which will occur when $T_E = \frac{1}{2} T_O$. That mean $T_E = 6.65 \text{ sec}$. When ship's speed reduced to be 10 knots, the results improved as shows in figure 2.

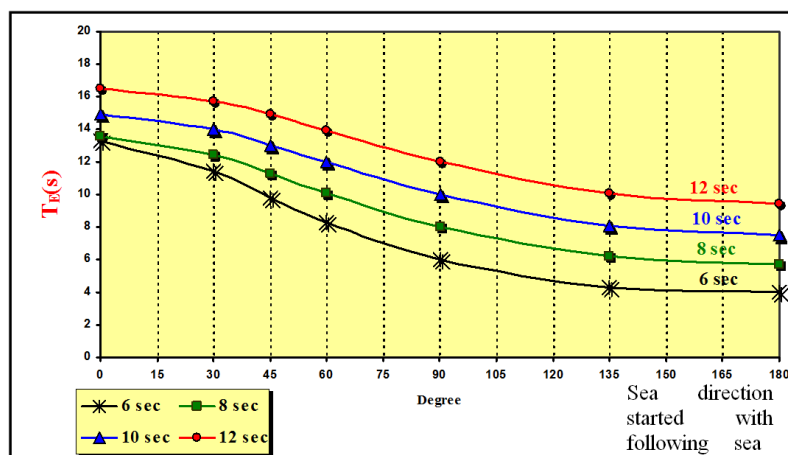


Figure 2: The probability of encounter periods when the ship running in *10 knots*.

In the third scenario was at $T_W = 6$ to 7 seconds and 30 degrees stern quartering sea. The ship achieves all the requirements of the stability conditions and assume to sail in speed *10*

knots to achieve less probability of roll resonance but the results were much different from the first and second scenarios because GM in this scenario was 0.55 meter .

The result of the third scenario compared with the dangerous resonance zone, Roll resonance will occur when ship's speed is 10 knots . The ship master can change the ship speed to 20 knots to get rid of roll resonance.

4.2 Using polar diagram to indicate dangerous zone

The polar diagram indicating dangerous zone of encountering to high wave is similar to the above results but in very general boundary. Each ship has its own dynamic behavior as a motion and the polar diagram in Figure 3 will not represent the accurate and the real situation of the individual ship.

Therefore, the next step is to plot $V(\text{knots}) / T(s)$ versus χ . See T_E curve in figure 3 to clarify an approximate boundary situation. When the speed is reduced to be $= 10 \text{ knots}$ with $T_W = 6$ seconds and $\chi = 30 \text{ degree}$, the result is $T_E = 11.4 \text{ seconds}$ and if $T_W = 6.5 \text{ seconds}$, the result is $T_E = 11.6 \text{ seconds}$. According to the value of $T_O = 21.8 \text{ seconds}$, the resonance will occur when $T_E = 21.8 \text{ seconds}$ to 10.9 seconds . Apply the polar diagram with the present $T_E = 11.6 \text{ seconds}$. See figure 3.

When the encounter wave period is nearly equal to double (i.e. about 1.5 to 2.8 time's approximately) of the observed wave period, the ship is considered to be situated in the dangerous zone as shown in figure 3.

The ship stills in the dangerous zone when $T_W/T_E = 6.5/11.6 = 0.56$ with $\chi = 30 \text{ degree}$. Reduce the speed more or increase the speed to come out of the dangerous zone.

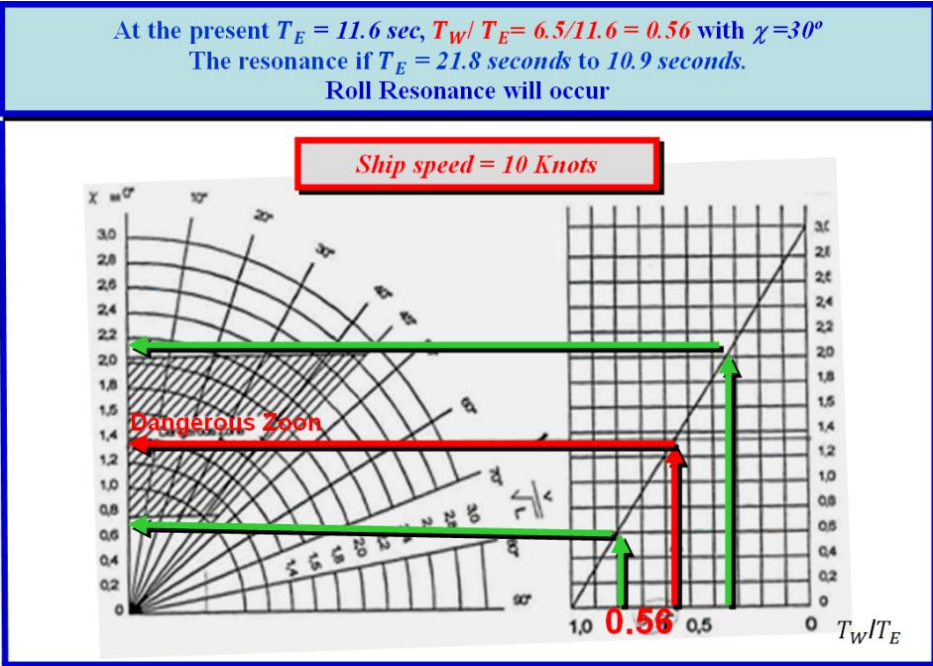


Figure 3: Operation diagram for the master as proposed by IMO, MCS/Circ.707.

According to this study in case of roll resonance, as the speed increase as encounter angle will increase and vice versa.

4.3 Dynamic characterizes of new ships are rapidly changing

An advanced research in George Mason University in USA to optimize the best average speed performance. Three optimal designs are selected from three sets of optimal solutions. In addition, the comparisons of body plan and sheer plan between the original hull and three optimal hulls are shown in Figure 4.

In order to check the performance of the different hulls, the wave drag coefficients, total drag coefficients, wave drag and total drag are evaluated for the original forms. The optimal hull from Case 3 has the best overall performance (C. Yang and F. Huang, 2016). As wave travels down along the hull, the stability (as indicated by GM) varies as the wave crests travel along the hull especially with modern container ships.

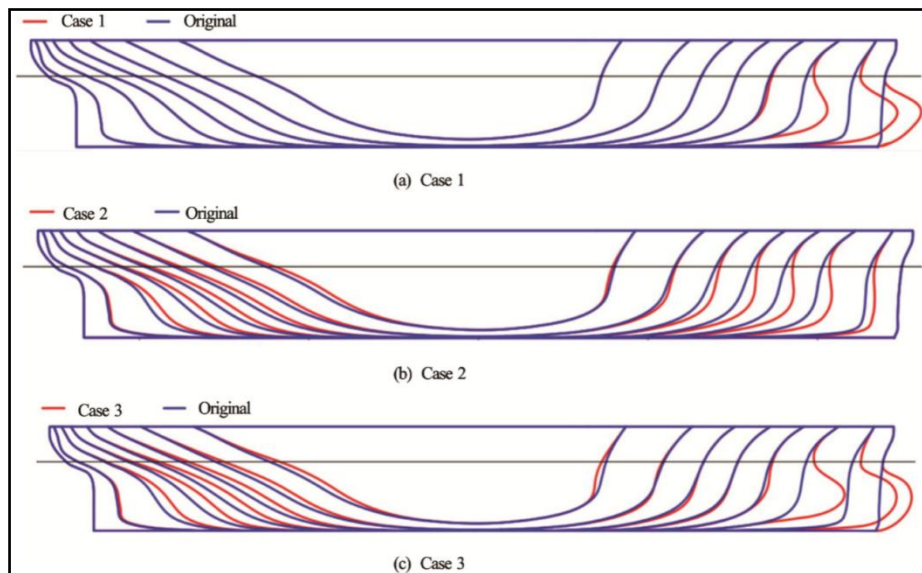


Figure 4: Comparison of sheer plans between the original hull and the optimal hulls

5 Results

In this context, a comprehensive analysis of the requirements and techniques to produce the geometry of ship models for modern ship. It has specified some important aspects that influence the ship motion. The comparison results of the different models were completely different. The behavior of the modified model in case 3 would have in general better performance in the dynamic stability and will decrease dramatically the risk of ship capsizing due to resonance or parametric rolling in bad weather, especially in the quartering and following seas due to decrease the transverse and longitudinal waves moment that case the risk of high excitation and capsizing.

To check the safety level of a specific ship, the analyses behaviour of the ship must be in waves and in the environment of the operation area. It should be noted that the current IMO operation guidance is not a valid criteria to guarantee the absolute safety.

A polar diagram listed in the IMO regulation does not take into account the actual stability and the dynamic characteristics of an individual ship, but provides a general unified boundary of safe and unsafe combination of the operational parameters for all types of conventional ships.

The three scenarios of *M/V Cementina* in item 4.1 demonstrate Condition for Mathieu resonance in quartering sea to be avoided and how is the *10 knots* ship's speed is very effective to ride out the resonance in the second scenario and it is not effective in the same condition in the third scenario when the *GM* was different.

6 Conclusion

This paper shows that the cognitive attitude of ship master/human fall short to coop with multi-variable problems such as handling a ship in a rough weather and it is essential to improve the MET syllabus of the nautical learners. The improvement will address the sea conditions, metrological condition, ships' design, cargo stowage, stability as a chain of evaluation for planning the real world of sea voyage in advance. This real chain of evaluation will defined as "Chain Assessment" in the MET institutes and special training such as work shop would be before this type of Assessments. The "Chain Assessment" shall capture multi disciplines link by link in unique integrated chain to tackle the real life of the practical sea.

IMO regulations and requirements have to define the required minimum safety standard and should allow for a comprehensive evaluation of a ship's dynamic performance in waves. There is a large demand for more reliable and up to date guidance than the current general guidelines e.g. the IMO MSC/Circ. 707 and MSC.1/Circ.1228.

In different sea states and weather conditions, ship masters and officers in the watch need to prepare for the voyage plan in advance the speeds/courses restrictions that have high probability of resonance to avoid the dangerous situations such as surf-riding, broaching to and high excitation in the synchronous condition and parametric rolling.

To plane for the optimal mode of navigation as safer voyage and clean ocean after this modern innovation and new ships design, the roll of MET assessment for the learners must address "Chain Assessment" instead of "One Link Assessment".

A system must be established to support the ship master decision making, by computer-based system. The system shall be able to predict and optimize the best mode of operation

(manoeuvre and sea keeping). At least a comprehensive guidance about the prediction of ship performance navigating in different weather condition must be available on the bridge.

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